An Assessment of the Factors Affecting Flood Peak Discharge Reduction Due to the Retarding Basin

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ABSTRACT

This research assesses the variables influencing flood reduction. The land use changes occur due to the residential demand and all supporting infrastructures and facilities. It is related to population increase, raising surface run-off and then resulting in flooding. The proposed methodology involves simulating various placements of retarding basins (R_{Ak}) and different maximum storage capacities (V_k) for several flood return periods (Q_T). This research is conducted in the urban agglomeration area of Wonosari, Gunungkidul Regency, Daerah Istimewa Yogyakarta-Indonesia. The results show that the variable representing the maximum capacity of retarding basin (V_k) has a logarithmic relationship with the response of ΔQ_p, with a correlation value (R) of 0.7894 and an adjusted determination coefficient (adjusted R^2) of 0.6207. In addition, the variable of the controlled watershed area ratio (R_{AK}) has linear, quadratic, cubic, and quartic relations with ΔQ_p, with the average correlation value being 0.4563 and the average adjusted determination coefficient (average adjusted R^2) being 0.2032. However, the variable of design flood for the T year-return-period (Q_T) has the logarithmic correlation, with a correlation value (R) of 0.3987 and an adjusted determination coefficient (adjusted R^2) of 0.1536. Finally, the three variables of V_k, R_{Ak}, Q_T have a multiple linear relationship with ΔQ_p, with the correlation value (R) being 0.7894 and the adjusted determination coefficient (adjusted R^2) being 0.6207. These results are essential to support the reduction of flood peak discharge modeling.

Keywords- influenced variable; evaluation; flood reduction; retarding basin

I. INTRODUCTION

Land use change is an important aspect in urban planning and environmental management. The increasing population number in a region causes an increasing demand for housing. More than half of the world population live in urban areas, and are predicted to have reached 80% by 2050 [1]. However, the land use change is due to the residential demand and all supporting infrastructures and facilities. It is related to the increasing population number and causes an increase in surface run-off, which then results in flooding [2]. Flooding often occurs in Indonesia, mainly in urban areas with high population density. The flooding causes significant material and non-material losses. Therefore, the activity of flood mitigation is necessary.

Nowadays, engineering science has developed methods to distribute the design flood discharge so as not to cause problems downstream. The problem can be solved by using an environmentally friendly retarding basin [3], such as a dam/

reservoir/conservation basin (retention/detention basin). Retention basin is a drainage infrastructure used for storing and permeating rainfall in the region [4]. However, if the change in land use is not adjusted to proper storage capacity, the retarding basin method will often fail.

There is a need to develop an application model due to the limitation of surface run-off by determining the controlled ratio value of the watershed area, defined as the ratio between the watershed area of retarding basin and watershed area (A_k/A) and the maximum storage capacity of retarding basin (V_k) in developing regions [5-7], for predicting the land carrying capacity related to the regional exploitation. However, this research intends to analyze the variables that influence flood reduction.

II. MATERIALS AND METHODS

The study focuses on the urban agglomeration of Wonosari in Gunungkidul Regency, Daerah Istimewa Yogyakarta, Indonesia, as depicted in Figure 1.

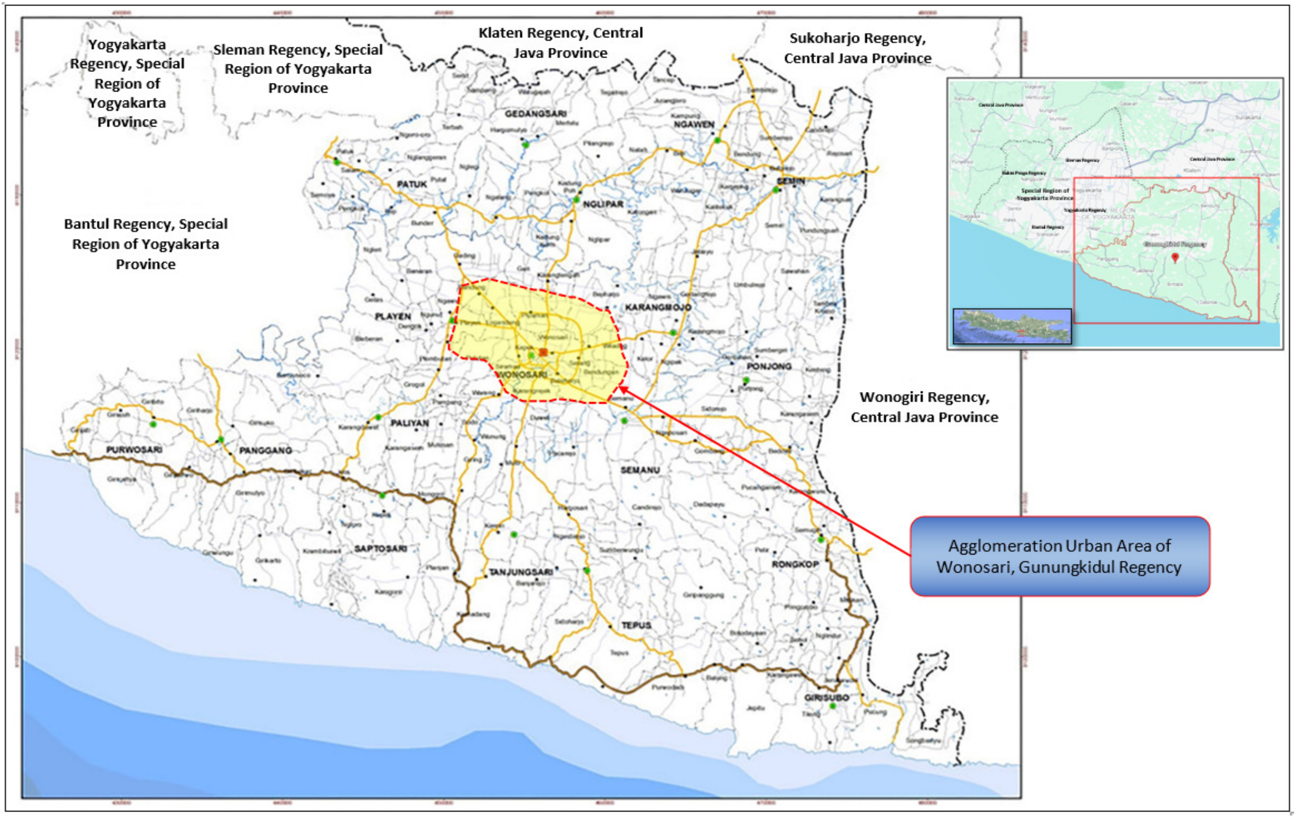

Fig. 1. Study area: the urban agglomeration of Wonosari, Gunungkidul Regency, Daerah Istimewa Yogyakarta, Indonesia.

A. *Synthetic Unit Hydrograph*

The Synthetic Unit Hydrograph (SUH) is used when there are no available hydrology data for deriving the unit hydrograph. The SUH is built based on the physical characteristics of a watershed [8]. In this research, the Soil Conservation Service (SCS) SUH is employed to analyze the upstream sub-watershed and the sub-watershed along the river stretch.

The SCS SUH employs a dimensionless hydrograph that was developed from the analysis of many unit hydrographs from field data with various watershed sizes and locations. If the effective rainfall is 1 mm, the peak discharge can be calculated according to [9]:

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

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

$$t_r = 0.6\,t_c \tag{3}$$

The parameters used are defined as: Q_p is the peak discharge of the unit hydrograph (m³/s), A is the watershed area (km²), T_p is the time to peak (h), t_p is the lag time from the centroid of effective rainfall to the hydrograph peak (h), t_r is the duration of effective rainfall (h), and t_c is the time of concentration (h).

B. *Flood Routing Through Level Pool*

Flood routing using the level pool method is employed to analyze the outflow hydrograph from a reservoir with a horizontal water surface [9]. In this study, flood routing is based on the continuity equation, which is solved numerically by discretization. In this approach, the unknown values are placed on the left-hand side of the equation, while the known values are placed on the right-hand side [10]:

$$\alpha_2 = I_1 + I_2 + \beta_1 \quad (4)$$

where:

$$\alpha_2 = \frac{2\,S_2}{\Delta t} + O_2 \quad (5)$$

$$\beta_1 = \frac{2\,S_1}{\Delta t} - O_1 \quad (6)$$

In this method, the geometric and hydraulic data of the reservoir are required, including reservoir hydraulics in the form of elevation–storage, elevation–outflow, and storage–outflow curves or tables. The elevation–storage curve is analyzed based on topographic data. The minimum elevation corresponds to zero storage, while the maximum elevation represents the peak elevation of the dam.

Flow simulation in an open channel is one of the methods used to study the flow pattern along that channel [11]. The simulation can be performed by flowing water in a channel made at laboratory scale or virtually by conducting a series of hydraulic analyses that are generally implemented in a series of computer programs. Through the physical model, several flow physical phenomena in a channel or a real river (prototype) are simulated in a channel or river that is made with the smallest size (model). The interpretation of the observed or measured phenomena in the model provides guidance on how the phenomena occur in the prototype. However, the mathematical model imitates the physical flow phenomenon in the real channel (prototype) through a series of mathematical equations that describe the relationship between flow variables (variables of geometric, kinematic, and dynamic). In the physical model, measurements or observations are conducted to obtain the flow parameters. In the mathematical model, these parameters are obtained by solving mathematical equations. The steps of the flow simulation using either a physical or a mathematical model are: preparation of the location, geometric imitation, flow imitation, measurement or analysis of the water velocity and depth, and presentation and interpretation of the results [12].

III. RESULTS AND DISCUSSION

A. Analysis of Factors Affecting Flood Peak Discharge Reduction

In this research, the factors influencing flood peak discharge reduction are analyzed, including the design flood [12, 13], soil type, land use, and the use of retarding basins [14], with reference to the flood conditions at the control point of Taman Pancuran.

The analysis results of the discharge reduction for Q_2, Q_5, Q_{10}, and Q_{20} under various design rainfalls and soil types at the control point of Taman Pancuran are presented in Figures 2 and 3. Meanwhile, the analysis results of discharge reduction of Q_2, Q_5, Q_{10}, and Q_{20} under different land use conditions and small capacity conservation basin volumes at the same control point are portrayed in Figures 4 and 5. As observed in Figure 2, a greater rainfall results in a smaller reduction in flood peak discharge. Figure 3 shows that soil types with higher run-off potential cause a smaller flood peak discharge. Figure 4 demonstrates that land uses with good cover and land preparation cause the biggest reduction in flood peak discharge. Figure 5 indicates that a larger maximum storage capacity or a smaller retarding basin volume also leads to a greater reduction of the flood peak discharge.

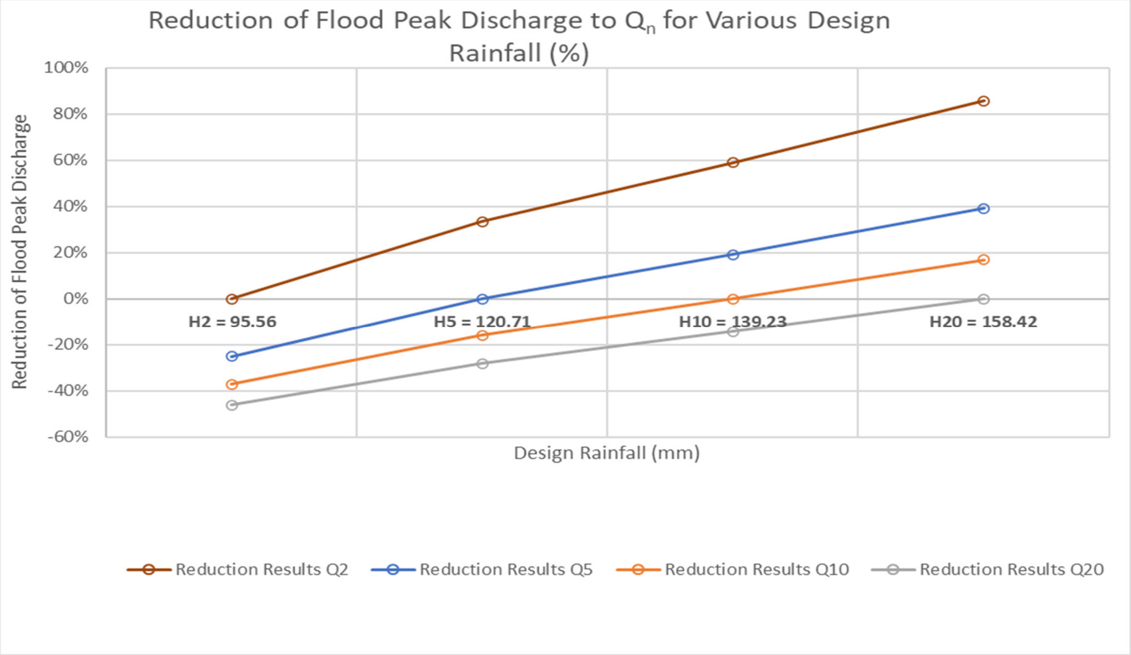

Fig. 2. Reduction of flood peak discharge (Qn) under various design rainfall scenarios at the control point of Taman Pancuran.

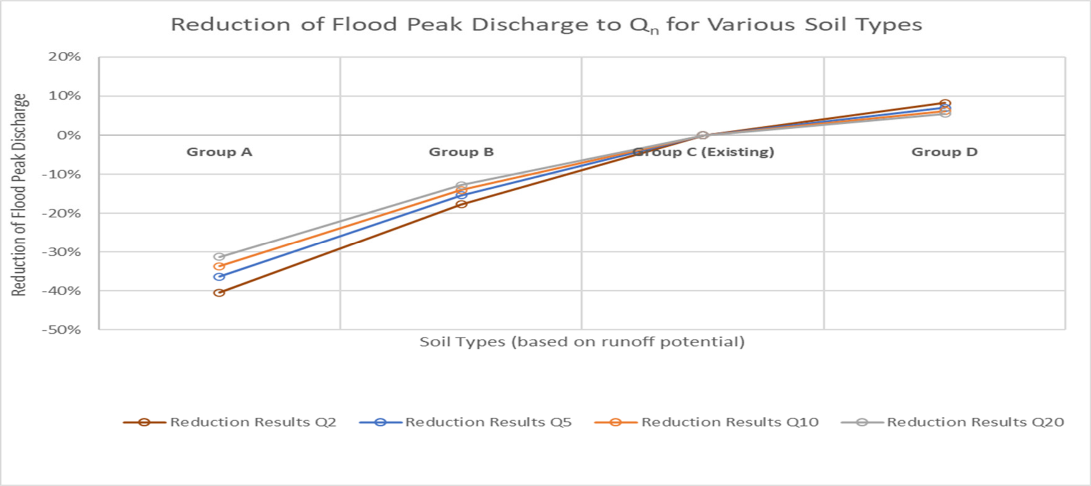

Fig. 3. Reduction of flood peak discharge (Qn) for various soil types at the control point of Taman Pancuran.

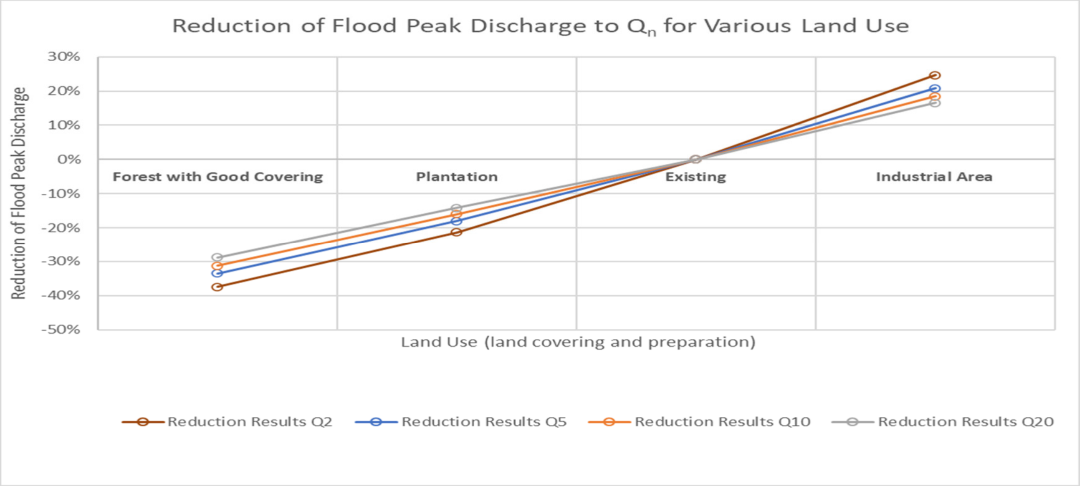

Fig. 4. Reduction of flood peak discharge (Qn) for various land use conditions at the control point of Taman Pancuran.

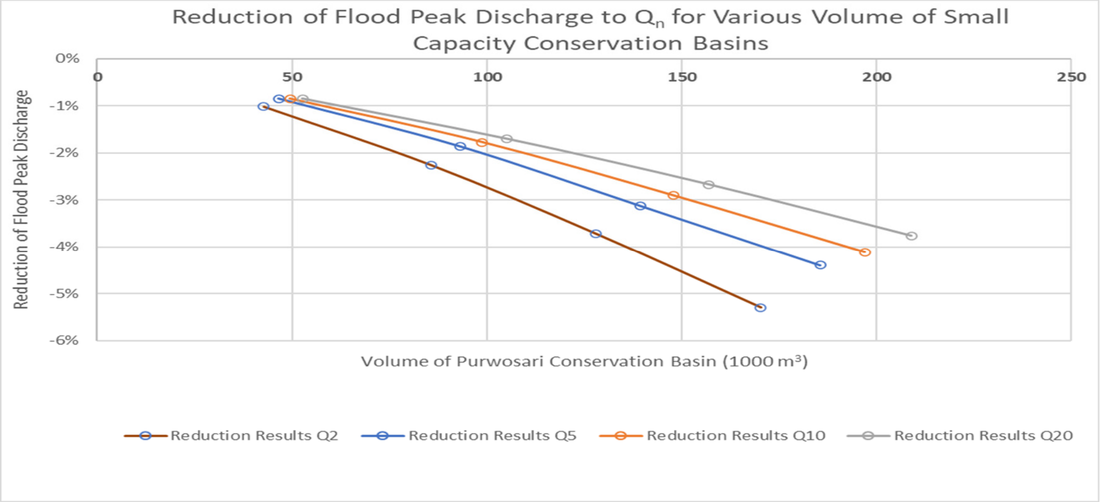

Fig. 5. Reduction of flood peak discharge (Qn) for various volumes of small-capacity conservation basins at the control point of Taman Pancuran.

B. Factor Analysis of Retarding Basin Placement

This research focuses on the placement of retarding basins within the watershed system, using five units: Purwosari, Trimulyo, Purbosari, Jeruk, and Kepek. The results of the discharge reduction for Q_2, Q_5, Q_{10}, and Q_{20} using Purwosari retarding basin are presented in Figure 6. The same analysis is then carried out for the Trimulyo, Purbosari, Jeruk, and Kepek retarding basins.

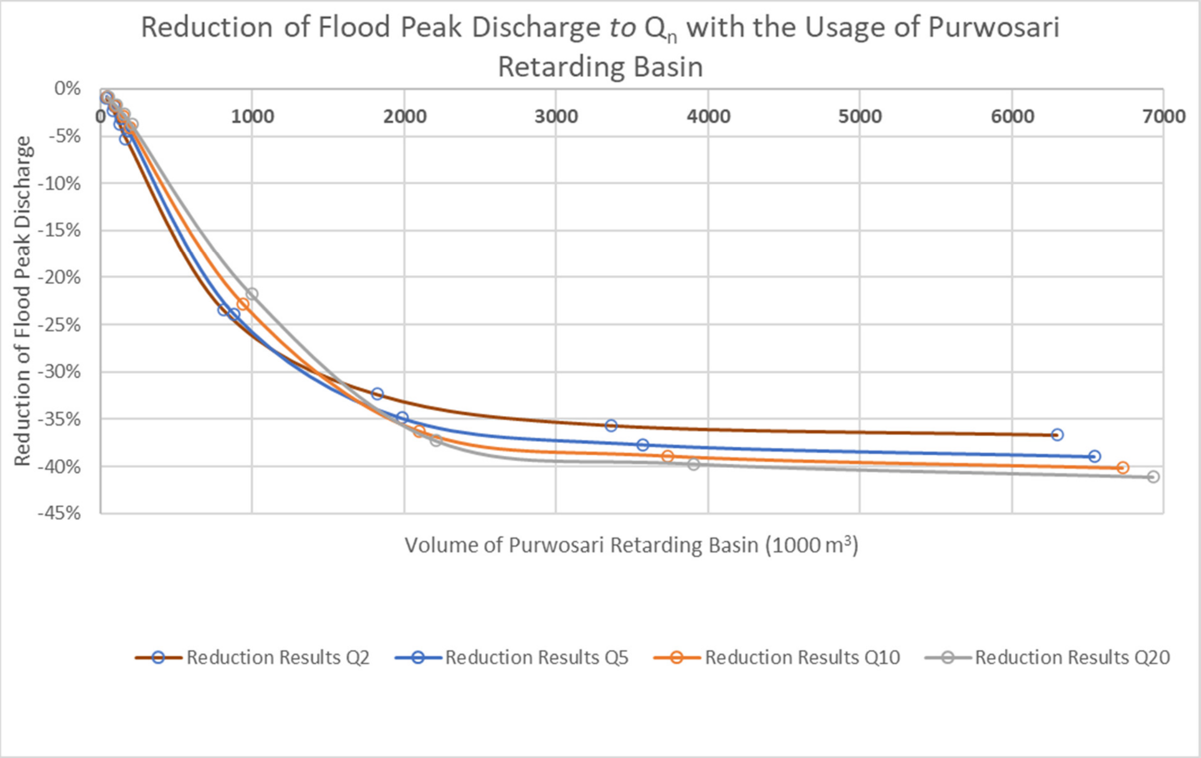

Fig. 6. Reduction of flood peak discharge (Qn) with the use of the Purwosari retarding basin at the control point of Taman Pancuran.

C. Determination of Predictors and Correlation Analysis of Vk, RAk, and QT with the Response ΔQp

The recapitulation of the simulation results for the flood peak discharge reduction (ΔQ_p) for several return periods (Q_T), considering several maximum storage capacities (V_k) and the placement of Purwosari retarding basin at the control point of Taman Pancuran are presented in Table I. The simulation results for Trimulyo, Purbosari, Jeruk, and Kepek retarding basins are also summarized. However, the data in the Table I are then used for carrying out the determination and correlation analyses of V_k, R_{Ak}, and Q_T (predictor/ independent variable) against ΔQ_p (response/ dependent variable). The results of this analysis are outlined in Table II.

In Table II, the independent variable of V_k shows a logarithmic relationship with the dependent variable of ΔQ_p, with a correlation coefficient (R) of 0.7894, which falls into the strong category (0.6000-0.7999). For the cubic and quadratic relationships, although the correlation coefficients (R) are 0.8379 and 0.8488 with the very strong category (0.8000-1.0000), arise the weakness for the bigger V_k as they produce an excessively high ΔQ_p trend. The determination coefficient (R^2) is 0.6231 and the adjusted R^2 is 0.627 or 62.07%, indicating that V_k can explain Q_p in an amount of 62.07% .

As shown in Table II, the independent variable of R_{Ak} exhibits linear, quadratic, cubic, and quartic relationships with the dependent variable of ΔQ_p, with an average correlation (R) of 0.4563, which is in the moderate category (0.4000-0.5999). The average determination coefficient is 0.2082 and the adjusted determination (R^2) is 0.2032 or 20.32%. This means that R_{Ak} can explain ΔQ_p in an amount of 20.32%.

Furthermore, the independent variable of Q_T has a logarithmic relation to the dependent variable of ΔQ_p, with a correlation (R) of 0.3987, which is in the low category (0.2000-0.3999) or it is close to the moderate category (0.4000-0.5999). The determination coefficient (R^2) is 0.1589 and the adjusted determination (adjusted R^2) is 0.1536, indicating that QT can explain of the variation in ΔQ_p.

Table II also demonstrates that the three independent variables V_k, R_{Ak}, and Q_T have a multiple linear relationship with the dependent variable ΔQ_p, with a correlation value (R) of 0.8379, which falls into the very strong category (0.8000–1.0000). The determination coefficient (R^2) is 0.7021, and the adjusted determination coefficient (adjusted R^2) is 0.6964, corresponding to 69.64%. This means that V_k, R_{Ak}, and QT together explain 69.64% of the variation in ΔQ_p, while the remaining variation is influenced by other factors.

TABLE I. RECAPITULATION OF THE SIMULATION RESULTS OF FLOOD PEAK DISCHARGE REDUCTION (ΔQP) FOR THE PURWOSARI RETARDING BASIN

Description		**V_k (1000 m^3) (1)**	**R_{Ak} (%) (2)**	**Q_T (m^3/s) (3)**	**ΔQ_p (%) (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	118.4	-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

IV. CONCLUSION

The aim of this research is to assess the variables influencing flood reduction. Three variables are examined to determine their effect on flood reduction using retarding basins. These variables consist of the maximum capacity of V_k, the controlled R_{Ak}, and the design flood corresponding to the return period (Q_T). The study was conducted in the urban agglomeration area of Wonosari, Gunungkidul Regency, Daerah Istimewa Yogyakarta-Indonesia. Based on the statistical analysis, the obtained results are:

The variable V_k has a logarithmic relationship with ΔQp, with a correlation coefficient (R) of 0.7894, which falls into the strong category (0.6000–0.7999). The coefficient of determination (R^2) is 0.6231, and the adjusted R^2 is 0.6207 (62.07%). This means that V_k explains 62.07% of the variation in ΔQ_p. The variable R_{Ak} has linear, quadratic, and quartic relationships with ΔQ_p, with a correlation coefficient (R) of 0.4563, which falls into the moderate category (0.4000–0.5999). The average coefficient of determination (R^2) is 0.2082, and the adjusted R^2 is 0.2032 (20.32%). This indicates that R_{Ak} explains 20.32% of the variation in ΔQ_p. The variable Q_T shows a logarithmic relationship with ΔQ_p, with a correlation coefficient (R) of 0.3987, which belongs to the low category (0.2000–0.3999), but is close to the moderate range (0.4000–0.5999). The coefficient of determination (R^2) is 0.1589, and the adjusted R^2 is 0.1536 (15.36%). Thus, Q_T explains 15.36% of the variation in ΔQ_p.

Finally, the three variables V_k, R_{Ak}, and Q_T have a multiple linear relationship with ΔQ_p, with a correlation coefficient (R) of 0.8379, which falls into the very strong category (0.8000–1.0000). The coefficient of determination (R^2) is 0.7021, and the adjusted R^2 is 0.6964 (69.64%). Therefore, V_k, R_{Ak}, and Q_T together explain 69.64% of the variation in ΔQ_p.

TABLE II. CORRELATIONS AND DETERMINATIONS OF V_K, R_{AK}, AND Q_T TO THE ΔQ_P

Predictor/ independent variable	Empirical equation	Correlation coefficient (R)	Determination coefficient (R^2)	Adjusted R^2	Correlation category
V_k	Linear regression				
	$\Delta Qp = - 3.375116 - 0.005329 V_k$	0.7451	0.5552	0.5524	strong
	Logarithmic regression				
	$\Delta Qp = 28.893956 - 6.557987 \ln(V_k)$	0.7894	0.6231	0.6207	strong
	Quadratic regression				
	$\Delta Qp = - 1.124411 - 0.010555 V_k + 9.10.10\text{-}7 V_k^2$	0.7791	0.6070	0.6045	strong
	Cubic regression				
	$\Delta Qp = 1.898887 - 0.025243 V_k + 7.81E\text{-}06 V_k^2 - 7.40E\text{-}10 V_k^3$	0.8379	0.7021	0.7002	very strong
	Quartic regression				
	$\Delta Qp = 0.314538 - 0.013645 V_k - 1.75E\text{-}06 V_k^2 + 1.64E\text{-}09{*}V_k^3 - 1.81E\text{-}13 V_k^4$	0.8488	0.7205	0.7187	very strong
R_{Ak}	Linear regression				
	$\Delta Qp = - 3.107163 - 0.251090 R_{Ak}$	0.4558	0.2077	0.2027	moderate
	Logarithmic regression				
	$\Delta Qp = 9.425549 - 6.718722 \ln(R_{Ak})$	0.4474	0.2002	0.1951	moderate
	Quadratic regression				
	$\Delta Qp = - 2.148070 - 0.353989 R_{Ak} + 0.001397 R_{Ak}^2$	0.4565	0.2083	0.2033	moderate
	Cubic regression				
	$\Delta Qp = - 1.720028 - 0.425428 R_{Ak} + 0.004178 R_{Ak}^2 - 0.000028 R_{Ak}^3$	0.4565	0.2084	0.2034	moderate
	Quartic regression				
	$\Delta Qp = 0.805028 - 0.954173 R_{Ak} + 0.034669 R_{Ak}^2 - 0.000636 R_{Ak}^3 + 3.93E\text{-}06 R_{Ak}^4$	0.4566	0.2085	0.2034	moderate
Q_T	Linear regression				
	$\Delta Qp = - 11.085912 - 0.001864 Q_T$	0.0037	0.0000	-0.0063	very low
	Logarithmic regression				
	$\Delta Qp = 106.551913 - 24.414963 \ln(Q_T)$	0.3987	0.1589	0.1536	low
	Quadratic regression				
	$\Delta Qp = - 11.000418 - 0.003288 Q_T + 5.64E\text{-}06 Q_T^2$	0.0037	0.0000	-0.0063	very low
	Cubic regression				
	$\Delta Qp = - 14.656831 + 0.088325 Q_T - 0.000736 Q_T^2 + 1.95E\text{-}06 Q_T^3$	0.0040	0.0000	-0.0063	very low
V_k, R_{Ak}, Q_T	Multiple linear regression				
	$\Delta Qp = 2.201135 - 0.005056 V_k - 0.212053 R_{Ak} + 0.007460 Q_T$	0.8379	0.7021	0.6964	very strong

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