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HEC-RAS MODEL FOR DRAINAGE CAPACITY ANALYSIS AND PEAK DISCHARGE SIMULATION OF CIMANDE RIVER

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ABSTRACT: Flooding occurs in Rancaekek District annually, affecting residential and industrial areas, particularly those along the Cileunyi-Nagrek highway. This research focuses on the drainage channel along the Cileunyi-Nagrek highway, which is always overpopulated by flood water. Given that the drainage channel empties into the Cimande River, the water level of the drainage channel is influenced by the Cimande River flow. The shallowing and narrowing of the river and the narrowing of the channel width and bridge abutment across the Cileunyi-Nagrek highway cause overtopping and inundation. Peak discharge of the Cimande River in various return periods is simulated for the analysis of existing drainage channel capacity and water level profile. Peak discharge in various return periods is determined using the Hydrological Engineering Centre – Hydrology Modeling System (HEC-HMS) 3.5. River and drainage channel hydraulic modeling are carried out simultaneously by using the cross section option of geometric data in Hydrological Engineering Centre – River Analysis System (HEC-RAS) 4.1. The river overtopping leads to backwater because of peak discharges: 36 m^3/s (10 years) and 52.9 m^3/s (25 years). The existing drainage channel dimension is insufficient for all simulated flood discharges. The drainage channel capacity must be increased to 0.80 m^2 fit to peak discharge in a 10 year return period.

Keywords: Drainage Capacity Analysis, HEC-RAS, Flood

1. INTRODUCTION

Despite being predictable natural disasters, floods continue to cause considerable economic, social, structural, and environmental losses and mortality, and thus, the impact of flooding has been extensively explored [1]. Rancaekek is often hit by quite high floods every rainy season, and the worst inundation occurs in residential areas around industrial areas along the Cileunyi-Nagrek highway [2]. Rancaekek District is a residential area that developed into an industrial area. Industry triggers an increase in population, but conversely, catchment areas are decreasing. Changes in land use decrease infiltration capacity and potentially increase the surface runoff volume [3]. Heavy precipitation intensity in impervious areas produces surface runoff discharge that exceeds the drainage channel capacity [4]. High rainfall coupled with low water infiltration, of course, will cause flooding. Floods in Rancaekek in the last two years have occurred around 9 times. According to statistical data from Rancaekek District, the worst flood ever occurred in January 2010, which claimed lives, but the largest and extreme floods were recorded in 2009 and 2011, with 1 – 1.5 meters peak depth of inundation, respectively [5]. In general, current floods have higher peak depth of inundation than floods in the past, namely 40 – 60 centimeters, increasing to 70 – 100 centimeters. Residential areas in Rancaekek were flooded to a peak inundation depth of 70 centimeters in April 2024, ultimately submerging settlements around the inundated area [6].

Floods in the past were caused by very high rainfall, but catchment areas are still available. The current flood occurs due to blocked river flow from upstream to downstream instead of the heavy precipitation intensity coupled with low water infiltration. The Cimande River narrows from a width of 14 meters upstream to 4 meters downstream. The upstream of Cimande River is meandering causing scouring and sedimentation to occur. Sedimentation in the upstream and changes in land use downstream cause narrowing and shallowing of the downstream. Both of these factors cause the river capacity to decrease.

Downstream of Cimande River is located on the plains area. The river embankments downstream are relatively very low compared to the width of the channel, so when the runoff discharge increases, the river water level will overflow into the drainage channel and even inundate the surrounding area. The existing drainage channel along the Cileunyi-Nagrek highway empties into the Cimande River. The water level of the drainage channel section is potentially affected by The Cimande River flow mechanism [7]. The river has a small watershed, and thus, the time of response to heavy precipitation is extremely short. Thus, the peak discharge can be instantly obtained [8]. Flooding is caused by the increase in river water level that causes overtopping in many embankment and inundation sites around riverbank areas [9]. The overtopping occurs at narrowed drainage channel section after the bridge crossing Cileunyi-Nagrek highway. Overtopping of the river flow might causes back water in drainage channel because river flow from the upper stream can not to pass the downstream of the river [10].

The latest Researches on structural flood management in Rancaekek was carried out a long time ago in 2016 [11]. The research was carried out by analyzing the water level of the Citarik River based on peak discharge with a return period of 25 years which resulted in a water level of 29 centimeters above the bridge. This research provides two flood control solutions, raising the bridge deck and the addition of culverts on the right and left of the bridge. The government has taken several actions to control the flood risk by both structural and non-structural flood management. Non-structural flood management, which has been carried out is sediment dredging so that the channel capacity increases, while structurally it includes adding 16 box culvert units, widening the river cross-section (river normalization), strengthening river banks and building inspection roads. The normalization of Cimande River is planned to provide a water discharge of 35-50 m^3/s from the previous 4.5-5 m^3/s [12]. The capacity of existing drainage channels has never been increased and analyzed, so in this research, capacity analysis of the existing channels was carried out in various return period. River and drainage channel hydraulic modeling is carried out simultaneously in order to determine the impact of river water level on drainage channel water level.

2. RESEARCH SIGNIFICANCE

Climate change affects the hydrological cycle by increasing the frequency and intensity of precipitation and even causes extreme precipitation occurrence neglectable [13]. Urbanization and population growth lead to land use changing. Rancaekek has heavy traffic, dense residential areas and multiple factories and flooding occurrence and risk might increase and affect these areas [14]. Thus, flood assessment for the district has been conducted through flood simulation and drainage channel capacity analysis for effective flood control, reduction of inundation, flooding points and their impacts [15]. Accurately and reliably predicting river water levels is an important step in the prevention of flood damage, planning of interventions in the event of major risks and mitigation of potential losses [16].

3. MATERIALS AND METHODOLOGY

3.1 Study Area

Research location is the drainage channel along the Cileunyi-Nagrek highway, especially the narrowed drainage section after the Cinunggal Bridge. Rancaekek has the confluence of Cimande and Cikijing Rivers, which are the upstream and the downstream areas, respectively. Both rivers are the tributaries of the Citarik River, which is turn is one of the tributaries of the Citarum River located downstream as shown in Figure 1.

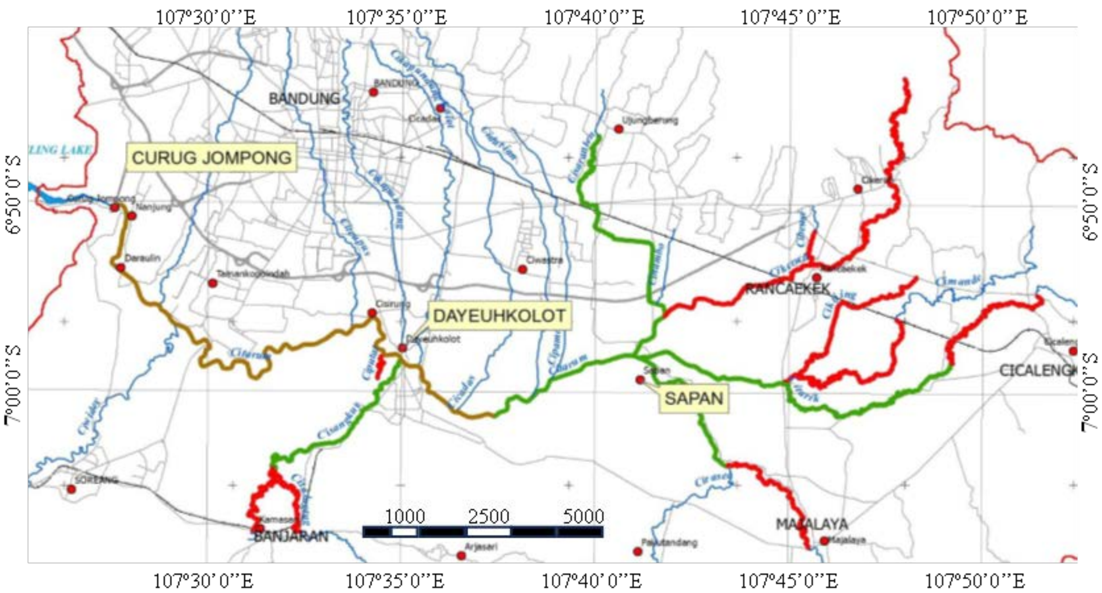


Fig.1 Study location in Rancaekek District

3.2 Data

Design discharge is essential to the measurement of channel dimensions and flooding points and assessment of their impacts through drainage channel capacity analysis [17]. Design discharge is peak discharge in various return period and is determined by HEC-HMS 3.5. This study used secondary hydrologic, topographic and geologic data. The hydrologic data are the maximum daily rainfall data for 10 years and was collected from Meteorology, Climatology and geophysics Agency in four different rainfall recorder stations around the study area. The rainfall recorders are located in Rancaekek, Cicalengka, Jatiroke and Cibiru.

Table 1 Rancaekek District land use

Land Use	Area (km^2)	Percentage (%)
Residential	4.060	14.0
Plantation	5.800	20.0
Rice field	3.538	12.2
Factories	0.493	1.7
Streets	0.667	2.3
Forest	0.725	2.5
Field	13.717	47.3
Total	29.294	100

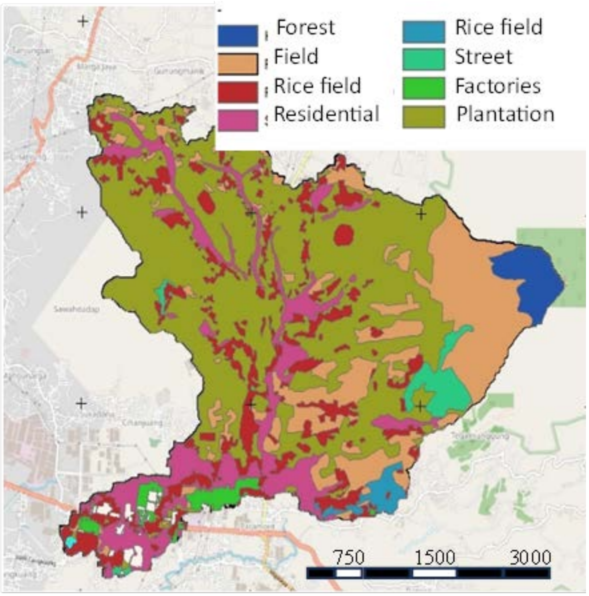


Fig.2 Land use in Rancaekek District

The topographic data included the map, land use types and ground covering types of the study area. The map of the Cimande River catchment area was obtained from Shuttle Radar Topographic Mission (SRTM). Geologic data included the hydrologic soil classification of the study area. Land use types, ground covering type and geologic data were collected from Volcanology and Geological Hazard Mitigation Centre of west Java Province.

Table 2 Sub-watershed describtion in Rancaekek

Sub-watershed	Area (km^2)	Length (Km)	Slope
W60	6.99	19.3	0.028
W70	10.384	23.3	0.029
W80	1.95	9.72	0.024
W90	6.24	17.91	0.031
W100	3.73	16.1	0.018

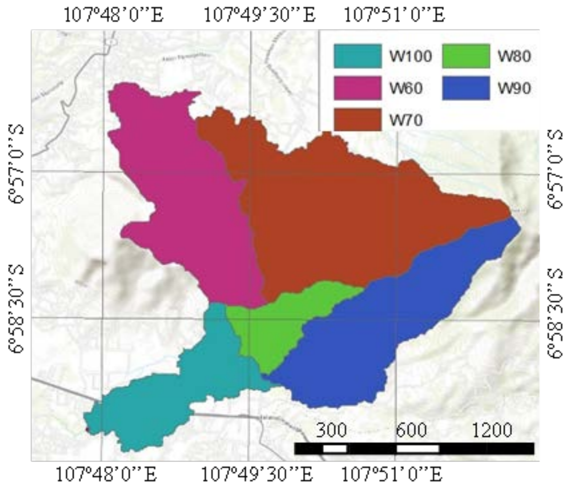


Fig.3 Topography of the Cimande River catchment area

3.3 Methods

Peak discharge, flood routing, flood simulation, inundation map, and flood risk identification can be obtained through flood assessment using advanced technology [18]. The feasibility of using a drainage channel for the simulation of an urban stormwater drainage system must be assessed through hydraulic analysis [19]. For hydraulic analysis, the drainage channel along the Cileunyi-Nagrek highway until the Cimande River was modeled in order to simulate the drainage channel water level profile and capacity that affected by the Cimande River discharge within a certain return period. Both river either drainage channel modeling and flood simulation carried out by using Hydrological Engineering Centre-River Analysis System (HEC-RAS) 4.1 software [20]. The study area is extracted from the DEM and digitization process had been previously performed in ArcGIS. Proper steady flow model of the river in HEC RAS established by inputted data, such as manning value, slope, banks, flow-track lines, centerline and cross-section in geometric data Since HEC-RAS version 4.0 has been equipped with two new tools in the geometric data editor, namely channel design and channel modification which makes it possible to create cross section and channel modification [21]. This research uses HEC-RAS version 4.1 that more capable of modeling rivers with cross sections so that it can also model rivers and drainage channels simultaneously. The drainage channel model is determined by adding drainage channel data by clicking on the junct icon where in the left side of the geometric data editor. Hydraulic modeling in HEC-RAS allows for steady, semi unsteady and unsteady flow with one either two-dimensional flow [22]. The river stationing is drawn from downstream to upstream as one-dimensional model. The boundaries of the one-dimensional model are the downstream water level and the upstream discharge that were calibrated and validated by using the observed water level and discharge data. River flow is a one-dimensional steady flow that can be calculated by using the Saint-Venant equation [23]. In a one-dimensional flow hydraulic modeling cannot be affected by alterations along the cross section such as meandering, narrowing and widening [24]. Bernoulli's formula that describes total energy conservation in a streamline, and is the primary law of fluid hydrodynamics in HEC-RAS.

4. RESULTS AND DISCUSSIONS

Design precipitation and design flood discharge hydrograph are determined through hydrologic analysis. Design precipitation is essential and potentially affected flood prediction and flood risk forecasting [25]. Design precipitation determined by using frequency analysis for various return periods, such as 2, 5, 10, and 25 years, according to the regulation and standards for urban drainage planning and flood control planning in Indonesia [26]. Precipitation data are fitted to Log-Pearson type III frequency distribution through chi-squared and Smirnov-Kolmogorov test [27]. Figure 4 shows design precipitation of Rancaekek rainfall recorder station is higher than another rainfall recorder station.

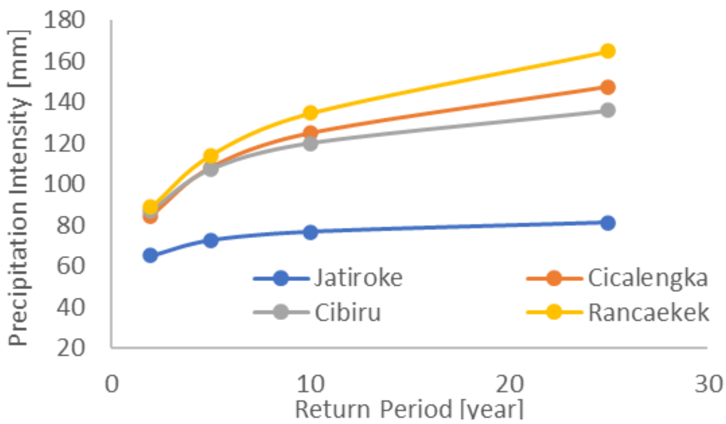


Fig. 4 Design precipitation intensity in the various return periods

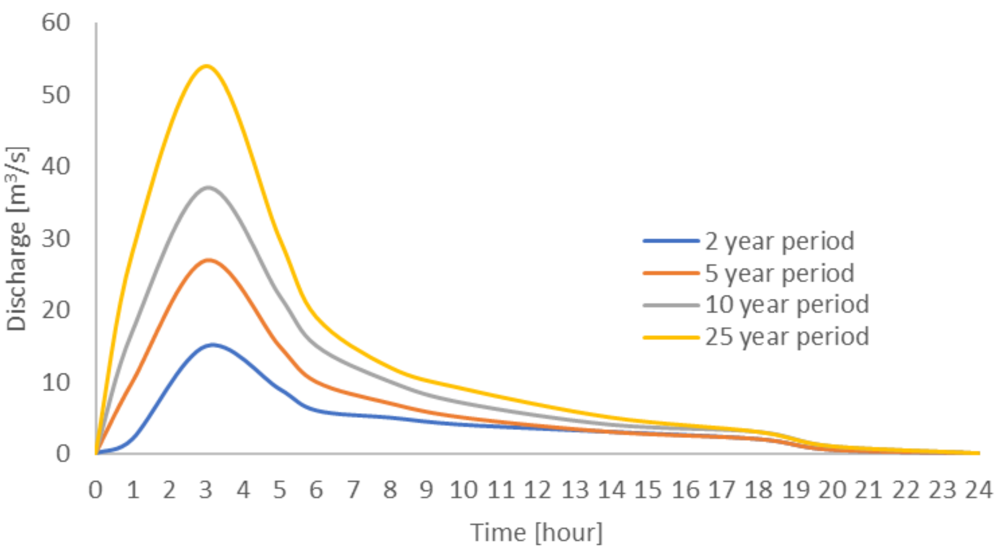


Fig.5 Direct runoff hydrograph in the various return periods of the Cimande River.

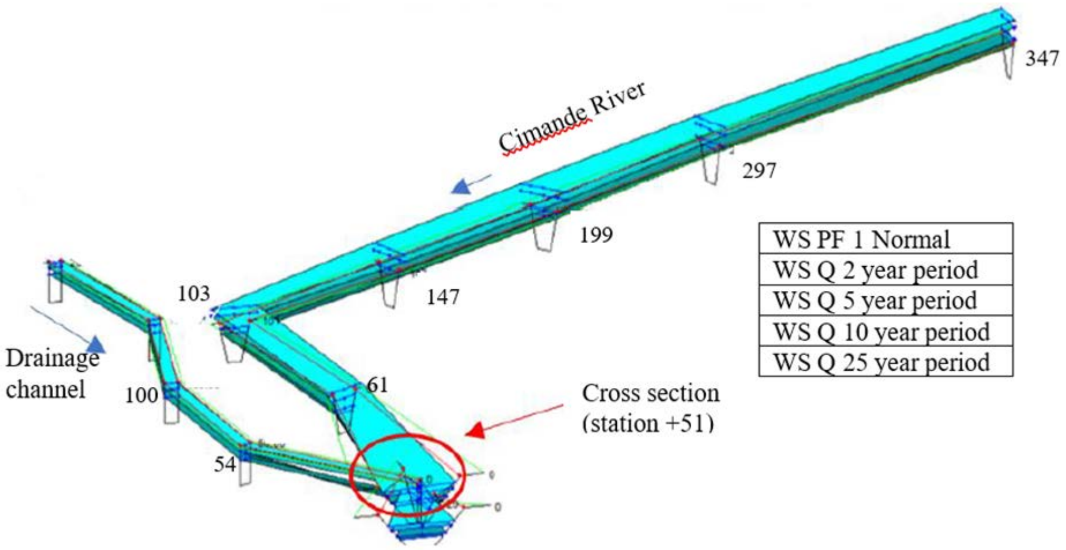


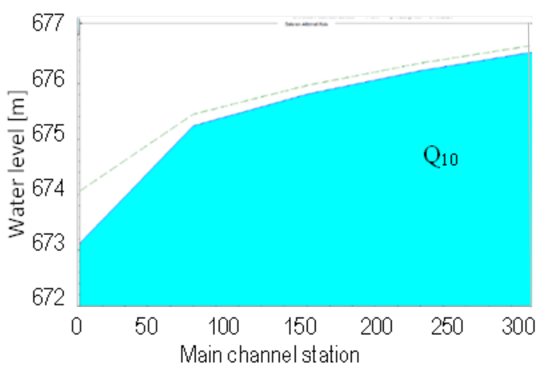
Fig.6 Cross section of the Cimande River and drainage channel scheme.

The flood discharge hydrograph is determined by Soil Conservation Service Curve Number method proposed by the USDA (now, NRCS). HEC-HMS Data geometric for SCS CN synthetic unit hydrograph include loss, transform, baseflow dan routing components [28]. The loss component in SCS curve number is affected by initial abstraction (Ia), curve number (CN) and impervious area [29]. The transform component determines the time lag of the SCS CN unit hydrograph. Baseflow is calculated by recession methods on the basis of initial discharge, recession constant ratio and peak.

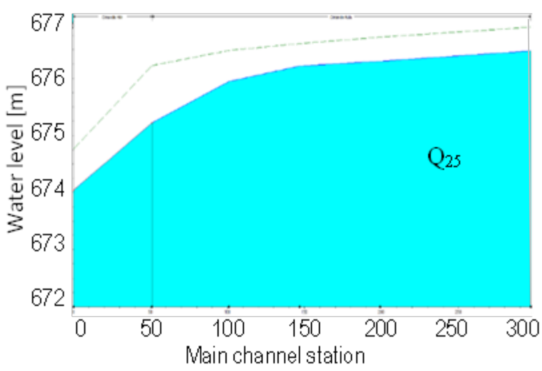
Routing component might trace the discharge from upstream to downstream [30]. Figure 5 shows the flood discharge hydrograph with peak discharge rates of 14 m^3/s for 2 years, 26 m^3/s for 5 years, 36 m^3/s for 10 years and 52.9 m^3/s for 25 years. These hydrographs were used to calculate steady flow analysis

A calibrated and validated static model of cross section and drainage channel of the Cimande River are needed for flood simulation [31]. The river and drainage channel scheme drawn in Figure 6 includes the length and direction of the river and the drainage channel flow. The cross section of the Cimande River is divided into six stations from the highest station upstream to the lowest station downstream. Each station has different geometrical borders, slope, shape, and river bed roughness. Drainage channel is divided into four stations and empties into river in station 0+51. HEC-RAS model calculates water level profiles corresponding to the design flood discharge of the river. Flooding with 2, 5, 10, and 25 year return period is modeled. The Cimande River top bank set at +675 m, while the top of the drainage channel at station 0+51 is set at +675.3 m.

Discharge simulation on Cimande River affects the water level of the drainage channel. Overtopping and backwater occur due to flood discharges for 10 and 25 years. The drainage channel capacity overtopping in station 0+51 for the 10 and 25 year return period which is due to back water from the Cimande River (Figure 7).



(a)



(b)

Fig.7 Water level of the Cimande River for (a) 10 year return period and (b) 25 year return period

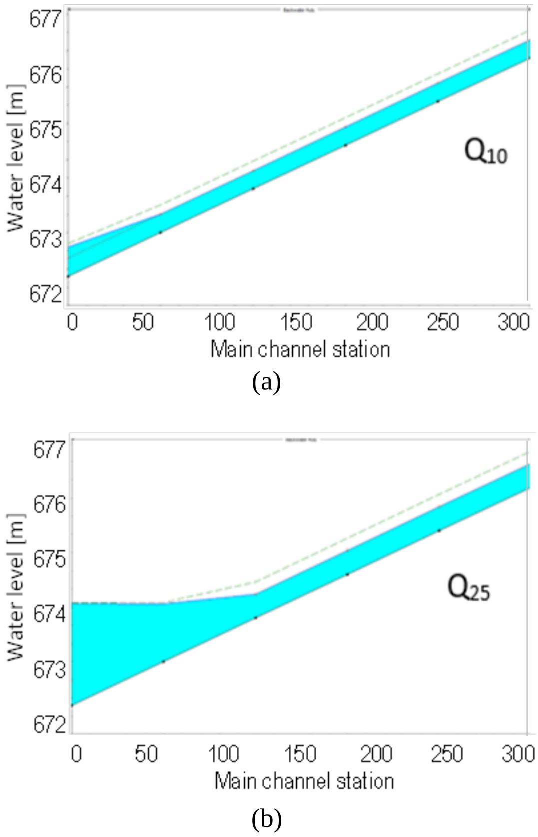


Fig.8 Back Water in the Cimande River for (a) 10 year return period and (b) 25 year return period

The drainage channel water level is depicted with the green curve and the possible maximum level of back water is described by dotted lines. Backwater occurs in drainage channel at the station 0+0 until 0+51 for 10 year return period and at station 0+0 until 0+100 for 25 year return period (Figure 8). Flood discharge for the 10 and 25 year return periods in the Cimande River produces subcritical flow with mild slope water level profile because the river slope is more sloping than the critical slope of the flood for 10 and 25 years.

Drainage channel water levels are compared to the Cimande River water levels for different return periods (Table 3) show that water level in river higher than the river top bank elevation (+675) for 10 and 25 year return period while water level in drainage channel higher than (+765.3) for 10 and 25 year return period. Flood discharge for 10 and 25 year return periods cause overtopping in the river through the drainage channel. Existing drainage channel capacity is determined by flood discharge for 5 year return period (0.6 m x 1 m). The Cimande River flow affects the drainage channel capacity. Overtopping in the drainage channel still occurs in the absence of back water because of flood discharge for 2 and 5 year return periods. Tabel 4 lists the recommendation for drainage channel capacity that accommodates flood discharge in various return periods.

Table 3 Water level profile in station 0+51

Flood	Water level (m)	
Discharge	Cimande River	Drainage channel
Q_2	674.20	675.24
Q_5	674.73	675.31
Q_{10}	675.17	675.33
Q_{25}	675.58	676.12

Table 4 Drainage channel capacity

Flood	Drainage channel capacity (m^2)	
Discharge	Area	Dimension (b x h)
Q_2	0.6756	0.70 x 1
Q_5	0.7264	0.75 x 1
Q_{10}	0.7812	0.80 x 1
Q_{25}	1.1005	0.9 x 1.25

5. CONCLUSION AND RECOMENDATION

A calibrated and validated static model of cross section and drainage channel of the Cimande River are needed before flood simulation. Hydrograph of 2, 5, 10, and 25 year return period flood frequency determined using Log-Pearson type III frequency distribution so that it was used to calculate steady flow analysis. Cimande River flow causes overtopping that also produces back water in the drainage channel due to flood discharge for the 10 and 25 year return period. Structural assessment to prevent back water is dredging [32] either river normalization otherwise it needs enough space and high in cost. The Cimande River flow affects the drainage channel capacity. The drainage channel capacity is insufficient to the discharge in all the simulated return period even for 2 and 5 year return period. The channel cannot pass backwater from the Cimande River that causes overtopping and inundation [33]. The drainage channel capacity needs to be increased to 0,8 m^2 to fit the design flood discharge for the 10 year return period according to drainage planning regulation and standard in Indonesia.

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