

Dam-Break Assessment of Ciawi-Sukamahi Parallel Dry Dams by Using HEC-RAS

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Abstract This research intends to evaluate dam-break in Ciawi and Sukamahi dams. Both Ciawi and Sukamahi dams are dry dams with parallel position. The concept of flood control pattern in Ciawi and Sukamahi dams is in the beginning of rainy season and the elevation of water level in both dams must be in low elevation. It is possible by the available tunnel to flow water into both dams. If the failure of Ciawi-Sukamahi parallel dry-dams happens together, it needs some observations for anticipating it. The methodology consists of data collecting; literature study of related previous research; analysis of the PMP (Probable Maximum Precipitation) rainfall by using Isohyet and Hersfield methods, design flood by using HEC-HMS, dambreak by using HEC-RAS, then the losses of parallel dams-break by using InaSAFE method. The research result shows that the potency of Ciawi-Sukamahi parallel dry dams will break in the worst scenario that is piping in Ciawi dam with PMF discharge of 1,389 m³/s and in Sukamahi dam with PMF (Probable Maximum Flood) discharge of 254 m³/s and causes the inundation of 50.9 km² that spreads in 8 cities/ regencies. The result is hoped as the consideration to the stakeholder related with flood mitigation due to the simulation of the dam-break potency of Cimahi-Sukamahi parallel dry dams.

Keywords Analysis of Dam-Break Together, Ciawi, Dry Dam, Parallel Dams, Sukamahi

1. Introduction

Dam plays a role in increasing the ability of capacity to reduce the risk due to the disaster. However, a dam can also be a threat if it happens dam-break. Water characteristic that is stored in dams is water flow with high velocity which will cause big discharge. If the water flow is more than river capacity, it will cause inundation in the dam downstream where the population is dense. Therefore, analysis of dam-break is needed so the risk in the area that is affected by disaster impact can be known [1]. Based on the Indonesian Ministry Rule of General Work and Public Housing No 7, 2023 about development and management of dam, its reservoir must be implemented based on the concept of dam safety in which the preparedness of emergence action is the third pillar, according to the Indonesian Laws No 24, 2007 about the action of disaster countermeasures through physical development as well as consciousness and the increasing of ability to face disaster threat [2].

The risk of dam-break can be predicted by using the variables of dam height and length, maximum flood volume, flood surface area, average of annual rainfall, watershed area and height, proportional of urban catchment area and forest, and maximum flood volume that is managed [3]. In addition, the simulation of flood danger can be known by using the multi-meter model approach of 1D and 2D hydro-dynamics flow [4]. However, the scenario of dam-break can use heavy, moderate, and controlled peak discharge [5].

Previous research uses some software to analyze flood in Ciawi-Sukamahi dam-break. First, the Zhong Xing HY-21 software functions for making outflow hydrograph from dam to analyze inundation depth [6] and slow down of flood, and to know the inundation area [1]. The second one, software of HEC-RAS v5.07 that functions for simulating and analyzing the Ciawi dam-break by using the InaSAFE software can calculate the economic loss [7]. There is also previous research using the dry dam method. The dry dam method is an ideal method to overcome flooding. The extreme flood [8] in the dam downstream can be caused by failure or without failure of dam. In this case, the Sukamahi dam is designed for reducing floods mainly in the downstream area of Bogor city and regency, Depok city, and Jakarta region. The dry dam method is assumed to be a suitable solution in solving floods in Sukamahi dam [9].

So far, there has not been related research with dam-break analysis and losses due to parallel dams of Ciawi and Sukamahi together. Therefore, it is necessary to observe the dam-break analysis of Ciawi and Sukamahi dams in Bogor Regency-West Java Province by using HEC-RAS software. This research uses the dam-break model of parallel dry dams to know the impact of dam-break effect and the dam worst scenario of parallel dry dams that happens together by probable maximum flood (PMF).

2. Materials and Methods

2.1. Research Location

Sukamahi Dam is in Cisukabirus River specifically a tributary of Ciliwung River. The area of Sukamahi Dam is 15.86 km², the length of Main River is 15 km, and the average slope is 14%. The upstream of Sukamahi Dam watershed is mountain range [10]. Figure 1 presents the study location of dam-break analysis in Ciawi and Sukamahi Dams.

2.2. Rainfall-Flow Model by Using HEC-HMS

The simulation of Hydrology model is carried out by using HEC-HMS software v4.10 for knowing the watershed parameters and rainfall that causes flood [11] as follows:

1. Determination of model

Determination of model is in accordance with data availability and boundary to simplify real watershed condition. The watershed parameters that are used as input are as follows: a) Rainfall model: hyetograph; b) Model of volume run-off: SCS curve number; c) Model of direct runoff: user-specified unit hydrograph; d) Model of base-flow: recession

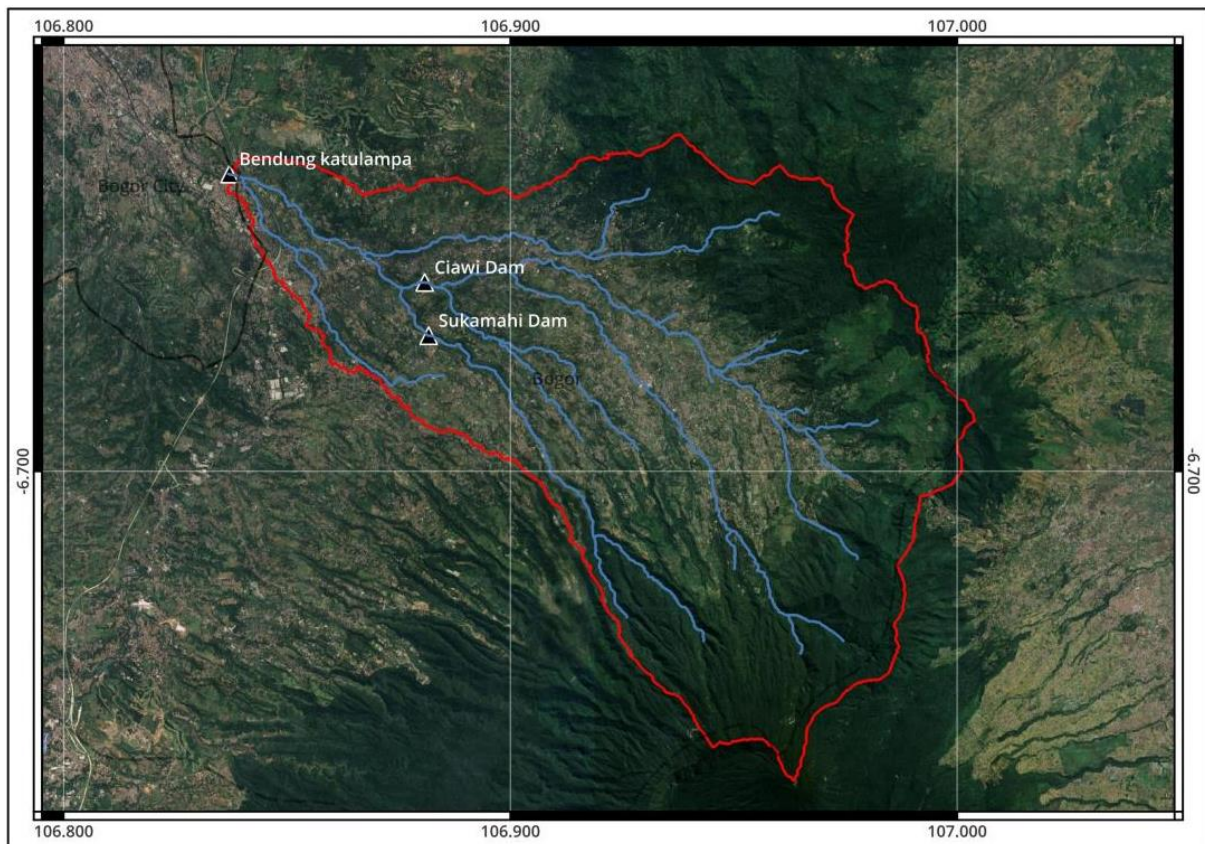


Figure 1. Study Location of Dam-Break Analysis in Ciawi and Sukamahi Dams

2. Procedures of HEC-HMS v4.10 modeling [12]:

a. Basin model

Ciliwung watershed is divided into some sub-watersheds with the control point that is in the AWLR station in Katulampa Weir. The duration of recording is from 1985 until 2020, and it is managed by PSDA Institution of West Java Province.

b. Meteorological model

Hydrology modeling uses the precipitation specified hyetograph in which the basin model relates to rainfall that is used as the input of simulation.

d. Control specification

This part is used for determining the time range of the simulation of hydrology model by filling starting time until simulation ending and its time interval.

e. Time series data

There is an available data limitation in research location, however, data that is filled in this part is precipitation data that is filled rainfall data and happens in happening date of flood with hourly distribution.

f. Paired data

The transformation method in the selected basin model is user specification unit hydrograph, so the paired data is entered into unit hydrograph curves that are SCS unit for every sub-watershed.

3. Calibration of hydrology model

After being carried out the flood event based on the available parameters, discharge in control point of simulation result is calibrated based on the flood discharge in control point that is recorded when flood happens by changing the available parameter.

4. Verification of hydrology model

After being carried out the calibration and obtaining the parameter of calibration result, then the verification by the other flood event is carried out.

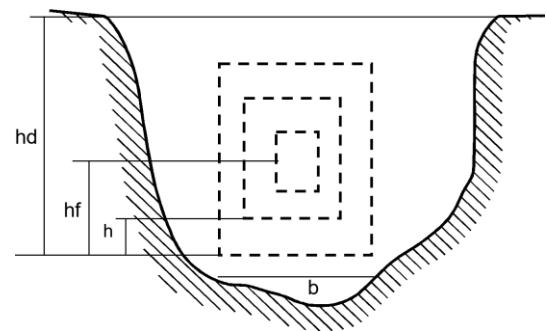
2.3. Model of Dam-Break

Before dam-break, cracks will happen formerly. Cracks are a hole that is formed in the dam body when there will be a break. Basically, the mechanism of break is not too understood for soil backfill dam as well as concrete dam. Some researchers of flood wave due to dam-break are as follows: Ritter (1892), Schoklich (1917), Dressler (1954), Stoker (1957), and Barnes (1969) who assumed that the cracks break down all of dam body and it has happened immediately. However, the other researchers that are Schoklitsch (1917) and United State Army Corps of Engineers (1960) confessed that it is needed part of cracks to be compared with the total of cracks, but they still

assume that the cracks happen immediately. The assumption about cracks total and instantaneous is used for making it easier if it is applied by mathematical technique for analyzing flood wave and dam-break. Sadly, this assumption is rather in accordance if to be used for concrete arch dam. However, for backfill dam and concrete gravity dam, it is not suitable. There are 2 types of cracks as follows [13]:

1. Piping

Dam-break due to piping can be simulated by determining the axis elevation of piping. This is simulated as orifice cracks with rectangle shape [13]. Figure 2 presents the cracks due to piping.



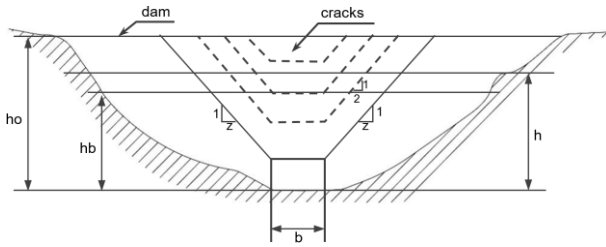
Explanation of Figure 2: hd = top cracking height; hf = low part cracking height; h = the lowest cracking height in the low part; b = base width of cracking

Figure 2. Cracks Due to Piping

Cracks due to piping are simulated as rectangular cracks hole that spread to the top and down in the dam body. The instantaneous flow through the cracks is calculated with the orifice formula or as broad crested weir depending on the position of reservoir water level and orifice peak. The outflow from both cracks is flood discharge that happens in cross section-0 (beginning) that must be routed downstream along the river valley with the unsteady flow [13].

2. Overtopping

Dam-break due to the overtopping can be simulated with rectangular, triangle, and trapezoidal cracks. The cracks grow over time progressively from dam peak to down until reaching the foundation. Flow that is through the cracks is calculated as broad crested weir. The form of terminal breach is determined by parameter of (Z) that identifies the side slope of cracks in which the vertical slope 1 : Z horizontal, and parameter of (b) are mentioned terminal width of cracks bed. The range of side parameter of Z is $0 < Z < 2$. This value depends on the natural slope of material that is compacted and moistened. The cracks shape is determined by using the value combination of Z and b . The terminal width- b is related to the average width of cracks (b), depth (h), and the cracks slope (Z) that is calculated by using equation (1). Figure 3 presents the cracks due to overtopping.



Explanation of Figure 3: h_o = top cracking height; h = water level; h_b = low part cracking height

Figure 3. Cracks Due to Overtopping

$$b = \bar{b} - 0.5Zh_d \tag{1}$$

\bar{b} = average fracture base width (ft)

Z = slope of the fracture

h_d = dam height (ft)

The figure above shows that cracks began in a point then grows up with linear or non-linear velocity in the breaking time range $\tau < 1$ minute, and cracks width began with the value of b from zero. It more shows that breaking event due to the collapse failure happens more than breaking due to erosion [13] as follows:

$$hb = h_d - (h_d - h_{bm}) \left(\frac{tb}{\tau}\right) \rho \tag{2}$$

for $0 < tb < \tau$

Note:

h_{bm} : final elevation of cracks bed

tb : time that is used since the cracks happens

The level that shows non-linearity and the value from 1 until 4 is as follows:

- If 1, it indicates the velocity of cracks is linear
- If 2, it indicates that the velocity of cracks is non-linear

The instantaneous bed width (b) of cracks is calculated by using the equation (3) as follows:

$$bi = b \left(\frac{tb}{\tau}\right) \rho \tag{3}$$

for $0 < b < \tau$

Note:

bi : width of cracks instantaneous

During the simulation of dam-break, the real cracks formation began when the elevation of water level (h) is more than the value of (h_f). It is possible to simulate an overtopping of a dam in which the cracks are not formed until the water flow is big enough through dam mercu [13].

2.4. Determination of the Influence of Parallel Dam-Break

Flood routing is an analysis of flood hydrograph in a river location that is based on the flood hydrograph in the other location. The aim of flood hydrograph is [14] as follows: 1) to know flood hydrograph of a location that does not have water level observation; 2) to forecast short

term flood; 3) to analyze downstream flood hydrograph based on the upstream hydrograph; 4) to safe flood by early warning.

2.5. Model of River Flow by Using HEC-RAS

The software that is used for analyzing hydraulics in this research is HEC-RAS v6.2 [15]. The simulation is carried out to know the water level profile so it can be known the location and run-off depth along Ciliwung River section. The river modelling by using HEC-RAS is as follows [16]:

1. Making project, it means to define the project.
2. Simulation of river geometry, it means to give input of river geometry data that includes long and cross section, and the condition of channel roughness (Manning coefficient). Besides that, it also means to simulate the available water structure in river channel (bridge).
3. Simulation of river hydraulics, it means to give the input of upstream and downstream boundary data, and the initial condition.
4. To analyze the flow hydraulics, it means to carry out the simulation (running program) like the simulation of steady and unsteady flow.
5. Presentation of analysis result is like figure or table.

Simulation of river channel section real condition is necessary to be carried out for obtaining the calibration to the model. The calibration is implemented by carrying out the simulation of steady flow with the model in the cross-section location (control point) that has data of water level depth observation (Katulampa Weir) in flood discharge condition of selected date. The calibration is also implemented to the change of Manning value for approaching water level depth that is in accordance with the control location. The simulation of unsteady flow is used for obtaining the flow response and critical location point of run-off in the river as available discharge data and water level depth [17].

2.6. Flood Map

The simulation result of dam-break is plotted for downstream area that is caught in the impact, inventory the parameter of flood maximum depth, time arrives of flood, flood duration, and flood maximum velocity. The parameter will be compared in scenario of HEC-RAS break model in which the model has RAS Mapper figure for processing data spatially. The flood inundation map presents the information about depth, duration, and velocity of flood that can be made with the available features; however, the management of spatial RAS Mapper is still carried out in every mesh. RAS Mapper has not accommodated the static analysis in the zone that is determined. This research inventories the impacted area with the boundary zone of district by using the program of Quantum GIS (QGIS). QGIS is a program for processing spatial information with open-source characteristics [18].

2.7. Determination of the Worst Scenario of Parallel Dam-Break

2.7.1. Scenario of Dam-Break

Analysis of parallel dry dams is carried out with the scenarios as follow [7]:

1. Scenario-0 is the determination to the overtopping or piping scenario. If the capacity of spillway is still enough to flow PMF flood discharge, the modeling of dam-break is by piping scenario.
2. Scenario-1 is the PMF flood condition with under piping model.
3. Scenario-2 is the PMF flood condition with medium piping model.
4. Scenario-3 is the PMF flood condition with over piping model.

2.7.2. The Impact of Dam-Break

The impact of dam-break in the downstream consists of direct impacts such as flood that is felt by human and environment surrounding it like residents, agricultural area, plantation, important buildings etc. One of the facilities for helping the impact analysis of dam-break is by using the

InaSAFE program that is in the QGIS program. InaSAFE (Indonesian Scenario Assessment for Emergencies) uses the parameter of loss unit price that has been determined by Damage Assessment Guide – BNPB (National Institution of Disaster Controlling).

One of InaSAFE inputs is a survey of mapathon digitation related with the arrangement of Open Street Map (OSM), and it is hoped to give illustration factually to some impacted parameter in dam downstream if dam failure happens. The category that dam failure impacted consists of number of populations, number of refugees, number of buildings, number of general facilities, roads and bridges, and object of agricultures and husbandries [7]. The loss analysis that is part of the inventories of area that is caught flood inundation risk becomes as the important part in supporting the preventive effort of dam-break because there is known the damage size that will be borne by society and local government mainly if there happens dam-break. Therefore, it is hoped that it can manage dam intensively [19]. Figure 4 presents the research steps systematically that will be carried out through the procedure of research implementation.

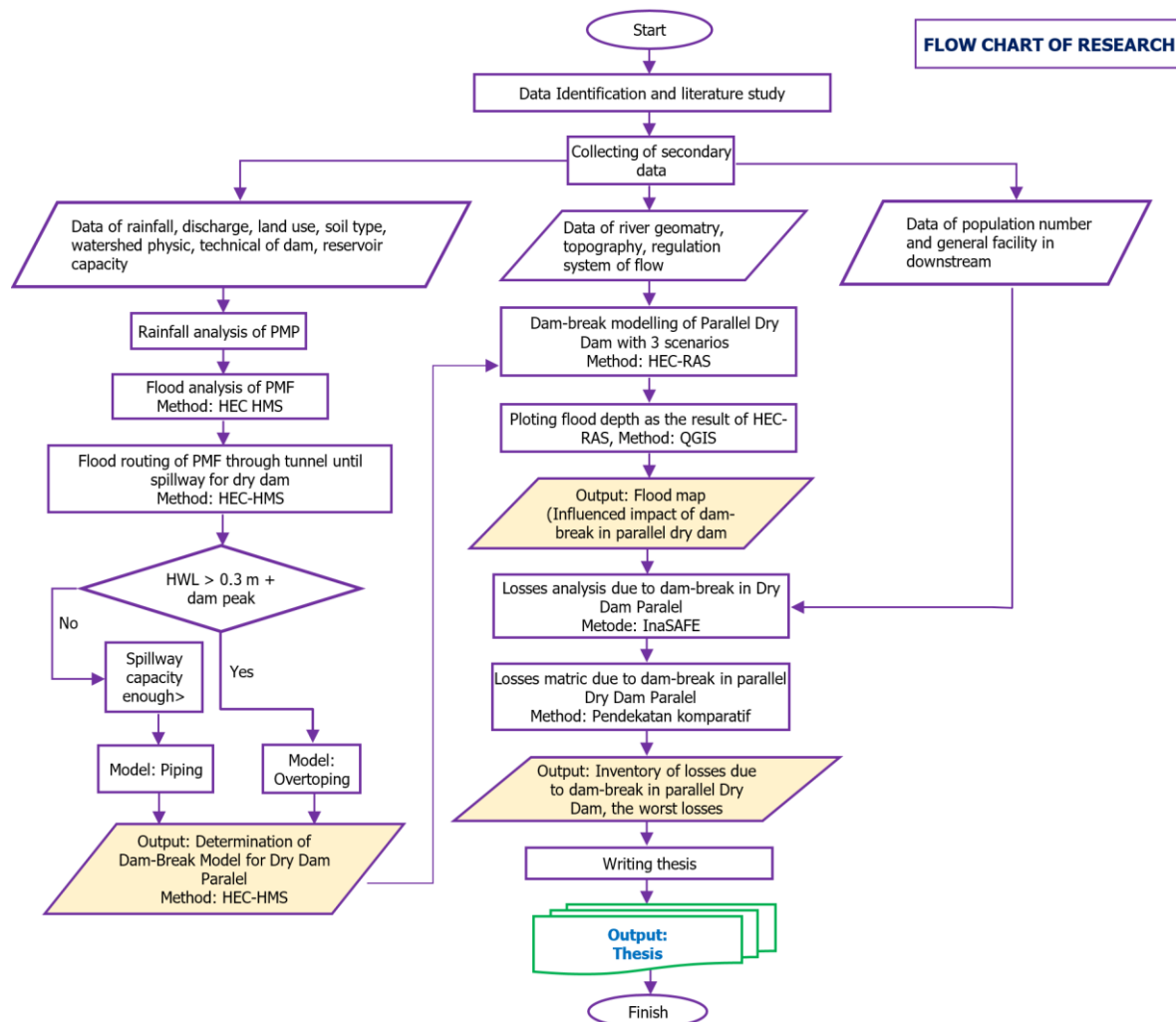


Figure 4. Research Flow Chart of Parallel Dry Dam-Break. Source: own study

3. Results and Discussion

3.1. Design Flood of PA Manggarai and PA Depok

Based on the related study with the master plan of flood handling that is designed by Japan International Cooperation Agency (JICA) Japan International Cooperation Agency (JICA) 2013, there is the activity of

analysis result in previous study for each water gate of watershed in dam downstream that is watersheds of PA Manggarai and PA Depok. The design certificate of Ciawi and Sukamahi dams 2016 is presented the design rainfall in accordance with the plan. Figure 5 presents the scheme of flow system in Ciliwung River and Figure 6 presents design flood in Ciliwung River.

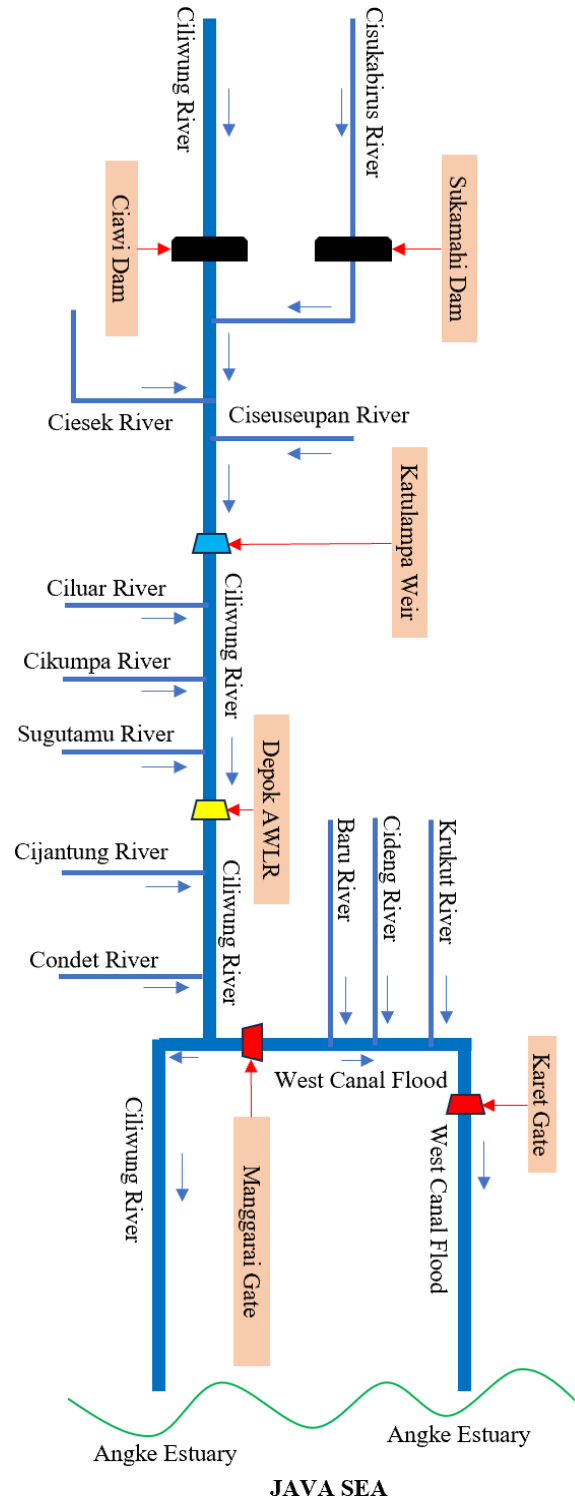


Figure 5. Scheme of Flow System in Ciliwung River. Source: own study

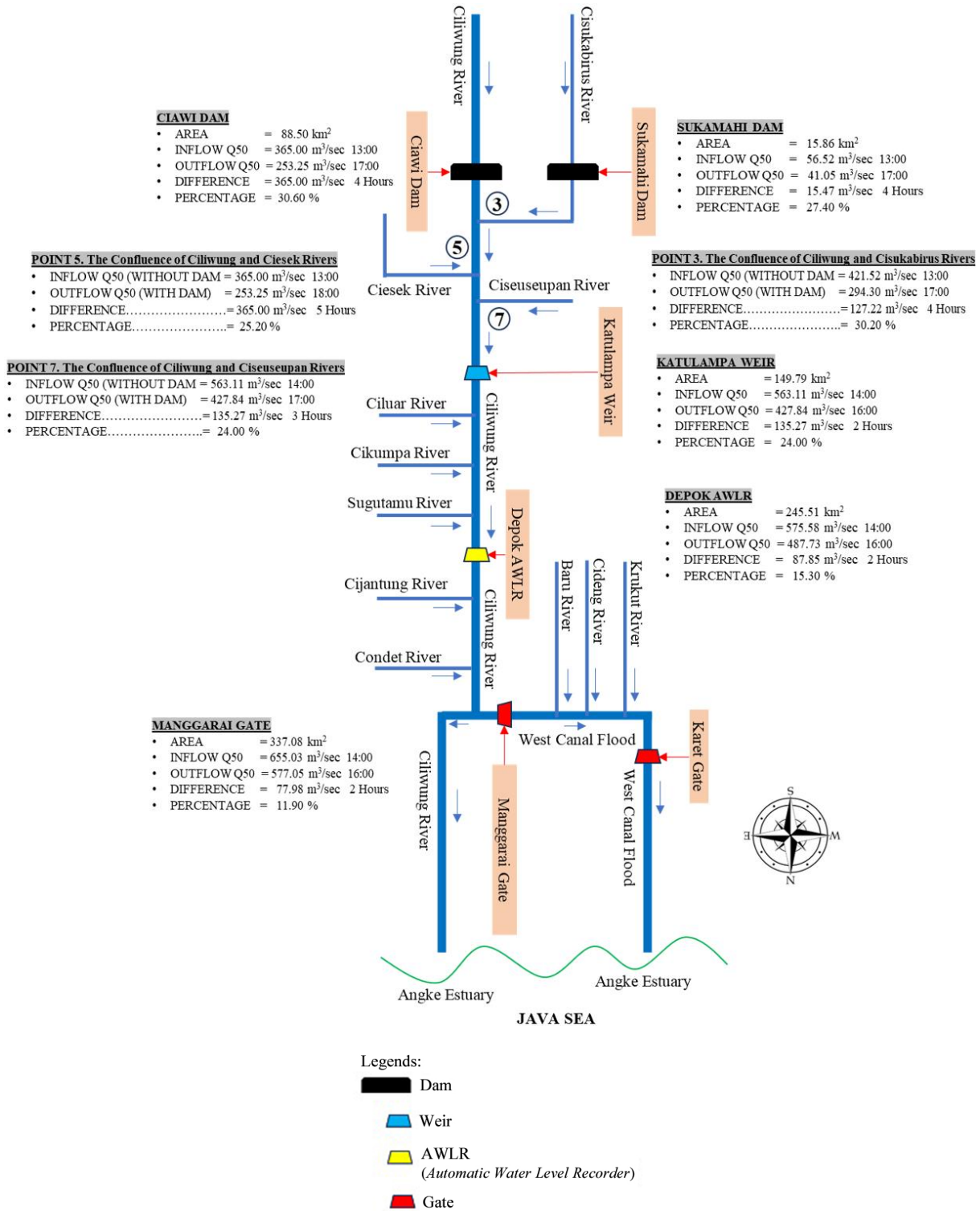


Figure 6. Scheme of Design Flood in Ciliwung River. Source: own study

3.2. The Criteria of Flood Alert in Katulampa Weir

The emergency condition is differentiated into two that are flood emergency condition and dam-break emergency condition. It is necessary to know that in the downstream of Ciawi and Sukamahi dams there is Katulampa weir that

functions as flood control towards downstream. In addition, the determination of flood alert status downstream depended on high and low water levels in Katulampa weir or depended on the operation system of Katulampa weir. However, flood emergency condition in the downstream of Ciliwung River is classified as presented in Table 1.

Table 1. Criteria of Flood Alert in Katulampa Weir

No.	Status of condition	Katulampa (watershed = 149.79 km ²)	
		Water level	Outflow
		m	m ³ /s
1	Normal	< 0.50	< 36
2	Flood alert-IV	0.50 – 0.80	36 – 90
3	Flood alert-III	0.80 – 1.50	90 – 276
4	Flood alert-II	1.50 – 2.00	276 – 442
5	Flood alert-I	> 2.00	> 442

Source: own study

3.3. Rating Curve of Ciawi Dam

To know the relation between water level elevation and outflow of Ciawi Reservoir when there is happening rainfall that is possible to cause flood in downstream area of dam, so the rating curve of Ciawi Dam related with determination of flood disaster alert status is presented as in Figure 7.

3.4. Rating Curve of Sukamahi Dam

Rating Curve of Sukamahi Dam related with determination of flood disaster alert status is presented as in Figure 8.

3.5. Determination of the Influence of Dam-Break in Parallel Dry Dam

To determine the influence of dam-break in parallel dry dam, the research is carried out with 4 alternatives as follows:

1. Scenario of Piping in bed Parallel Dry Dams with design flood of PMF
2. Scenario of Piping in middle Parallel Dry Dams with design flood of PMF
3. Scenario of Piping in peak Parallel Dry Dams with design flood of PMF
4. Scenario of Piping in Parallel Dry Dams bed with design flood

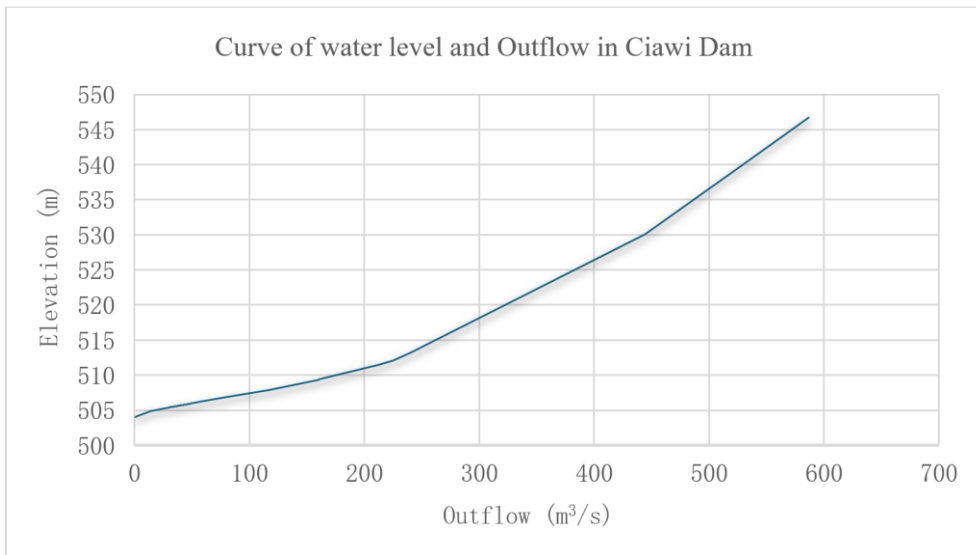


Figure 7. Rating Curve of Ciawi Dam. Source: own study

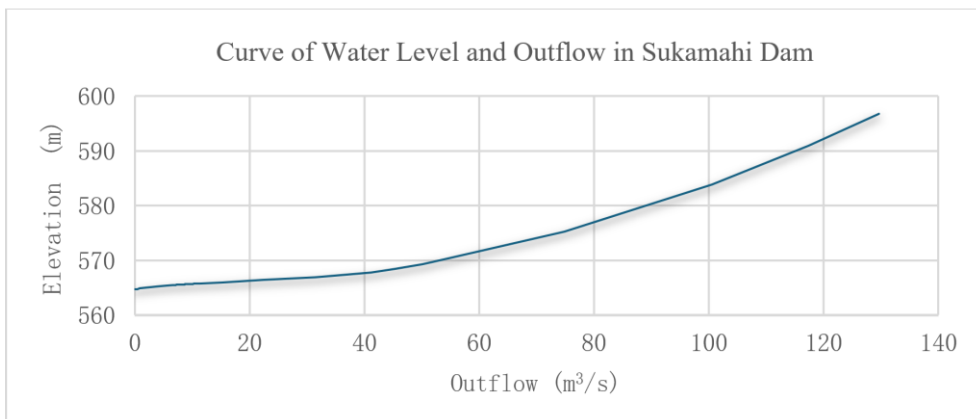


Figure 8. Rating Curve of Sukamahi Dam. Source: own study

3.6. Scenario of Parallel Dry Dam-Break

The simulation of dam-break uses the scheme of unsteady flow modeling or non-permanent flow in which the flow condition changes to time based on the inflow for 72 hours. The simulation of dam-break is carried out with 2 scenarios of dam-break, with the parameters of dam break being presented in Table 2 and Table 3.

From the simulation result, in the flood of dam-break for scenarios 1-3 with QPMF, the flood inundation area obtained is 50.9 km², however in scenario 4 that is flood of dam-break with design flood of Q100 the flood inundation area obtained is 44.6 km². The flood map of dam-breaks is presented in Figure 9.

Flood maps of Parallel Dry Dam-Break are presented in Figures 10-12.

Table 2. Parameter of Dam-Break Scenario in Ciawi Dam

Scenario of Dam-Break	1	2
	Dam break in sunny weather	Dam-break in design flood condition
Dam-break	Piping	Piping
Elevation of reservoir water level	NWL	FWL
Elevation of reservoir water level (m)	544	549.94
Hydrograph of Inflow	-	Q-PMF
Design Flood (m ³ /s)	-	1388.68
Bed width of break (m)	25	25
Bed elevation of break (m)	525	525
Cracks shape	Trapezoidal	Trapezoidal
Right slope (1 : H)	2	2
Left slope (1 : H)	2	2
Coefficient of Mercu	2.6	2.6
Break time (hour)	2	2
Elevation of initial break (m)	-	-
Elevation of under piping (m)	525	525
Elevation of middle piping (m)	535	535
Elevation of over piping (m)	546.75	546.75

Source: own study

Table 3. Parameter of Dam-Break Scenario in Sukamahi Dam

Scenario of dam-break	1	2
	Dam break in sunny weather	Dam-break in design flood condition
Dam-break	Piping	Piping
Elevation of reservoir water level	NWL	FWL
Elevation of reservoir water level (m)	596.75	599.867
Hydrograph of Inflow	-	QPMF
Design Flood (m ³ /s)	-	254.03
Bed width of break (m)	30	30
Bed elevation of break (m)	585	585
Cracks shape	Trapezoidal	Trapezoidal
Right slope (1 : H)	1.5	1.5
Left slope (1 : H)	1.5	1.5
Coefficient of Mercu	2.6	2.6
Break time (hour)	2	2
Elevation of initial break (m)	-	-
Elevation of under piping (m)	585	585
Elevation of middle piping (m)	590	590
Elevation of over piping (m)	596.75	596.75

Source: own study

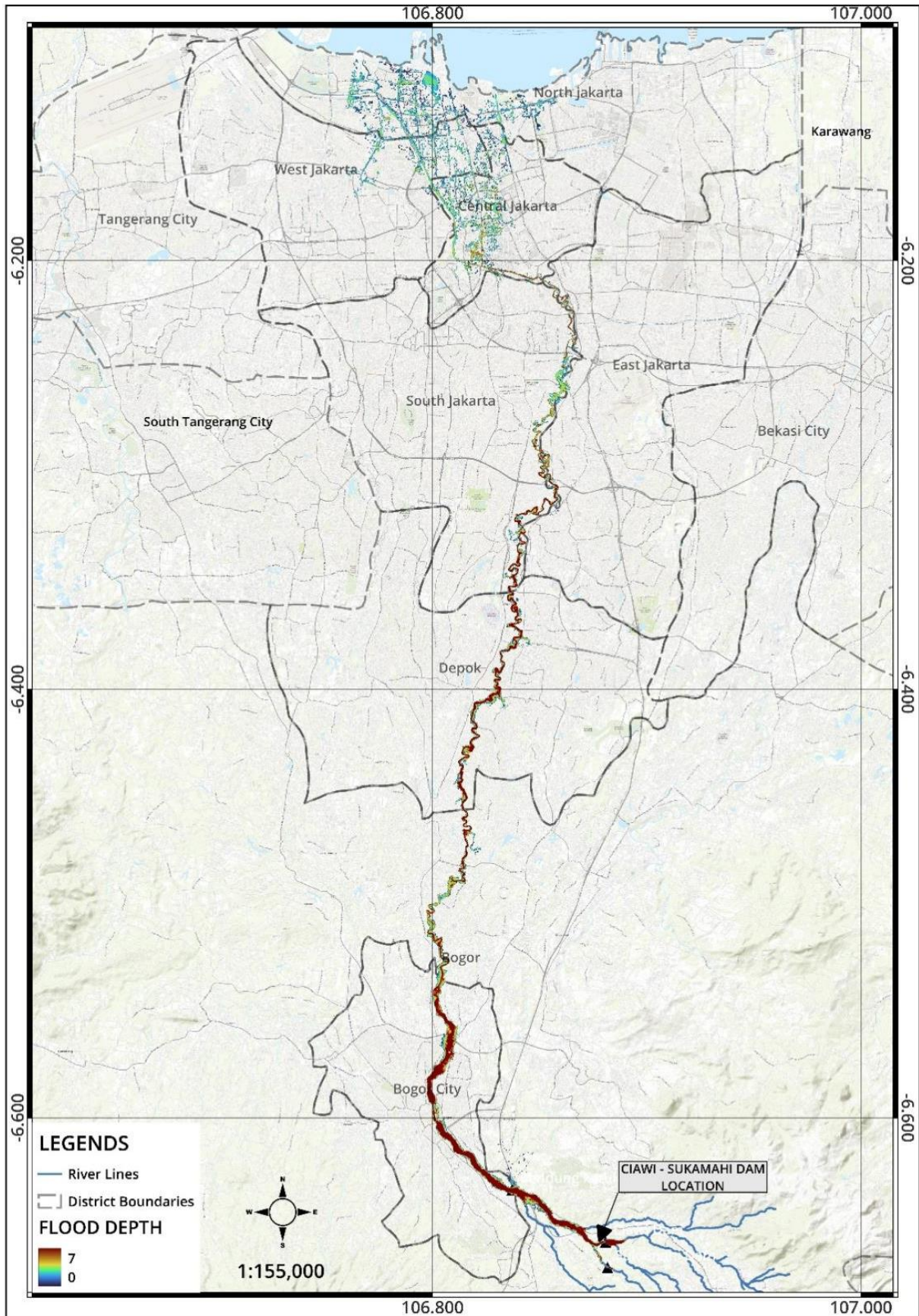


Figure 9. Map of Dam-Break Due to Dam-Break in Ciawi Sukamahi Dam with Design Flood of Q_{100} . Source: own study

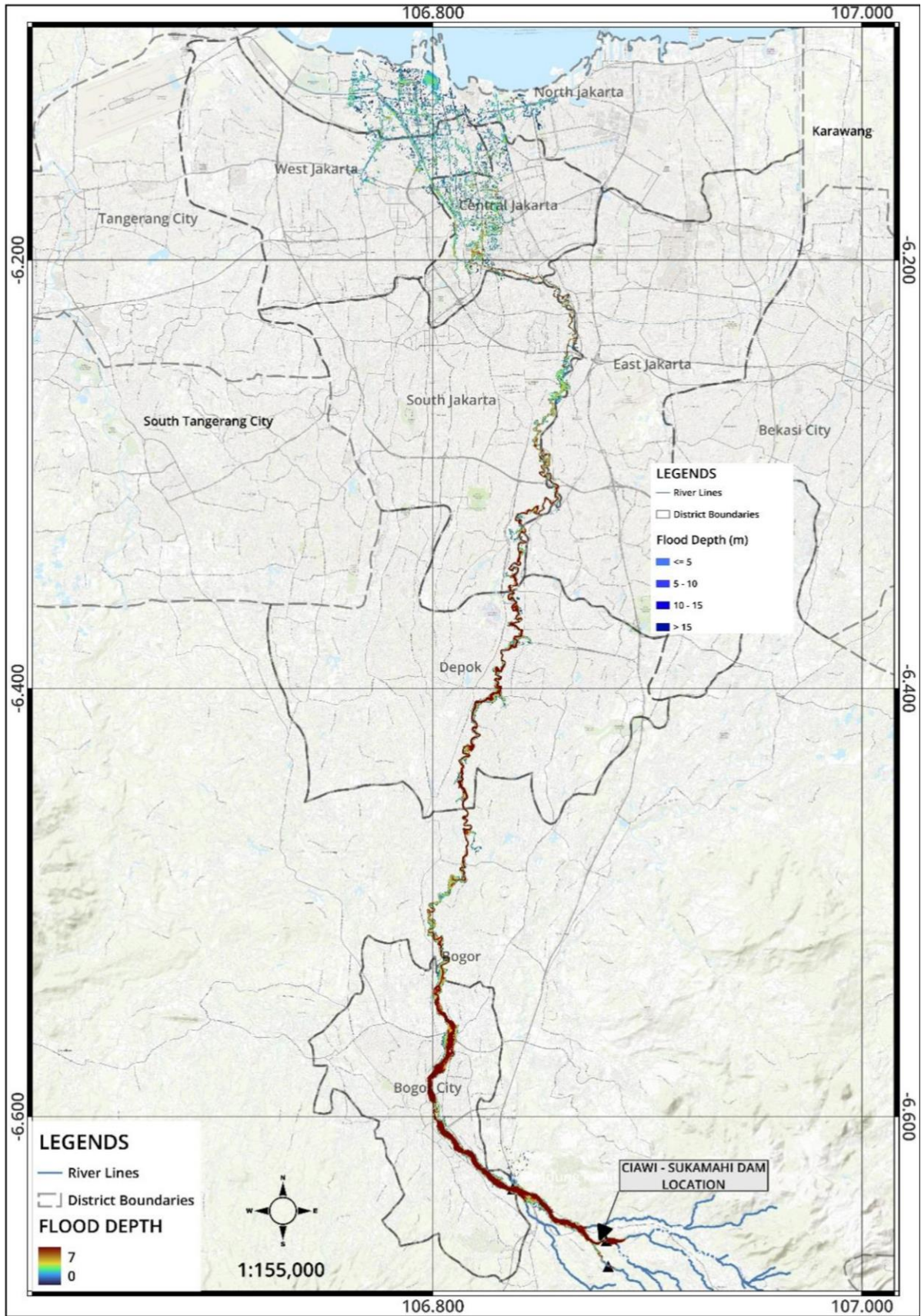


Figure 10. Map of Flood Depth Due to Dam-Break in Ciawi Sukamahi Dam with Design Flood of Q_{100} . Source: own study

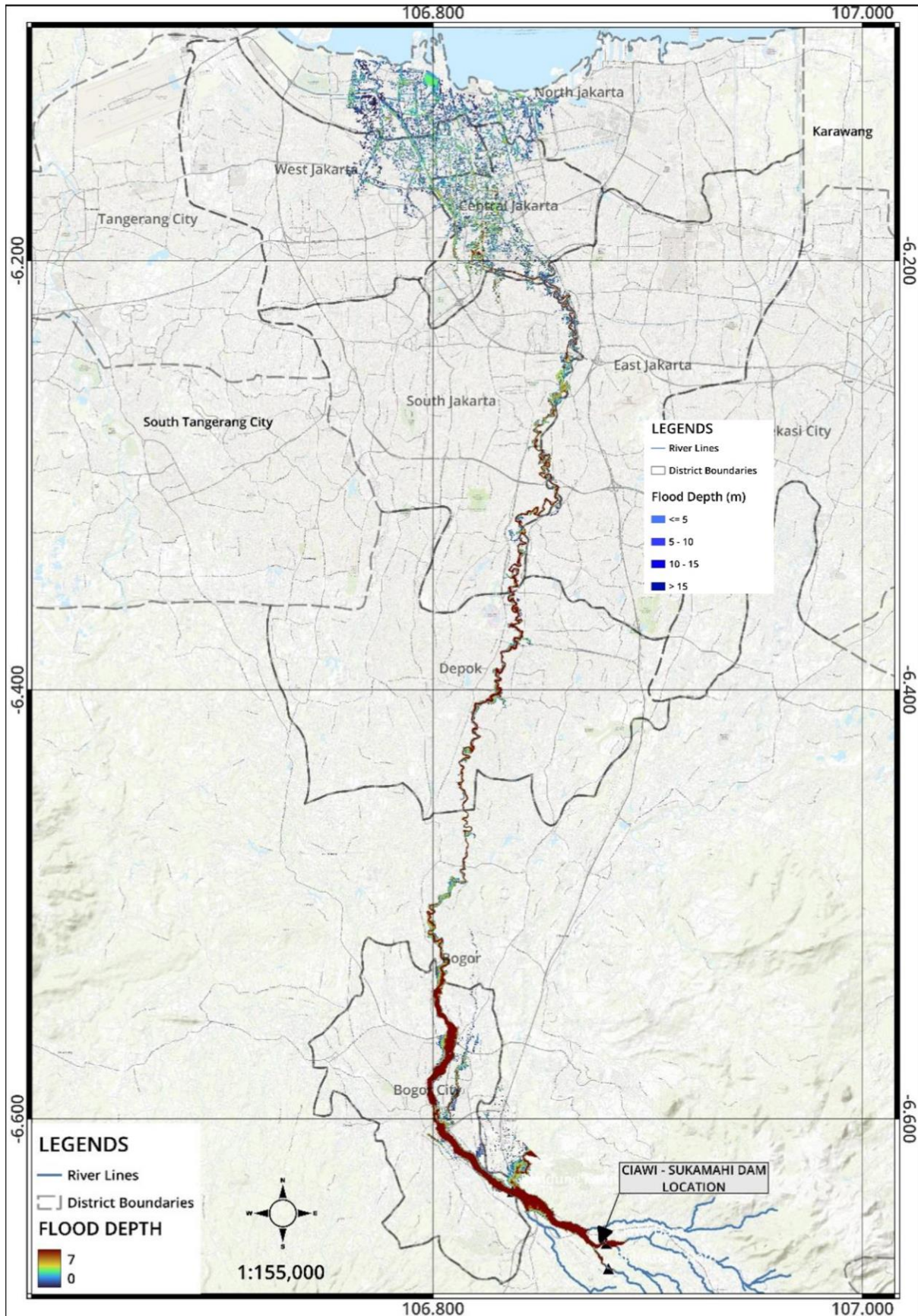


Figure 11. Map of Flood Depth Due to Dam-Break in Ciawi Sukamahi Dam with Design Flood of Q_{PMF} . Source: own study

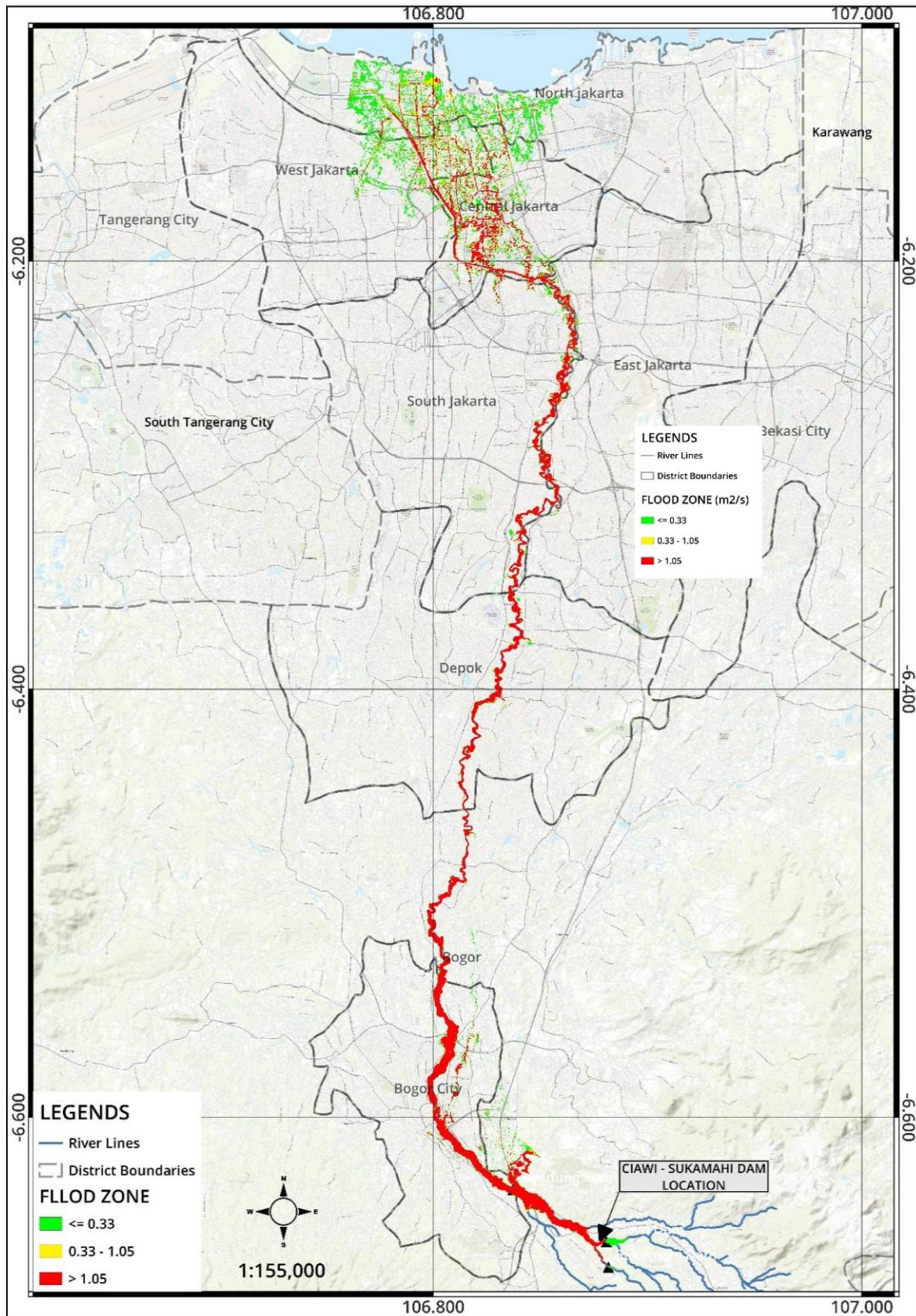


Figure 12. Map of Potential Flood Zone Due to Dam-Break in Ciawi Sukamahi Dam with Design Flood of Q_{PMF} . Source: own study

Table 4. Minimum Demand and Cost for Evacuation

No	Component	Number of refugees	Unit price (2021)	Total
			(Rp)	(Rp)
I	BASE DEMAND (weekly)			
1	Paddy	1,176,252	Rp10,650	Rp12,527,083,800
2	Drinking water	7,351,575	Rp3,000	Rp22,054,725,000
3	Clean water	28,146,030	Rp300	Rp8,443,809,000
4	Family base equipment	84,018	Rp2,000,000	Rp168,036,000,000
II	FASILITY DEMAND (ONCE)			
1	Toilet Demand	21,004	Rp10,000,000	Rp210,040,000,000
	TOTAL OF EVACUATION DEMAND			Rp421,101,617,800

From the flood inundation map due to the potency of dambreak in CIawi and Sukamahi dam with design flood of PMF above, the number of impacted villages is 162 villages in 40 districts that are spreading in 8 regencies/ cities.

3.7. Social-Economic Loss Due to Parallel Dry-Dams Dam-Break

The social-economic loss that is caused by the potency of Ciawi-Sukamahi Dams is simulated by using InaSAFE (Indonesia Scenario Assessment for Emergencies) through the software of QGIS and by using the parameter of loss unit price that has been determined by Damage Assessment Guide-BNPPB (National Institution of Disaster Controlling).

The program of InaSAFE is by combining one layer of exposure data and one layer of threat, then it will produce the spatial impact layer from the disaster, the summary of statistical information, and several questions for making an action. The output result from InaSAFE will produce some information of disaster impact such as layer of impact map like spatial data and report of impact analysis, minimum demand, and list of action in table and teks. However, the number of exposed populations in Ciawi-Sukamahi Dams downstream is about 720,000 persons that spreads in 8 cities/ regencies. This result is total of the threat index class of low, moderate, and high. However, the number of populations that must evacuate based on the number of moderate and high threat index is 420,090 persons. The minimum demand and cost that is needed is presented in Table 4.

4. Conclusions

The model of Ciawi-Sukamahi dry dams-break is piping type. Based on the result by 4 scenarios each in Ciawi and Sukamahi dams, it indicates that the spillway capacity is adequate to flow the PMF (Probable Maximum Flood)-design flood. The PMF in Ciawi is 1,389 m³/s, with

the spillway capacity 1,010 m³/s and the outlet facility with 2 gates opening in 1,010 m³/s, so there is still a 20 cm freeboard. However, the PMF in Sukamahi is 254 m³/s, with spillway capacity 136 m³/s and the outlet facility with opening 2 gates in 172 m³/s so there is still a 144 cm freeboard. The impact of CIawi-Sukamahi parallel dry dams-break is inundation in 50.9 km² area that spreads in 8 cities/ regencies with the number of impacted flood population is 720,000 persons.

Scenario of piping due to the dam-break of Ciawi-Sukamahi parallel dry-dams causes the social-economic losses as follows: a) the number estimation of impacted population based on the hazard zone includes high hazard zone is 292,000 persons, moderate hazard zone is 300,000 persons, and low hazards zone is 720,000 persons; b) total of population that must be evacuated is 421,000 persons; c) vulnerability estimation of impacted population based on the age includes less than 5 years old is 38,1000 persons; more than 60 years old is 45,800 persons, and disable is 62,100 persons, woman of childbearing age is 109,000; and pregnant woman is 9,600 persons; and d) the minimum cost for evacuation is 421 milyards rupiah that consists of the demand of paddy, drinking water, clean water, family base equipment, and toilet.

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