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# Benefit-Cost Analysis of Bioretention for Suburban Drainage Load Reduction Induced by Surface Runoff

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**A B S T R A C T**

Suburban areas with predominantly residential land use and low soil infiltration rates are highly vulnerable to surface runoff and local flooding. This study examines the effectiveness and economic performance of bioretention systems as a runoff management solution in the Wonojati and Jenggawah areas, Jember Regency. Hydrological simulations were conducted using SWMM 5.2 software for two intervention scenarios, namely the application of bioretention in 10% and 20% of the subcatchment areas. The effectiveness of the system was evaluated based on runoff volume reduction, while the economic aspect was assessed using the Benefit-Cost Ratio (BCR) approach. The simulation results showed that the system reduced runoff by 13.6% in Plan 1 and 17.4% in Plan 2. However, BCR values of 0.014 and 0.022, respectively, indicate that the annual financial benefits are not sufficient to cover the system's annualized costs. These findings highlight the need for alternative approaches that are more economically efficient. The use of decentralized LID systems such as rain barrels is considered more adaptive for dense residential areas and is recommended as a complementary solution to enhance the resilience of drainage systems in flood-prone suburban regions.

## 1. Introduction

Flooding is a recurring problem in suburban areas, especially in areas that have experienced land conversion from green areas to settlements [1], [2]. One of these phenomena occurred in Griya Wonojati Indah Housing, Wonojati Village, Jenggawah District, Jember Regency, where heavy rainfall caused stormwater channels to overflow, inundating roads and residential properties [3]. Similar incidents also often occur at other points in the Wonojati and Jenggawah areas, such as in front of markets, petrol stations, and around the Sub-district Office [4]. Although several drainage channels have been widened and routine community clean-up activities have been conducted, conventional systems remain inadequate to handle the high

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runoff volume during intense rainfall events [5], [6]. This problem is exacerbated by the high rate of population growth and the increasing extent of watertight land, which leads to an increase in peak discharge and surface flow volume. Traditional drainage systems that rely solely on quickly conveying water to the main channels are often not adaptive enough to cope with the rising frequency of extreme rainfall [7].

In this context, the concept of Low Impact Development (LID) is one of the increasingly relevant approaches, including through the application of bioretention. Bioretention systems work by holding, filtering, and infiltrating runoff water into the soil, thereby reducing surface runoff, alleviating pressure on drainage channels, and contributing to groundwater recharge, especially during high-intensity rainfall events [8]. Previous studies have shown that bioretention systems are effective in reducing runoff volumes as [9] reported that simulated bioretention setups retained between 43.33% and 93.84% of runoff volume. Similarly, [10] observed greater runoff volume reduction at the subbasin scale compared to the watershed scale. However, the implementation of LID in Indonesia, especially in small-scale residential areas, still faces several challenges, especially related to financing aspects. Although LID is theoretically more cost-effective than conventional drainage systems, in practice, the upfront cost of installing bioretention systems can be substantial, particularly in areas without dedicated flood management budgets. According to [11], in addition to requiring space, bioretention also requires planting media, gravel layers, and other additional construction that are quite expensive, in contrast to other LIDs such as rain barrels which only require containers. Studies suggest that the integration of green infrastructure into residential areas may increase construction costs, which in turn can influence housing prices and affordability. For instance, green infrastructure projects have been associated with rising property values and environmental gentrification, particularly in densely populated urban environments where green amenities are scarce and highly valued by the market [12].

In the midst of budget and infrastructure constraints faced by many residential areas, a Benefit Cost Ratio (BCR) is important as a basis for technical and economic decision-making in the implementation of a local-scale flood control system [13]. Therefore, evaluating the effectiveness of bioretention should consider not only the reduction in runoff volume but also its potential monetary benefits. In this context, this study examines the benefit-cost ratio of bioretention systems based on two application scenarios aimed at reducing runoff in drainage channel segments that have been identified as prone to overflow. This approach is intended to provide a more realistic and applicable assessment of the technical and economic performance of bioretention interventions in residential areas at risk of localized flooding. Thus, this study aims to evaluate the economic feasibility of implementing a bioretention system in reducing the load on drainage networks in the flood-prone areas of Jenggawah and Wonojati Villages.

## 2. Research Method

This research method describes the procedures and techniques used to evaluate the implementation potential of bioretention systems in flood-prone suburban residential areas. The approach used combines hydrological modeling with economic analysis based on BCR [14]. In general, the research process consists of three main stages, namely: (1) hydrological simulation using Storm Water Management Model (SWMM) software, (2) quantification of benefits and costs of two bioretention intervention scenarios, and (3) BCR calculation to assess the economic performance of each scenario. Two intervention scenarios were designed based on the availability of land in the study area, namely the application of bioretention in 10% of the subcatchment area (Plan 1) and 20% of the subcatchment area (Plan 2) as shown in Figure 1.

ISSN (Online) 2620-7222
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## 3. Description and Technical

### 3.1 Population and Samples

The drainage system model in the study area was constructed using SWMM 5.2 software developed by the U.S. EPA [1]. The model consists of 75 channels, 70 nodes, and three final disposal points, with a total network length of 9,705 meters, covering a catchment area of 72.12 hectares in the Wonojati and Jenggawah areas of Jember Regency. The study population included all subcatchments in the model. From this population, channel segments were determined as samples based on the presence of a history of overflow during the rainy season recorded in reports from residents and local media, observed inundations during field visits, and the results of the initial SWMM simulation which showed runoff discharge exceeding the capacity of the channel.

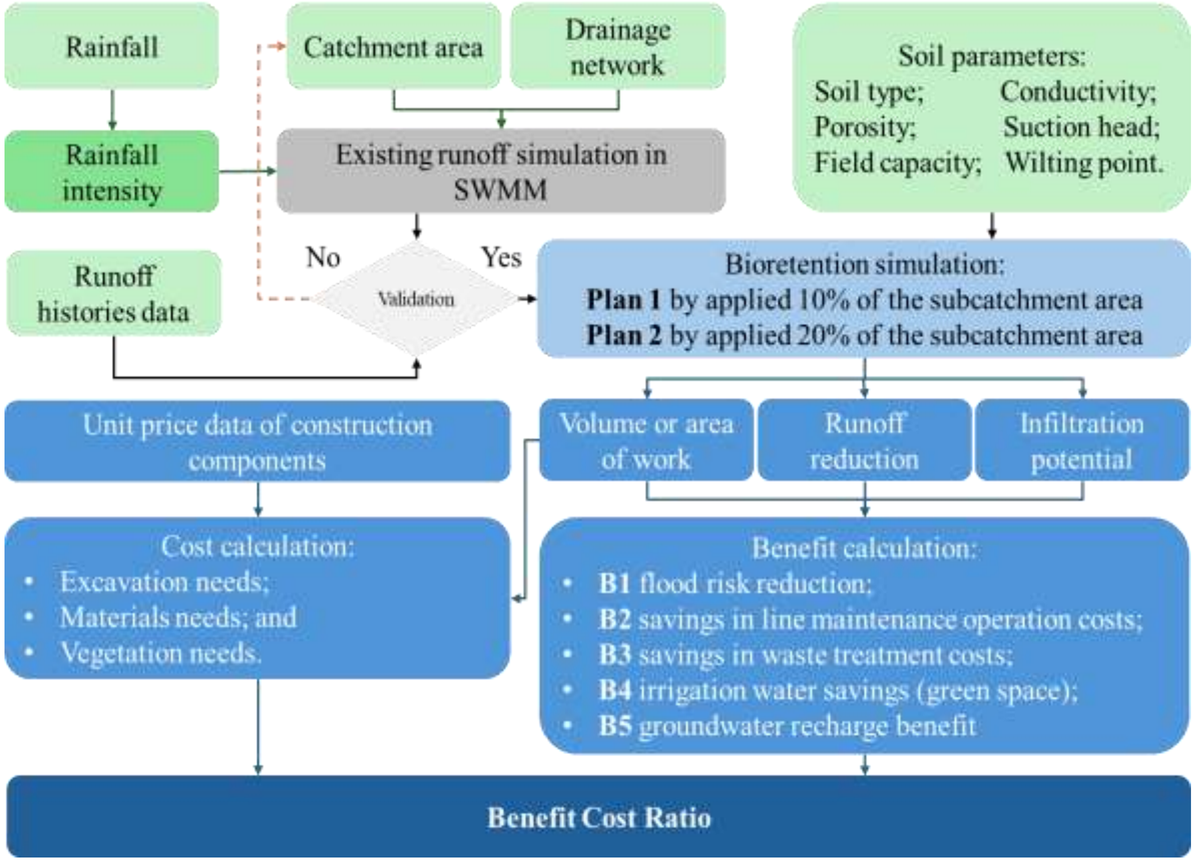


**Figure 1.** Research method

Source: Research data, 2025.

### 3.2 Sampling Techniques

Sample determination was carried out using a purposive sampling approach. The selected segments represent areas with the highest urgency for intervention, based on the frequency of historical overflows, evidence of significant inundation in the field, and hydrological simulation outputs indicating a high risk of overflow. Through this approach, the application of bioretention can be strategically focused on critical locations with the potential to significantly reduce runoff.

### 3.3 Definition of Variable Operations

The main variables in this study include hydrological and economic aspects. Runoff volume (Qv) in cubic meters ($m^3$) indicates the total amount of surface runoff that occurred in each subcatchment during a single rainfall event. Bioretention effectiveness was calculated

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based on the percentage reduction in Qv between existing conditions and each intervention scenario. Adopting the study of [14], five types of economic benefits (B1 to B5) were calculated using an annual financial value approach. The benefits of reducing flood risk (B1), calculated using the formula:

$$\mathrm{B1} = \mathrm{m} \times \mathrm{A} \times \left(\frac{\mathrm{j}(1+\mathrm{j})^{\mathrm{n}}}{(1+\mathrm{j})^{\mathrm{n}-1}}\right) \quad (1)$$

where m refers to the flood prevention charge-imposed amount (IDR/$m^2$), A refers to the actual area of stormwater reduction and utilization facilities implemented, j refers to the discount rate (%), and n refers to the service period of LID facilities (years).

In addition, the benefit of savings in line maintenance operation costs (B2) and the benefit of waste treatment costs (B3), calculated using the formula:

$$\mathrm{B2} = \mathrm{s} \times \mathrm{Qv} \quad (2)$$
$$\mathrm{B3} = p_s \times \mathrm{Qv} \quad (3)$$

where s refers to the Operation Cost per $m^3$ of stormwater (IDR/$m^3$), $p_s$ refers to the sewage treatment cost (IDR/$m^3$).

Meanwhile, the environmental benefit such as saving green space irrigation (B4) and the benefit of groundwater recharge (B5), calculated using the formula:

$$\mathrm{B4} = p_g \times V_g \times \mathrm{c} \quad (4)$$
$$\mathrm{B5} = p_b \times V_b \times \beta \quad (5)$$

where, $p_g$ refers to the price of irrigation water (IDR/$m^3$), $V_g$ refers to the amount of rainwater infiltration from the estimated result ($m^3$), c refers to the reduction of irrigation due to infiltration (%), $p_b$ refers to the groundwater price (IDR/$m^3$), $V_b$ refers to the infiltration increased amount from the estimated result ($m^3$), and β refers to the groundwater recharge coefficient.

The total initial investment cost (C) is calculated from all the physical components needed to build a bioretention system, calculated using the formula:

$$\mathrm{C} = \sum (V_i \; x \; h_i) \quad (6)$$

where $V_i$ is the volume or area of work, and $h_i$ is the unit price of each component of the work such as excavation, materials, and vegetation. This cost is then converted into an annual cost through the annualized cost method [15], calculated using the formula:

$$C_{annual} = \mathrm{C} \times \left(\frac{\mathrm{j}(1+\mathrm{j})^{\mathrm{n}}}{(1+\mathrm{j})^{\mathrm{n}-1}}\right) \quad (7)$$

This allows the cost to be proportional to the annual benefits.

### 3.4 Instrument Analysis Tool

Hydrological simulations were carried out in which the bioretention system is modeled through the LID Controls module with a configuration of four main layers, namely surface, soil, storage, and drain as shown in Table 1. The technical parameters of each layer were determined based on the results of field observations and adjusted to the characteristics of the study area and SWMM technical recommendations.

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**Table 1.** Bioretention system configuration in SWMM.

| Component | Parameters | Value | Unit |
|---|---|---|---|
| Surface | Berm height | 390 | mm |
| | Vegetation volume fraction | 0.2 | - |
| | Surface roughness (Manning's n) | 0.13 | - |
| | Surface slope | 0 | - |
| Soil | Thickness | 700 | mm |
| | Porosity (vol. fraction) | 0.453 | - |
| | Field capacity | 0.19 | - |
| | Wilting Point | 0.085 | - |
| | Conductivity | 0.43 | mm/h |
| | Conductivity slope | 55.4 | - |
| | Suction head | 4.33 | mm |
| Storage | Thickness | 300 | mm |
| | Void ratio | 0.75 | - |
| | Seepage rate | 0 | mm/h |
| | Clogging factor | 0 | - |
| Drain | Flow coefficient | 6.578 | - |
| | Flow exponent | 0.5 | - |
| | Offset | 13 | mm |
| | Open level | 0 | mm |
| | Closed level | 0 | mm |

Source: Research data, 2025.

Meanwhile, the economic analysis was conducted separately using spreadsheets. The calculation was based on the simulation results and local unit price data from the cost budget plan document or local technical references. The economic criteria and values used in the evaluation of benefits and costs as shown in Table 2.

**Table 2.** Economic criteria for bioretention implementation.

| Component | Unit | Value |
|---|---|---|
| s | IDR/m$^3$ | 164* |
| $p_s$ | IDR/m$^3$ | 2457* |
| $p_g$ | IDR/m$^3$ | 2294* |
| $V_g$ Plan 1 | m$^3$ | 2566.90** |
| $V_g$ Plan 2 | m$^3$ | 5133.70** |
| c | % | 40* |
| $p_b$ | IDR/m$^3$ | 2294* |
| $V_b$ Plan 1 | m$^3$ | 537.50** |
| $V_b$Plan 2 | m$^3$ | 1075** |
| β | % | 20* |
| Excavation of the soil | m$^3$ | 61272.79* |
| Structural wall brick installation | m$^2$ | 102722.04* |
| Structural wall stucco | m$^2$ | 43251.38* |
| Gravel fill | m$^3$ | 133522.27* |
| Soil plants fill | m$^3$ | 133522.27* |
| Plant planting | m$^2$ | 125986.04* |

Source: *[14] with 1 USD value conversion = 16383.10 IDR; and ** Research data, 2025.

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### 3.5 Data Analysis Techniques

Data analysis was carried out in two main stages. The first stage involved hydrological analysis to evaluate the effectiveness of the bioretention system by comparing Qv values under three conditions, namely no intervention (existing), Plan 1, and Plan 2. The simulation results of each scenario demonstrated the contribution of bioretention in reducing runoff. The second stage focused on economic analysis. By adopting the method from [16], the annual benefits of each scenario were calculated by summing B1 to B5 and were compared to the annual cost of constructing the system using BCR, calculated using the formula:

$$\mathrm{BCR} = \frac{B1+B2+B3+B4+B5}{C_{annual}} \quad (1)$$

The calculation is carried out based on the one-year rainfall re-period as the basis for calculating benefits, as represented in the SWMM model. A BCR value greater than 1 indicates economic viability, while a value less than 1 indicates that the intervention is not cost-effective under the given assumptions [17].

## 4. Results and Discussions

### 4.1 Bioretention Effectiveness

The results of hydrological simulations show that there are eight channel segments, namely Segment 1 to Segment 8, that are unable to accommodate rainwater runoff during high-intensity rainfall events. This inability is indicated by the flood volume values that exceed the capacity of the existing channels, as shown in Figure 2.

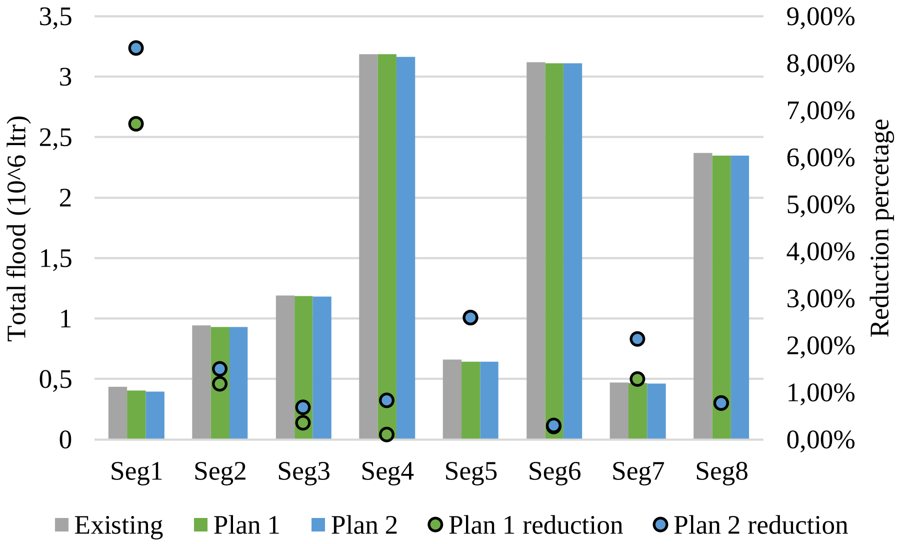


**Figure 2.** Effectiveness of bioretention in each channel segment.

Source: Research result, 2025.

The application of bioretention systems in two planning scenarios produced different impacts on hydrological load reduction. Plan 1 reduced the flood volume by 13.6 percent, while Plan 2 demonstrated increased effectiveness, reaching up to 17.4 percent. In detail, Segment 1 experienced the highest reduction in flood volume, with 6.70 percent in Plan 1 and 8.31 percent in Plan 2. In contrast, other segments showed relatively small reductions, ranging from 0.09 percent to 0.29 percent. These results indicate that the effectiveness of bioretention is strongly influenced by topographic conditions and the spatial location of each segment. Based on [10], bioretention performance dropped as bioretention areas became smaller, soil infiltration rates

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decreased, and precipitation depth increased. Thus, a broader scope of intervention generally provides a more significant impact on runoff reduction.

### 4.2 Estimated Benefit from Bioretention Implementation

The benefits of bioretention systems are categorized into five main components as shown in Table 3. The largest benefit component was obtained from B1, which represents the economic value of flood risk reduction as IDR 137,784,340 in Plan 1 and IDR 275,568,680 in Plan 2. Other benefits range from B2 to B5, although their contributions are smaller than B1. The total annual benefit in Plan 1 was IDR 144,658,423, while in Plan 2 it increased to IDR 286,302,677. The dominance of B1 in the benefit structure highlights that the bioretention system offers strategic value in reducing potential flood-related losses [10].

**Table 3.** Benefits of bioretention implementation.

| Component | Plan 1 (Rp) | Plan 2 (Rp) |
|---|---|---|
| B1 | 137,784,340 | 275,568,680 |
| B2 | 267,045 | 345,683 |
| B3 | 4,005,668 | 5,185,251 |
| B4 | 2,355,012 | 4,709,932 |
| B5 | 246,359 | 493,131 |
| Total | 144,658,423 | 286,302,677 |

Source: Research result, 2025.

### 4.3 Estimated Cost from Bioretention Implementation

The initial construction cost was calculated based on the volume of work and the local unit prices. The largest cost component was associated with vegetation planting and the filling of planting media and gravel, as shown in Table 4. The total investment cost in Plan 1 was IDR 25,624,928,911, and in Plan 2 was IDR 33,078,765,431. To make the cost comparable with annual benefits, it was converted into an equivalent annual cost using a 10 percent discount rate and a project benefit period of 3 years. As a result, Plan 1 incurred an annual cost of IDR 10,304,163,257, while Plan 2 reached IDR 13,301,461,266. Most of the costs were concentrated on substructure and vegetation components, which are essential to the effectiveness of the system [11].

**Table 4.** Costs of bioretention implementation.

| Component | Plan 1 (Rp) | Plan 2 (Rp) |
|---|---|---|
| Volume excavation | 6,142,401,526 | 12,284,803,051 |
| Structural wall brick | 539,591,908 | 1,079,183,816 |
| Structural wall stucco | 227,196,593 | 454,393,186 |
| Gravel fill | 2,888,887,726 | 5,777,775,451 |
| Soil plants fill | 6,740,738,026 | 13,481,476,053 |
| Plant planting | 9,086,113,133 | 1,133,874 |
| Cost (C) | 25,624,928,911 | 33,078,765,431 |

Source: Research result, 2025.

### 4.4 BCR Analysis

A BCR analysis was conducted to evaluate the economic performance of both intervention scenarios. The ratio was calculated by comparing the total annual benefit to the equivalent annual cost. Plan 1 yielded a BCR value of 0.014, while Plan 2 showed an increase to 0.022. Although both values remain below 1, the increase in Plan 2 indicates that larger-scale interventions may result in better economic efficiency.

In this study, the bioretention system was not designed to replace conventional drainage channels, but rather to complement them by helping reduce the flow load on existing

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infrastructure. By allowing a portion of the rainwater to infiltrate into the ground, the system lowers pressure on the drainage channels and potentially prevents local overflows. Therefore, although the BCR values do not yet reflect optimal financial feasibility, the implementation of this system remains relevant in supporting the sustainability of drainage networks, especially in areas where channel expansion is not feasible. In addition, non-financial benefits such as improved environmental quality, urban aesthetics, and the sustainability of water resources have not been quantitatively assessed but are believed to contribute significantly to the overall value of these interventions [18]–[20].

### 4.5 Strategic Implications and Potential Development of Alternative LIDs

The conditions of the study area indicate that LID systems have the potential to support the management of excessive runoff in existing drainage channels. The Wonojati and Jenggawah areas are suburban regions with relatively flat topography, predominantly occupied by residential development. The high proportion of built-up land makes these areas major contributors to surface runoff, especially during periods of high-intensity rainfall [21]. Hydrological factors, such as the soil's low infiltration capacity with a permeability rate of only 0.66 centimetres per hour, which is considered slow that further increase the potential for inundation. Record-high monthly rainfall levels at Jenggawah Station further underscore the area's vulnerability to localized flooding.

Although previous analyses have shown that bioretention systems contribute to reducing runoff volume, the results of the economic evaluation reveal that the financial benefits do not yet justify the associated costs. Therefore, more adaptive and economically efficient LID alternatives are needed, particularly for densely populated residential environments. Based on [11], one potential option is the use of rain barrels, which are rainwater storage systems installed on residential buildings. Rain barrels offer advantages such as low implementation cost, ease of installation, and a decentralized nature that allows for widespread adoption without reliance on large-scale infrastructure [22]. This system captures rainwater from rooftops, which would otherwise be discharged directly into drainage channels, thereby significantly reducing the hydrological burden on existing infrastructure [23].

Thus, effective runoff management in this region requires an approach that is not only technically sound but also socially and economically adaptive. Recommendations for integrating bioretention systems in strategic locations, complemented by the widespread adoption of other LID, may serve as a suitable policy direction to strengthen the resilience of drainage systems in suburban areas like Wonojati and Jenggawah.

## 5. Conclusion and Suggestion

### 5.1 Conclusion

The implementation of bioretention systems in the suburban areas of Wonojati and Jenggawah resulted in a relatively modest reduction in runoff volume as 13.6% in Plan 1 and 17.4% in Plan 2. This level of effectiveness is not sufficient to comprehensively address overflow problems. In addition, the results of the economic analysis show that both scenarios fall short of financial viability, with BCR values well below 1 due to the high initial construction costs. These findings suggest that although bioretention can function as a complementary element to drainage systems, its implementation should be considered more selectively and contextually. Therefore, more cost-effective and decentralized runoff control strategies, such as household-scale rain barrels, are recommended as alternative approaches. Integrating limited bioretention systems in strategic locations with more affordable rain barrels in densely populated areas offers the potential to improve both technical efficiency and economic rationality in managing local flood risks in suburban environments.

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## 5.2 Suggestion

Further research is recommended to explore more affordable and decentralized alternatives. In addition, evaluating long-term benefits, including non-financial aspects, is important to capture the comprehensive value of green infrastructure. Strategic integration between site-specific bioretention and household-based LID systems is encouraged to enhance both runoff management effectiveness and economic sustainability.

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