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Effectiveness of Infrastructure Flood Control Due to Development Upstream Land Use: Case Study of Ciliwung Watershed

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Abstract**—**Various infrastructures such as dams, flood control dams and reservoirs have been developed in the 19th century until the 20th century. These infrastructures are very effective in controlling the river flows and in preventing inundation in the urban area prone to flooding. Flooding in the urban area often brings large impact, affecting every aspect of life and also environment. Ciliwung is one of the rivers allegedly contributes to the flooding problems in Jakarta; various engineering work has been done in Ciliwung river to help controlling the flooding. One of the engineering work is to build Ciawi Dam and Sukamahi Dam. In this research, author is doing the flood calculation with Nakayasu Method, while the previous flooding in that case study is computed using Level Pool Routine. The effectiveness of these dams can be identified by using flood simulation of existing condition and compare it to the flood simulation after the dam construction. The final goal of this study is to determine the effectiveness of flood mitigation infrastructure located at upstream area in reducing the volume of flooding in Jakarta.

Keywords**—**Effectiveness, flood simulation, infrastructure flooding, level pool routine.

I. Introduction

LAND arrangement in upstream areas has influence on the runoff in the downstream area. If the downstream area of a watershed is urban area, it can be ascertained that the flooding will be a threat to the urban areas. It is like in the capital Jakarta in which Ciliwung river coming from the highlands, located in the border district of Bogor and Cianjur Regency (Gunung Gede, Gunung Pangrango and Puncak area), which is the longest river in the Greater Jakarta area with a length of nearly 120 km and Waterbasin area of 387 km^2 [1].

Jakarta city is located below the surface tides and traversed by 13 rivers [1], in which one of them is Ciliwung River. Because Ciliwung River is the largest river that crosses Jakarta, it has the greatest impact in the rainy season since it flows across many villages, densely populated residential and slum settlements. Due to changes in land use and uncontrolled use of river banks for settlement and population activities; such as changes of floodplain area into residential areas; the water level is often high, which is actually still in the original river profile. This causes flood in the residential areas. For example, some households in Kampung Melayu, East Jakarta, are located on the banks of the river, so during the rainy season, these areas are flooded as a result of living in the river banks. This also happens in other residential areas along Ciliwung River to the border of Jakarta - Bogor.

Various efforts have been made by the government in responding to the floods, both structural and non-structural. Structural flood control system in Ciliwung includes the manufacture of a number of water gates or flood observation post, flood prevention to a certain height with dikes, and also lowering the water level by normalization, diversion, canal, and interconnection of the rivers. The core concept of the flood channel is controlling the flow of water from upstream and regulating the volume of water coming into Jakarta. In addition, the government also seeks to reduce the flood discharge at the dam as well as attempting to reduce the pool of the polder pumping and drainage system. The main problem in the control rainfall runoff in urban areas generally consists of the need to control the depth of peak discharge and flow throughout the system, in order to avoid unwanted puddles. Fig. 1 is an overview map of the 13 rivers that pass Jakarta and water management system in Jakarta.

Damping peak discharge using the reservoirs is a common alternative. This reservoir has the added advantage of allowing the ongoing infiltration and evaporation so that in addition to dampen peak flows, they also reduce runoff volume. Reservoirs such as dams can also be a sediments reservoir in addition of being water quality control. Fig. 2 shows rain runoff management approaches in sequence according to the Minnesota Storm Water Steering Committee [2].

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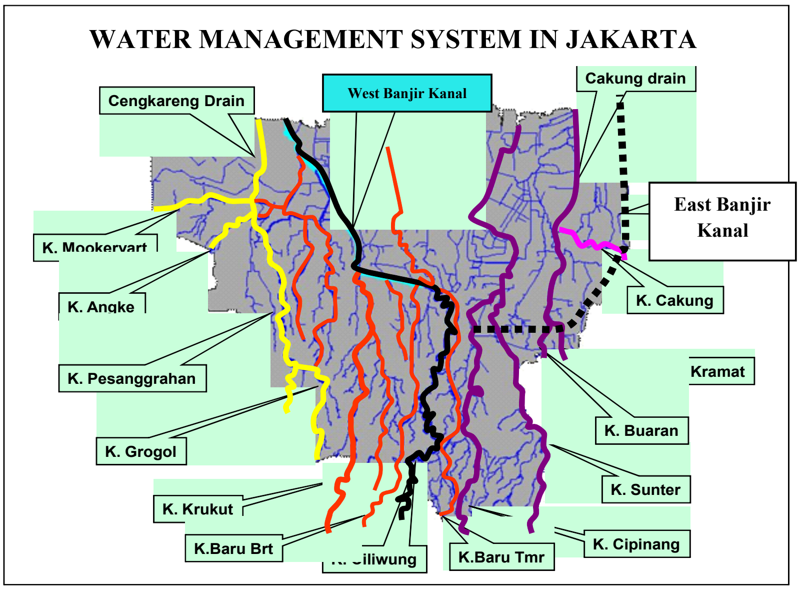

Fig. 1 Water Management System in Jakarta

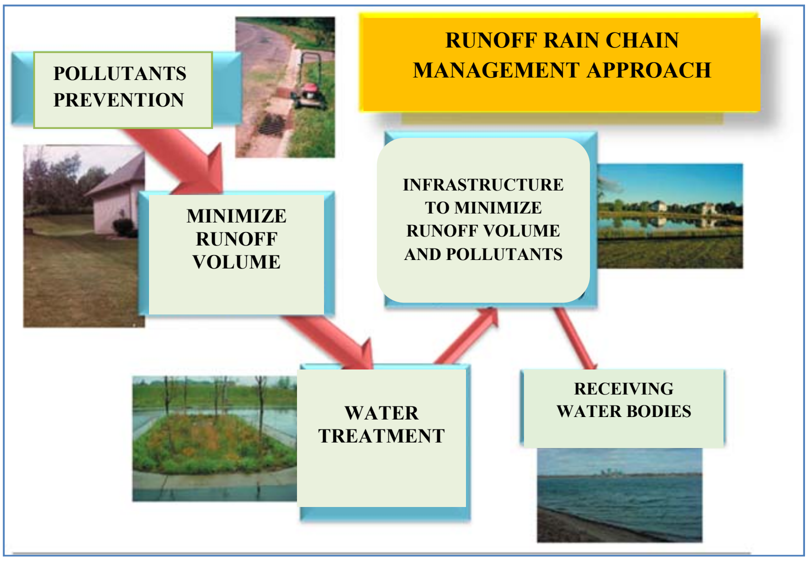

Fig. 2 Runoff Rain Chain Management Approach

With rainfall runoff chain management approach, it is possible to initiate the management of rainfall runoff by using a simple method that can minimize the amount of runoff that comes from an area. This management is and also a method that can prevent contaminants accumulating on the surface of the land carried by rain runoff. Although it is recognized that this goal will be very difficult to achieve, with the implementation of a variety of facilities/infrastructure to minimize the volume of runoff and pollutants, this management will reduce runoff volume and pollutant content originating from an area [3].

The results of studies on the construction of Ciawi and Sukamahi dams at Ciliwung water basin on the upstream side as a retention pond or reservoir retention is an illustration of the concept application of this rain runoff management. By the construction of these reservoirs, it is expected that the volume of flooding in the Jakarta area can be reduced. In addition, this study also aims to examine the effectiveness of dam construction of Ciawi and Sukamahi as one of the infrastructure that will function as a means of flood control Jakarta.

II. Literature Review

Land use in the upstream region has actually been done since the days of the Netherlands occupation. In 1920, Von Breen anticipated the opening of the tea gardens in Puncak area that will alter land use in the upstream region into plantation crops [1]. Thus, there will be changes in the pattern of runoff water in the downstream area. To prevent the overflow basin in Ciliwung River through the city of Batavia, construction of canals to drain flood peak of Ciliwung river to the canal was planned, in which they meet with the Krukut river as shown in Fig. 1.

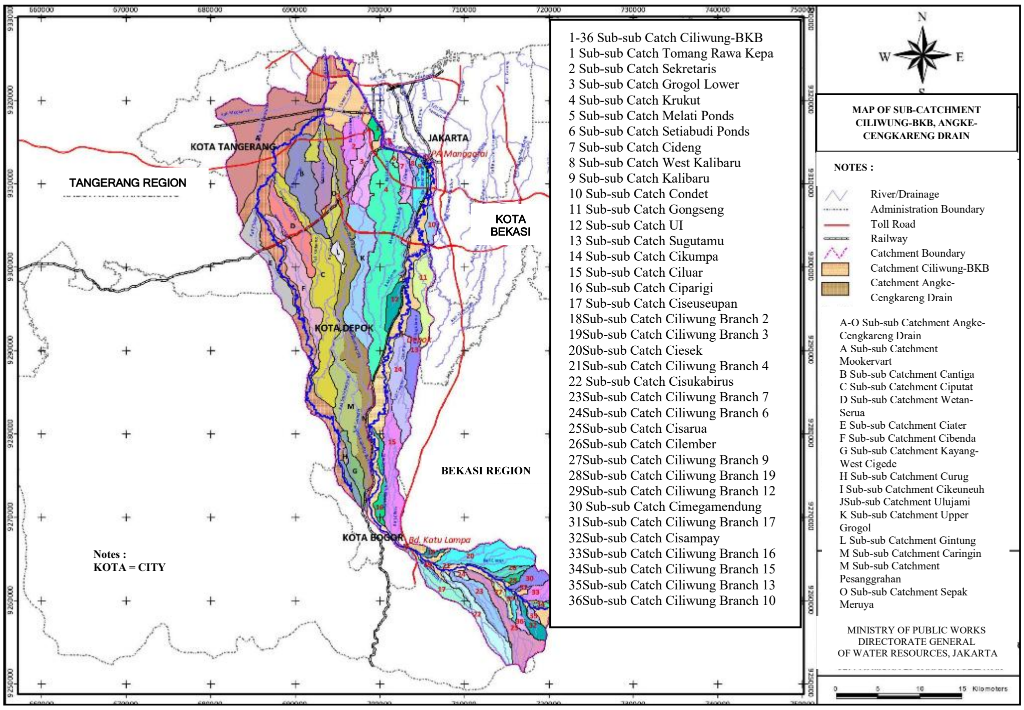

Fig. 3 Ciliwung River Waterbasin

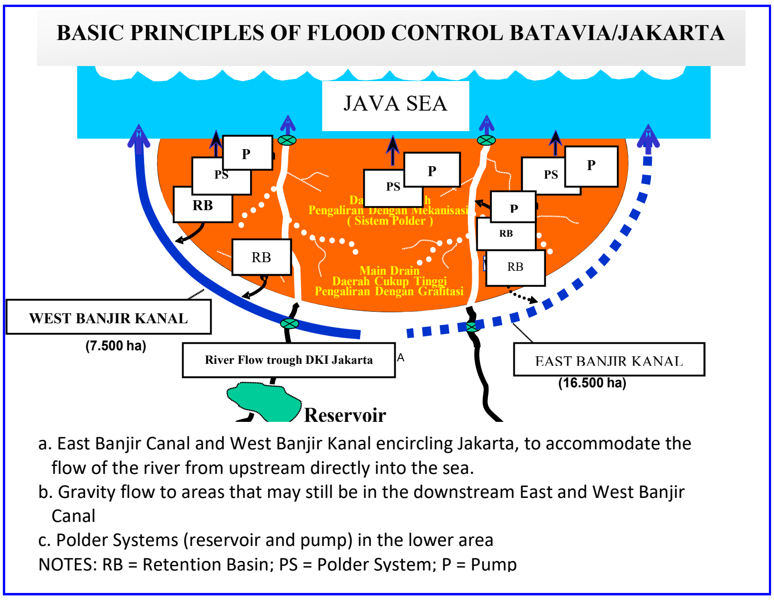

Fig. 4 Basic Principles of Flood Control Batavia / Jakarta

With the anticipation of change in the upstream land use that will have an impact on the city of Batavia, the basic principles of flood control in the area of Batavia are to manage Ciliwung River, which is the largest river crossing in Batavia, preserve dams as retention pond located around Ciliwung and propose building the flood control dams at the upstream of Ciliwung River.

Once the flow reaches the urban areas, then the water from Ciliwung will be arranged through the Manggarai water gate to Ciliwung Lama (Old Ciliwung) and to Banjir Canal, while normal debit will still be streamed to Old Ciliwung so that it still can be used as water transportation and also to stream the wastewater of Batavia.

In the 1900s, Ciliwung still played a role in the water transportation from the upstream to Angke and the Upstream of Manggarai water gate is used as long storage to keep water during dry season. The other function of Manggarai water gate is to act as an intake if at any time the drainage channel dividing Menteng needs to be flushed. Then to reduce flooding, weir was made in Jalan Perwira that divides water to Ancol area alongside the old stream towards Sunda Kelapa Harbour.

At this time, the problem encountered in the surrounding area of Ciliwung River are that this region is inhabited by approximately 350,000 people along the Ciliwung River bank with a total 70,000 units of building [1]. Therefore, Ciliwung River is regarded as the worst River among other Rivers flowing in Jakarta caused by change of the land use.

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After more than 50 years, management of Ciliwung River that only relies on Katulampa weir, Banjir Canal and Manggarai water gate is not sufficient enough. Thus, the construction of retention pond in upstream area such as Ciawi Dam and Sukamahi Dam is needed to cut the peak flood that happens in Ciliwung River. Administratively, the location plan of Ciawi Dam located at the upstream of Ciliwung in Ciawi Village, Megamendung, Bogor. Meanwhile, the Sukamahi Dam is planned to be located in Cisukabirus river and Sukamahi village, Megamendung, Bogor.

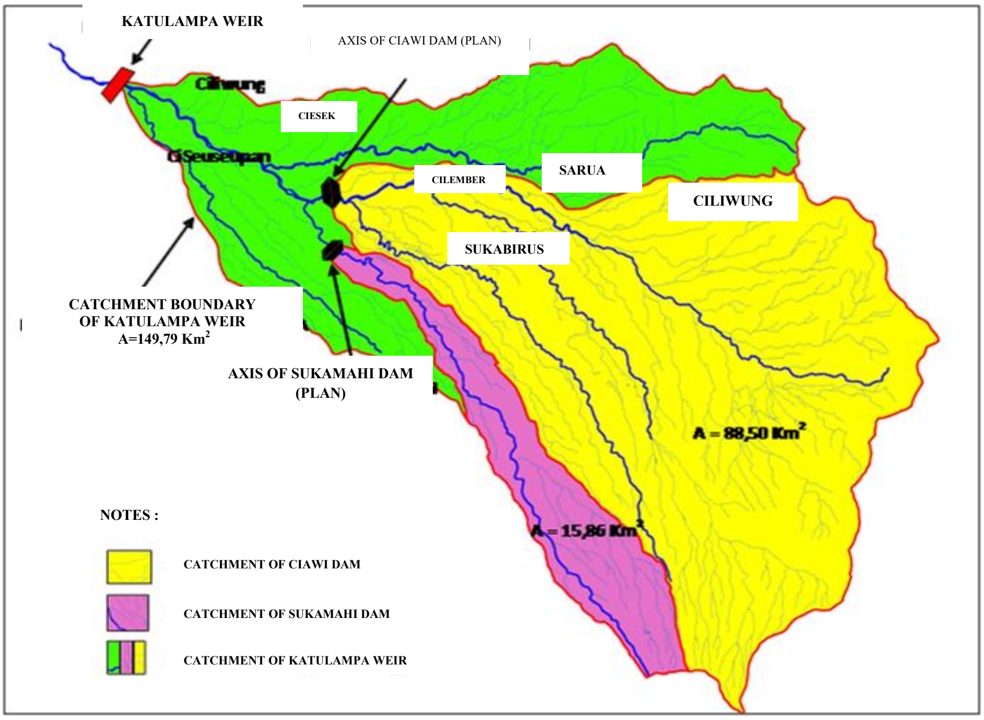

Fig. 5 Upstream Zone of Ciliwung and Reservoir Plan of Ciawi and Sukamahi, [14]

At the review point of Katulampa weir, it is known that the catchment area as 159.79 km^2 with a length of river of 27,120km [1]. Catchment Area is determined by the topography of the area as bounded by the ridges between two rivers. On topographic maps can be determined how to create an imaginary line connecting point having the highest elevation contours at left and right of the river being reviewed. Planimeter can be used to determine the extent of the catchment area [3].

Selection of flood discharge for building of water infrastructure is highly determined by the availability of existing data, both quantity and quality. So if there are no reliable data, it will not be expected to obtain good estimates of the flood. Nevertheless, efforts should be made so that it can be used in ways that best hydrology, according to the circumstances and nature of the river basin [9]. The formula used is rational method [5]:

$$Q = C\ I\ A$$

where Q = the flood discharge plan (m^3/s); C = coefficient of runoff; I = intensity of rain (mm); A = basin area (m^2).

To obtain the data of rainfall, the necessary amount of rainfall stations is installed in such a way to represent the amount of rainfall in the basin. In this regard, there are two factors that determine the accuracy of measurement of rain, the amount and pattern of rainfall stations spread [5].

A. Analysis of Regional Rainfall

Hydrology analysis of Ciliwung Upstream river basin uses 3 rainfall stations closest to the reservoir Ciawi, Sukamahi and Katulampa. Rainfall data are measured with a rain-meter in the form point rainfall. To obtain data average rainfall of water basin, several methods can be used, such as:

1. Algebra Average Method

This method is the simplest method of determining areal average rainfall. The placement of the measuring instrument (gages) should be uniformly distributed over the area and the rainfall data between stations do not vary greatly or rainfall that occur in the water basin is homogeneous. Usually this method is used in a flat area [5].

2. Thiessen Method

This method is based on the average weigh, where each observation station has formed the influenced area of the axis perpendicular to the connecting line between the two stations with planimeter, so the area of each station can be calculated [5]. Note that in this method, the minimum number of observation stations is three, while if there are additional stations, it will change the entire network. The topography of the area is not taken into account. It gives a certain weight to each station, with the understanding that each station is considered to represent rain in an area, and the area is a weighing factor for rain.

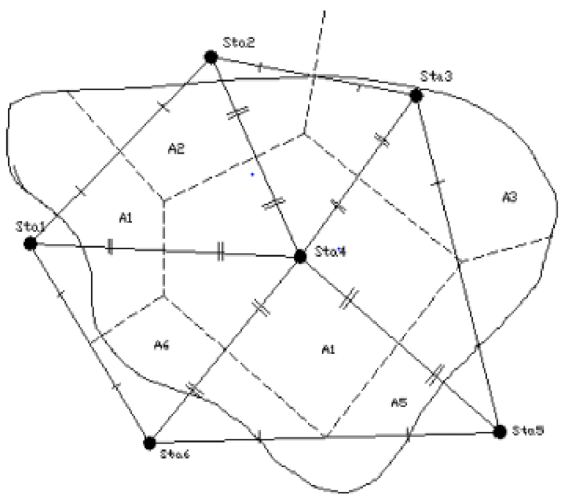

Fig. 6 Poligon Thiessen

3. Isohyets Methods

This method is used if the spread of rainfall stations in the region were unevenly reviewed. An isohyetal is a line joining places or point where the rainfall amounts are equal on a rainfall map of a basin. This map shows contours of equal rainfall over the basin. Where there is a dense network of rain gages, isohyetal maps can be constructed using computer programs for automated contouring [5]. Thus, isohyetal method is able to be used on flat or mountainous areas. The results of this method should be good enough for a very short rain.

B. Frequency Analysis

The Log Pearson Type III can be used for calculation of rainfall analysis, and HSS Nakayasu can be used for calculation of runoff or flood discharge.

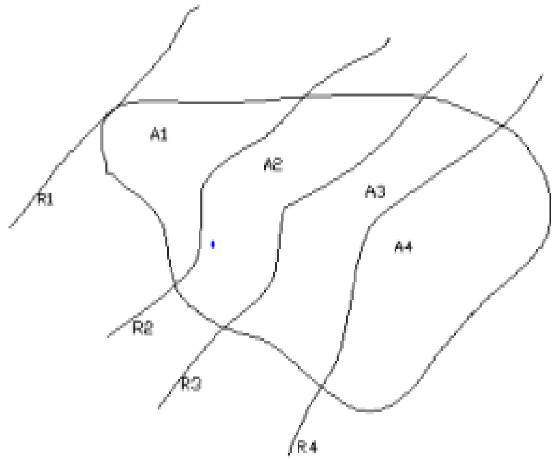

Fig. 7 Isohyets Method

1. Analysis of Regional Rainfall Method Log Pearson Type III [4]

$$\mathbf{Log\ X = \overline{Log\ X} + G\ .Sd}$$
$$\mathbf{Log\ X = 1{,}9326 + G\ .0{,}0847}$$
$$\mathbf{X = 10^{1{,}9326+G\ .0{,}0847}}$$

where: X = Rainfall design with a certain return period (mm); G = frequency factor for the Log Pearson Type III distribution, its value is affected by Cs (skewness).

TABLE I
RAINFALL ANALYSIS WITH LOG PERSON METHOD AT CIAWI

Return Period (T) Year	G	Rainfall Design (X_T) (mm)
2	0.049	101.189
5	0.83	127.925
10	1.319	145.786
20	1.682	160.617
25	1.863	168.589
50	2.225	185.688
100	2.555	202.78

2. Analysis of Flood River Basin with HSS Nakayasu Method

The use of this method requires some parameters characteristic of the region of flow as [3]:

R = 1 - (1 - P) n = 1- {1-period from the beginning of the rain until time of peak)}

R = 1 - (1 - P) n = 1- {1-period from the point of heavy rain to heavy point hydrograph (time lag)}

R = 1 - (1 - P) n = 1- (1time base of hydrograph)

R = 1 - (1 - P) n = 1- (1-waterbasin area)

R = 1 - (1 - P) n = 1- {1length of the longest channel)}

The formula of Nakayasu hydrograph unit is: Qp = peak flood discharge (m^3/s); Ro = rainfall unit (mm); Tp = period from the beginning of the rain until the flood peak (hours); $T_{0,3}$ = time required by a reduction in discharge, from the peak of up to 30% of peak discharge (hours); A = area of river basin.

To determine Tp and $T_{0,3}$, use the formula:

$$T_p = T_g + 0{,}8\ T_r$$
$$T_{0,3} = \alpha\ T_g$$
$$T_r = \mathbf{0{,}5\ T_g} \text{ up to } \mathbf{T_g}$$

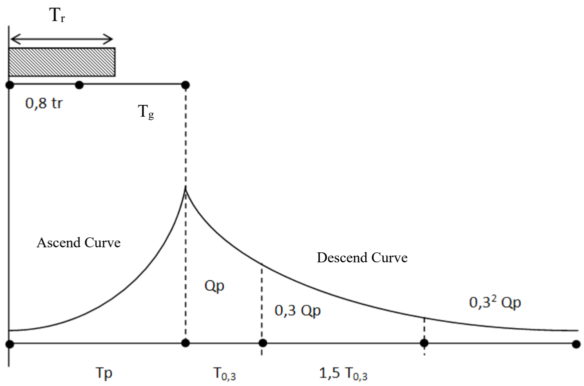

Fig. 8 The Nakayasu Hydrograph Unit

At the review point of Katulampa weir, the known catchment area is 159.79 km^2 with the length of the river 27,120 km. From the results of calculations, it is known that unit rainfall value (Ro) is 1 mm. Based on the length of the river, value of Q_p can be calculated as:

$$T_g = 0.4 + (0.058 \text{ x } 27.120)$$

$$T_g = 1.97 \text{ hr},$$

$$T_p = T_g + \{0.8\ (0.75 \text{ x } T_g)\} = 3.16 \text{ hr}$$

If the unknown coefficient α = 2, then

$$T_{0.3} = \alpha \text{ x } T_g = 3.815 \text{ hr}$$

Based on the above data using Nakayasu Methods:

$$Qp = \frac{C.A.Ro}{3{,}6(0{,}3Tp + T_{0{,}3})} = \frac{1*159.79*1}{3.6(0.3*3.16+3.815)} = 9.317 m^3/s$$

III. Material and Method

A. LID (Low Impact Development)

LID is a concept with different approaches to water management where LID concept modifies the development practices so that the function of the natural hydrology of the area is maintained. LID is a regional development that considers the environmental elements in every step in the planning, design and construction. The purpose of the LID is to eliminate and minimize the impact of urbanization on the natural water system. Mainly, the state of the natural system of water before and after the construction will not change too much [7].

LID is an effective and attractive approach to control the quality of rainwater and protect the development of River basins for the city in the whole region. LID is an overall concept with an approach based on technology to manage rainfall in an urban area and also cost effective enough. The concept of source control that LID uses is quite different from the conventional method of managing rain. In addition, land vegetation combined with filter media, can control not only the quantity of excess water, but also the quality of environment because it can reduce the amount of bacteria, metals, and nutrients from surface water runoff.

B. Dams Planning as Flood Control

According to the concept of LID, it is mentioned that one of the functions of the reservoir is a retention pond where reservoir storage capacity is expected to reduce the volume of flooding. In this case, the reservoir function is as a temporary catchment before it is flowed slowly towards other water bodies. Fig. 9 shows the efficiency of the reduction of pollutant parameters and a decrease in flood peak which occurs if the retention pond functions optimally.

Besides of being a flood control, retention pond can be used as a means to improve water quality if it has a large enough volume and has a quite long retention time which allows for the deposition of sediments or decomposition of certain elements. To obtain optimal function as flood control, there must be some criteria to be met, including the storage capacity of reservoirs and integrated flood management systems.

According to several considerations, Ciawi Dam located on the Ciliwung River is at the confluence of Upper Ciliwung and Cisuren River. The shape of Ciawi watershed is fan-type and some tributaries of Ciliwung River incoming at the upstream of Ciawi Dam. Ciawi Dam watershed area is 88.50 km^2, the length of the main river is ± 16.7 km, the river morphology is undulating mountainous areas.

Sukamahi Dam is located on the Cisukabirus River and the shape of watershed is feather-shaped. Sukamahi Dam watershed area is 15.86 km^2, the length of the main river is ± 15 km, the river morphology is undulating mountainous areas.

IV. Result and Discussion

Effect of Ciawi Dam and Sukamahi Dam to the Flood Discharge in Katulampa Weir

TABLE II
Flood Alert Limits Katulampa Weir

Condition	Water height, H (cm)	Debit, Q (m3/dt)
Normal	< 80	< 90
Siaga III	80 – 150	90 – 276
Siaga II	150 – 200	276 – 442
Siaga I	> 200	> 442

In the upstream scheme of Ciliwung River (Fig. 9), there are some streams that enter the Katulampa Weir, which are Ciesek

River, Ciseuseupan River and other small rivers at Ciesek downstream.

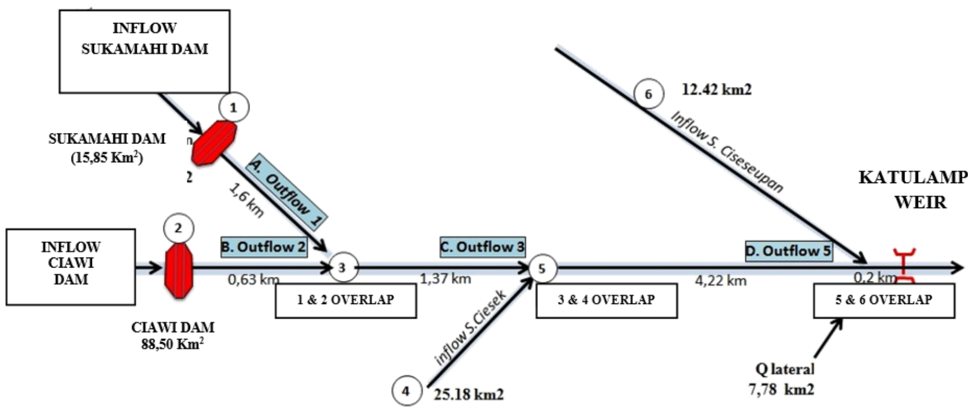

Fig. 9 Scheme of Upstream Ciliwung River

The plan of building the dams is to reduce flooding, so that with these 2 dams, the discharge of Katulampa weir can be reduced. Katulampa Weir has been used as the reference for early warning flood disaster in the downstream of Ciliwung River.

From the calculation of river system in Ciliwung upstream, it is obtained the Probable Maximum Flood (PMF) that enters the Katulampa weir with and without the presence of Ciawi Dam and Sukamahi Dam, as presented in Table III.

TABLE III
FLOOD ROUTING AT KATULAMPA WEIR

Return Period (Year)	Without Dam (m^3/dt)	Notes	With Dam (m^3/dt)	Notes	Flood Reduction (m^3/dt)
2	326.07	Siaga II	261.13	Siaga II	64.94
5	405.33	Siaga II	278.66	Siaga II	126.67
10	457.81	Siaga I	300.97	Siaga II	156.83
20	508.14	Siaga I	316.02	Siaga II	192.12
25	524.11	Siaga I	322.60	Siaga II	201.51
50	573.30	Siaga I	346.07	Siaga II	227.23
100	622.12	Siaga I	381.30	Siaga II	240.82
1000	729.94	Siaga I	622.22	Siaga I	107.72
PMF	2,277.86	Siaga I	2,265.35	Siaga I	12.51

From the Nakayashu calculation, the flood return period is 100th on the 3 point as Ciawi Dam, Sukamahi Dam and Katulampa Dam. Therefore, produced debit flooding on Ciawi Dam is 546.20 m^3/s; Sukamahi Dam, 143.22 m^3/s and Katulampa floodgate, 734.51 m^3/s. The flood calculation above then is routed with method to produce outflow debit at each of the Dams. On Ciawi is 478.56 m^3/s and 117.07 m^3/s on Sukamahi. Therefore, effectiveness of the Flooding Debit with 100 year return period is 12.38% at Ciawi Dam and 18.26% at Sukamahi Dam. On the second routing of the two dams, the flooding debit of floodgate Katulampa is 664.32 m^3/s with flood reduction of 70.19 m^3/s and effectiveness of 9.56% [14].

Tables and flood hydrograph calculation results in Katulampa water gates demonstrating the effectiveness of both infrastructure developments can be seen in Table IV and Fig. 10.

TABLE IV
FLOOD DISCHARGE

Location	Discharge calculation			
	Inflow	Outflow	Reduction	Effectiveness
	m^3/sec	m^3/sec	m^3/sec	%
Ciawi Dam	546.2	478.56	67.64	12.38
Sukamahi dam	143.22	117.07	26.15	18.26
Katulampa weir	734.51	664.32	70.19	9.56

The effectiveness of Sukamahi and Ciawi Dam construction in reducing the flood peak at the Katulampa weir in the return period of 100 year is 9.56%. This value is less significant compared to the huge development costs. Flood planning should be done comprehensively and integrated by proper management of the rainfall runoff to reduce the risk of flooding, and taking into account the environment. This is consistent with the terminology of rain management by Pollution [8], regarding to the utilization of rain runoff as illustrated in Fig. 11.

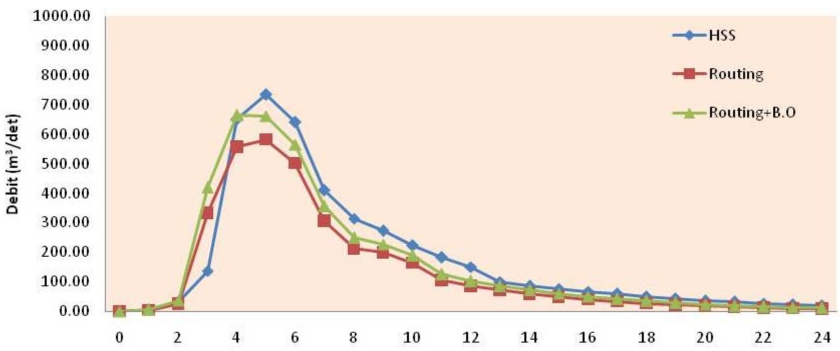

Fig. 10 Flooding Hydrograph Katulampa

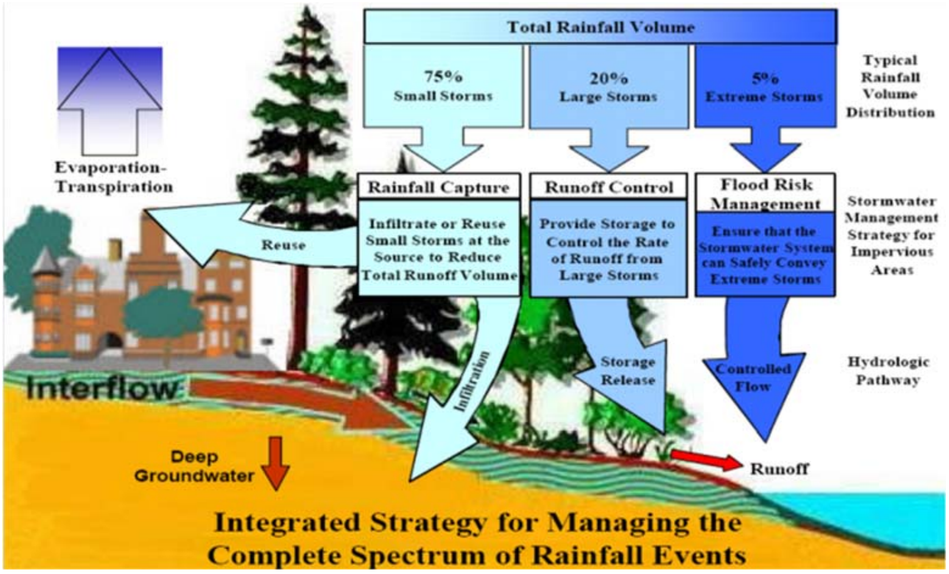

Fig. 11 Integrated Strategy for Managing the Complete Spectrum or Rainfall Events

V. Conclusion

Developments in the river basin create a greater scale of flooding, while the population along the river basin in the downstream area is also denser. In resolving the flooding problems which is getting more complex, generally require enormous costs and cannot be done by the local governments. Various facilities and infrastructures that have been developed are expected to optimize the economic efficiency of land use, and also to be able to support the sustainable development efforts of the entire river basin.

Facilities and infrastructure development in an integrated manner are intended to increase security against flooding, flood alert and flood resistance in order to minimize the risk through efforts to reduce the probability of flooding and reduce the impact of flooding. If the provincial government Jakarta regional budget funds amounting to 1.2 trillion for land acquisition reservoir Ciawi and Sukamahi [4] and these costs do not include the cost of construction of these reservoirs while Damping flooding on the Upper Ciliwung (Katulampa weir) only by 9%, then the flood losses after the dam is built will not be significant.

Because according to “Urban Flood Management” [12] and “The role of these reservoir in reducing flood discharge in Jakarta” [14], an important criterion used to evaluate, assign ratings and choose the appropriate option is the financial benefits measured in terms of reduction of losses due to flooding. Flood control should be done in an integrated manner to obtain maximum results.

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