

## Model of Flood Attenuation by Combining Dry Dam and Retention Pond Distribution

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**Abstract:** This research aims to find the most optimum condition for the position and capacity of the retention pond for decreasing the design flood and increasing the time concentration. This research was conducted in the Ciawi and Sukamadu dams-Indonesia. Based on the design, the Ciawi and Sukamadu dry dams only can reduce the flood peak to amount of 13%, so it is still needed the supporting infrastructure for increasing the efficiency in reducing flood. The combination of high- and low-intensity rainfall-runoff management methods can support the performance of dry dams in making an effort to reduce the design flood. The methodology consists of collecting the primary and secondary data, conducting the analysis based on the concepts of flood control and low impact development, then analyzing by using the HEC-HMS software. The results show that by adding the Ciawi and Sukamahi dams that have a storage capacity of 15 million m<sup>3</sup>, there is success to decrease the flood peak to 13% and the additional time concentration (Tc) is during 20 min. The additional retention pond will be able to reduce the number of flood peaks. The results show that the additional retention pond that is combined with the Ciawi dan Sukamahi dams can increase the performance of the Ciawi and Sukamahi dams with the percentage flood reduction is 19% and the additional time concentration is 50 min. The formulation that illustrates the flood reduction in the downstream of the Ciliwung watershed was proposed.

**Keywords:** model, retention pond, flood reduction, Ciawi, Sukamahi.

### 幹壩與蓄水池分佈相結合的防洪模型

**摘要：**本研究旨在尋找蓄水池的位置和容量的最佳條件，以減少設計洪水和增加時間濃度。這項研究是在印度尼西亞的恰維和蘇卡馬杜水壩進行的。根據設計，恰維和蘇卡馬杜幹壩只能將洪峰降低 13%，因此仍需要配套基礎設施來提高減洪效率。高強度和低強度降雨徑流管理方法的結合可以支持幹壩在努力減少設計洪水方面的表現。該方法包括收集一手和二手數據，根據防洪和低影響開發的概念進行分析，然後使用 HEC-HMS 軟件進行分析。結果表明，通過增加蓄水量為 1500 萬立方米的恰維和蘇卡瑪希大壩，成功將洪峰降低到 13%，附加時間濃度在 20 分鐘內。額外的蓄水池將能夠減少洪水高峰的數量。結果表明，與恰維和蘇卡瑪希大壩相結合的附加蓄水池可以提高恰維和蘇卡瑪希大壩的性能，減洪百分比為 19%，附加時間集中為 50 分鐘。提出了說明慈利旺流域下游洪水減少的公式。

**关键词：**模型，蓄水池，減洪，恰維，蘇卡瑪希。

## 1. Introduction

The impact of human activities in these ecosystems has long been recognized. Currently, some evidence is

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increasing to support the hypothesis nowadays that we have entered into the Anthropocene [1]. However, the human activities have been recorded and documented as one of the urgent changes of driving forces and certainly cause simultaneous changes in the natural environment [2]. The ecosystem services and goods availability [3], also the spatial pattern of the landscape [3], [4], and the increasing vulnerability of regional human well-being and biomes to the global climate change [5], [6].

One of the largest problems in applied hydrology and hydrology approaches is related to the floods dan flooding are as the flood predictions that are produced from the heavy and very heavy rain over a catchment or watershed [7]. The design and management of hydraulic structure demands the reliable information that is concerning the peak flow or design flood that is expected after a given probability of a return period and event. Therefore, some hydrologists often face with the extreme rainfall and flood events predicted on the basis of historical flood records [8], [9].

The Ciawi and Sukamahi dams are as the infrastructure that is designed by the government for being able to decrease the flood, and to strengthen the flood traveling time in Jakarta. Based on the design, the Ciawi and Sukamahi dry dams are only able to reduce the flood peak about 13%, so it is still needed the supporting infrastructure for increasing the effectivity of reducing the flood. The combination of high- and low-intensity rainfall-runoff management methods can support the performance of dry dams in making an effort to reduce the design flood. There is no formulation for combining the function of the dry dam with the retention pond in Indonesia in making efforts to reduce the design flood in the downstream [10], [11].

This research will attempt combining high - spectrum rainfall management by using dry dam with a method for managing the light until medium spectrum rainfall that is suitable to the concept of Low Impact Development (LID) that is the usage of retention pond. By combining the two methods, it is hoped will be able to increase the function of flood attenuation of Ciawi and Sukamahi dams. This research intends to find the most optimum condition of the position and retention pond capacity and the function is to reduce the design flood and to increase the time concentration.

## 2. Materials and Methods

### 2.1. Research Location

This research is conducted in the upstream Ciliwung watershed where there will be built 2 dry dams that are Ciawi and Sukamahi dams. Astronomically, the Ciliwung river is in the south longest of  $6^{\circ}05' - 6^{\circ}50'$  and east longest of  $106^{\circ}40' - 107^{\circ}00'$ . The Ciliwung watershed is restricted by the Cisadane watershed to the west and the Citarum watershed to the east.

Astronomically, the Ciawi dam is in the east longest of  $106^{\circ}52'20''$  and the south longest of  $06^{\circ}39'28''$ , however, Sukamahi dam is in the east longest of  $106^{\circ}52'20''$ -inch needle and south longest of  $06^{\circ}40'12''$ . The research location is in the downstream of the Ciawi dam development (upstream of Ciliwung river in the Ciawi village-Megamendung district-Bogor regency), and the Sukamahi dam (Cisukabirus in the Sukamahi village-Megamendung district-Bogor regency). The research location is presented in Fig. 1.

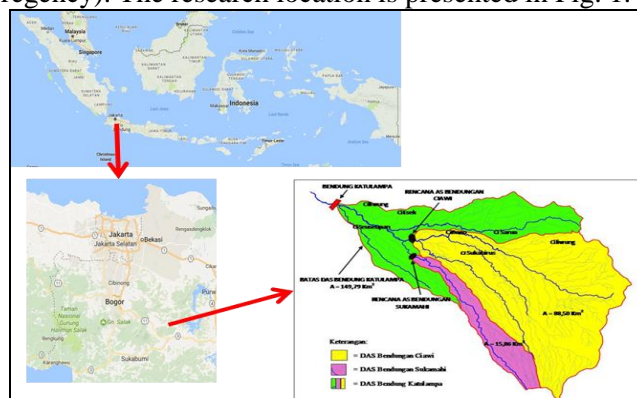


Fig. 1 Map of location

### 2.2. Division of Ciliwung Watershed and Sub-Watershed

This research was conducted in the upstream Ciliwung Hulu. Astronomically, the Ciliwung river is in the south longest of  $6^{\circ}05' - 6^{\circ}50'$  and east longest of  $106^{\circ}40' - 107^{\circ}00'$ . Fig. 2 presents the upstream Ciliwung watershed and the location of Ciawi and Sukamahi dams.

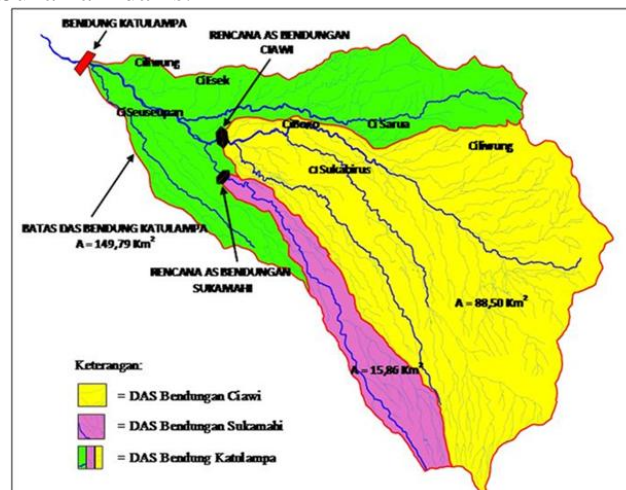


Fig. 2 Ciliwung Hulu watershed and location of Ciawi and Sukamahi dams

### 2.3. SCS-CN Model Sebagai Unit Estimasi Debit Banjir Rencana

The method of Soil Conservation Service (SCS-CN) is a hydrological modeling for estimating the flood by adopting the watershed characteristic. The SCS-CN estimates the flood based on the land use and soil moisture content that is represented by rainfall during 5 days before the day when is analyzed and soil type [12]. This method is highly dependent on the runoff curve number or CN, where the CN coefficient is a

constant to determine the value of the maximum soil storage capacity [13]. The equation of the SCS-CN model based on the rainfall depth analysis is as follows [13]:

$$Q = \frac{(P - I_a)^2}{((P - I_a) + S)} \text{ for } P > 0,2 S \quad (1)$$

$$Q = 0 \text{ for } P < 0,2 S \quad (2)$$

where:

Q - discharge (m<sup>3</sup>/s)

P - accumulation of rainfall (mm)

S - maximum storage capacity after run-off happens (mm)

I<sub>a</sub> - initial abstraction (mm), I<sub>a</sub> can be estimated using the empirical formula:

$$I_a = 0.2 S \quad (3)$$

By missing the I<sub>a</sub> as the independent parameter, and distributing it into the equations (1) and (2), so there is obtained the formulation as follows:

$$Q = \frac{(P - 0,2S)^2}{(P + 0,8S)} \quad (4)$$

The parameter S accommodates the relation between land use and soil type through the equation as follows, where CN is in the range of 0–100.

$$S = 1000/CN - 10 \quad (5)$$

## 2.4. Concept of Flood Control

The control and security of a flood can be carried out non-structurally. The approach of non-structure is as an alternative of control and security to the flood structurally. This approach focuses on the: 1) human behavior and strategies for changing (to keep away human from flood, to evaluate them by using the flood early warning system, etc.); and 2) The usage of spatial design as a guidance instrument in planning and designing the communities in the areas where is free from the flood threat, or to increase their ability to be adaptive to the flood impact.

Intensive efforts, special attention, and adequate allocation of water resources are required for non-structural applications of flood control and safety (flood assessment, land use regulation, flood safety, flood preparedness, flood insurance). This approach can be carried out both without and in parallel with the structural efforts.

## 2.5. Concept of Low Impact Development

Low Impact Development (LID) is a concept with a different approach for managing water in which the LID modifies the practice of regional development in such a way that the regional hydrology function is naturally maintained. LID is as a regional development that considers the environmental unsure in every step of design and construction. The aim of LID is to eliminate and minimize the effect of urbanization on the water natural system. The main thing is the

condition of water natural system in several areas is not too much changed before and after development. The technology of LID is more applied in several regions. Some LID technology that are generally applied are as follows: bioretention and rains garden, rain barrels and cisterns, permeable sidewalk, green roofs, retention ponds, filter strip, vegetated swale, etc.

The main aim of LID is to recommend the hydrology function in every usage unit of urban region in a relatively small scaled catchment area (sub-watershed, sub-sub-watershed, etc.) to the conditions on the pre-development [14]. Additionally, the other aim of LID is as the run-off control that has some aims as follows: to decrease the impact of rainfall-run-off, to maintain and to create back the priority of natural conditions that are still natural, to decrease the waterproof area effectively, to improve the hydrology balance due to the cut of the hydrological cycle, to increase the function of temporary storage, and to ease easy the effects of infiltration and retention as the groundwater conservation.

## 2.6. HEC-HMS as a Flood Simulator by Using Spatial Distribution

The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) is as the software that is developed by the United States Department of Agriculture in 1992 and it replaces the HEC-1 model. This model is designed for simulating the process of rainfall-run-off completely for watershed with the dendritic shape. The hydrology system in the HEC-HMS is represented in some model components that are model of watershed, meteorology, control specification, and input data. The watershed response in transforming rainfall into flow is simulated based on the meteorology model that is applied. The control specification is used for defining the period and stage of time in a simulation. The components of data input-like data series, data pairs etc. are used as the parameters or boundary conditions of a watershed and meteorology model.

## 3. Results and Discussion

### 3.1. Simulation of Flood Attenuation-1

The first simulation is carried out by positioning the Ciawi and Sukamahi dams in the downstream Ciliwung watershed and there is combined by adding a retention pond in the upstream Ciawi dam, The Ciawi dam itself has 3 main affluent that are upstream Ciliwung river itself, Cisarua river, and Cisubah river.

The scenario-2 is worked by adding 6 retention ponds in the upstream Ciawi dam. The running result of scenario-2 can be seen in Fig. 3. Based on the running result, it is seen that the time peak of Scenario-2 happened on 18.30–18.40 with each discharge is

414.42 m<sup>3</sup>/s due to the 2 years return period; 459.66 m<sup>3</sup>/s due to the 5-year return period; 530.78 m<sup>3</sup>/s due to the decade return period; 676.92 m<sup>3</sup>/s due to the 25 years return period; 829.43 m<sup>3</sup>/s due to the 50 years return period; and 1,206.57 m<sup>3</sup>/s due to the century return period.

### 3.2. Simulation of Flood Attenuation-2

On the second simulation, there is carried out by positioning the Ciawi and Sukamahi dams in the upstream Ciliwung watershed and is combined by adding the retention pond in the upstream Sukamahi dam. The Sukamahi dam is in the downstream of Cisukabirus dam. The same as scenario-2, the positioning retention pond itself is carried out based on the basin analysis in the DEM map with a scale of 1:8,000 and actual conditions in the field. The overlapping is not carried out with the Regional Spatial Plan (RTRW) because the conditions of land use now are more crowded compared with the RTRW in 2030 for the Bogor regency.

The running result of scenario-3 can be seen in Fig. 4. Based on the running result, it is seen that the time peak of Scenario-3 happened on 18.40–18.50 with each discharge is 411.15 m<sup>3</sup>/s due to the 2 years return period; 433.2 m<sup>3</sup>/s due to the 5-year return period; 529.77 m<sup>3</sup>/s due to the decade return period; 667.93 m<sup>3</sup>/s due to the 25 years return period; 827.47 m<sup>3</sup>/s due to the 50 years return period; and 1,200.92 m<sup>3</sup>/s due to the century return period.

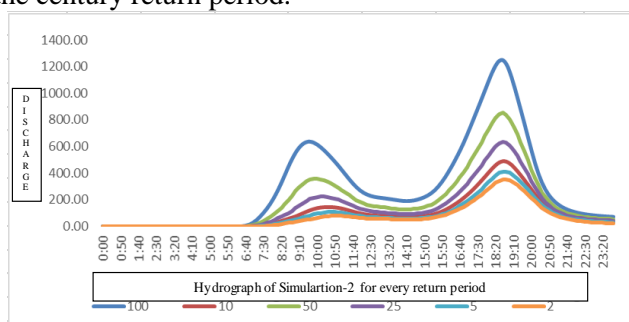


Fig. 4 Running result hydrograph of scenario-3

### 3.3. Simulation of Flood Attenuation-3

Scenario-4 implements the positioning of the Ciawi and Sukamahi dams upstream Ciliwung watershed and is combined by adding the retention pond in the Ciesek sub-watershed. The same as the previous simulation, the positioning retention pond itself is carried out based on the basin analysis in the DEM map with a scale of 1:8,000 and actual conditions in the field.

The running result of scenario-4 can be seen in Fig. 5. Based on the running result, it is seen that the time peak of Scenario-3 happened on 18.50–19.00 with each discharge is 409.66 m<sup>3</sup>/s due to the 2 years return period; 441.32 m<sup>3</sup>/s due to the 5-year return period; 517.60 m<sup>3</sup>/s due to the decade return period; 638.56 m<sup>3</sup>/s due to the 25 years return period; 809.56 m<sup>3</sup>/s due to the 50 years return period; and 1,178 m<sup>3</sup>/s due to the century return period.

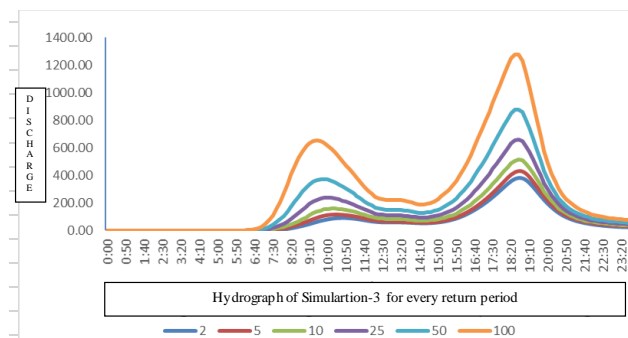


Fig. 5 Running result hydrograph of scenario-4

### 3.4. Simulation of Flood Attenuation-4

Scenario-5 implements the positioning of the Ciawi and Sukamahi dams upstream Ciliwung watershed and combines all conditions in the previous simulations. The same as the previous simulation, the positioning retention pond itself is carried out based on the basin analysis in the DEM map with a scale of 1:8,000 and actual conditions in the field. Scenario-5 is carried out by adding 9 retention ponds in the Ciesek sub-watersheds, upstream of the Ciawi dam and upstream of the Sukamahi dam.

The running result of scenario-3 can be seen in Fig. 5. Based on the running result, it is seen that the time peak of Scenario-3 happened on 19.00–19.10 with each discharge is 383.85 m<sup>3</sup>/s due to the 2 years return period; 416.28 m<sup>3</sup>/s due to the 5-year return period; 485.29 m<sup>3</sup>/s due to the decade return period; 602.29 m<sup>3</sup>/s due to the 25 years return period; 784.72 m<sup>3</sup>/s due to the 50 years return period; and 1,131.12 m<sup>3</sup>/s due to the century return period.

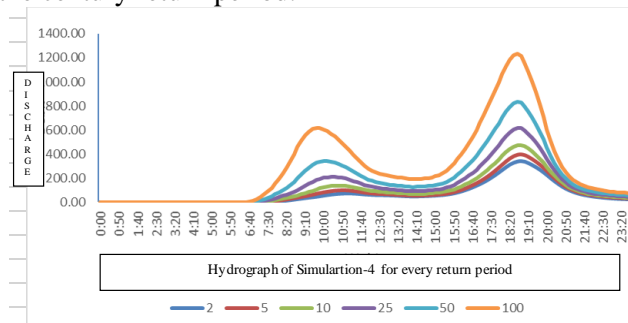


Fig. 6 Running result hydrograph of scenario-5

### 3.5. Combined Simulation of Various Scenario Flood Attenuations

After finishing the simulations, then there a comparison among the four simulation results carried out. The comparison is carried out for seeing the development efficiency of the Ciawi dam, Sukamahi dam, and some additional retention ponds.

Based on the running results, it can be known that the 2 years, 5 years, 10 years, 25 years, 50 years, and 100-year design flood hydrographs. Then, the flood hydrograph is separated for every return period flood discharge to know the difference in the hydrograph of each scenario. The flood hydrographs for each return period can be seen in Fig. 7 until 12:00.

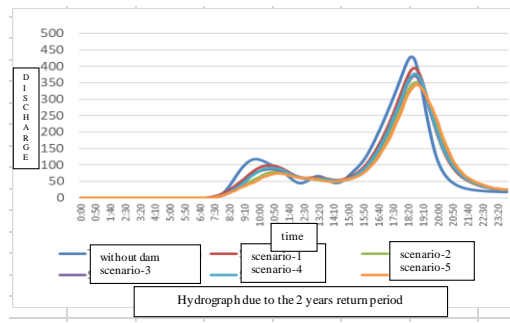


Fig. 7 Hydrograph with 2 years return period

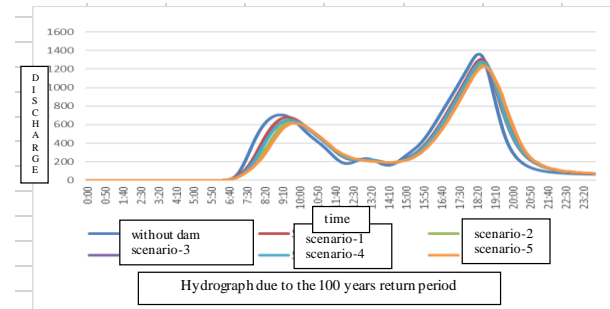


Fig. 12 Hydrograph with 100 years return period

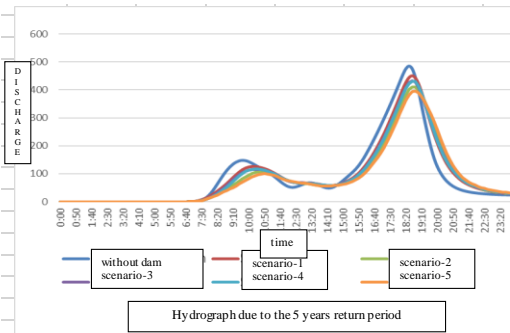


Fig. 8 Hydrograph with 5 years return period

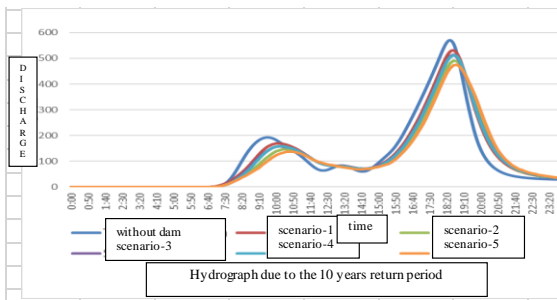


Fig. 9 Hydrograph with 10 years return period

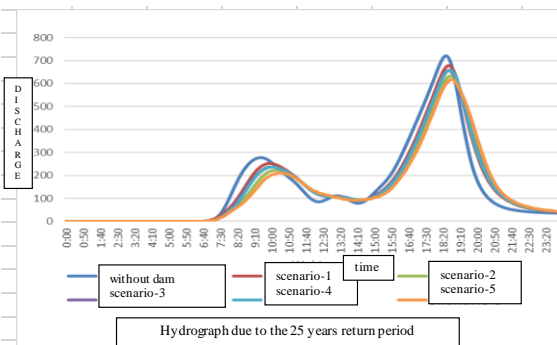


Fig. 10 Hydrograph with 25 years return period

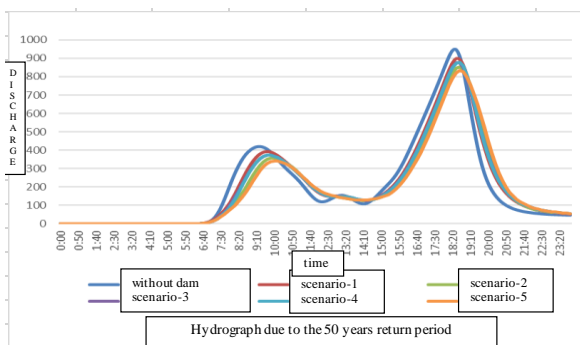


Fig. 11 Hydrograph with 50 years return period

From the 6 hydrographs, it can be known the trend difference of hydrograph for each scenario. Based on the hydrograph above, it is seen that scenario-2 and scenario-5 produce the significant changes in the time to peak and peak discharge than the other scenarios. Scenario-2 is which the development of Ciawi and Sukamahi dams is carried out by combining the development with the retention ponds in the upstream Ciawi dam. However, scenario-5 in which the development of Ciawi and Sukamahi dams is carried out by combining with the development of retention ponds in the whole sub-watershed.

### 3.6. Multiple Linear Regression Model of Flood Attenuation

Based on the analysis above related to the additional number of retention ponds, positioning, and flood reduction that is hoped to happen, there is built a formula by using the variables as follows: pond capacity, time to peak, and flood reduction that happened. The retention pond positioning is varied regarding the sub-watershed in the upstream Ciliung that is produced from some simulations that are scenario-1 until 5. Based on the simulations, there is obtained, as presented in Table 1.

Table 1 Variable of flood reduction with retention pond

Scenario	$Q_p$ (m <sup>3</sup> /s)	$X_1$ (ha)	$X_2$ (hour)
Scenario 1	394.41861	0	18.5
	449.66111	0	18.5
	530.78497	0	18.5
	676.92249	0	18.5
	899.42738	0	18.5
Scenario 2	1303.5749	0	18.3
	351.78993	49.35	18.6
	410.86312	49.35	18.6
	491.48755	49.35	18.6
	634.8175	49.35	18.6
Scenario 3	853.65644	49.35	18.6
	1250.66734	49.35	18.5
	372.15309	68.13	18.8
	433.19919	68.13	18.8
	513.77128	68.13	18.8
Scenario 4	657.93457	68.13	18.8
	876.47397	68.13	18.8
	1276.91621	68.13	18.6
	377.65855	55.14	18.6
	431.317	73.92	18.6

Scenario	Q, (m <sup>3</sup> /s)	X <sub>1</sub> (ha)	X <sub>2</sub> (hour)
Scenario 5	512.60433	73.92	18.6
	658.56321	73.92	18.6
	878.55514	73.92	18.6
	1278.00243	73.92	18.5
	343.84568	96.74	19.2
	396.27895	96.74	19.2
	475.29057	96.74	19.2
	616.29073	96.74	19.2
	834.7188	96.74	19.2
	1231.11691	96.74	19

To find the equation that illustrates the relationship between the variable of time to peak and storage capacity to for flood reduction, we used the multiple linear regression. Multiple linear regression is used if the effected variable is more than one variable. By assuming that the effected variable is flood reduction (Y), however, the variables that effect are storage capacity (X<sub>1</sub>) and time to peak (X<sub>2</sub>), so there is obtained t is selected by the assumption that if there are no variables X<sub>1</sub> and X<sub>2</sub>, but there is the flow discharge in the river).

$$Y = 3.696 X_2 - 664.668 X_1 + 12908.6$$

The equation illustrates that the additional retention ponds in the upstream Ciliwung will cause the decreasing discharge in the outlet.

#### 4. Conclusion

The development of Ciawi and Sukamahi dams in the upstream Ciliwung watersheds are as one of the government efforts to decrease the flood discharge in Jakarta and increase the time to peak before reaching Jakarta, so the standby time is longer. These dams hope to reduce the flood peak in the downstream and lengthen the time to peak before reaching Jakarta. The Ciawi and Sukamahi dams are the dry dams. Based on some previous researches, the dams are effective enough to reduce flood. Based on the analysis above, it can be concluded as follow: 1) The additional Ciawi and Sukamahi dams that have the storage capacity of 15 million m<sup>3</sup> is success to reduce the flood peak in amount of 13% and the additional time concentration (Tc) during 20 minutes; 2) The additional retention ponds in the upstream Ciawi and Sukamahi dams are able to reduce flood in amount of 18% and the additional of time concentration (Tc) during 50 minutes; 3) The equation that illustrates the flood reduction in the upstream Ciliwung watershed is as follow:  $Y = 3.696 X_2 - 664.668 X_1 + 12908.6$ ; 4) The combination of dry dam and retention pond can be applied in the watershed with the similar characteristic with the upstream Ciliwung watershed (dendritic).

This research will attempt combining high - spectrum rainfall management by using dry dam with a method for managing the light until medium spectrum rainfall that is suitable to the concept of Low Impact Development (LID) that is the usage of retention pond. By combining the two methods, it is hoped will be able to increase the function of flood attenuation of Ciawi

and Sukamahi dams.

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