Available online at www.CivileJournal.org

Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 11, No. 12, December, 2025

A Model for the Reduction of Flood Peak Discharge (ΔQ_p) Due to the Retarding Basin

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Received 25 August 2025; Revised 23 October 2025; Accepted 06 November 2025; Published 01 December 2025

Abstract

This research aims to develop a model for flood peak discharge reduction (ΔQ_p) through the placement of retarding basins within a watershed system, represented by the area ratio of the controlled watershed (R_{Ak}) and the maximum storage capacity of the retarding basin (V_k). The area ratio of the controlled watershed (R_{Ak}) is defined as the ratio between the catchment area of the retarding basin and the total watershed area (A_k/A). The methodology involves simulating various retarding basin placements (R_{Ak}) and different maximum storage capacities (V_k) for several flood return periods (Q_T). This study was conducted in the urban agglomeration area of Wonosari, Gunungkidul Regency, Special Region of Yogyakarta, Indonesia. The placement and utilization of retarding basins result in varying levels of flood peak discharge reduction (ΔQ_p) at the downstream control point (Taman Pancuran), depending on the maximum storage capacity of the retarding basin (V_k) and its placement within the watershed (R_{Ak}). The resulting empirical equations for flood peak discharge reduction (ΔQ_p) using the retarding basin method are as follows: $\Delta Q_p = 0.105654 - 0.014593\ V_k - 0.029251\ R_{Ak} + 0.011089\ Q_T$ for V_k values in the range (V_1–V_4) = 36.4–208.8 × 10^3 m³, and $\Delta Q_p = 1.374989 - 0.003702\ V_k - 0.338381\ R_{Ak} + 0.004773\ Q_T$ for V_k values in the range (V_4–V_{200}) = 136.2–7039.1 × 10^3 m³. An observed anomaly was identified, where ΔQ_p became positive at small values of V_k and R_{Ak}, indicating an increase in peak discharge (Q_p).

Keywords: Flood Peak Reduction; Retarding Basin; Area Ratio of Watershed.

1. Introduction

Land use change is an important aspect of environmental management and urban planning. Population growth in a region leads to an increase in residential areas. Currently, more than half of the world's population lives in urban areas, and this proportion is estimated to reach 80% by 2050 [1]. In addition, land use change is driven by residential demands and the associated supporting facilities and infrastructure. The critical issue is the continuously increasing population, which contributes to increased surface runoff and ultimately results in flooding [2, 3]. Flooding occurs frequently in Indonesia, particularly in regions with high urban population density [4–6]. Such flooding causes significant material and non-material losses, highlighting the urgent need for flood mitigation measures [7, 8].

In recent years, engineering science has advanced in the distribution of design flood discharge; however, these developments have not fully resolved downstream river flooding problems. Retarding basins represent an environmentally friendly and effective option for addressing this issue [9,10], functioning similarly to dams, reservoirs, detention basins, or retention (conservation) basins. A retention basin serves as a drainage infrastructure designed to infiltrate and store rainfall within a specific area [11, 12]. However, if land use changes are not aligned with the available storage capacity, the application of retarding basin methods may result in numerous failures.

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http://dx.doi.org/10.28991/CEJ-2025-011-12-012

Land use change is a consequence of increasing demand driven by population growth. The main factors influencing the estimation of surface runoff in a watershed include rainfall volume [13, 14], soil type, land cover type [15], and area management practices [16]. Therefore, it is necessary to develop environmentally friendly retarding basin methods, such as the use of dams or reservoirs and conservation basins (retention or detention basins), to address downstream flooding while still considering land use changes that are adjusted to storage capacity. In addition, it is necessary to determine flood peak discharge reduction (ΔQ_p) in a watershed area in relation to land use change. Furthermore, the ratio of the controlled watershed area (R_{Ak}) [17], defined as the ratio between the catchment area of the conservation basin and the total watershed area (A_k/A), as well as the maximum storage capacity of the conservation basin (V_k), must be determined as part of conservation efforts that remain safe with respect to flood hazards [18–20].

This study aims to reduce surface runoff by evaluating the placement of conservation basins, which is represented by the ratio of the controlled watershed area ($R_{Ak} = A_k/A$) and the planned maximum storage capacity of the conservation basin (V_k). The research produces analytical results of flood peak discharge reduction (ΔQ_p) in graphical form and mathematical formulations that can be used by stakeholders for decision-making. Previous studies have not analyzed the R_{Ak} variable using a four-dimensional (4D) graphical approach, nor have they developed empirical equations for flood peak reduction (ΔQ_p) using the retarding basin method.

The structure of this article consists of the title, abstract, introduction, materials and methods, results and discussion, conclusion, declarations, and references. Table 1 presents the gap analysis related to flood peak discharge reduction.

Table 1. Gap Analysis of Flood Peak Discharge Reduction (ΔQ_p)

Review of aspect	Ideal condition	Present condition	Gap
Evaluation of flood peak reduction without using the retarding basin method.	There are graphics and formulations that can determine the flood peak discharge reduction due to the improvement variables of soil type, land cover type, and land management.	Evaluation of flood peak discharge reduction through the efforts of vegetative and mechanical conservation as the improvements of soil type, land cover type, and land management.	To estimate the runoff by using SCS-CN, there has not been an analysis of the reduction of runoff by carrying out the placements of retarding basins.
Evaluation of flood peak discharge reduction by using the retarding basin method.	There are graphics and formulations that can determine the flood peak discharge reduction due to the ratio between controlled watershed area (R_{Ak}=A_k/A) and maximum storage capacity (V_k) from the retarding basin in a watershed system.	Evaluation of flood peak discharge reduction by using a dam/reservoir/retention basin without analyzing the controlled watershed area (R_{Ak}=A_k/A) and maximum storage capacity (V_k) from the retarding basin in a watershed system.	There has not been the influenced analysis between the controlled watershed area (R_{Ak}=A_k/A) and the maximum storage capacity (V_k) from the retarding basin in a watershed system.

2. Materials and Methods

The research location is in the agglomeration area of Wonosari urban, Gunungkidul Regency, Daerah Istimewa Yogyakarta, Indonesia (Figure 1). The selection of locations in the retarding basin of Purwosari, Purbosari, etc. is regarding the land availability that can be released.

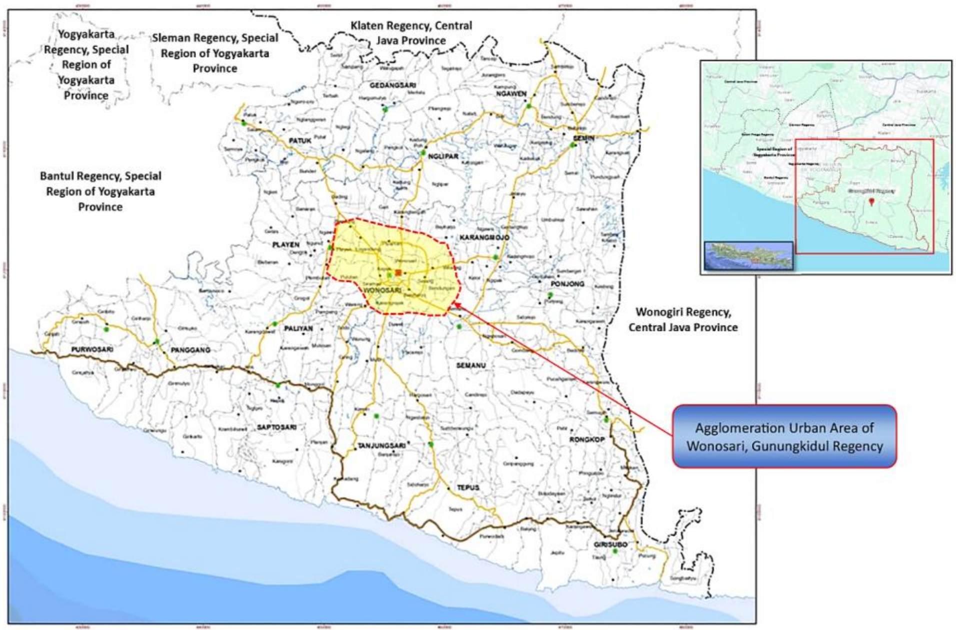


Figure 1. Research Location

2.1. Synthetic Unit Hydrograph

The synthetic unit hydrograph (SUH) is used if the hydrology data are not available to differentiate the unit hydrograph [21]. The synthetic unit hydrograph is differentiated based on the physical characteristic of a watershed [22]. This research uses the SCS-SUH (Soil Conservation Service-SUH) for analysis in the upstream sub-watershed and in the tributary sub-watershed. The SCS-SUH uses the non-dimensionless hydrograph that is developed from the analysis of a large number of unit hydrographs from field data with the various size of watersheds and from different locations. If the effective rainfall depth is 1 mm, so the peak discharge is as follows [23]:

$$Q_p = \frac{0.208\ A}{T_p} \tag{1}$$

$$T_p = \frac{t_r}{2} + t_p \tag{2}$$

$$t_p = 0.6\ t_c \tag{3}$$

with: Q_p: peak discharge of unit hydrograph (m^3/s); A: watershed area (km^2); T_p: time to peak (hour); t_p: time lag, time from the weighted point of effective rainfall to the unit hydrograph peak (hour); t_r: duration of effective rainfall (hour); t_c: concentration time (hour); T_b: time base (2.67 T_p) (hour).

2.2. Flood Routing through the Level Pool

The flood level pool routing is a procedure for analyzing the outflow hydrograph from reservoir that has the horizontal water surface [19]. The flood routing equation in the continuity equation form that is numerically solved by making the numerical discretization which classifies the unknown values on the left section and the known values on the right section [24] is as follows:

$$\alpha_2 = I_1 + I_2 + \beta_1 \tag{4}$$

where:

$$\alpha_2 = \frac{2\ S_2}{\Delta t} + O_2 \tag{5}$$

$$\beta_1 = \frac{2\ S_1}{\Delta t} - O_1 \tag{6}$$

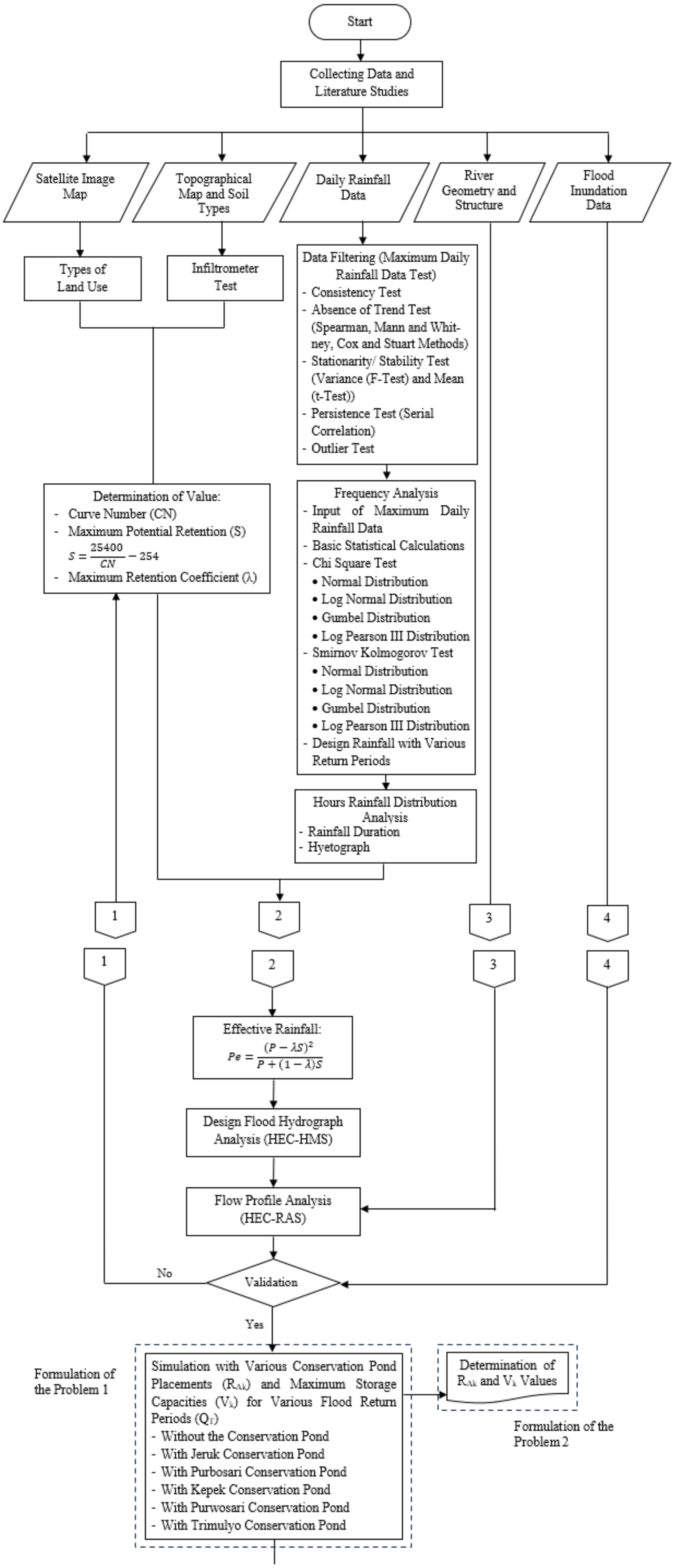
This method needs the data of reservoir hydraulic and geometric as curve or table of storage-elevation, outflow-elevation, outflow-storage. The curve of storage-elevation is analyzed based on the topography data. The minimum elevation is an elevation which the storage is zero, however, the maximum elevation is the elevation of dam peak.

2.3. Simulation of Flow

According to Istiarto [24], the simulation of flow in open channel is one of the methods to study the flow pattern along the channel. Simulation is really carried out by flowing water in the channel that is made based on the laboratory scale (physical model) or virtually by carrying out a series of hydraulic analysis that is generally accommodated in one device of computer application (mathematical model). Through the physical model, a number of flow physical phenomenon in channel or real river (prototype) is simulated in the channel or river that is built with smaller size (model). The interpretation to the observed or measured phenomenon in the model will give a guidance to the phenomenon that as if it happened in the prototype. The mathematical model imitates the flow physical phenomenon in the real channel (prototype) through a series mathematical equation that describe the relation between flow variables (variables of geometric, kinematic, and dynamic). If the physical model is measured or observed for obtaining the flow parameters, however, in the mathematical model, the flow parameters are obtained by analyzing or solving the mathematical equation. The model is based on the historical data from the selected rainfall stations.

Principally, the steps of flow simulation by using physical model or mathematical model consists of five base steps that are preparation of place, imitation of geometry, imitation of flow, measuring or analysis of velocity and water depth, presentation and interpretation of result [25].

Figure 2 presents the flow chart of research study.


Start
Collecting Data and Literature Studies
Satellite Image Map
Topographical Map and Soil Types
Daily Rainfall Data
River Geometry and Structure
Flood Inundation Data
Types of Land Use
Infiltrometer Test
Data Filtering (Maximum Daily Rainfall Data Test)
- Consistency Test
- Absence of Trend Test (Spearman, Mann and Whitney, Cox and Stuart Methods)
- Stationarity/ Stability Test (Variance (F-Test) and Mean (t-Test))
- Persistence Test (Serial Correlation)
- Outlier Test
Determination of Value:
- Curve Number (CN)
- Maximum Potential Retention (S)
$S = \frac{25400}{CN} - 254$
- Maximum Retention Coefficient (λ)
Frequency Analysis
- Input of Maximum Daily Rainfall Data
- Basic Statistical Calculations
- Chi Square Test
• Normal Distribution
• Log Normal Distribution
• Gumbel Distribution
• Log Pearson III Distribution
- Smirnov Kolmogorov Test
• Normal Distribution
• Log Normal Distribution
• Gumbel Distribution
• Log Pearson III Distribution
- Design Rainfall with Various Return Periods
Hours Rainfall Distribution Analysis
- Rainfall Duration
- Hyetograph
1
2
3
4
1
2
3
4
Effective Rainfall:
$Pe = \frac{(P - \lambda S)^2}{P + (1 - \lambda)S}$
Design Flood Hydrograph Analysis (HEC-HMS)
Flow Profile Analysis (HEC-RAS)
No
Validation
Yes
Formulation of the Problem 1
Simulation with Various Conservation Pond Placements (R_{Ak}) and Maximum Storage Capacities (V_k) for Various Flood Return Periods (Q_T)
- Without the Conservation Pond
- With Jeruk Conservation Pond
- With Purbosari Conservation Pond
- With Kepek Conservation Pond
- With Purwosari Conservation Pond
- With Trimulyo Conservation Pond
Determination of R_{Ak} and V_k Values
Formulation of the Problem 2

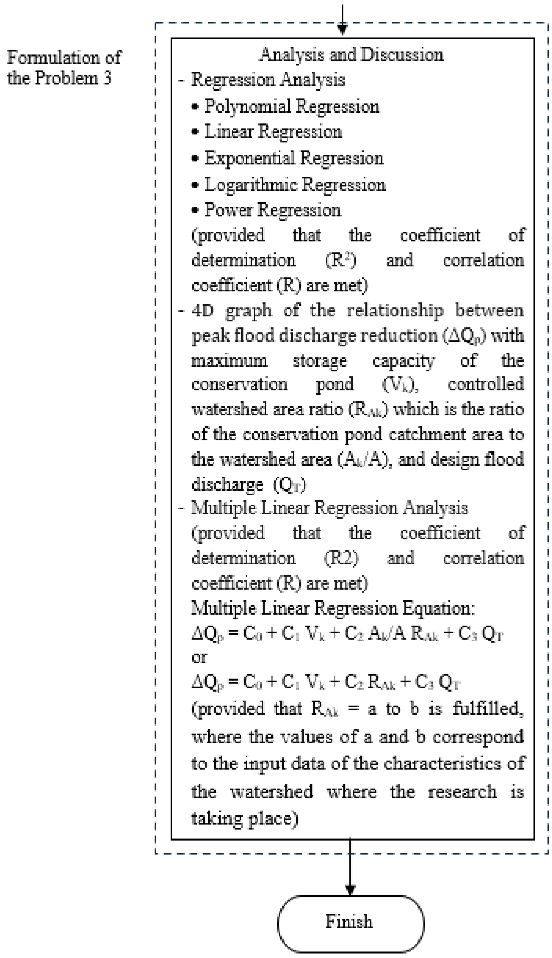


Figure 2. Research Flowchart

2.4. Methodology

The steps of the research methodology are as follows:

- Data collection and literature review, including satellite imagery (land use types), topographic maps, soil type and infiltrometer test results, daily rainfall data, river geometry and structural data, and flood inundation records.
- Data filtering and maximum daily rainfall testing, including consistency tests; non-trend tests (Spearman, Mann–Whitney, and Cox–Stuart methods); stationarity and stability tests (variance using the F-test and mean using the t-test); persistence tests (series correlation); and outlier tests.
- Frequency analysis, using maximum daily rainfall data as input, including basic statistical analysis; Chi-square and Kolmogorov–Smirnov tests for normal, log-normal, Gumbel, and Log Pearson Type III distributions; and the determination of design rainfall for various return periods.
- Analysis of hourly rainfall distribution, including rainfall duration and hyetograph curves.
- Analysis of effective rainfall.
- Analysis of the design flood hydrograph using HEC-HMS.
- Analysis of the flow profile using HEC-HMS.
- Verification and validation of the results.
- Simulation of various retarding basin placements (R_{Ak}) and maximum storage capacities (V_k) for different return periods (Q_T), including scenarios without retarding basins and with retarding basins at Jeruk, Purbosari, Kepek, Purwosari, and Trimulyo.
- Analysis and discussion, including four-dimensional (4D) graphical analysis and the development of empirical equations relating ΔQ_p to V_k, R_{Ak} (A_k/A), and Q_T.

3. Results and Discussion

The reduction factor of flood peak discharge was analyzed using the retarding basin method [26] under existing flood conditions at the control point of Taman Pancuran in the study area. The placement factor of retarding basins within a watershed system is represented by the area ratio of the controlled watershed (R_{Ak}) and the volume of the retarding basin (V_k). The area ratio of the controlled watershed (R_{Ak}) is defined as the ratio between the catchment area of the retarding basin and the total watershed area (A_k/A). The flood peak discharge reduction model using the retarding basin method was developed through four-dimensional (4D) graphical analysis and empirical equations of flood peak discharge reduction (ΔQ_p).

The SCS-SUH method was applied because the watershed area is relatively small and consists of several sub-catchment areas along the river section. Flood routing through a plain pool was conducted by considering the crest height of the weir or side spillway of the retarding basin, which is generally designed with a height of only 1–2 m. The flood routing results obtained using the plain pool method were compared with those from reservoir routing and showed relatively similar flood peak discharge reductions (ΔQ_p). However, the volume of water stored in the retarding basin differs depending on the crest height of the weir or side spillway. This difference occurs because the retarding basin area is relatively constant, or because the retarding basin pool area influences the lag time value at the downstream control point.

3.1. Analysis of the Area Ratio Variable of Controlled Watershed (R_{Ak}) and 4D Graphic of Flood Peak Discharge Reduction (ΔQ_p) by Using Retarding Basin Method

The four-dimensional (4D) graphics of flood peak discharge reduction for return periods Q_2, Q_5, Q_{10}, and Q_{20} using the retarding basin method, considering various maximum storage capacities or volumes of retarding basins (V_k) and different placement variables of retarding basins (R_{Ak}), at the control point of Taman Pancuran are presented in Figures 3 to 6.

From Figures 3 to 6, it can be observed that for the same design discharge (Q_T), a larger maximum storage capacity or volume of the retarding basin (higher V_k) results in a greater reduction in flood peak discharge (higher ΔQ_p). Conversely, for the same maximum storage capacity or volume of the retarding basin (V_k), a larger area ratio of the controlled watershed (higher R_{Ak}) generally leads to a smaller flood peak discharge reduction (lower ΔQ_p), particularly when the retarding basin storage capacity is relatively small. However, when the maximum storage capacity or volume of the retarding basin is relatively large, the flood peak discharge reduction becomes more significant. This occurs because a larger retarding basin storage capacity increases the lag time and effectively reduces the flood peak discharge.

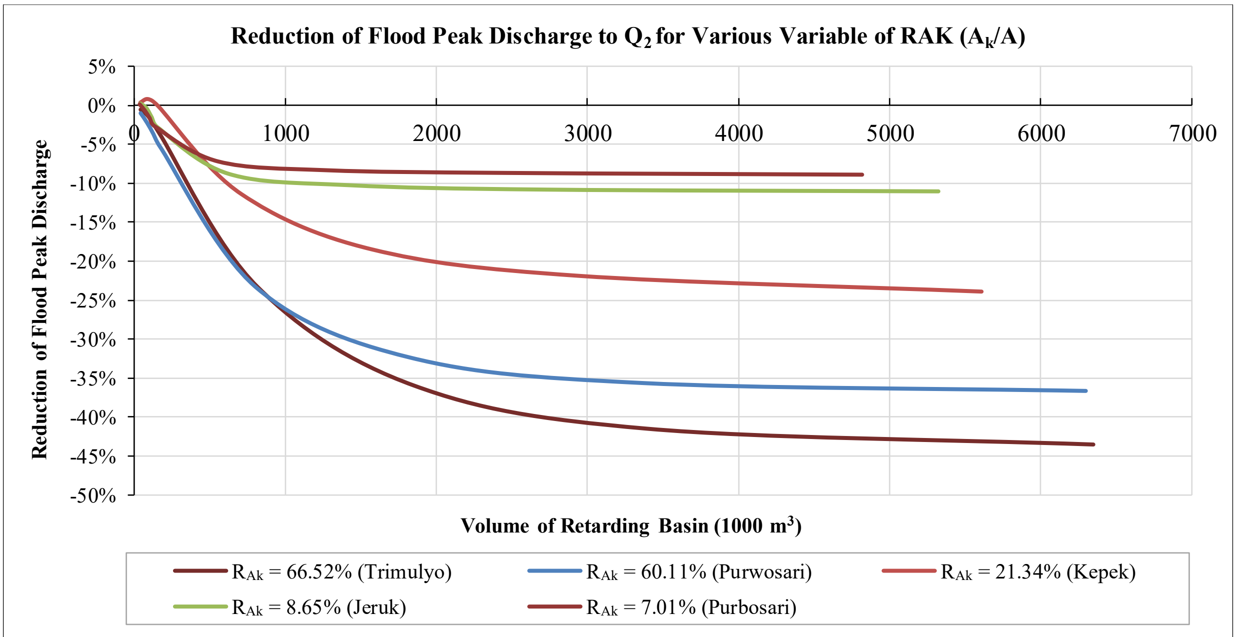


Figure 3. Reduction of Flood Peak Discharge (Q_2) with Various Variables of R_{Ak} (A_k/A) on the Control Point of Taman Pancuran

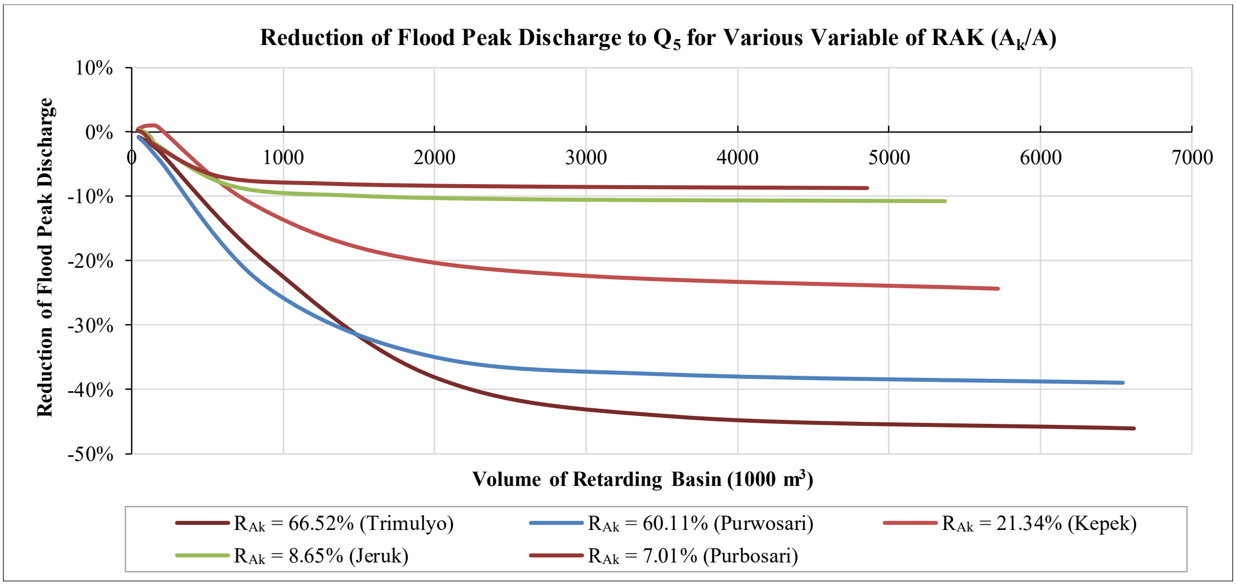


Figure 4. Reduction of Flood Peak Discharge (Q_5) with Various Variables of R_{Ak} (A_k/A) on the Control Point of Taman Pancuran

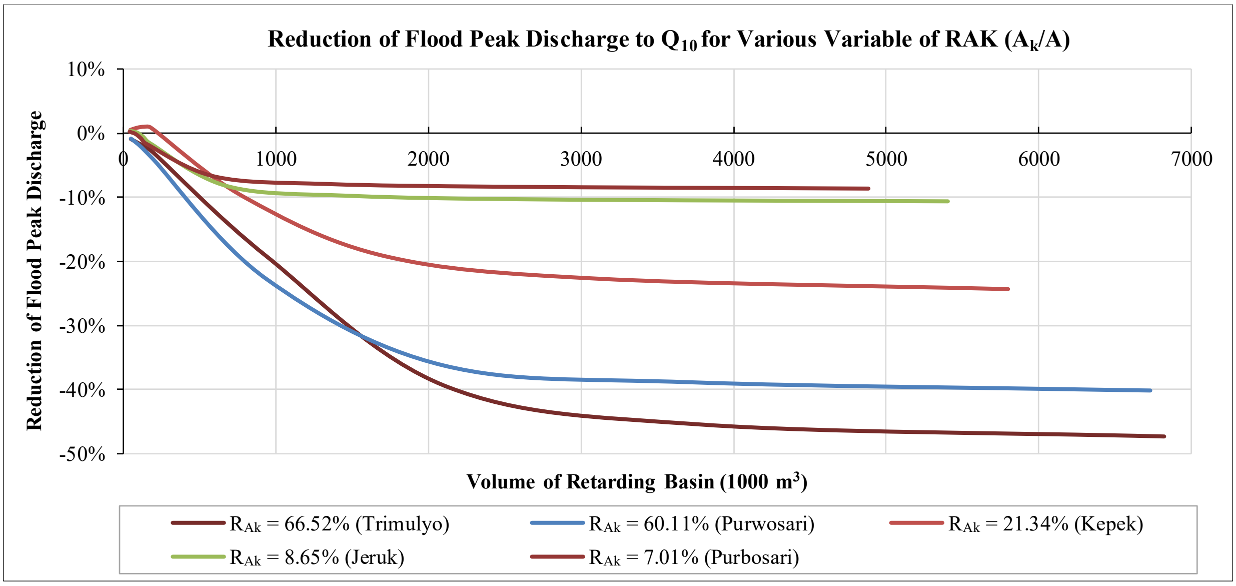


Figure 5. Reduction of Flood Peak Discharge (Q_{10}) with Various Variables of R_{Ak} (A_k/A) on the Control Point of Taman Pancuran

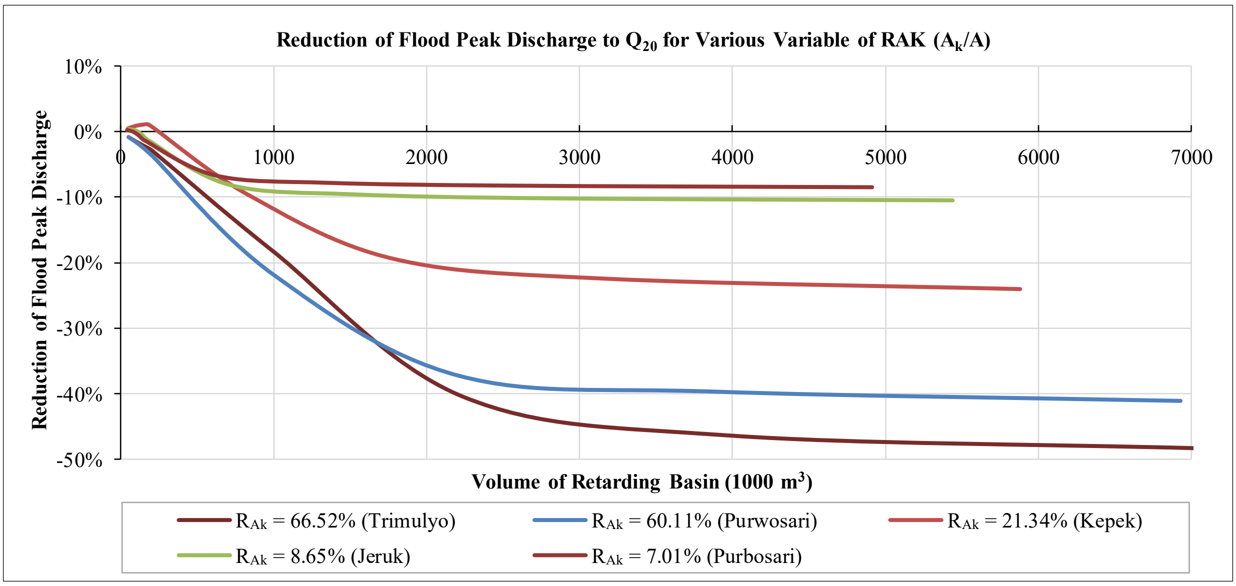


Figure 6. Reduction of Flood Peak Discharge (Q_{20}) with Various Variables of R_{Ak} (A_k/A) on the Control Point of Taman Pancuran

When the maximum storage capacity or volume of the retarding basin is relatively small (small V_k) and the area ratio of the controlled watershed is also relatively small (small R_{Ak}), an anomaly in flood peak discharge reduction (positive ΔQ_p) may occur at the downstream control point (Taman Pancuran), where the flood peak discharge increases. This phenomenon occurs because the relatively small retarding basin storage capacity and controlled watershed area produce only a slight change in the flood discharge hydrograph in terms of added lag time and flood peak reduction. As a result, the recession limb of the flood hydrograph at a certain time (t-hour) becomes higher than the flood peak discharge prior to the construction of the retarding basin. Consequently, the flood hydrograph with the retarding basin resonates with the flood peak discharge from another tributary with a relatively larger sub-watershed area through hydrograph superposition at the Taman Pancuran control point, leading to an increase in the flood peak discharge.

The observed anomaly (positive ΔQ_p or increased Q_p under conditions of small V_k and small R_{Ak}) represents a hydrological behavior that occurs because the design flood hydrograph produced by the addition of lag time and slight flood peak reduction is not significantly altered. Specifically, the recession limb of the design flood hydrograph at a certain time becomes higher than that of the design flood hydrograph without a retarding basin. The design flood hydrograph influenced by the retarding basin resonates with the design flood hydrograph from another tributary with a relatively larger sub-watershed area due to hydrograph superposition at the downstream control point (Taman Pancuran), causing an increase in the flood peak discharge. Since this hydrological behavior occurs only under conditions of small V_k and small R_{Ak} and results in a relatively small and positive ΔQ_p, mitigation measures are generally unnecessary. However, if mitigation is required, the storage capacity (V_k) can be increased by expanding the retarding basin area, where feasible.

3.2. Empirical Equation of Flood Peak Discharge Reduction (ΔQ_p) by Using Retarding Basin Method

Based on the recapitulated simulation results of flood peak discharge reduction (ΔQ_p) for various flood return periods (Q_T), different maximum storage capacities of the retarding basin (V_k), and varying area ratios of controlled watersheds (R_{AK}) at the Taman Pancuran control point (as shown, for example, in Tables 2 and 3 for the Purwasari retarding basin), multiple linear regression analysis was conducted to obtain the empirical equation for flood peak discharge reduction (ΔQ_p), as presented in Table 4.

Table 2. Design of Flow Simulation

No	Scenario	Design Flood Hydrograph			
		Q_2	Q_5	Q_{10}	Q_{20}
1	**Without Retarding Basin**	√	√	√	√
2	**With retarding basin of Purbosari (A_{k1})**				
	- Maximum storage capacity V_1	√	√	√	√
	- Maximum storage capacity V_2	√	√	√	√
	- Maximum storage capacity V_3	√	√	√	√
	- Maximum storage capacity V_4	√	√	√	√
	- Maximum storage capacity V_{20}	√	√	√	√
	- Maximum storage capacity V_{50}	√	√	√	√
	- Maximum storage capacity V_{100}	√	√	√	√
	- Maximum storage capacity V_{200}	√	√	√	√
3	**With retarding basin of Jeruk (A_{k2})**				
	- Maximum storage capacity V_1	√	√	√	√
	- Maximum storage capacity V_2	√	√	√	√
	- Maximum storage capacity V_3	√	√	√	√
	- Maximum storage capacity V_4	√	√	√	√
	- Maximum storage capacity V_{20}	√	√	√	√
	- Maximum storage capacity V_{50}	√	√	√	√
	- Maximum storage capacity V_{100}	√	√	√	√
	- Maximum storage capacity V_{200}	√	√	√	√
4	**With retarding basin of Kepek (A_{k3})**				
	- Maximum storage capacity V_1	√	√	√	√
	- Maximum storage capacity V_2	√	√	√	√
	- Maximum storage capacity V_3	√	√	√	√
	- Maximum storage capacity V_4	√	√	√	√
	- Maximum storage capacity V_{20}	√	√	√	√
	- Maximum storage capacity V_{50}	√	√	√	√
	- Maximum storage capacity V_{100}	√	√	√	√
	- Maximum storage capacity V_{200}	√	√	√	√

	With retarding basin of Purwosari (A_{k4})				
	- Maximum storage capacity V_1	√	√	√	√
	- Maximum storage capacity V_2	√	√	√	√
	- Maximum storage capacity V_3	√	√	√	√
5	- Maximum storage capacity V_4	√	√	√	√
	- Maximum storage capacity V_{20}	√	√	√	√
	- Maximum storage capacity V_{50}	√	√	√	√
	- Maximum storage capacity V_{100}	√	√	√	√
	- Maximum storage capacity V_{200}	√	√	√	√
	With retarding basin of Trimulyo (A_{k5})				
	- Maximum storage capacity V_1	√	√	√	√
	- Maximum storage capacity V_2	√	√	√	√
	- Maximum storage capacity V_3	√	√	√	√
6	- Maximum storage capacity V_4	√	√	√	√
	- Maximum storage capacity V_{20}	√	√	√	√
	- Maximum storage capacity V_{50}	√	√	√	√
	- Maximum storage capacity V_{100}	√	√	√	√
	- Maximum storage capacity V_{200}	√	√	√	√

Table 3. Simulation Result Recapitulation of Flood Peak Discharge Reduction (ΔQ_p) for Purwasari Retarding Basin (For example)

Description		**V_k**	**R_{Ak}**	**Q_T**	**ΔQ_p**
		(1000 m³)	**(%)**	**(m³/s)**	**(%)**
		(1)	**(2)**	**(3)**	**(4)**
Without the Retarding Basin	Q_2			88.7	
	Q_5			118.4	
	Q_{10}			141.0	
	Q_{20}			164.7	
With the Retarding Basin	Purbosari		7.01		
	Jeruk		8.65		
	Kepek		21.34		
	Purwosari		60.11		
	Trimulyo		66.52		
		V_k	**R_{Ak}**	**Q_T**	**ΔQ_p**
With Purwosari Retarding Basin	V_1	42.8	60.11	88.7	-1.01
	V_2	85.6	60.11	88.7	-2.25
	V_3	128.0	60.11	88.7	-3.72
	V_4	170.2	60.11	88.7	-5.30
	V_{20}	812.1	60.11	88.7	-23.45
	V_{50}	1824.5	60.11	88.7	-32.36
	V_{100}	3360.3	60.11	88.7	-35.63
	V_{200}	6298.1	60.11	88.7	-36.64
	V_1	46.6	60.11	1184	-0.84
	V_2	93.1	60.11	118.4	-1.86
	V_3	139.5	60.11	118.4	-3.13
	V_4	185.5	60.11	118.4	-4.39
	V_{20}	883.6	60.11	118.4	-23.90
	V_{50}	1987.7	60.11	118.4	-34.88
	V_{100}	3573.2	60.11	118.4	-37.67
	V_{200}	6543.8	60.11	118.4	-38.94
	V_1	49.5	60.11	141.0	-0.85
	V_2	98.8	60.11	141.0	-1.77
	V_3	148.0	60.11	141.0	-2.91
	V_4	196.9	60.11	141.0	-4.11
	V_{20}	938.5	60.11	141.0	-22.77
	V_{50}	2100.8	60.11	141.0	-36.24
	V_{100}	3735.7	60.11	141.0	-38.87
	V_{200}	6731.2	60.11	141.0	-40.14
	V_1	52.7	60.11	164.7	-0.85
	V_2	105.0	60.11	164.7	-1.70
	V_3	156.9	60.11	164.7	-2.67
	V_4	208.9	60.11	164.7	-3.76
	V_{20}	996.6	60.11	164.7	-21.80
	V_{50}	2213.0	60.11	164.7	-37.28
	V_{100}	3907.6	60.11	164.7	-39.71
	V_{200}	6929.7	60.11	164.7	-41.11

Table 4. Empirical Equation of Flood Peak Discharge Reduction (ΔQ_p) by Using Retarding Basin Method

Maximum Storage Capacity (Vk)	Empirical Equation	Value Limits of Maximum Storage Capacity Vk (1000 m³)	Correlation Coefficient (R)	Determination Coefficient (R^2)	Adjusted R^2	Correlation Category
	Alternate-1					
V_1 - V_{200}	$\Delta Q_p = 2.201135 - 0.005056\ V_k - 0.212053\ R_{Ak} + 0.007460\ Q_T$	36.4 - 7039.1	0.8379	0.7021	0.6964	very strong
	Alternate-2					
V_1 - V_4	$\Delta Q_p = 0.105654 - 0.014593\ V_k - 0.029251\ R_{Ak} + 0.011089\ Q_T$	36.4 - 208.8	0.7681	0.5900	0.5738	strong
V_4 - V_{20}	$\Delta Q_p = -\ 0.770655 - 0.020144\ V_k - 0.093325\ R_{Ak} + 0.041891\ Q_T$	136.2 - 997.3	0.9539	0.9099	0.9024	very strong
V_{20} - V_{200}	$\Delta Q_p = -\ 0.684102 - 0.002152\ V_k - 0.436284\ R_{Ak} - 0.003681\ Q_T$	556.1 - 7039.1	0.9407	0.8850	0.8804	very strong
	Alternate-3					
V_1 - V_4	$\Delta Q_p = 0.105654 - 0.014593\ Vk - 0.029251\ R_{Ak} + 0.011089\ Q_T$	36.4 - 208.8	0.7681	0.5900	0.5738	strong
V_4 - V_{200}	$\Delta Q_p = 1.374989 - 0.003702\ V_k - 0.338381\ R_{Ak} + 0.004773\ Q_T$	136.2 - 7039.1	0.8620	0.7431	0.7351	very strong

The flow simulation design was carried out using several flood hydrograph scenarios. The flow simulations conducted using the HEC-HMS program are described as follows:

- ***Scenario-1***

Scenario 1 represents a simulation using flood hydrograph data with return periods of 2, 5, 10, and 20 years (Q_T) without a retarding basin at the Taman Pancuran control point, considering its watershed area (A).

- ***Scenario-2***

Scenario 2 represents a simulation using flood hydrograph data with return periods of 2, 5, 10, and 20 years (Q_T) by optimizing the retarding basin function of Purbosari (A_k) with several maximum storage capacities (V_k) to reduce flood peak discharge at the downstream control point of Taman Pancuran (A).

- ***Scenario-3***

Scenario 3 represents a simulation using flood hydrograph data with return periods of 2, 5, 10, and 20 years (Q_T) by optimizing the retarding basin function of Jeruk (A_k) with several maximum storage capacities (V_k) to reduce flood peak discharge at the downstream control point of Taman Pancuran (A).

- ***Scenario-4***

Scenario 4 represents a simulation using flood hydrograph data with return periods of 2, 5, 10, and 20 years (Q_T) by optimizing the retarding basin function of Kepek (A_k) with several maximum storage capacities (V_k) to reduce flood peak discharge at the downstream control point of Taman Pancuran (A).

- ***Scenario-5***

Scenario 5 represents a simulation using flood hydrograph data with return periods of 2, 5, 10, and 20 years (Q_T) by optimizing the retarding basin function of Purwosari (A_k) with several maximum storage capacities (V_k) to reduce flood peak discharge at the downstream control point of Taman Pancuran (A).

- ***Scenario-6***

Scenario 4 represents a simulation using flood hydrograph data with return periods of 2, 5, 10, and 20 years (Q_T) by optimizing the retarding basin function of Trimulyo (A_k) with several maximum storage capacities (V_k) to reduce flood peak discharge at the downstream control point of Taman Pancuran (A).

For practical application, it is recommended to use the empirical equation of Alternate 3. This recommendation is based on the observation that the empirical equation for the range (V_1–V_4) exhibits an anomaly in flood peak discharge reduction; therefore, it is preferable to treat it separately, even though the correlation coefficient is 0.7681, which still falls within the strong category (0.6000–0.7999). In addition, the empirical equation for the range (V_4–V_{200}) can be combined, as its correlation coefficient is 0.8620, which belongs to the very strong category (0.8000–1.0000).

The empirical equation for the range (V_1–V_4) has a coefficient of determination (R^2) of approximately 0.5900, with an adjusted R^2 of 0.5738, or 57.38%. This indicates that the variables V_k, R_{Ak}, and Q_T explain about 57.38% of the variation in ΔQ_p, while the remaining variation is influenced by other factors. Furthermore, the empirical equation for the range (V_4–V_{200}) has a coefficient of determination (R^2) of approximately 0.7431, with an adjusted R^2 of 0.7351, or 73.51%, indicating that V_k, R_{Ak}, and Q_T explain about 73.51% of the variation in ΔQ_p, with the remainder attributed to other factors.

However, the constraint related to implementation cost is more closely associated with the capacity of regional funding, particularly the Regional Original Revenue (PAD) of Gunungkidul Regency. Based on the sensitivity analysis, the results are as follows:

- For the equation $\Delta Q_p = 0.105654 - 0.014593\ V_k - 0.029251\ R_{Ak} + 0.011089\ Q_T$, an increase in R_{Ak} of approximately 5% results in a 3.24% increase in ΔQ_p, whereas an increase in R_{Ak} of about 10% leads to a 6.48% increase in ΔQ_p.
- For the same equation, $\Delta Q_p = 0.105654 - 0.014593\ V_k - 0.029251\ R_{Ak} + 0.011089\ Q_T$, an increase in V_k of approximately 5% increases ΔQ_p by 7.09%, while an increase in V_k of about 10% results in a 14.18% increase in ΔQ_p.
- For the equation $\Delta Q_p = 1.374989 - 0.003702\ V_k - 0.338381\ R_{Ak} + 0.004773\ Q_T$, an increase in R_{Ak} of approximately 5% leads to a 3.84% increase in ΔQ_p, whereas an increase in R_{Ak} of about 10% increases ΔQ_p by 7.69%.
- For the same equation, $\Delta Q_p = 1.374989 - 0.003702\ V_k - 0.338381\ R_{Ak} + 0.004773\ Q_T$, an increase in V_k of approximately 5% results in a 2.71% increase in ΔQ_p, while an increase in V_k of about 10% leads to a 5.41% increase in ΔQ_p.

These equations can be applied to other watersheds within the following boundaries: $\Delta Q_p = 0.105654 - 0.014593\ V_k - 0.029251\ R_{Ak} + 0.011089\ Q_T$, with the limitation range of $(V_1–V_4) = (36.4–208.8) \times 10^3\ m^3$, and $\Delta Q_p = 1.374989 - 0.003702\ V_k - 0.338381\ R_{Ak} + 0.004773\ Q_T$, with the limitation range of $(V_4–V_{200}) = (136.2–7039.1) \times 10^3\ m^3$.

4. Conclusion

The aim of this research is to develop a model for flood peak discharge reduction through the placement of retarding basins, presented in the form of a 4D graphic and an empirical equation. This research was conducted in the agglomeration area of Wonosari Urban, Gunungkidul Regency, Daerah Istimewa Yogyakarta, Indonesia.

The use and placement of retarding basins produce varying levels of flood peak discharge reduction (ΔQ_p) at the downstream control point (Taman Pancuran), depending on the maximum storage capacity of the retarding basin (V_k) and the placement of the retarding basin (R_{Ak}).

The results of the multiple linear regression used to derive the empirical equations for flood peak discharge reduction (ΔQ_p) using the retarding basin method are as follows: $\Delta Q_p = 0.105654 - 0.014593\ V_k - 0.029251\ R_{Ak} + 0.011089\ Q_T$ for values of $(V_1–V_4) = (36.4–208.8) \times 10^3\ m^3$, and $\Delta Q_p = 1.374989 - 0.003702\ V_k - 0.338381\ R_{Ak} + 0.004773\ Q_T$ for values of $(V_4–V_{200}) = (136.2–7039.1) \times 10^3\ m^3$.

5. Declarations

5.1. Author Contributions

Conceptualization, H.Y. and L.M.L.; methodology, H.Y.; validation, H.Y.; formal analysis, H.Y.; investigation, H.Y. and M.S.; resources, H.Y. and L.M.L.; data curation, H.Y. and H.S.; writing—original draft preparation, H.Y. and H.S.; writing— review and editing, L.M.L. and M.S.; visualization, M.B. and W.S. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in the article.

5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

5.4. Conflicts of Interest

The authors declare no conflict of interest.

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