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Integrating Hydrology and Green Infrastructure for Urban Flood Resilience: A Hypothetical Catchment in Bandar Lampung

Muhammad Hakiem Sedo Putra[1], Hendi Warlika Sedo Putra[2]

[1] Integrated Water Resources Management Engineering Study Program, Faculty of Infrastructure and Regional Technology, Institut Teknologi Sumatera (ITERA), South Lampung, Indonesia
[2] Department of Building Architecture, Civil Engineering, State Polytechnic of Sriwijaya, South Sumatra, Indonesia

Corresponding author:
Muhammad Hakiem Sedo Putra | muhammad.sedo@tka.itera.ac.id

ABSTRACT

This paper proposes a screening-level framework that treats hydrological performance as an explicit design criterion for landscape architectural and urban design interventions. The framework is applied to a hypothetical 120-hectare mixed-use catchment in the Kali Balau Kencana area, Bandar Lampung. Two scenarios are compared using an illustrative rainfall event of 120 mm over 120 minutes: an existing-condition scenario (S0) and an integrated scenario (S1) combining rain gardens, bioswales, permeable pavement, a retention pond, and green corridors. Land-cover proportions, runoff coefficients (0.72 for S0 and 0.56 as the S1 target), and intervention dimensions are assumed rather than measured. Screening calculations yield runoff volumes of 103,680 m³ for S0 and 80,640 m³ for S1, equivalent to a 22.2% reduction, with peak discharges of 14.41 and 11.21 m³/s. These values are not EPA SWMM simulation outputs. Estimated geometric storage is 14,150 m³, or 13.6% of S0 runoff, indicating that the reduction target requires simulation-based verification. The study also outlines the required SWMM configuration and discusses implications for planning, regulation, financing, maintenance, and institutional responsibility.

Keywords: Flood Resilience; Green Infrastructure; Screening Model; Stormwater Management

ABSTRAK

Artikel ini mengusulkan kerangka skrining yang menempatkan kinerja hidrologi sebagai kriteria desain eksplisit bagi intervensi arsitektur lanskap dan desain perkotaan. Kerangka ini diterapkan pada daerah tangkapan air campuran hipotetis seluas 120 hektare di kawasan Kali Balau Kencana, Bandar Lampung. Dua skenario dibandingkan menggunakan kejadian hujan ilustratif sebesar 120 mm selama 120 menit, yaitu skenario kondisi eksisting (S0) dan skenario terpadu (S1) yang menggabungkan taman hujan, bioswale, perkerasan permeabel, kolam retensi, dan koridor hijau. Proporsi tutupan lahan, koefisien limpasan (0,72 untuk S0 dan 0,56 sebagai target S1), serta dimensi intervensi merupakan asumsi, bukan hasil pengukuran. Perhitungan skrining menghasilkan volume limpasan 103.680 m³ untuk S0 dan 80.640 m³ untuk S1, atau penurunan sebesar 22,2%, dengan debit puncak masing-masing 14,41 dan 11,21 m³/detik. Nilai tersebut bukan keluaran simulasi EPA SWMM. Kapasitas tampungan geometris diperkirakan sebesar 14.150 m³ atau 13,6% dari limpasan S0, sehingga target penurunan tersebut masih perlu diverifikasi melalui simulasi. Studi ini juga menjelaskan konfigurasi SWMM yang diperlukan serta implikasinya bagi perencanaan, regulasi, pembiayaan, pemeliharaan, dan tanggung jawab kelembagaan.

Kata Kunci: Infrastruktur Hijau; Ketahanan Banjir; Manajemen Air Hujan; Model Skrining

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INTRODUCTION

Rapid urbanization in Indonesian cities has often outpaced the capacity of existing drainage systems. Flood-risk modelling for Jakarta has shown that future risk is strongly influenced by land-use trajectories (Budiyono et al., 2016), while Bandar Lampung faces comparable pressures. Recent GIS-based research has mapped flood vulnerability in the city to support the prioritization of adaptive infrastructure, including floodable parks (Hutriani et al., 2026). Previous studies by the authors in the region have assessed urban drainage performance using a flood resilience index (Putra & Fatkhurrozi, 2026), examined the effects of urbanization on flow response in a small catchment (Putra et al., 2026), and analyzed the destructive power of surface flow during a flash flood in the Way Kuripan sub-basin using forensic hydrology (Putra & Ulya, 2026). Channel-based responses alone are increasingly regarded as insufficient, and the literature has progressively shifted from flood control toward flood resilience (Wang et al., 2022).

Low Impact Development (LID), sponge-city, and water-sensitive approaches seek to restore infiltration and storage close to where rainfall occurs (Chan et al., 2018; Eckart et al., 2017). Modelling studies indicate that their performance depends on storm characteristics and the manner in which interventions are implemented (Ekmekcioglu et al., 2021; Yang et al., 2020), while the spatial allocation of measures has itself become an important research topic (Zhang & Chui, 2018). However, much of the available evidence originates outside humid tropical contexts, hydrological studies often treat land use as fixed, and implementation may be constrained by governance barriers such as unclear institutional responsibility and limited funding (Qiao et al., 2018).

This study therefore documents a screening-level framework for evaluating landscape architectural and urban design interventions using hydrological indicators. The framework is applied to a hypothetical 120-hectare mixed-use catchment situated in the Kali Balau Kencana area of Kedamaian District, Bandar Lampung. Building footprints, roofs, setbacks, and plots are assumed to remain unchanged; accordingly, the term “architectural” refers to site-scale interventions involving open space, streets, and pavements.

The study addresses three research questions: (1) What assumptions define the existing-condition scenario? (2) What reductions in runoff volume and peak discharge are implied by screening calculations for a combined package of five interventions, and how plausible are these reductions given the intervention geometry? (3) What parameters, SWMM representations, and verification

steps are required to validate the framework, and what are the implications for infrastructure policy and management? The contribution of the study lies in providing a transparent record of assumptions, calculations, and verification requirements, together with their policy implications. The catchment is hypothetical, the parameters are assumed, and no EPA SWMM outputs, flood extents, or flood depths are reported.

THEORETICAL FRAMEWORK

Urban Hydrology and Flood Risk

The replacement of pervious surfaces with impervious cover increases runoff volume and peak discharge while shortening the time to peak. Urban pluvial flood prediction encompasses empirical methods, one-dimensional drainage models, and two-dimensional hydrodynamic models, which differ in their data requirements and ability to represent surface flow (Bates, 2022; Bulti & Abebe, 2020). GIS-based susceptibility maps, such as the weighted-overlay approach applied in Bandar Lampung (Hutriani et al., 2026), identify areas that are more likely to experience flooding but generally treat the built environment as static. Thus, scenario-based simulation is needed to examine how design changes may alter runoff behavior.

Land use should also be understood as a planning variable rather than merely a fixed model input. Future flood risk in Jakarta, for example, has been shown to depend strongly on land-use trajectories (Budiyono et al., 2016). Forensic hydrology and drainage-performance studies conducted in Lampung (Putra & Fatkhurrozi, 2026; Putra et al., 2026; Putra & Ulya, 2026) provide the regional context for the present study.

The concept of urban resilience is used inconsistently and requires clarification regarding resilience for whom and resilience to what (Meerow et al., 2016). In flood research, a broader shift from flood control toward flood resilience has been documented (Wang et al., 2022). The indicators used in this study—runoff volume, peak discharge, and runoff coefficient—represent only the physical-hazard dimension of resilience. They do not measure flood extent, flood depth, recovery capacity, social vulnerability, or institutional capacity.

Landscape Architecture and Green Infrastructure Measures

Rain gardens, vegetated swales, permeable pavement, retention ponds, and green corridors can increase infiltration, slow runoff conveyance, or store stormwater close to its source (Eckart et al., 2017). In a calibrated SWMM study of an Istanbul watershed, combinations of green roofs and permeable pavement reduced peak flow and runoff volume more effectively than individual measures, with a maximum reported runoff reduction of 56.02% for a 10-year storm (Ekmekcioglu et al., 2021). A long-term SWMM study in Dresden found that performance was influenced mainly by the duration of the precipitation scenario and the implementation scheme (Yang et al., 2020).

Reported reductions therefore cannot be interpreted independently of storm characteristics, the proportion of the catchment treated, and the way interventions are represented in the model. For this reason, the present study explicitly reports these inputs. Spatial layout is itself a design decision with hydrological consequences (Zhang & Chui, 2018), while infiltration-based measures are also sensitive to soil conditions and maintenance practices (Blecken et al., 2017). Such measures should therefore be understood as complements to, rather than replacements for, conventional drainage infrastructure.

Policy, Governance, and Management

A review of 44 studies identified unclear leadership and institutional responsibilities, inadequate funding and cost information, limited space and knowledge, the absence of uniform guidelines, and insufficient stakeholder participation as major governance barriers to sustainable stormwater management (Qiao et al., 2018). China's Sponge City experience highlights the urgency of land-use guidance and assessment tools that incorporate flood-risk considerations (Chan et al., 2018; Griffiths et al., 2020; Jiang et al., 2018). Stormwater policy has also been described as requiring a broader paradigm shift in which costly interventions are treated as more than purely economic problems (Novaes & Marques, 2022).

In Indonesia, urban drainage is regulated through Ministry of Public Works regulations (Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2014). The Spatial Planning Law requires at least 30% of an urban area to be designated as green open space (Republik Indonesia, 2007), while further technical provisions are established through regulations of the Ministry of Agrarian Affairs and Spatial Planning/ National Land Agency. These instruments establish area-based and institutional requirements but do not specify hydrological performance targets at the individual-site level.

Against this background, three gaps remain. First, transparent and reproducible reporting of intervention parameters and model inputs for site-scale designs in Indonesian secondary cities remains limited. Second, the relationship between hydrological indicators and landscape architectural decisions is not always made explicit. Third, greater attention is needed to how hydrological evidence can inform planning approval, financing, maintenance, and institutional arrangements.

METHODOLOGY

Research Setting and Hypothetical Catchment

The geographic and flood-history context of the study is the Kali Balau Kencana area in Kedamaian District, Bandar Lampung, Indonesia (Figure 1). The analysis, however, is applied to a hypothetical 120-hectare mixed-use catchment. Its boundary has not been delineated from a Digital Elevation Model (DEM), and its land-cover proportions have not been verified using GIS analysis or field surveys.

Flooding affecting Kedamaian District has been reported by the regional disaster management agency (BPBD). For example, 37 flood points were reported across Bandar Lampung, including Kedamaian, following heavy rainfall in early March 2026 (Ardiansyah, 2026), while flooding was also reported in 16 subdistricts of the city, including Kedamaian, on 14 April 2026 (Hadiyatna, 2026). These reports establish the flood context at the district level but do not provide catchment-scale inundation extents, flood depths, or water levels and therefore cannot be used for model validation. The hypothetical catchment is not intended to represent Bandar Lampung as a whole, and the results cannot be transferred directly to a real catchment without rerunning the analysis using surveyed and spatially verified inputs.



Figure 1. Conceptual illustration of the hypothetical 120-ha catchment in the Kali Balau Kencana setting. The catchment boundary, drainage network, outlets, flood points, and land-cover patterns are illustrative. They were not delineated from a DEM or derived from GIS data or field surveys and do not represent measured conditions.

The assumed land-cover composition consists of 68% built-up area (81.6 ha), 18% green open space (21.6 ha), and 14% roads and road surfaces (16.8 ha), as presented in Table 1. These proportions are screening assumptions and must remain mutually exclusive in the final model. In a fully specified model, roofs, yards, roads, and open spaces should be represented separately according to their runoff characteristics. Green open space should not be assumed to be permeable because compacted or paved portions may also generate runoff. Elevation, slope, soil group, and drainage dimensions have not yet been determined and require DEM data, soil information, and a drainage survey.

Table 1. Assumed characteristics of the hypothetical catchment (scenario S0)

Parameter	Value	Status
Total area	120 ha (1,200,000 m²)	Design value for the hypothetical catchment
Geographic context	Kali Balau Kencana	Context only; boundary not delineated
Built-up area	68% (81.6 ha)	Assumed; to be verified by GIS
Green open space	18% (21.6 ha)	Assumed; permeable share not yet determined
Roads and road surfaces	14% (16.8 ha)	Assumed; to be verified by GIS
Elevation and slope	Not yet determined	Requires DEM and catchment delineation
Soil / hydrologic soil group	Not yet determined	Requires soil data or infiltration testing
Drainage network	Not yet determined	Requires field survey or agency data

Research Design

This study adopts a design-oriented, screening-level approach that combines simple hydrological calculations with a documented EPA SWMM configuration. The research framework (Figure 2) comprises six stages: (1) definition of rainfall assumptions; (2) hydrological characterization of the existing condition; (3) definition of flood-hazard indicators; (4) spatial analysis of land cover and built form; (5) formulation of the design strategy; and (6) evaluation of the proposed design.

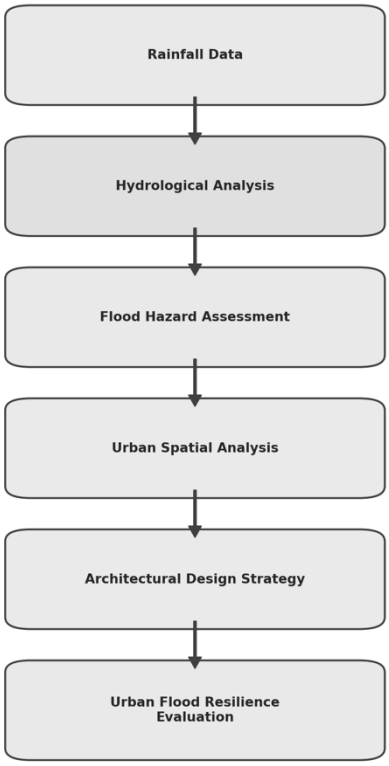


Figure 2. Research framework integrating hydrological analysis and architectural planning

Two scenarios are compared using the same rainfall assumptions, catchment boundary, and boundary conditions. Scenario S0 represents a conceptual existing condition based on the assumed land cover and drainage network, while Scenario S1 represents an integrated design in which rain gardens, bioswales, permeable pavement, a retention pond, and green corridors are implemented together. The comparison is intended to assess the potential performance of the combined intervention package. It does not isolate the contribution of individual measures, and no alternative spatial layouts are compared.

Rainfall Assumptions

The target design storm has a return period of 10 years, corresponding to an annual exceedance probability of 10%. This does not imply that flooding will occur exactly once every 10 years. A return period alone does not define a design storm because a location-specific Intensity–Duration–Frequency (IDF) relationship must also be derived from rainfall records. Such rainfall records have not yet been selected for this study.

For illustrative screening calculations, a total rainfall depth of 120 mm over 120 minutes is assumed, corresponding to an average intensity of 60 mm/h, as shown in Equation 1. This value is illustrative and must not be interpreted as a verified 10-year design rainfall.

$$i_{avg} = P / t = 120 \text{ mm} / 2 \text{ h} = 60 \text{ mm/h} \quad \text{(Equation 1)}$$

For subsequent SWMM implementation, rainfall is intended to be entered as a 10-minute time series using an alternating-block distribution constructed from a location-specific IDF curve. The average intensity used in the screening calculation should not be confused with the peak rainfall intensity represented within the design hyetograph.

EPA SWMM Configuration

EPA SWMM represents a catchment as a system of subcatchments and computes runoff before routing flow through drainage networks and storage elements. Table 2

presents the initial model configuration proposed for S0 and S1. The roughness and depression-storage values are initial values for model testing rather than field measurements. Similarly, Green–Ampt infiltration parameters, including saturated hydraulic conductivity, suction head, and initial moisture deficit, should not be assigned arbitrarily. They must be derived from the hydrologic soil group, field testing, or traceable technical sources. The model has not yet been executed, and no calibration or validation has been performed.

Table 2. Rainfall and initial EPA SWMM configuration for S0 and S1

Item	Initial Value	Status/Note
Model	EPA SWMM	Not yet executed
Target return period and duration	10 years; 120 minutes	Design target; return period requires IDF analysis
Illustrative rainfall	120 mm; mean intensity 60 mm/h	Illustrative assumption, not an IDF-derived value
Rainfall time series	10-minute interval; alternating-block method	To be constructed from the IDF curve
Sub-catchments	Total area of 120 ha divided into several sub-catchments	Avoid double counting areas converted to LID
Manning's *n*, impervious/ vegetated surfaces	0.013/0.15	Initial values; Sensitivity analysis required
Depression storage, impervious/pervious surfaces	1.5 mm/5 mm	Initial values
Infiltration method	Green–Ampt	Soil parameters pending
Routing	Dynamic wave	Selected for drainage-network analysis
Outfall condition	Free outfall	Assumption; should be checked against downstream conditions
Reporting/routing time step	5 min/maximum 30 s	Numerical stability should be checked; reduce if necessary
Calibration and validation	Not performed	Requires observed rainfall, discharge, or flood data

Intervention Design Parameters

Scenario S1 combines five interventions whose initial design parameters are presented in Table 3. These dimensions are conceptual design values for model development and do not represent surveyed conditions. The combined footprint of the five interventions is approximately 6.7 ha, equivalent to about 5.6% of the catchment, when the bioswale footprint is calculated using its 4.5-m top width. Building footprints, roofs, setbacks, and plots are assumed to remain unchanged between S0 and S1.

Meanwhile, Table 4 compares the principal model inputs for S0 and S1. The area, storage, and infiltration characteristics of each intervention must be assigned to clearly defined subcatchments to ensure that areas converted to LID are not counted again as additional infiltration areas.

Table 3. Initial design parameters of the proposed interventions (S1; conceptual values pending survey)

Intervention	Design Parameters	Representation in SWMM	Geometric Storage
Rain gardens	Total area: 1.2 ha; surface ponding depth: 0.15 m	LID control: bioretention cell	1,800 m³ (12,000 m² × 0.15 m)
Bioswales	Total length: 1,500 m; bottom width: 1.5 m; total depth: 0.5 m; side slope: 3H:1V; top width: 4.5 m	Vegetated channel and/or LID swale	2,250 m³ at full depth (1.5 m² × 1,500 m; before freeboard)
Permeable pavement	Area: 2 ha; aggregate layer: 0.30 m; assumed void ratio: 0.35	LID control: permeable pavement	2,100 m³ pore capacity (20,000 m² × 0.30 m × 0.35)
Retention pond	Design water-surface area: 0.8 ha; effective depth: 1.0 m	Storage unit with elevation–volume curve and outlet	8,000 m³ (8,000 m² × 1.0 m)
Green corridors	2 ha of additional permeable area	Permeable sub-catchment and connected flow path	Not applicable
Total computed storage			14,150 m³ (geometric capacity before accounting for dead volume, initial saturation, and freeboard)

Table 4. Comparison of main model inputs for S0 and S1

Model Input	S0: Existing	S1: Proposed	Changed?
Rainfall and catchment boundary	Same	Same	No
Outfall condition	Free outfall	Free outfall	No
Land cover	68% built-up; 18% green open space; 14% roads	Sub-catchments redefined to accommodate approximately 6.7 ha of interventions	Yes
Runoff coefficient (screening only)	0.72 (assumed)	0.56 (target assumption, not a model output)	Yes
Surface storage facilities	None assumed	14,150 m³ geometric capacity (Table 3)	Yes
Infiltration and surface parameters	Base values	LID parameters according to Table 3	Yes
Drainage network	Base network	Same dimensions, roughness, elevations, and outlet as S0; any enlargement would constitute a separate scenario	No

Screening Calculations and Indicators

Rainfall volume over the catchment is $V_P = (P/1000)\ A$ (Equation 2). Screening runoff volume is $V_R = C\ V_P$ (Equation 3), where C is the assumed runoff coefficient. Peak discharge is estimated with the rational method, $Q_p = 0.00278\ C\ i\ A$ (Equation 4), with Q_p in m³/s, i in mm/h, and A in ha. The relative change of an indicator is $R_X = (X_{S0} - X_{S1})/X_{S0} \times 100\%$ (Equation 5). Because (C) is assumed, the rational-method estimate serves only as a screening-level plausibility check. The mean rainfall

intensity over two hours is not necessarily the appropriate design intensity for the catchment time of concentration, and the rational method does not explicitly represent storage or routing. For indicators subsequently generated by the model, such as runoff volume and peak discharge at the outlet, the same relative-change equation should be applied using identical indicator definitions for both scenarios.

Flooded area and flood depth are not calculated in this study because their estimation requires an appropriate surface-flow or hydraulic modelling framework and a spatial mapping method; outlet discharge from SWMM alone does not provide these quantities.

RESULTS

Rainfall Volume and Screening Runoff

With the illustrative rainfall of 120 mm and a catchment area of 1,200,000 m², the rainfall volume is $V_P = 0.12 \times 1{,}200{,}000 = 144{,}000$ m³ in both scenarios. With the assumed coefficients, the screening runoff volume is 103,680 m³ for S0 (C = 0.72) and 80,640 m³ for S1 (C = 0.56). The difference is 23,040 m³, a reduction of 22.2% (Table 5).

Rational-Method Peak Discharge

With the average intensity of 60 mm/h, A = 120 ha, and the same coefficients, the rational-method peak discharge is about 14.41 m³/s for S0 and 11.21 m³/s for S1, a reduction of 22.2% (Table 5). This equals the reduction in C by construction, because only C differs between the two calculations. It is therefore not independent evidence that the interventions reduce the peak. It is a check that the assumed coefficients lead to values of a reasonable order of magnitude.

Table 5. Screening results (assumption-based calculations)

Indicator	S0: Existing	S1: Proposed	Change
Rainfall volume (m³)	144,000	144,000	—
Runoff coefficient (assumed)	0.72	0.56	−22.2%
Screening runoff volume (m³)	103,680	80,640	−22.2%
Rational-method peak discharge (m³/s)	14.41	11.21	−22.2%

Note: Values are calculated from assumed runoff coefficients and illustrative rainfall. They are not outputs of an executed EPA SWMM simulation. Flood extent and flood depth were not calculated.

Plausibility Check of the Assumed Reduction

The geometric storage capacities in Table 3 comprise 1,800 m³ for rain gardens, 2,250 m³ for bioswales at full depth, 2,100 m³ of pore capacity within the permeable-pavement aggregate layer, and 8,000 m³ for the retention pond, resulting in a total geometric storage capacity of 14,150 m³. This capacity is equivalent to approximately 13.6% of the S0 screening runoff volume of 103,680 m³ and +/- 9.8% of the total rainfall volume.

These values represent geometric capacities rather than effective stormwater-retention volumes. Storage elements may not fill completely, while inflow and outflow during the storm may increase their effective contribution to runoff management. Conversely, initial saturation, dead storage, and freeboard may reduce usable capacity. The comparison therefore should not be interpreted as a direct measure of intervention effectiveness. Additional runoff reduction may also occur through infiltration associated with rain gardens, permeable pavement, bioswales, and green corridors.

The combined intervention footprint is approximately 6.7 ha, or 5.6% of the catchment. Because the calculated geometric storage alone is smaller than the 22.2% screening reduction target, whether an effective runoff coefficient equivalent to 0.56 can be achieved depends on the contributing area treated, infiltration characteristics, storage behavior, and runoff routing. These relationships can only be evaluated through the proposed SWMM simulation.

The value of 0.56 should be retained as a scenario target to be tested rather than treated as an achieved performance value. If subsequent modelling does not produce the targeted reduction, the actual model result should be reported or the intervention dimensions revised; the target value should not be imposed on the simulation results.

Mechanisms and Conceptual Layout

Figure 3 presents the conceptual layout, while Figure 4 shows the typical intervention sections using the dimensions specified in Table 3. Runoff from built-up areas is conceptually intercepted by rain gardens, conveyed through bioswales and permeable surfaces, and directed toward the retention pond before entering the main drainage system. Rain gardens and permeable pavement provide infiltration and shallow storage, bioswales provide slower conveyance combined with infiltration, the retention pond provides temporary storage with a controlled outlet, and green corridors increase permeable area and hydrological connectivity. The quantitative contribution of each intervention has not been assessed separately.

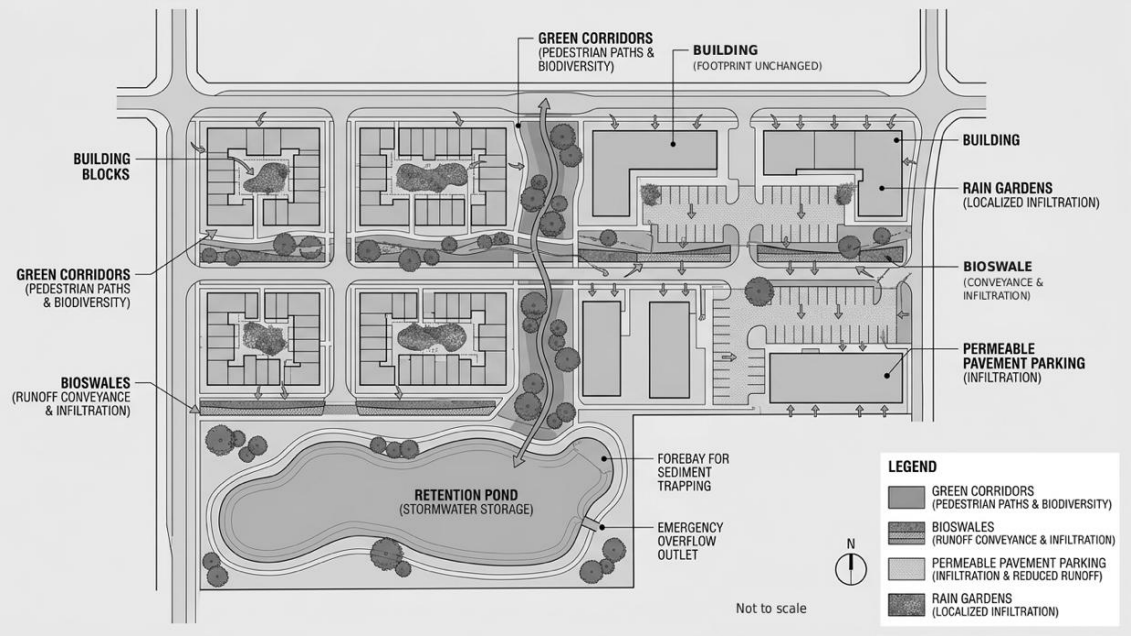


Figure 3. Conceptual plan of the integrated design scenario (S1), showing building blocks with unchanged footprints, rain gardens, bioswales, permeable-pavement parking areas, green corridors, and a retention pond with a forebay and emergency overflow outlet. The figure is schematic and not to scale; the layout is illustrative, and the design parameters correspond to those listed in Table 3.

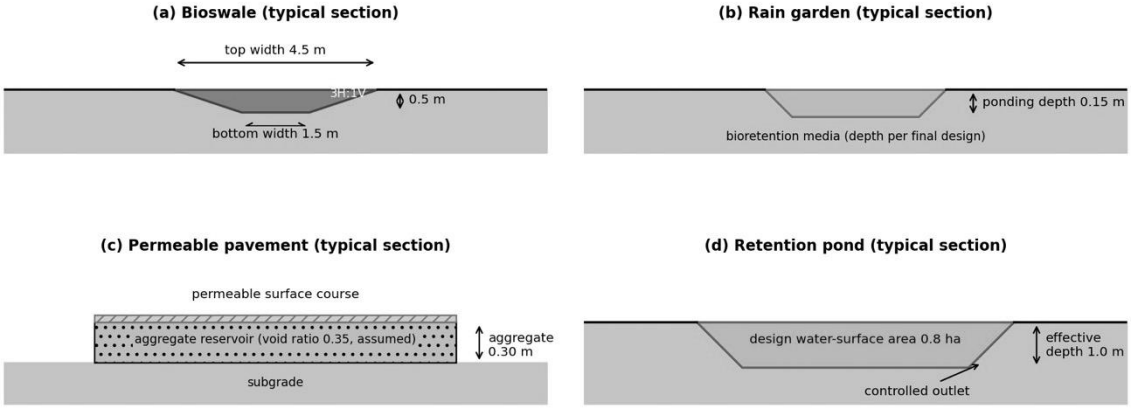


Figure 4. Conceptual typical sections of (a) a bioswale, (b) a rain garden, (c) permeable pavement, and (d) a retention pond, showing only the dimensions specified in Table 3.

ANALYSIS

Interpretation of the Screening Results

The screening calculations show the implications of the assumed runoff coefficients: a 22.2% reduction in both runoff volume and rational-method peak discharge, from 103,680 to 80,640 m³ and from 14.41 to 11.21 m³/s, respectively. These calculations do not demonstrate that the proposed interventions will achieve these reductions.

The plausibility check shows that the total geometric storage capacity, 14,150 m³, is equivalent to approximately 13.6% of the S0 screening runoff volume, which is lower than the 22.2% reduction target. Achieving the target therefore depends on whether infiltration, storage behavior, contributing area, and routing effects are sufficient, which must be evaluated through model execution. Studies using executed and calibrated SWMM models have shown that intervention performance varies according to storm characteristics and implementation configuration (Ekmekcioglu et al., 2021; Yang et al., 2020). Accordingly, the magnitude of runoff reduction for the hypothetical catchment cannot be established from the present screening analysis or compared directly with those studies until the model has been executed.

Spatial Configuration and the Contribution of Individual Interventions

Only one conceptual layout is considered, and the five interventions are evaluated as a combined package. The study therefore cannot determine the individual contribution of each intervention, demonstrate that one spatial configuration performs better than another, or rank the measures by hydrological effectiveness. Assessing spatial-allocation effects would require comparison of alternative configurations with equivalent total intervention area and storage capacity, consistent with the allocation approaches reviewed by Zhang and Chui (2018).

The performance of infiltration-based measures also depends strongly on local soil permeability and may decline because of clogging or inadequate maintenance (Blecken et al., 2017). By contrast, the effectiveness of the retention pond is less directly dependent on soil infiltration characteristics, which supports the importance of preserving space for stormwater storage in dense urban catchments. Potential co-benefits, including shade, pedestrian connectivity, amenity value, and other urban-design benefits, were not evaluated in this study.

Implications for Infrastructure Policy and Management

The framework suggests several policy and management proposals for further consideration, summarized in Table 6. These proposals should not be interpreted as recommendations validated by simulation results because the proposed SWMM model has not yet been executed.

Spatial planning and development approval

Existing area-based green-space requirements (Republik Indonesia, 2007; Kementerian Agraria dan Tata Ruang/Badan Pertanahan Nasional, 2022) do not directly indicate the hydrological response of individual development sites. In the present screening scenario, for instance, the assumed baseline includes 18% green open space while adopting a runoff coefficient of 0.72.

Detailed spatial plans (*Rencana Detail Tata Ruang* [RDTR]) could therefore consider incorporating site-level hydrological performance criteria, such as a maximum allowable peak runoff or runoff coefficient for a specified design storm. Larger developments could also be required to submit standardized hydrological performance statements for technical review. This approach is consistent with Sponge City practices that integrate flood-risk assessment into land-use management (Chan et al., 2018) and responds to the lack of uniform guidelines identified by Qiao et al. (2018).

Drainage regulation and infrastructure planning

Urban drainage regulation (Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2014) provides a framework for drainage master planning and institutional responsibilities. Distributed stormwater measures could be explicitly incorporated into drainage master plans, with their assumed storage and infiltration functions clearly documented.

Public land could also be reserved for retention storage in low-lying areas of dense catchments. Because the screening calculation for S1 still implies approximately 11.21 m^3/s of peak discharge requiring conveyance, source-control measures should be treated as complements to, rather than substitutes for, adequate channel and outfall capacity.

Financing, maintenance, and institutional responsibility

Inadequate funding, limited cost information, and unclear institutional leadership are recurring barriers to sustainable stormwater management (Qiao et al., 2018; Novaes & Marques, 2022). Because this study does not estimate intervention costs, local pilot data are required before capital and recurrent expenditure can be evaluated. Both initial construction costs and long-term operation and maintenance costs should be considered. Poor maintenance is a common cause of declining infiltration performance (Blecken et al., 2017); therefore, any implementation framework should specify inspection intervals, maintenance tasks such as sediment and litter removal and clogging assessment, responsible parties, and monitoring indicators.

Responsibility for an integrated intervention package is likely to be distributed across public works agencies, spatial-planning and building-approval units, disaster-management authorities, and property owners or community groups. Clear designation of a lead institution, together with formal handover, maintenance, and inspection procedures, would therefore be important for long-term implementation.

Table 6. Proposed policy and management implications

Policy Area	Proposed Action	Indicative Actors	Management Consideration
Spatial planning	Add site-level hydrological performance criteria, such as maximum peak runoff or runoff coefficient for a specified design storm, to RDTR requirements alongside green-open-space ratios	Spatial-planning agency; city public works	Define the design storm and calculation method; establish compliance monitoring
Development approval	Require a standardized hydrological performance statement for larger developments	Building-approval and permitting units	Develop technical guidance and review checklists; strengthen reviewer capacity
Stormwater regulation/ drainage planning	Recognize distributed measures and their assumed storage and infiltration capacities in drainage master plans	City public works; river-basin authority	Coordinate source-control measures with primary drainage capacity
Infrastructure planning	Reserve public land for retention storage in low-lying areas of dense catchments	Spatial planning; public works	Land availability may be a major constraint (Hutriani et al., 2026; Qiao et al., 2018)
Financing	Budget for capital and recurrent costs and assess potential incentive or fee mechanisms	City government; finance agency	Collect local cost data; cost–benefit analysis remains future work
Maintenance and long-term management	Establish maintenance plans specifying tasks, frequencies, responsible parties, and monitoring indicators	Lead agency; owners/ communities	Inadequate maintenance can reduce infiltration performance (Blecken et al., 2017)

Limitations and Uncertainty

The assumptions concerning catchment characteristics, storage, soil parameters, and intervention materials are documented in Tables 1–4 together with their current status. The limitations discussed here concern aspects that remain outside the present analysis.

The catchment is hypothetical, and its land cover, rainfall, runoff coefficients, and intervention dimensions remain unverified assumptions. The reported results are screening calculations rather than outputs from an executed EPA SWMM model. Accordingly, no calibration, validation, or sensitivity analysis has been performed, and flood extent and flood depth have not been calculated either.

Only one illustrative rainfall event with an unverified return period was used. Potential effects of climate change, clogging, and intervention costs were not considered. The authors evaluated the five interventions as a combined package using a single conceptual layout, so they cannot determine their individual contributions or the effects of alternative spatial configurations. Governance and institutional issues were discussed qualitatively rather than evaluated empirically.

Further work should delineate the catchment using a DEM and verify its land-cover characteristics; derive the 10-year design storm from a location-specific IDF analysis; obtain soil, infiltration, and drainage-network data; execute and evaluate S0 and S1 in EPA SWMM; undertake calibration, validation, and sensitivity analysis using appropriate

observations; incorporate a surface-flow or hydraulic model if flood extent is to be estimated; and test individual interventions and alternative layouts separately.

CONCLUSION

This paper presents a screening-level framework for evaluating landscape architectural and urban design interventions using hydrological indicators, applied to a hypothetical 120-hectare catchment in Kali Balau Kencana, Bandar Lampung. Under the assumed land-cover conditions, an illustrative rainfall event of 120 mm over 120 minutes, and assumed runoff coefficients of 0.72 for S0 and 0.56 for S1, the screening runoff volume decreases from 103,680 to 80,640 m³. In contrast, the rational-method peak discharge decreases from 14.41 to 11.21 m³/s. Both represent an assumed 22.2% reduction.

These values are derived directly from the assumed runoff coefficients and are not simulation outputs. The combined geometric storage capacity of the proposed interventions is approximately 13.6% of the S0 screening runoff volume. Therefore, achievement of the 22.2% reduction target depends on infiltration, storage behavior, contributing area, and routing and must be tested through an executed and verified EPA SWMM model. Flood extent, flood depth, individual intervention contributions, and alternative spatial configurations were not assessed.

For infrastructure policy and management, the framework suggests that area-based green-space requirements could be complemented by site-level hydrological performance criteria, standard hydrological performance statements could be incorporated into development approval, source-control measures could be recognized explicitly in drainage planning, and institutional responsibility, financing, and maintenance arrangements should be clearly defined.

Future work should apply the framework to a delineated and surveyed catchment, derive the design storm from location-specific IDF analysis, execute and validate the SWMM model, test interventions individually and under alternative layouts, and incorporate cost and governance analysis.

DATA AVAILABILITY

The conceptual model parameters and preliminary screening calculations are documented in this manuscript. The rainfall inputs, catchment data, and model files required for a reproducible EPA SWMM simulation have not yet been finalized because the model has not yet been implemented using verified site-specific data. The availability of completed model files and supporting datasets should therefore be specified only after model implementation and verification.

ABOUT THE AUTHORS

Muhammad Hakiem Sedo Putra is affiliated with the Integrated Water Resources Management Engineering Study Program, Faculty of Infrastructure and Regional Technology, Institut Teknologi Sumatera (ITERA), Indonesia. His research interests include, but are not limited to, urban hydrology, stormwater management, and flood-risk mitigation in rapidly urbanizing catchments. He can be contacted at muhammad.sedo@tka.itera.ac.id.

Hendi Warlika Sedo Putra is affiliated with the Department of Building Architecture, Department of Civil Engineering, State Polytechnic of Sriwijaya, Palembang, South Sumatra, Indonesia. His research mainly focuses on the issues and policies of sustainable urban design, water-sensitive architecture, and the integration of green infrastructure into urban planning practice.

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