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Supporting SDG 11 Through Green Stormwater Infrastructure: SWMM-Based Flood Mitigation in a Tropical Watershed

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Abstract: The study sub-watershed covers 3475 ha with a main river length of 9.03 km. Rapid land-use change—residential areas grew by 623.84 ha while rice paddies declined by 1390.40 ha between 2013 and 2023—has reduced infiltration areas, increased impervious cover, and intensified peak runoff. Existing drainage infrastructure is insufficient to convey the 2-year design discharge, resulting in recurrent downstream flooding. This study analyzes existing hydrological and hydraulic conditions and designs rainwater management solutions through Green Stormwater Infrastructure (GSI) for flood mitigation and groundwater conservation. Design rainfall was estimated using Log Pearson III frequency analysis, while runoff and hydraulic responses were simulated using EPA SWMM 5.2. Three GSI alternatives were evaluated: 3946 infiltration wells reduced peak flood discharge by 15.64%; 37 retention ponds reduced peak flood discharge by 47.48%; and a combined system of 3181 infiltration wells and 33 retention ponds achieved the highest reduction of 64.11%. Channel normalization of the critical river segment (2U–3U) is essential regardless of the GSI alternative selected. The combined alternative is recommended as it simultaneously addresses flood peaks and groundwater recharge.

Keywords: Flood mitigation; Green stormwater infrastructure; Infiltration wells; Retention ponds; Sub-watershed; SWMM

Introduction

Rapid land-use changes driven by population growth are among the primary causes of increased surface runoff and flooding in rapidly urbanizing peri-urban and semi-rural regions of Indonesia. When natural vegetation is replaced by impervious surfaces—roads, roofs, and pavements—rainwater infiltration capacity declines sharply, increasing runoff volume and velocity entering drainage networks and rivers (Budianto et al., 2022; Surya et al., 2021; Basthoni, 2020; Abighail et al., 2022). These hydrological shifts disrupt the natural water cycle, diminish groundwater recharge, and amplify flood frequency and severity.

Grobogan Regency, Central Java, has undergone substantial land-use transformation at the regency scale, providing context for the pressures acting on its constituent watersheds. Between 2013 and 2023, residential areas expanded from 2081.15 ha to 2704.99 ha (+623.84 ha) while rice paddy fields contracted from 6208.36 ha to 4817.96 ha (−1390.40 ha), and dryland agriculture increased by 6027.35 ha (Badan Pusat Statistik Kabupaten Grobogan, 2024; Mulyaningsih, 2014; Zahrani et al., 2026). The regency's 2023 population of 1514301 places growing pressure on ageing drainage infrastructure, and rivers—including the Renggong River—frequently overtop during heavy rainfall because of sediment accumulation and inadequate channel cross-sections, reflecting broader patterns of watershed degradation reported across Indonesia (Tutuarima et al., 2021; Hartini, 2017).

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The study focuses on the Renggong Sub-Watershed, a 3,475 ha tributary system nested within the broader Grobogan Regency described above, draining through three subdistricts before discharging into the receiving river. Historical flooding events—such as the 2025 inundation of approximately 15 ha of rice fields in Tanggirejo Village, Tegowanu Subdistrict, triggered by an embankment breach along the Renggong River (Bhinneka Nusantara, 2025) illustrate the sub-watershed's vulnerability. Compound problems of flood risk in the wet season and water scarcity in the dry season highlight the need for integrated stormwater management. Comparable flood vulnerabilities have been documented across other Indonesian sub-watersheds using GIS-, HEC-RAS-, and morphometric-based approaches (Aditama et al., 2025; Arifianto et al., 2026; Ghaisani et al., 2024; Indrawan et al., 2025; Maulana et al., 2025; Purwanto & Paiman, 2023; Sari & Hermon, 2025; Virgota et al., 2024), reinforcing that land-use change and inadequate channel capacity are widespread drivers of flood risk in Indonesian sub-watersheds rather than a site-specific anomaly.

Green Stormwater Infrastructure (GSI) offers a sustainable alternative that mimics natural hydrological processes. Unlike conventional gray infrastructure that rapidly conveys runoff to receiving water bodies, GSI reduces runoff volume through infiltration, evapotranspiration, and storage (Jayasooriya & Ng, 2014). GSI typologies—infiltration wells, retention ponds, bioretention cells, green roofs, and constructed wetlands—simultaneously address flood risk, groundwater recharge, water quality improvement, urban heat island mitigation, and ecological habitat enhancement (Ferrans et al., 2022; Jeon et al., 2021; Fletcher et al., 2015; Kim & Kim, 2021; Koc et al., 2021; Kumar et al., 2022; Fu et al., 2020; Li et al., 2018; Liang et al., 2018; Taghizadeh et al., 2021).

Indonesian studies have demonstrated the effectiveness of infiltration wells and retention ponds in reducing peak runoff across various watersheds (Hidayat & Suprayogi, 2017; Astuti & Suprayogi, 2015; Prayitno et al., 2021; Khoiri et al., 2022; Hidayah et al., 2024). However, integrated multi-typology GSI applications in semi-rural Central Java watersheds remain limited, largely because prior local studies have evaluated infiltration wells and retention ponds separately rather than as a combined, spatially-optimized system (Yudianto & Roy, 2019; Zevri, 2019), and because site-specific soil and rainfall data needed to size such systems are rarely available at the sub-watershed scale (Maulana et al., 2025; Indrawan et al., 2025). This study addresses that gap by jointly evaluating single-typology and combined GSI alternatives within an EPA SWMM 5.2 model of 127 sub-catchments, providing a replicable, data-driven approach for GSI design in semi-rural watersheds facing simultaneous flood risk and groundwater decline. EPA SWMM provides a robust, peer-validated framework for simulating GSI hydrological performance under local rainfall conditions (Ferrans et al., 2022; Rossman, 2015; Wafiyah & Dewi, 2024; Putra et al., 2022; Putri et al., 2023).

The objectives of this study are: to analyze existing hydrological and hydraulic conditions, including land use, channel capacity, and flood behavior; to design and evaluate three GSI alternatives—infiltration wells, retention ponds, and a combined system—using EPA SWMM 5.2 simulation; and to compare the effectiveness of each alternative in reducing peak flood discharge and their suitability for integrated stormwater and groundwater management.

Method

Study Location

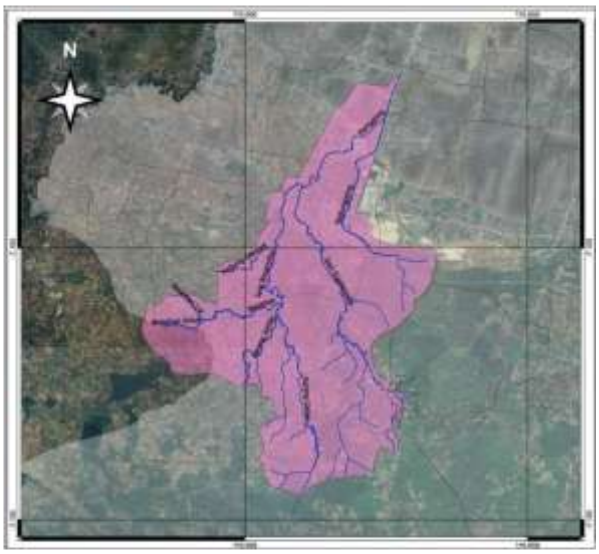

Figure 1. Drainage network and sub-catchment delineation of the study sub-watershed

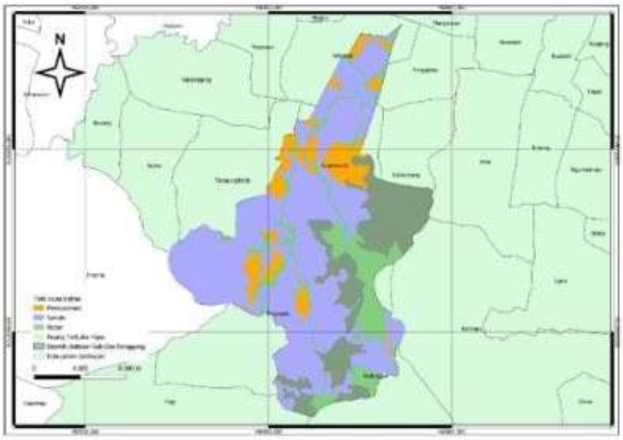

Figure 2. Map of the study sub-watershed and land use (2024)

The study area is the Renggong Sub-Watershed in Grobogan Regency, Central Java Province, Indonesia. Covering approximately 3475 ha, the sub-watershed contains the 9.03 km-long Renggong River as its primary watercourse, see Figure 1. Terrain elevations range from +25 m to +115 m above mean sea level, with generally flat to slightly rolling topography in the downstream reaches. Dominant land uses include rice paddies, dryland agriculture, plantations, and residential settlements, as shown at Figure 2.

Data Collection

Primary data were collected through field surveys documenting drainage channel conditions, trapezoidal and rectangular cross-section geometry, channel bed elevations, and flow directions. Secondary data obtained from government agencies included topographic maps, flood inundation maps, spatial land-use plans, soil type maps, population data, land- use maps, and 10-year daily rainfall records (2015– 2024) from six rain-gauging stations within and around the study sub-watershed.

Areal Rainfall Analysis

The average regional rainfall was computed using the Arithmetic Mean method (Equation 1), which is appropriate when gauges are evenly distributed across the watershed.

$$\overline{R} = \frac{1}{n}(R_1 + R_2 + \cdots + R_n) \quad (1)$$

where $\overline{R}$ = average areal rainfall (mm); R_i = rainfall at the i-th gauge (mm); n = number of gauges.

Statistical parameters of the 10-year series were computed: mean (X), standard deviation (S), skewness coefficient (Cs), kurtosis coefficient (Ck), and coefficient of variation (Cv).

$$S^2 = \frac{\sum(X_i - \overline{X})^2}{(n-1)} \quad (2)$$

$$C_s = \frac{n \cdot \sum(X_i - \overline{X})^3}{[(n-1)(n-2)S^3]} \quad (3)$$

$$C_k = \frac{n^2 \cdot \sum(X_i - \overline{X})^4}{[(n-1)(n-2)(n-3)S^4]} \quad (4)$$

$$C_v = \frac{S}{\overline{X}} \quad (5)$$

Design rainfall Xt for return periods T = 2, 5, 10, and 25 years was calculated using:

$$\log X_t = \log \overline{X} + K \cdot S \quad (6)$$

Rainfall intensity I for various concentration times tc was derived from the Mononobe equation:

$$I = \frac{R_{24}}{24}\left(\frac{24}{t_c}\right)^{\frac{2}{3}} \quad (7)$$

Design Discharge Calculation

The Modified Rational Method was applied because the sub-watershed includes both urban and peri-urban areas. Concentration time tc combines overland flow time t Design discharge and infiltration-well sizing followed relevant national technical standards (Standar Nasional Indonesia (SNI) 2415, 2016; (Standar Nasional Indonesia (SNI) 8456, 2017)$_0$ and channel travel time td:

$$t_0 = C_k \cdot L_{land}^{0.77} \cdot S^{-0.385} \quad (8)$$

$$t_d = \frac{L_{sal}}{60 \cdot V_s} \quad (9)$$

Peak design discharge:

$$Q = 0.00278 \cdot \beta \cdot C_s \cdot C \cdot I \cdot A \quad (10)$$

where Q = peak discharge (m^3/s); β = peak factor (= 1.0); Cs = storage coefficient [= 2tc/(2tc + td)]; C = composite runoff coefficient; I = design rainfall intensity at tc (mm/h); A = sub-catchment area (ha). Composite runoff coefficients were calculated as:

$$C = \frac{\sum(C_i \cdot A_i)}{\sum A_i} \quad (11)$$

Hydraulic Channel Capacity Evaluation

Field-surveyed cross-sections were classified as trapezoidal (main river), rectangular (artificial drains), or irregular (natural streams). Manning's equation was applied:

$$v = \frac{1}{n} \cdot R^{\frac{2}{3}} \cdot S^{\frac{1}{2}} \quad (12)$$

$$Q_{cap} = A \cdot v \quad (13)$$

where v = mean flow velocity (m/s); n = Manning roughness coefficient (0.075 for natural channels; 0.013 for concrete lined channels); R = hydraulic radius = A/P (m); A = wetted cross-sectional area (m^2); P = wetted perimeter (m); S = bed slope.

EPA SWMM 5.2 Hydrological Modeling

EPA Storm Water Management Model (SWMM) version 5.2 was used to simulate surface runoff generation, channel routing, and GSI performance. The model was built with 127 sub-catchments, junctions, conduits, and one outfall node at the KB.1 River confluence. Simulation was accepted when the continuity error remained within ± 10% (Rossman, 2015); achieved errors were −0.11% (surface runoff) and 0.04% (flow routing).

Data Analysis

Rainfall Frequency Analysis

Annual maximum daily rainfall at the sub-watershed level ranged from 69 mm (2018) to 112 mm (2021) over the 2015–2024 record period, broadly consistent with the inter-annual rainfall variability reported for Indonesia under non-ENSO/IOD conditions (Zaini et al., 2023). Statistical parameters of the log-transformed series: log $\bar{X}$ = 1.94, S = 0.07, Cs = 0.38, Ck = 3.16, Cv = 0.03. The criteria for selecting a distribution, based on these statistical parameters, are summarized in the following Table 1, and the Log Pearson III distribution was selected, a selection outcome consistent with comparative Gumbel–Log Pearson III distribution evaluations reported elsewhere in Java (Pradigta et al., 2024; Pratiwi & Negara, 2023), including a prior flood-discharge design study within Grobogan Regency itself (Sarminingsih, 2018).

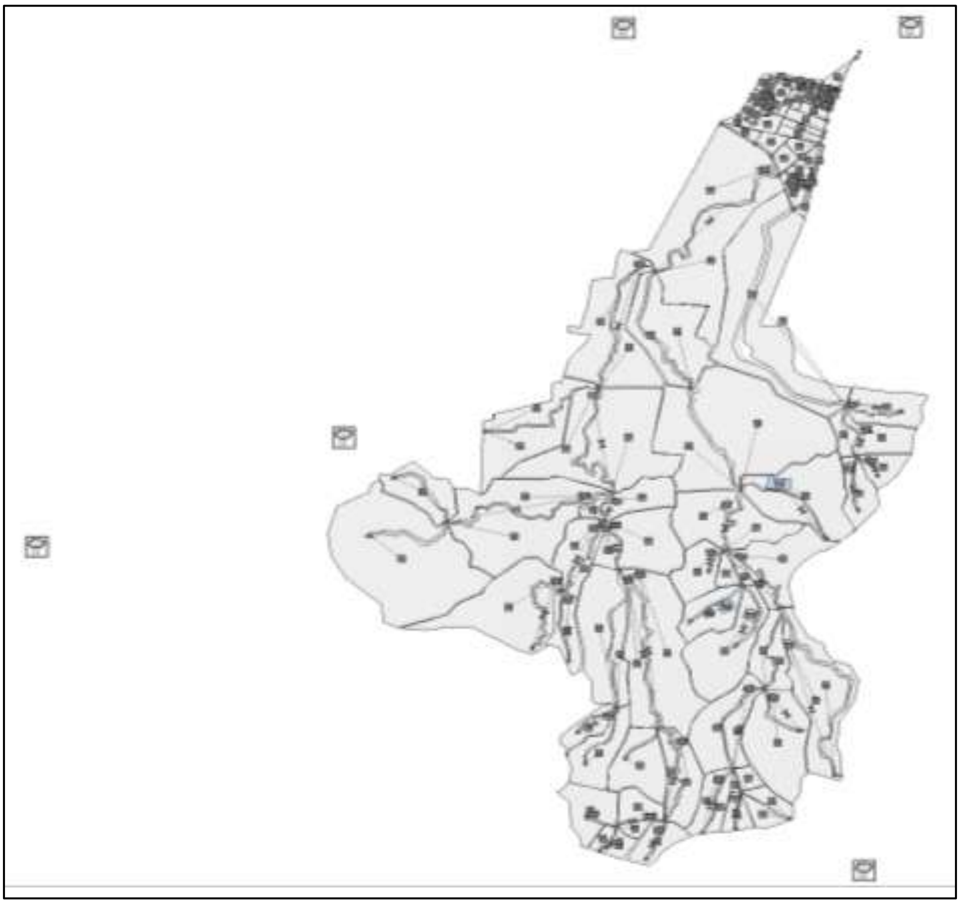

Figure 3. EPA SWMM model schematic of the study sub-watershed

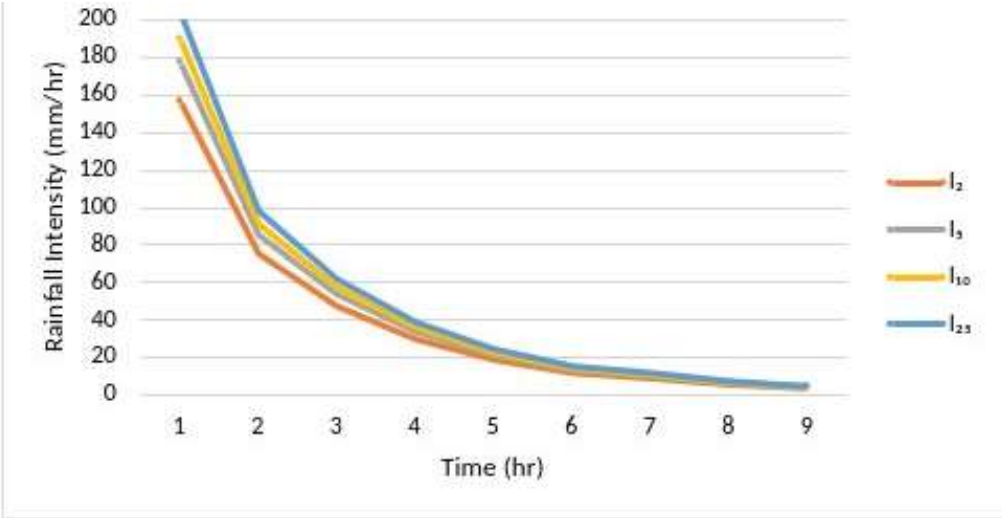

Figure 4. IDF curves for the study sub-watershed (Mononobe method)

Table 1. Frequency distribution selection results

Distribution	Criteria	Result	Status
Gumbel	Cs ≤ 1.1396 / Ck ≤ 5.4002	0.60 / 3.31	Fail / Pass
Log Pearson III	Cs ≠ 0 /Cv ≈ 0	0.38 / 0.03	Pass / Pass
Log Normal III	Cs = 3 /Ck = 5.383	0.38 / 3.16	Fail / Fail

Based on the values of the skewness coefficient and return period for the Log-Pearson Type III distribution, the design rainfall for various return periods can then be calculated, as shown in Table 2.

Table 2. Design rainfall by return period (Log Pearson III)

Return Period (Years)	log X	K	S	log Xt	Xt (mm)
2	1.94	0.000	0.07	1.936	86.23
5	1.94	0.814	0.07	1.990	97.78
10	1.94	1.245	0.07	2.019	104.52
25	1.94	1.717	0.07	2.051	112.43

Table 3. Design rainfall intensity by duration (Mononobe equation) in mm/h

tc (min)	tc (h)	I_2	I_5	I_{10}	I_{25}
5	0.083	156.69	177.68	189.93	204.29
15	0.250	75.33	85.42	91.31	98.21
30	0.500	47.45	53.81	57.52	61.87
60	1.000	29.89	33.90	36.24	38.98
90	1.500	22.81	25.87	27.65	29.75
120	2.000	18.83	21.36	22.83	24.55
240	4.000	11.86	13.45	14.38	15.47
360	6.000	9.05	10.27	10.97	11.80

Based on the design rainfall for these various return periods, a rainfall intensity analysis was then conducted using the Mononobe method. The results are presented in Table 3, and the Intensity-Duration-Frequency (IDF) curve is presented in Figure 4.

Design Discharge and Hydraulic Capacity Comparison

Example calculation for sub-DTA 111 (a representative tributary, A = 28.90 ha, C = 0.30, tc = 1.04 h, I_2 = 29.12 mm/h, β = 1.00, Cs = 0.78): Q = 0.00278 × 1.00 × 0.78 × 0.30 × 29.12 × 28.90 = 0.55 m^3/s.

Table 4. Selected channel capacity versus 2-year design discharge (bankfull capacity) comparison

River	Segment	Qexist (m^3/s)	Qdesign (m^3/s)	Status
River A	2–3	12.87	10.15	Pass
River A	2S–3S	22.43	22.87	Fail
River B	3S–1U	11.88	34.73	Fail
River C	5–2U	11.02	19.20	Fail
Main River	1U–2U	6.63	39.16	Fail
Main River	2U–3U	3.20	60.83	Fail
River D	3–4	1.57	3.05	Fail

SWMM Simulation – Existing Conditions

Simulation of existing conditions under the 2-year design storm (R_2 = 86.23 mm, duration = 1.5 h) revealed significant flooding at 50 nodes. Peak total flooding discharge reached 50330.13 L/s at t = 02:15 after storm start.

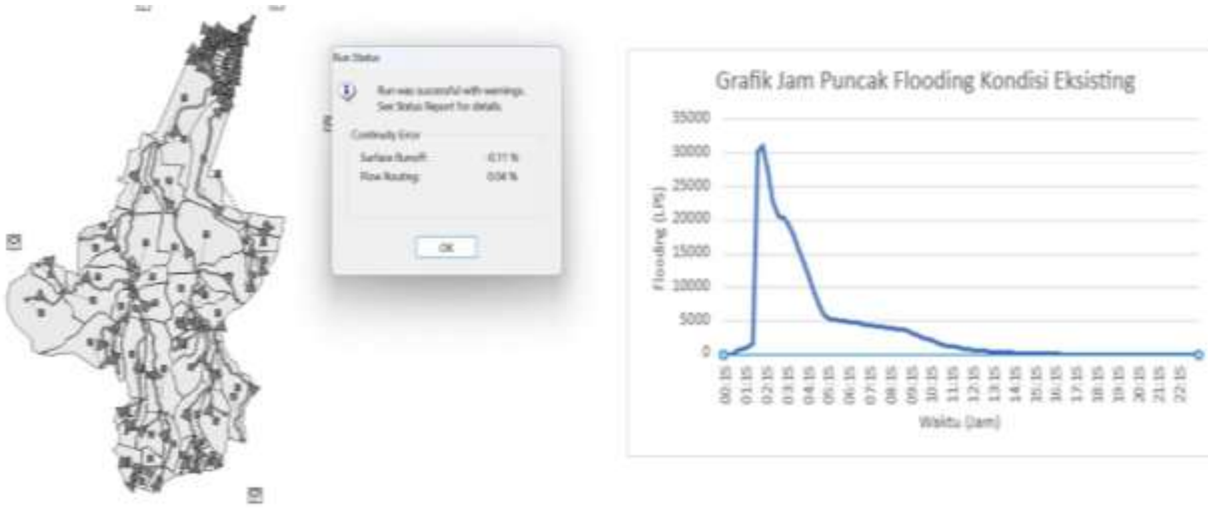

Figure 5. SWMM peak flood hydrograph for existing conditions (50330.13 L/s peak)

Land Suitability Analysis for GSI Site Selection

A multi-criteria spatial analysis was conducted to identify locations suitable for infiltration wells and retention ponds. Five weighted criteria were evaluated: rock/soil type (weight = 5), annual rainfall (weight = 4), soil cover/texture (weight = 3), land slope (weight = 2), and current land use (weight = 5). The study sub-watershed achieved a composite score of 67, falling in the High suitability category.

Infiltration Well Design (Alternative 1)

Infiltration wells were designed according to SNI 8456:2017 requirements. Technical specifications: circular cross-section, diameter = 1 m, depth = 5 m, porous concrete pipe casing. Distribution of infiltration wells across the study sub-watershed is shown in Figure 6 (upstream watershed) and Figure 7 (downstream watershed). Total infiltration well in this scenario are 3946 units. The infiltration capacity per well:

$$Q_{inf} = H \cdot \omega \cdot \pi \cdot r \cdot K \tag{14}$$

For alluvial soil: Qinf = 13.61 m^3/h. For grumusol soil: Qinf = 7.81 m^3/h. The catchment area served per well:

$$A_{land} = \frac{Q_{inf}}{0.00278 \cdot C \cdot I} \tag{15}$$

The number of wells per sub-catchment:

$$n = \frac{A_{perum}}{A_{land}} \tag{16}$$

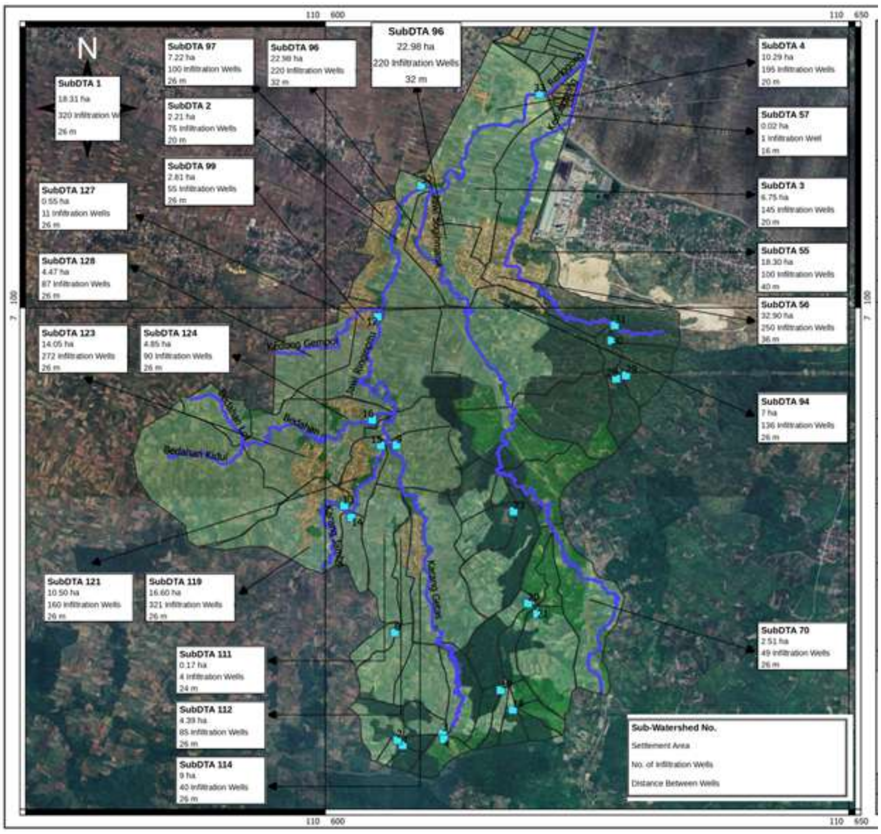

Figure 6. Map of infiltration well distribution in the upstream of the study sub-watershed

Retention Pond Design (Alternative 2)

Retention ponds were designed to temporarily store peak inflow and release it gradually via a controlled weir outlet. Pond storage volume:

$$V = Q_{inflow} \cdot T \quad (17)$$

Four standard pond sizes were developed based on the range of inflow discharges. Pond widths B were calculated as:

$$B = \sqrt{\frac{V}{2H}} \quad (18)$$

Weir discharge formula:

$$Q_{out} = C_w \cdot L \cdot H^{\frac{3}{2}} \quad (19)$$

where Cw = weir coefficient (1.7); L = weir length (1 m designed); H = head above weir crest (0.2 m). Thus Qout = 1.7 × 1 × $0.2^{3/2}$ = 0.152 m^3/s.

The retention pond is planned to be 5 meters deep, including the freeboard. There are four types of retention ponds based on their surface area as shown in Table 5. A total of 37 retention ponds are planned for the study sub-watershed, with the distribution of the retention ponds shown in Figure 8.

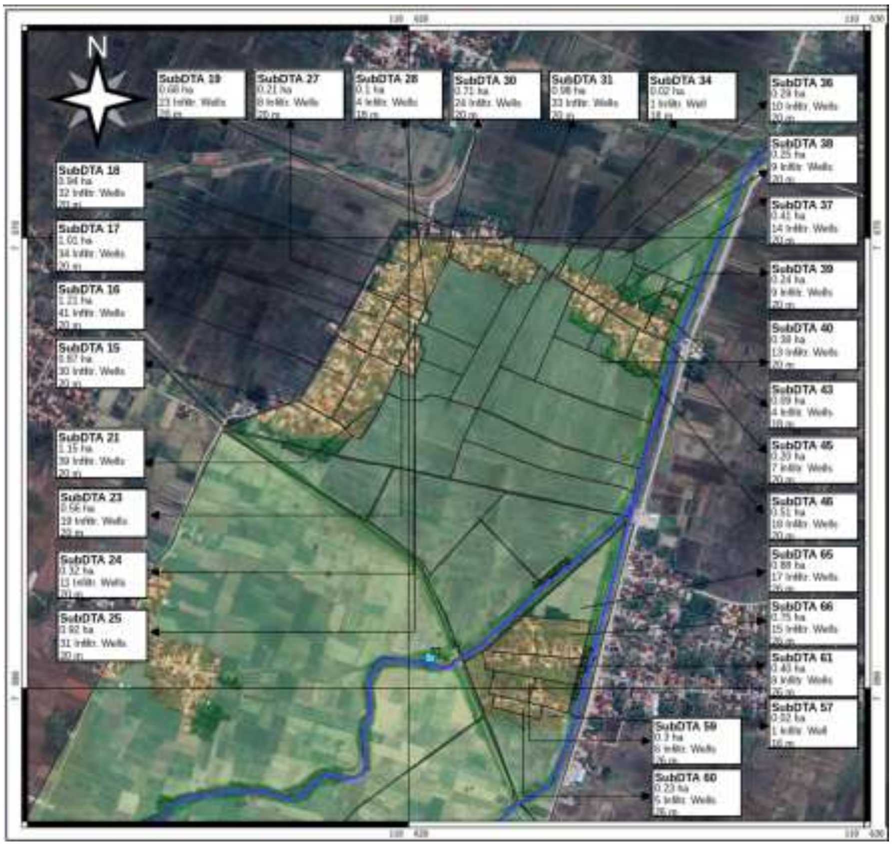

Figure 7. Map of infiltration well distribution in the downstream of the study sub-watershed

Table 5. Typical dimension of retention pond

Typical No	Dimension of pond	Number
1	26 m x 52 m x 5 m	23
2	37 m x 74 m x 5 m	11
3	45 m x 104 m x 5 m	2
4	52 m x 104 m x 5 m	1

Combined GSI Design (Alternative 3)

Figure 8. Map of retention pond distribution in the study sub-watershed

The combined system integrates 3181 infiltration wells and 33 retention ponds. Infiltration wells were prioritized for residential sub-catchments with adequate soil permeability, while retention ponds were placed at strategic downstream nodes. The optimization objective minimizes the total land footprint while maximizing flood peak attenuation and groundwater recharge distribution across the watershed.

Result and Discussion

Existing Conditions and Land Use Analysis

The study sub-watershed encompasses parts of three subdistricts with a combined population of approximately 89000. At the regency scale, the 2023 land-use composition for Grobogan Regency is: rice paddies 4817.96 ha (dominant), dryland agriculture 9463.79 ha, plantations 1489.13 ha, and residential settlements 2704.99 ha. Comparison with 2013 data reveals a net gain of +623.84 ha in residential area and a loss of 1390.40 ha in rice paddies. Within the smaller 3475 ha study sub-watershed itself, land use is dominated by rice paddies, dryland agriculture, plantations, and residential settlements, as mapped in Figure 2; these sub-watershed-scale patterns are consistent with the broader regency-wide trends described above.

Table 6. Hydraulic parameters and capacity of the critical river cross-section

Parameter	Value	Unit
Base width (b)	3.00	m
Top width (B)	3.90	m
Left bank height	4.20	m
Right bank height	3.70	m
Manning's n	0.075	–
Channel length	2190	m
Bed slope (S)	0.006	–
Wetted area (A)	12.77	m^2
Flow velocity (v)	1.008	m/s
Channel capacity (Q)	12.87	m^3/s

Comparing this against the 2-year design discharge of 60.83 m^3/s for the critical river segment (2U–3U) confirms a severe capacity deficit, necessitating either structural improvement (normalization) or upstream flow attenuation via GSI.

Table 7. SWMM node flooding summary – existing conditions (top 10 nodes by peak rate)

Node	Hours Flooded	Max. Rate (L/s)	Hour of Max.	Flood Vol. (10^6 L)
139	3.47	19265.22	02:01	143.08
125	0.88	10581.98	01:47	20.35
214	5.51	2486.14	03:27	36.57
151	4.59	1232.00	03:00	18.52
84	3.00	869.82	03:00	9.08
5	4.02	837.94	03:20	8.43
9	5.36	401.11	03:20	6.24
202	1.04	90.95	01:14	0.26
203	0.93	18.41	00:50	0.04
201	0.47	21.78	01:35	0.02

GSI Performance Evaluation

Alternative 1: Infiltration Wells

A total of 3946 infiltration wells were distributed across 127 sub-DTAs. The sub-watershed-wide SWMM simulation yielded a peak flood discharge reduction from 50330.13 L/s to 42457.42 L/s, a decrease of 7872.71 L/s (15.64%). The modest overall reduction reflects the fact that infiltration wells only intercept roof runoff from residential areas, which constitute 38% of sub-watershed land use.

Alternative 2: Retention Ponds

Thirty-seven retention ponds (23 Type 1, 11 Type 2, 2 Type 3, 1 Type 4) were strategically distributed to intercept high-discharge sub-catchments. SWMM simulation achieved a peak flood discharge reduction from 50330.13 L/s to 26431.37 L/s, a 47.48% decrease. The superior performance of retention ponds over infiltration wells can be attributed to: larger storage volumes; controlled outflow via the weir mechanism; and the ability to serve large agricultural catchments.

Alternative 3: Combined GSI System

The combined system (3181 infiltration wells + 33 retention ponds) achieved the highest overall peak flood discharge reduction of 64.11%, reducing the peak from 50330.13 L/s to 18063.07 L/s—a decrease of 32267.06 L/s. The performance exceeds either single-technology alternative through the synergistic complementarity of the two GSI types.

An evaluation of the effectiveness of rainwater management alternatives can be seen in one example section from Node 139-84. Channel water levels under existing conditions, and after the installation of infiltration wells, retention ponds, and a combination of both, can be seen in Figure 9.

The reduction in peak flood discharge from the three rainwater management alternatives in the downstream section of the study sub-watershed is presented in Table 8 and Figure 10.

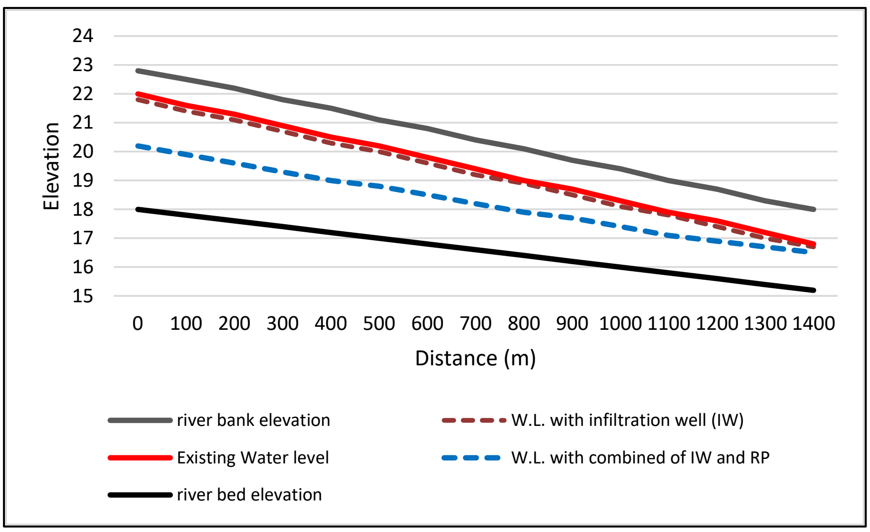

Figure 9. Differences in water level elevation among the three rainwater management alternatives on one section of the channel

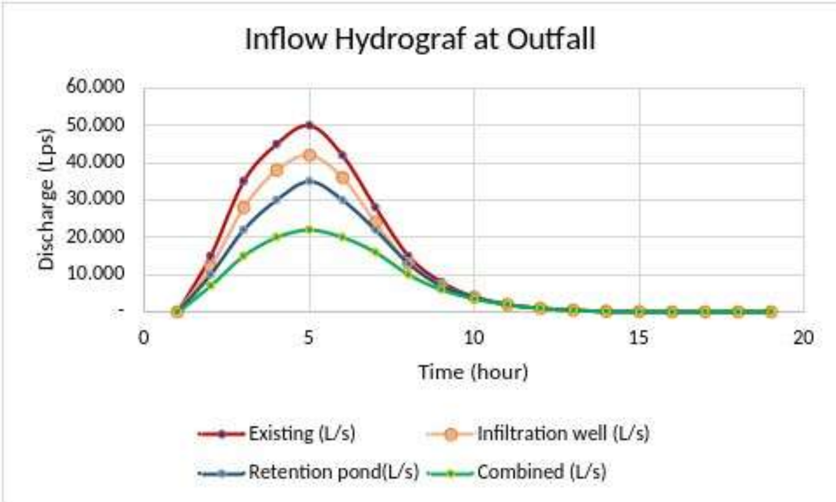

Figure 10. SWMM flood hydrograph comparison – existing conditions and three GSI alternatives

Table 8. Comparison of peak flood discharge under three GSI alternatives

Scenario	Peak Discharge (L/s)	Reduction (L/s)	Reduction (%)
Existing Conditions	50330.13	–	–
Alt. 1: Infiltration Wells (3946 units)	42457.42	7872.71	15.64
Alt. 2: Retention Ponds (37 units)	26431.37	23898.76	47.48
Alt. 3: Combined GSI (wells + ponds)	18063.07	32267.06	64.11

Channel Normalization Assessment

Regardless of the GSI alternative implemented, the critical river segment 2U–3U (nodes 139–84) requires channel normalization. This segment functions as the primary hydraulic bottleneck. Normalization design increases top width from 4.5 to 8.2 m and bottom width from 1.5 to 3.44 m, raising hydraulic capacity to accommodate post-GSI peak flows.

Groundwater Recharge and Environmental Co-Benefits

Beyond flood attenuation, the three GSI alternatives offer differentiated environmental co-benefits. Infiltration wells directly contribute to groundwater recharge, routing roof runoff into the vadose zone. Over a typical 1.5-h design storm, 3946 wells collectively infiltrate approximately 46000–80500 m^3, significantly supplementing groundwater storage. Retention ponds provide additional co-benefits as recreational and aesthetic amenities that can enhance local property values and improve downstream water quality.

Comparison with Related Studies

The findings are consistent with the existing literature. Astuti & Suprayogi (2015) reported retention pond peak discharge reductions of 55–70% in Payung Sekaki, Riau Province, consistent with the 47.48% achieved by Alternative 2. Hidayat & Suprayogi (2017) documented 10–25% peak runoff reduction from infiltration well networks in Sleman, Yogyakarta, comparable to the 15.64% achieved by Alternative 1. Ferrans et al. (2022) reviewed 87 peer-reviewed SWMM modeling studies and confirmed its reliability as a decision-support tool.

Similar infiltration-well interventions elsewhere in Indonesia—for example in Malang (Prayitno et al., 2021) and Makassar (Tumpu et al., 2021)—have likewise reported measurable reductions in local inundation, reinforcing the applicability of small-scale infiltration structures documented here. Retention-pond performance comparable to Alternative 2 has also been reported using EPA SWMM in Sidoarjo (Khoiri et al., 2022) and Surabaya (Putra et al., 2022), both of which found that pond storage substantially outperformed channel widening alone in reducing peak discharge. At the regional scale, land-use-driven increases in flood discharge consistent with the trends observed in the Renggong Sub-Watershed have been documented in the Keyang-Slahung-Tempuran sub-watershed (Basthoni, 2020), the Ciliwung watershed (Abighail et al., 2022), and in rapidly urbanizing Makassar (Surya et al., 2021), underscoring that the residential expansion and paddy-field contraction reported here reflect a broader national pattern rather than a site-specific anomaly. The reliability of EPA SWMM as a decision-support tool is further supported by its recent application to Indonesian drainage networks (Wafiyah & Dewi, 2024; Putra et al.,

2022) and by a systematic review of low-impact development practices tailored to Indonesian conditions (Putri et al., 2023), which similarly identifies infiltration- and retention-based interventions as the most transferable GSI typologies for the country's tropical rainfall regime. Internationally, the effectiveness of combined infiltration and storage-based GSI aligns with findings from green-roof and infiltration-trench optimization in Delhi (Kumar et al., 2022), permeable-pavement trials in China (Fu et al., 2020; Li et al., 2018), and LID performance evaluations in South Korea (Kim & Kim, 2021), all of which report that combined or multi-typology GSI configurations outperform single-typology alternatives—consistent with the superior 64.11% reduction achieved by the combined alternative in this study. Similar SWMM-LID hybrid optimization approaches (Taghizadeh et al., 2021; Koc et al., 2021) further corroborate that pairing infiltration with detention/retention storage is the most robust strategy for peak-discharge attenuation under variable rainfall intensities. Regional flood-risk assessments published using comparable GIS-, HEC-RAS-, and morphometric-based approaches (Aditama et al., 2025; Arifianto et al., 2026; Ghaisani et al., 2024; Indrawan et al., 2025; Maulana et al., 2025; Purwanto & Paiman, 2023; Sari & Hermon, 2025; Virgota et al., 2024; Zahrani et al., 2026) similarly identify land-use change and inadequate channel capacity as dominant drivers of flood risk across Indonesian sub-watersheds, reinforcing the generalizability of the drainage-capacity and land-use findings reported here.

A contextual distinction of this study is the semi-rural peri-urban setting with mixed land use, creating challenges absent in fully urbanized watersheds. Critically, the high proportion of non-residential land limits the effectiveness of infiltration-well-only approaches—a finding with important implications for GSI planning in similar Central Javanese agricultural-residential watersheds.

Conclusion

This study demonstrates that Green Stormwater Infrastructure can significantly reduce flood risk in the study sub-watershed while simultaneously providing groundwater conservation benefits. Key conclusions are: First, existing drainage infrastructure at the critical river segment (2U–3U) is critically inadequate to convey the 2-year design discharge, resulting in a peak flood discharge of 50330.13 L/s across the sub-watershed. Land-use change (+623.84 ha residential, 2013–2023) has directly intensified runoff generation. Channel normalization of the critical river segment 2U–3U is essential regardless of GSI alternative chosen. Second, all three GSI alternatives significantly reduced peak flood discharge: 3946 infiltration wells — 15.64% reduction; 37 retention ponds — 47.48% reduction; combined system of 3181 wells + 33 ponds — 64.11% reduction (the highest). Retention ponds demonstrate superior hydraulic performance due to larger storage volumes and controlled weir outflow. Third, Alternative 3 (combined GSI) is recommended as the optimal complementary solution when both hydraulic performance and groundwater conservation are prioritized. It does not eliminate the need for channel normalization at segment 2U–3U, but it reduces the frequency and severity of overtopping in the interim and may allow a smaller normalization design than would otherwise be required, distributing hydrological management benefits across the entire sub-watershed by addressing both residential-area source runoff (wells) and main-channel peak attenuation (ponds) simultaneously. Future research should evaluate sediment management requirements, long-term operation and maintenance costs, and socio-ecological co-benefits of each GSI typology under changing climate scenarios.

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Conceptualization, A.S., B.P.S., N.P., A.D.A., and A.H.; methodology, formal analysis, investigation, writing—original draft, N.P., A.D.A., and A.H.; software, data curation, N.P. and A.D.A.; writing—review and editing, supervision, A.S. and B.P.S.; visualization, A.D.A. and A.H. All authors have read and approved the published version.

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References

Abighail, S. H., Kridasantausa, I., Farid, M., & Moe, I. R. (2022). Pemodelan Banjir akibat Perubahan Tata Guna Lahan di Daerah Aliran Sungai Ciliwung. *Jurnal Teknik Sipil*, *29*(1). https://doi.org/10.5614/jts.2022.29.1.6

Aditama, D. H., Harisuseno, D., & Hendrawan, A. P. (2025). Flood Prone Area Analysis in the Wonosari Sub Watershed, Bondowoso Regency, East Java.

Jurnal Penelitian Pendidikan IPA, *11*(5), 359–369. https://doi.org/10.29303/jppipa.v11i5.11130

Arifianto, S., Andawayanti, U., & Sumiadi, S. (2026). The Impact of Land Use on Flood Management: A Case Study of the Banjir Kanal Barat River in Semarang with HEC-RAS. *Jurnal Penelitian Pendidikan IPA*, *12*(6), 512–523. https://doi.org/10.29303/jppipa.v12i6.15149

Astuti, D., & Suprayogi, I. (2015). Analysis of Retention Ponds as Inundation Flood Control in Payung Sekaki District. *Journal Online Mahasiswa Universitas Riau*, *3*(1), 1–14. Retrieved from https://www.neliti.com/publications/189661/analisis-kolam-retensi-sebagai-pengendalian-banjir-genangan-di-kecamatan-payung

Badan Pusat Statistik Kabupaten Grobogan. (2024). *Grobogan Regency in Figures 2024*. Grobogan: BPS Grobogan Regency.

Basthoni, M. K. R. (2020). Analisis Perubahan Tata Guna Lahan Terhadap Debit Banjir Sub-Sub DAS Keyang-Slahung-Tempuran (KST). *Teras Jurnal: Jurnal Teknik Sipil*, *10*(2), 189–202. https://doi.org/10.29103/tj.v10i2.309

Bhinneka Nusantara. (2025, May 17). *Banjir Landa Sejumlah Desa di Grobogan, Ratusan Rumah dan Sawah Terendam*. Retrieved from https://bhinnekanusantara.id/banjir-landa-sejumlah-desa-di-grobogan-ratusan-rumah-dan-sawah-terendam/

Budianto, M. B., Harianto, B., Salehudin, S., Hartana, H., & Hidayat, S. (2022). Dampak Perubahan Tata Guna Lahan dan Implikasinya Terhadap Besaran Debit Banjir pada Kawasan Ekonomi Khusus (KEK) Mandalika. *Jurnal Sains Teknologi & Lingkungan*, *8*(2), 102–114. Retrieved from https://jstl.unram.ac.id/index.php/jstl/article/view/748

Ferrans, P., Torres, M. N., Temprano, J., & Sánchez, J. P. R. (2022). SUDS Modeling Supporting Decision-Making: A Systematic Quantitative Review. *Science of the Total Environment*, *806*, 150447. https://doi.org/10.1016/j.scitotenv.2021.150447

Fletcher, T. D., Shuster, W., Hunt, W. F., Ashley, R., Butler, D., Arthur, S., Trowsdale, S., Barraud, S., Semadeni-Davies, A., Bertrand-Krajewski, J.-L., Mikkelsen, P. S., Rivard, G., Uhl, M., Dagenais, D., & Viklander, M. (2015). SUDS, LID, BMPs, WSUD and More – The Evolution and Application of Terminology Surrounding Urban Drainage. *Urban Water Journal*, *12*(7), 525–542. https://doi.org/10.1080/1573062X.2014.916314

Fu, X., Liu, J., Shao, W., Mei, C., Wang, D., & Yan, W. (2020). Evaluation of Permeable Brick Pavement on the Reduction of Stormwater Runoff Using a Coupled Hydrological Model. *Water*, *12*(10), 2821. https://doi.org/10.3390/w12102821

Ghaisani, S. F., Saadi, Y., Setiawan, E., I Wayan, Y., Salehudin, S., & Suroso, A. (2024). Effectiveness Analysis of Meninting Dam's Diversion Tunnel Using HEC-RAS. *Jurnal Penelitian Pendidikan IPA*, *10*(4), 2091–2101. https://doi.org/10.29303/jppipa.v10i4.7207

Hartini, E. (2017). *Applied Hydrology & Hydraulics*. Semarang: Dian Nuswantoro University.

Hidayah, E., Putri, A. P. P., & Saifurridzal, S. (2024). Analysis of Potential Application of Rainwater Harvesting System in Bedadung River Basin, Jember Regency. *Jurnal Teknik Sipil*, *30*(2), 233–244. https://doi.org/10.5614/jts.2023.30.2.11

Hidayat, A., & Suprayogi, S. (2017). Design of Infiltration Wells as Stormwater Runoff Control in Griya Taman Asri, Sleman. *Jurnal Bumi Indonesia*, *6*(4). Retrieved from https://www.neliti.com/publications/228869/rancangan-sumur-resapan-sebagai-upaya-pengendalian-aliran-limpasan-di-perumahan

Indrawan, I., Dangkua, T., & Jaya, R. (2025). Comparative Morphometric Analysis for Flood Risk Assessment in Alo and Molamahu Sub-Watersheds, Gorontalo Regency. *Jurnal Penelitian Pendidikan IPA*, *11*(8), 535–545. https://doi.org/10.29303/jppipa.v11i8.11924

Jayasooriya, V. M., & Ng, A. W. M. (2014). Tools for Modeling Stormwater Management and the Economics of Green Infrastructure Practices: A Review. *Water, Air, & Soil Pollution*, *225*, 1–20. https://doi.org/10.1007/s11270-014-2055-1

Jeon, S., Kim, S., Lee, M., An, H., Jung, K., Um, M., An, K., & Park, D. (2021). Insights into the Pollutant Removal Performance of Stormwater Green Infrastructures: A Case Study of Detention Basins and Retention Ponds. *International Journal of Environmental Research and Public Health*, *18*(19), 10104. https://doi.org/10.3390/ijerph181910104

Khoiri, A. H., Andawayanti, U., & Haribowo, R. (2022). Kajian Efektivitas Kolam Retensi dalam Mereduksi Banjir Jalan Raya Porong Kabupaten Sidoarjo dengan Storm Water Management Model. *Jurnal Teknologi dan Rekayasa Sumber Daya Air*, *2*(2), 142–155. https://doi.org/10.21776/ub.jtresda.2022.002.02.12

Kim, H., & Kim, G. (2021). An Effectiveness Study on the Use of Different Types of LID for Water Cycle Recovery in a Small Catchment. *Land*, *10*(10), 1055. https://doi.org/10.3390/land10101055

Koc, K., Ekmekcioğlu, Ö., & Özger, M. (2021). An Integrated Framework for the Comprehensive

Evaluation of Low Impact Development Strategies. *Journal of Environmental Management*, *294*, 113023. https://doi.org/10.1016/j.jenvman.2021.113023

Kumar, S., Guntu, R. K., Agarwal, A., Villuri, V. G. K., Pasupuleti, S., Kaushal, D. R., Gosian, A. K., & Bronstert, A. (2022). Multi-Objective Optimization for Stormwater Management by Green-Roofs and Infiltration Trenches to Reduce Urban Flooding in Central Delhi. *Journal of Hydrology*, *606*, 127455. https://doi.org/10.1016/j.jhydrol.2022.127455

Li, Y., Li, W., He, J., Zhang, X., & Li, X. (2018). Infiltration and Anti-Filtration Recharge-Pumping Well and Laboratory Recharge Tests. *Water*, *10*(12), 1834. https://doi.org/10.3390/w10121834

Liang, X., Zhan, H., & Zhang, Y. K. (2018). Aquifer Recharge Using a Vadose Zone Infiltration Well. *Water Resources Research*, *54*(11), 8847–8863. https://doi.org/10.1029/2018WR023409

Maulana, K. M., S, A. S. R., Dangkua, T., Jaya, R., & Mulabbi, A. (2025). Morphometric Characteristics and Their Relation to Flood Events in Paguyaman Watershed, Gorontalo. *Jurnal Penelitian Pendidikan IPA*, *11*(8), 476–488. https://doi.org/10.29303/jppipa.v11i8.11909

Mulyaningsih, T. (2014). *Analysis of Land Use Change in Grobogan Regency*. Semarang: UNDIP Press.

Pradigta, M. D. I., Susanto, S., & Pratikto, H. (2024). Comparison of Gumbel Method and Log Pearson Method in Flood Control in Konto River Jombang. *CIVED*, *11*(3), 1008–1015. https://doi.org/10.24036/cived.v11i3.645

Pratiwi, D. W., & Negara, A. S (2023). Perbandingan Pola Distribusi Hujan Terukur dan Metode Empiris dalam Perhitungan Debit Banjir Rencana DAS Jurug. *Jurnal Teknik Sumber Daya Air*, *3*(1), 29–42. https://doi.org/10.56860/jtsda.v3i1.55

Prayitno, G., Bisri, M., Juwono, P. T., Anwar, M. R., Harimurti, H., Sari, N., Dinanti, D., & Wigayatri, M. (2021). Planning and Assistance the Making of Infiltration Wells. *JCES (Journal of Character Education Society)*, *4*(1), 212–220. https://doi.org/10.31764/jces.v4i1.3564

Purwanto, A., & Paiman, P. (2023). Flood Risk Spatial Modeling Based on Geographical Information Systems and Remote Sensing in the Pemangkat Regency. *Jurnal Penelitian Pendidikan IPA*, *9*(11), 9554–9563. https://doi.org/10.29303/jppipa.v9i11.5264

Putra, M. A. R., Andawayanti, U., & Lufira, R. D. (2022). Studi Evaluasi dan Penanganan Genangan Menggunakan Aplikasi SWMM 5.1 pada Sistem Drainase Darmo Kali Kota Surabaya. *Jurnal Teknologi dan Rekayasa Sumber Daya Air*, *2*(2), 141–155. https://doi.org/10.21776/ub.jtresda.2022.002.02.11

Putri, F. K., Hidayah, E., & Ma'ruf, M. F. (2023). Enhancing Stormwater Management with Low Impact Development (LID): A Review of the Rain Barrel, Bioretention, and Permeable Pavement Applicability in Indonesia. *Water Science and Technology*, *87*(9), 2345–2361. https://doi.org/10.2166/wst.2023.095

Rossman, L. A. (2015). *Storm Water Management Model – User's Manual Version 5.1*. EPA/600/R-14/413b. Cincinnati: US EPA. Retrieved from https://www.epa.gov/sites/default/files/2019-02/documents/epaswmm5_1_manual_master_8-2-15.pdf

Sari, N., & Hermon, D. (2025). Flood Disaster Adaptation Model in Kampar Regency Riau Province. *Jurnal Penelitian Pendidikan IPA*, *11*(3), 70–79. https://doi.org/10.29303/jppipa.v11i3.10544

Sarminingsih, A. (2018). Pemilihan Metode Analisis Debit Banjir Rancangan Embung Coyo Kabupaten Grobogan. *Jurnal Presipitasi: Media Komunikasi dan Pengembangan Teknik Lingkungan*, *15*(1), 53–61. https://doi.org/10.14710/presipitasi.v15i1.53-61

Standar Nasional Indonesia (SNI) 2415. (2016). *Procedures for Calculating Design Flood Discharge*. Jakarta: BSN.

Standar Nasional Indonesia (SNI) 8456. (2017). *Rainwater Infiltration Wells and Trenches*. Jakarta: BSN.

Surya, B., Salim, A., Hernita, H., Suriani, S., Menne, F., & Rasyidi, E. S. (2021). Land Use Change, Urban Agglomeration, and Urban Sprawl: A Sustainable Development Perspective of Makassar City, Indonesia. *Land*, *10*(6), 556. https://doi.org/10.3390/land10060556

Taghizadeh, S., Khani, S., & Rajaee, T. (2021). Hybrid SWMM and Particle Swarm Optimization Model for Urban Runoff Water Quality Control by Using Green Infrastructures (LID-BMPs). *Urban Forestry & Urban Greening*, *60*, 127032. https://doi.org/10.1016/j.ufug.2021.127032

Tumpu, M., Samad, A., Daming, H., & Sari, W. W. (2021). Implementation of Infiltration Wells for Rainwater Runoff Control in Makassar. *Journal of Engineering Research*, *25*(1), 1–9. https://doi.org/10.25042/jpe.052021.01

Tutuarima, C. T., Talakua, S. M., & Osok, R. M. (2021). Penilaian Degradasi Lahan dan Dampak Sedimentasi Terhadap Perencanaan Bangunan Air di Daerah Aliran Sungai Wai Ruhu, Kota Ambon. *Jurnal Budidaya Pertanian*, *17*(1), 43–51. https://doi.org/10.30598/jbdp.2021.17.1.43

Virgota, A., Farista, B., Suripto, S., Gunawan, L. A., & Ernawati, E. (2024). Identification and Mapping of

Flood Vulnerability in the Meninting Watershed, West Lombok. *Jurnal Penelitian Pendidikan IPA*, *10*(7), 3759–3769. https://doi.org/10.29303/jppipa.v10i7.8201

Wafiyah, N. A., & Dewi, V. A. K. (2024). Evaluasi Kapasitas Saluran Drainase Menggunakan Software EPA SWMM Versi 5.1 di Desa Suciharjo. *Jurnal Teknik Sipil dan Lingkungan*, *9*(2), 241–250. https://doi.org/10.29244/jsil.9.2.241-250

Yudianto, D., & Roy, A. F. (2019). Pemanfaatan Kolam Retensi dan Sumur Resapan pada Sistem Drainase Kawasan Padat Penduduk. *Jurnal Teknik Sipil*, *5*(2), 103–121. https://doi.org/10.28932/jts.v5i2.1317

Zahrani, N., Suhartanto, E., & Andawayanti, U. (2026). Reliable Assessment of Long-Term Land Use Change to Support Sustainable Watershed Management Using Multi-Sensor Landsat Imagery. *Jurnal Penelitian Pendidikan IPA*, *12*(2), 515–523. https://doi.org/10.29303/jppipa.v12i2.14076

Zaini, A. Z. A., Vonnisa, M., Marzuki, M., & Ramadhan, R. (2023). Seasonal Variation of Rainfall in Indonesia under Normal Conditions without ENSO and IOD Events from 1981-2021. *Jurnal Penelitian Pendidikan IPA*, *9*(11), 9899–9909. https://doi.org/10.29303/jppipa.v9i11.4569

Zevri, A. (2019). Desain Kolam Retensi pada Daerah Aliran Sungai Bekala. *Jurnal Rekayasa Sipil (JRS-Unand)*, *15*(2), 90–102. https://doi.org/10.25077/jrs.15.2.90-102.2019