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Optimization of the Retarding Basin Maximum Capacity to Reduce Flood Peak Discharge

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ABSTRACT

This research intends to analyze optimal storage capacity of retarding basin (V_k optimal) in reducing the flood peak discharge (ΔQ_p) in the downstream control point. The methodology consists of simulation in several placing of retarding basins (R_{AK}) and various maximum storage capacity (V_k) for various flood return periods (Q_T). This research is conducted in agglomeration urban area of Wonosari, Gunungkidul Regency, Daerah Istimewa Yogyakarta-Indonesia. There are planned 5 retarding basins that are Purbosari, Jeruk, Kepek, Purwosari, and Trimulyo. The optimal result of maximum storage capacity (V_k) due to the reduction of flood peak discharge (ΔQ_p) for the retarding basin of Purbosari (R_{Ak} = 7.01%) produces the optimal storage capacity (V_k optimal) about 886.45 x 10^3 m^3 and it can reduce the flood peak discharge (ΔQ_p) about 6.20%; however, for the retarding basin of Jeruk (R_{Ak} = 8.65%) produces the optimal storage capacity (V_k optimal) about 1000.01 x 10^3 m^3 and it can reduce the flood peak discharge (ΔQ_p) about 7.56%; for the retarding basin of Kepek (R_{Ak} = 21.34%) produces the optimal storage capacity (V_k optimal) about 1069.88. x 10^3 m^3 and it can reduce the flood peak discharge (ΔQ_p) about 14.23%; for the retarding basin of Purwosari (R_{Ak} = 60.11%) produces the optimal storage capacity (V_k optimal) about 1266.92. x 10^3 m^3 and it can reduce the flood peak discharge (ΔQ_p) about 26.45%; and for the retarding basin of Trimulyo (R_{Ak} = 66.52%) produces the optimal storage capacity (V_k optimal) about 1266.94. x 10^3 m^3 and it can reduce the flood peak discharge (ΔQ_p) about 29.27%.

Keywords: Maximum Storage Capacity, Optimization, Flood Reduction, Retarding Basin

INTRODUCTION

Human activities impact on the ecosystems has long been recognized that supports evidence about the hypothesis that we have entered into an Anthropogenic (Adhikari, 2013). However, the human activities have been addressed as one of the urgent changes of driving forces and there is simultaneously changed in the natural environments (Smith and Zedar, 2013), and also the availability of ecosystem goods and services (Kabba and Li, 2011), the spatial pattern of landscape (Kabba and Li, 2011; Wang, 2013) and human well-being to climate change and the increase vulnerability of regional biomes (Salazae et.al, 2015). The flooding and inundation cases are more crucial due to the climate change in general and in rainfall pattern/ intensity change in particular. During the monsoon months from June until September, the whole rivers are in spate with bank-full discharges and cause flooding and inundation in several parts of region (Adhikari, 2013).

There is long enough period of rainy season in Indonesia. The rainy season period is more than six months. Therefore, it is needed more attention due to the basic factor to regulate and arrange an urban area (Suripin, 2018). The infrastructure development is carried out for making guarantee to the social prosperity of society. It also means the land use change; however, the land use change will cause rainfall and the rainfall cannot permeate again into soil on the rainy season (Limantara et.al, 2018). Therefore, it potential to cause the surface run-off that will be becoming flooding (Bisri et.al, 2017; Tung et.al, 1987; Limantara, 2009a). The infiltration and run-off processes are one of the urgent processes in hydrological cycle (Limantara, 1009b; Priyantoro and Limantara, 2017). The land use change in the interception area due to the development for industry, urban facilities, and residence are predicted will disturb the hydrology cycle.

Run-off is water that is flowing on the surface due to the full capacity of soil infiltration. To carry out the analysis of surface flow there must attend 4 (four) main factors that are rainfall depth (P), soil type, land cover type, and land preparation. Nowadays, there have been developed several methods for analyzing run-off due to the rainfall data that are generally knows as rainfall–run-off models. The United States Department of Agriculture (USDA, 1986) has developed a model that simplified the complex hydrology cycle for estimating run-off and peak discharge in a watershed. This model is known as the Soil Conservation Service (SCS)-Curve Number (CN) or SCS-CN method and it is an empirical model.

The philosophy of retarding basin usage is to prevent water that flows from upstream by building the retarding basins before flowing into downstream. The reservoir and basin are strategically placed in the flow path for saving the surface run-off temporarily (Ferguson, 1988 and White, 2022). To solve the flood event with high return period, the mechanism of multi-reservoir is applied for affecting the condition of critical rainfall and the flood inundation in urban area (Iacobellis et.al, 2013). The reservoir karst unit in the karst system has an impact to hydrology that effectively holds the flood peak and increases the sub-surface water run-off (Mo et.al, 2021). Meanwhile, dry and wet retention reservoir can give the more significant decreasing of flood peak. If the suitable location is available, it can be implemented with the cost that can be accepted by the decision maker (Bezak et.al, 2021). Based on the previous research, there are no studies yet about reduction of flood peak discharge (ΔQ_p) due to the controlled ratio variable of watershed area and retarding basin ($R_{Ak}=A_k/A$), and the maximum storage capacity of retarding basin (V_k) in a watershed system. Therefore, it is needed to carry out the research about a reduction model of flood peak discharge (ΔQ_p) by using retarding basin method. This research intends to analyze the optimal of maximum storage capacity and retarding basin in reducing flood

MATERIALS AND METHODS

The research location is in agglomeration urban area of Wonosari, Gunungkidul Regency, Daerah Istimewa Yogyakarta-Indonesia (Figure 1)

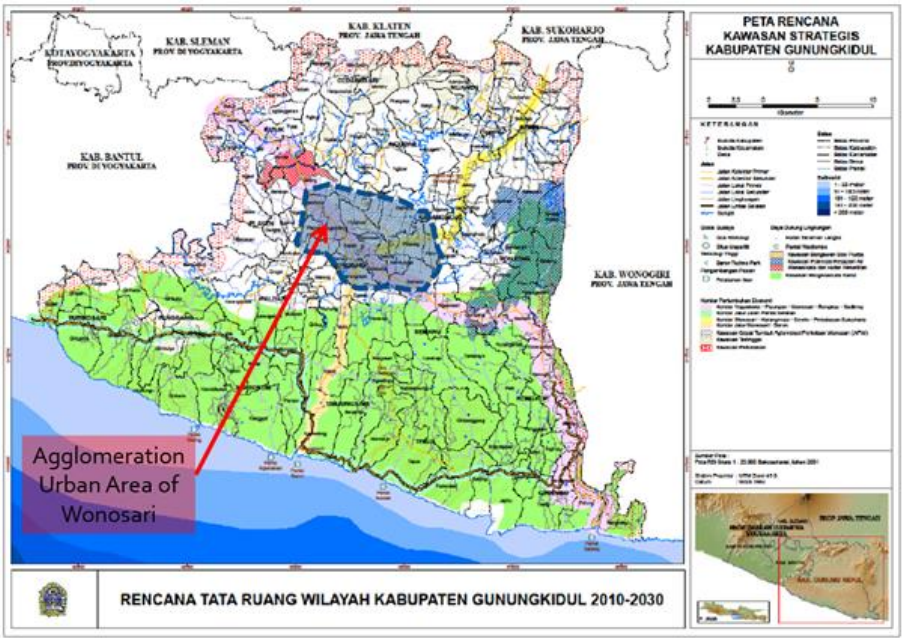

Figure 1. Research Location
Source: RTRW of Gunungkidul Regency 2010-2030.

Synthetic Unit Hydrograph

The synthetic unit hydrograph (SUH) is used if the hydrology data are not available for differentiating the unit hydrograph (Bisri et.al, 2018). However, the synthetic unit hydrograph is built based on the physical characteristic of watershed (Priyantoro and Limantara, 2017). This research uses the SCS (Soil Conservation Service) SUH for upstream sub-watershed and sub-watershed on the river section.

The SCS SUH uses the dimensionless hydrograph that is developed from a large number of unit hydrograph analysis from field data with various watershed size and different location. If the effective rainfall is 1 mm, so the peak discharge is as follows (Gupta, 1989):

$$Q_p = \frac{0.208\,A}{T_p} \quad (1)$$

$$T_p = \frac{t_r}{2} + t_p \quad (2)$$

$$t_p = 0.6\,t_c \quad (3)$$

With:

Q_p: Peak discharge of unit hydrograph (m^3/s).
A: Watershed area (km^2).
T_p: Time to peak (hour).
t_p: Lag time (time from weight point of effective rainfall to the peak of unit hydrograph) (hour).
t_r: Duration of effective rainfall (hour).
t_c: Concentration time (hour).
T_b: Time base (2.67 T_p) (hour).

Flood Routing Through Level Pool

Flood routing through the level pool is a procedure for analyzing outflow hydrograph from reservoir that has horizontal water surface (Triatmodjo, 2016). However, flood routing in the continuity equation that is numerical solved by making the numerical discretization that classifies the values which have not been known on the left side and the values on the right side has been known (Triatmodjo, 2016) is as follows:

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

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, there is needed the geometric data and reservoir hydraulics as curve or table of elevation-storage, elevation-outflow, storage-outflow. The curve of elevation -storage is analyzed based on the topography data. The minimum elevation is an elevation that the storage is zero; however, the maximum elevation is a peak elevation of dam.

RESULTS AND DISCUSSION

Analysis of Inflection Point on Logarithmic Curve of V_k to ΔQ_p

In this case, there will be analyzed the reduction factor of flood peak discharge (□ Qp) by using retarding basin (Yazdi et.al, 2021) to the existing condition of flood on the control point of Taman Pancuran in research location.

Simulation result recapitulation of flood peak discharge reduction (ΔQ_p) for several return periods (Q_T) with some maximum storages capacity (V_k) and the placing of Purwosari retarding basin (R_{AK}) (for example) on the control point of Taman Pancuran as presented in Table 1. Then, there are also recapped the simulation result for the retarding basins of Purbosari, Jeruk, Kepek, and Trimulyo. However, the data in Table 1 is used for carrying out the optimization analysis of maximum storage capacity (V_k) to reduction of flood peak discharge (ΔQ_p) and the result is presented in Table 2 and Table 3.

In design of retarding basin for flood control, there is needed the volume/ capacity of the most effective maximum storage capacity in controlling flood in the downstream. Therefore, it is needed the optimization analysis of the storage capacity. The understanding of optimization in this case is if it is illustrated in the logarithmic curve form, the inflection point of the curve is the optimum point of retarding basin volume/ storage capacity change that has not given significantly the additional reduction of flood peak discharge.

To carry out the analysis of inflection point in logarithmic curve, it cannot use the differential equation because the differential value is zero from the equation y = ln(x), the y'= 1/x, therefore, it is carried out by finding the linear equation of tangent from both parts of straight line from the logarithmic curve (for example: $y = m_1 x + c_1$ and $y = m_2 + c_2$). Then, to find the coordinate of cut point and the angle between both linear lines, after that is to find the angle between lines (m_1 or m_2) with the perpendicular line to the logarithmic curve. After finding the line angle (m_1 or m_2) and the angle of perpendicular line to the logarithmic curve, then the linear equation of perpendicular line to the logarithmic curve (for example y = c x + d) is substituted with the equation of logarithmic curve (for example y

= a + b ln(x)), and by simple iteration analysis it can be analyzed the coordinate of inflection point from the logarithmic curve. Analysis of inflection point on logarithmic curve (V_k) to ΔQ_p for Purwosari retarding basin is presented in Table 2, Table 3 and Figure 2. Then, there is carried out the same analysis for the retarding basins of Trimulyo, Purbosari, Jeruk, and Kepek, as well as an analysis of inflection point on average logarithmic curve (V_k) to ΔQ_p.

Optimization Analysis of Maximum Storage Capacity (V_k) to Flood Peak Discharge Reduction (ΔQ_p)

The result of inflection point analysis is as the optimal of maximum storage capacity (V_k optimal) for each retarding basin (Purbosari, Jeruk, Kepek, Purwosari, and Trimulyo) in reducing the flood peak discharge (ΔQ_p) as presented in Figure 3, however, the optimal average of maximum storage capacity can be seen in Figure 4.

Table 2 and Table 3 present the optimization analysis result of maximum storage capacity (V_k) to the reduction of flood peak discharge (ΔQ_p) for Purbosari retarding basin (R_{Ak} = 7.01%), it is obtained the optimal of maximum storage capacity (V_k optimal) about 886.45 x 10^3 m^3 and gives the reduction of flood peak discharge (ΔQ_p) about 6.20%; for KK Jeruk (R_{Ak} = 8.65, the V_k optimal is 1000.01 x 10^3 m^3 and gives ΔQ_p about 7.56%; for KK Kepek (R_{Ak} = 21.34%), the V_k optimal is 1069.88 x 10^3 m^3 and gives ΔQ_p about 14.23%; for KK Purwosari (R_{Ak} = 60.11%), the V_k optimal is 1266.92 x 10^3 m^3 and gives ΔQ_p about 26,45%, and for KK Trimulyo (R_{Ak} = 66.52%), the V_k optimal is 1266.94 x 10^3 m^3 and gives ΔQ_p about 29.27%.

However, for the average of V_k optimal is 1069.96 x 10^3 m^3 and gives ΔQ_p about 16.85% which this value is similar with the value of V_k optimal and ΔQ_P for KK Kepek (R_{Ak} = 14.23 % and ΔQ_p is 1069.88 x 10^3 m^3).

Table 1. Simulation Result Recapitulation of Flood Peak Discharge Reduction (ΔQp) For Purwosari Retarding Basin

Description		**V_k**	**R_{Ak}**	**Q_T**	**DQ_p**
		(1000 m^3)	**(%)**	**(m^3/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	DQ_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

Table 2. Optimizations Analysis of maximum Storage Capacity (V_k) to the Flood Peak Discharge Reduction (ΔQ_p) (1)

Independent Variable	Empirical Equation $DQ_p = f(V_k)$	Linear Equation of Line m_1				Linear Equation of Line m_2				Coordinate of Cut Point between Line m_1 and Line m_2	
										X	Y
V_k	Logarithmic Partial Regression										
R_{Ak} = 7.01%	DQ_p = 8.571870 - 2.176413 ln(V_k)	Y =	-0.0066	X +	-1.6300	Y =	-0.0006	X +	-6.9796	886.44	-7.52
R_{Ak} = 8.65%	DQ_p = 11.625225 - 2.776954 ln(V_k)	Y =	-0.0076	X +	-1.5626	Y =	-0.0007	X +	-8.4803	1000.00	-9.19
R_{Ak} = 21.34%	DQ_p = 28.105800 - 6.069014 ln(V_k)	Y =	-0.0159	X +	-0.8705	Y =	-0.0014	X +	-16.3588	1069.85	-17.88
R_{Ak} = 60.11%	DQ_p = 39.880037 - 9.284020 ln(V_k)	Y =	-0.0215	X +	-5.0195	Y =	-0.0018	X +	-29.9101	1266.85	-32.19
R_{Ak} = 66.52%	DQ_p = 46.736292 - 10.638582 ln(V_k)	Y =	-0.0246	X +	-4.7142	Y =	-0.0021	X +	-33.2365	1266.85	-35.85
	Logarithmic Regression										
R_{Ak} = 7.01% - 66.52%	DQ_p = 28.893956 - 6.557987 ln(V_k)	Y =	-0.0185	X +	-2.4573	Y =	-0.0012	X +	-21.0115	1069.91	-22.27

Table 2. Optimizations Analysis of maximum Storage Capacity (V_k) to the Flood Peak Discharge Reduction (ΔQ_p)

Angle between Line m_1 and Line m_2 (°)	Angle between Line m_1 and Perpendicular Line to Logarithmic Curve (°)	Angle of Line m_1 (°)	Angle of Perpendicular Line to Logarithmic Curve (°)	Gradient of Perpendicular Line to Logarithmic Curve	Linear Equation of Perpendicular Line to Logarithmic Curve				Coordinate of Inflection Point from Logarithmic Curve	
									V_k	DQ_p
0.35	89.83	-0.38	-90.21	275.49	Y =	275.49	X +	-244212	886.45	-6.20
0.40	89.80	-0.44	-90.24	239.92	Y =	239.92	X +	-239928	1000.01	-7.56
0.83	89.59	-0.91	-90.50	115.51	Y =	115.51	X +	-123597	1069.88	-14.23
1.13	89.44	-1.23	-90.67	86.02	Y =	86.02	X +	-109002	1266.92	-26.45
1.29	89.36	-1.41	-90.76	75.07	Y =	75.07	X +	-95134	1266.94	-29.27
0.99	89.50	-1.06	-90.56	101.52	Y =	101.52	X +	-108640	1069.96	-16.85

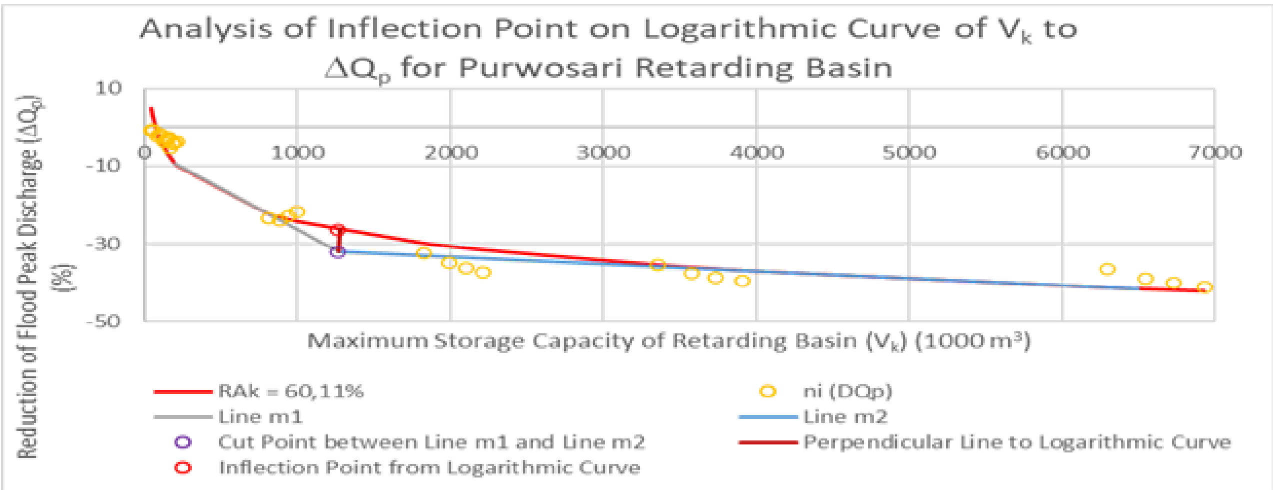

Figure 2. Analysis of Inflection Point on Logarithmic Curve of V_k to ΔQ_p for Purwosari Retarding Basin

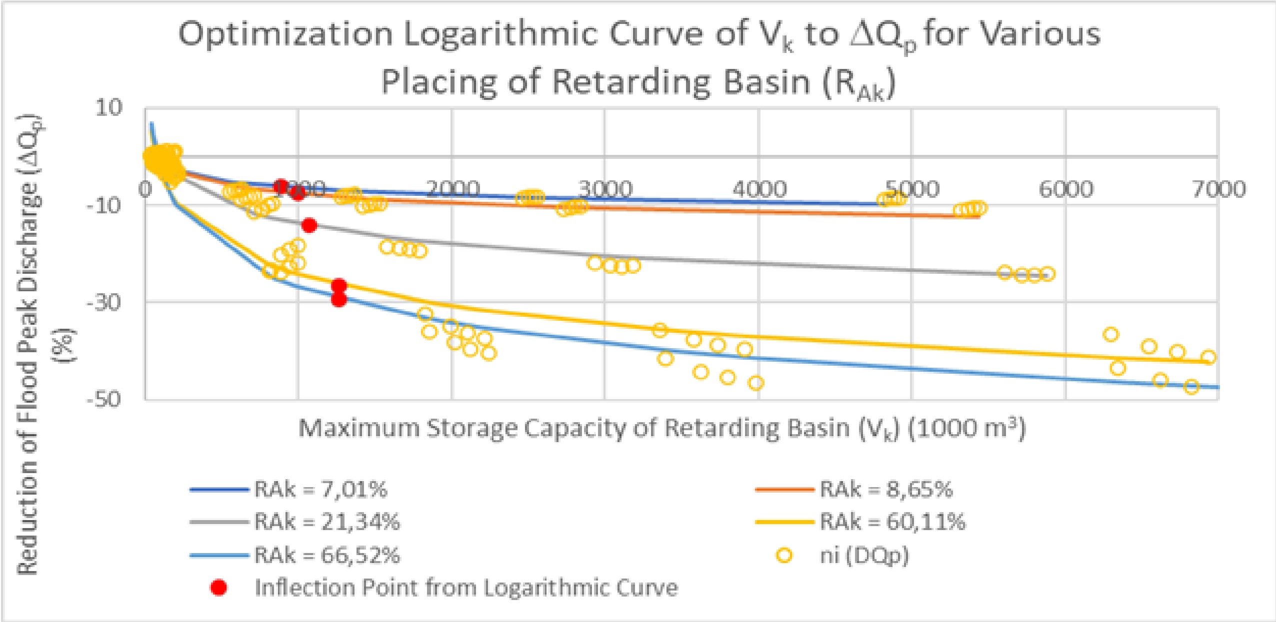

Figure 3. Optimization Logarithmic Curve of V_k to ΔQ_p for Various Placing of Retarding Basin (R_{Ak})

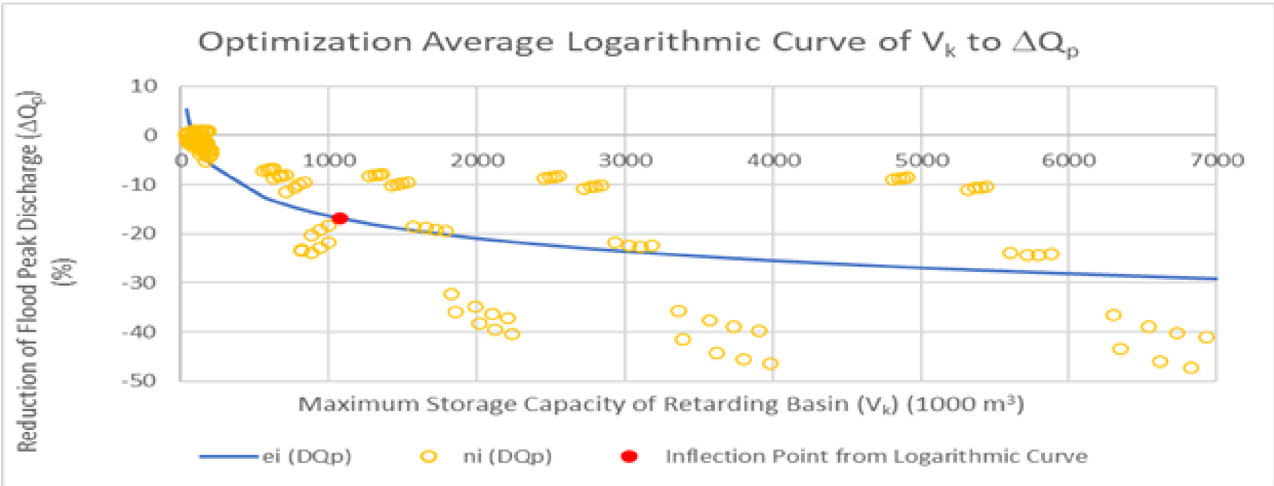

Figure 4. Optimization Average Logarithmic Curve of V_k to ΔQ_p

CONCLUSION

The aim of this research is to obtain the optimal of maximum storage capacity (V_k optimal) from the retarding basin in reducing the flood peak discharge (ΔQ_p) on the downstream control point. The optimization analysis is carried out by finding the infection point for logarithmic curve of V_k to ΔQ_p for each retarding basin (Purbosari, Jeruk, Kepek, Purwosari, and Trimulyo). This research is conducted in agglomeration urban area of Wonosari, Gunungkidul Regency, and Daerah Istimewa Yogyakarta-Indonesia. Based on the optimization analysis for the retarding basin of Purbosari (R_{Ak} = 7.01%) produces the optimal storage capacity (V_k optimal) about 886.45 x 10^3 m^3 and it can reduce the flood peak discharge (ΔQ_p) about 6.20%; however, for the retarding basin of Jeruk (R_{Ak} = 8.65%) produces the optimal storage capacity (V_k optimal) about 1000.01 x 10^3 m^3 and it can reduce the flood peak discharge (ΔQ_p) about 7.56%; for the retarding basin of Kepek (R_{Ak} = 21.34%) produces the optimal storage capacity (V_k optimal) about 1069.88. x 10^3 m^3 and it can reduce the flood peak discharge (ΔQ_p) about 14.23%; for the retarding basin of Purwosari (R_{Ak} = 60.11%) produces the optimal storage capacity (V_k optimal) about 1266.92. x 10^3 m^3 and it can reduce the flood peak discharge (ΔQ_p) about 26.45%; and for the retarding basin of Trimulyo (R_{Ak} = 66.52%) is produced the optimal storage capacity (V_k optimal) about 1266.94. x 10^3 m^3 and it can reduce the flood peak discharge (ΔQ_p) about 29.27%.

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