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Hydrological Risk Valuation on The Design of Sukamahi Dry Dam, Bogor, West Java

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Abstract. The flooding risk has always been considered as an important factor of the risk safety management of dams. The extreme flooding in the downstream of a dam could be either due to dam failure or sometimes without failure. In both cases, they give serious risks to people and property in the downstream of the dam. Sukamahi dry dam at Cisukabirus River is a part of the upper Ciliwung Watershed, located in Bogor regency. Sukamahi dry dam was designed for flood reduction purpose especially for the downstream region e.g. Bogor City, Bogor Regency, Depok City and Jakarta. Sukamahi dam has a capacity in flood reduction of 13.53 m³/s with probability exceeded 2 %, and time to concentration (tc) of peak discharge (Qp) at least 4 hours longer than the existing condition. Construction of dry dam might increase the magnitude of flood prone risk especially on the dam breach caused by spillway capacity failure case, although with lower probability. Simulation using HEC RAS 4.1 and an ex-ante hydrological risk valuation Xrisk model were performed with three scenarios, i.e. normal risk, risk averse and risk takers, with simplified option value and option risk calculation. Risk valuation can be used by decision makers to evaluate the technical and risk feasibility of Sukamahi dry dam construction.

Keywords: Dam breach, risk valuation, overtopping, Sukamahi, flood reduction

1. Introduction

Dams play a vital role in our lives. They meet demand for drinking, irrigation and industrial water supply; they control floods, increase dry-weather flows in rivers and creeks and give opportunities for various recreational activities. Sukamahi dry dam at Cisukabiru River, a part of the upper Ciliwung Watershed which is located in Bogor Regency, was designed for flood reduction purpose, especially for the downstream region such as Bogor City, Bogor Regency, Depok City and Jakarta. Besides being a valuable resource, dams can also be a source of risks to downstream communities as dam failures are potentially resulting in unacceptable damage to property and losing of life. One of the main causes of dam failure is the overtopping of dams because of inadequate flood carrying capacity [1].



In terms of safety, the traditional engineering approach has always been done to specify the required flood discharge capacity of the dam in the design based on the relevant hydrological data, flood estimating and flood routing procedures. Hydrologic safety was considered specifically from other risks, which resulted in identification of inadequate spillway capacity as a major cause of dam failures [2][6]. This study aims to provide a risk analysis that involves economic valuation of value options and option prices of the Sukamahidam construction project.

Therefore, the objectives of this study are: (1) doing risk analysis of an extreme flood related to the design of the Sukamahi dam; (2) analyzing flood inundation area on the Sukamahi dam failure caused by overtopping case; and (3) defining economic valuation of option value and option price on the risk of the Sukamahi dam construction project and operation. In doing this research the scopes of works are: (1) developing Sukamahi dam failure scenario limited to overtopping; (2) dam failure occurs on the Q_{PMF}; (3) assessment of losses due to the risk of dam failure is only seen from an extent of the inundated area and an increase in the extreme discharge of the Ciliwung River.

2. Methods

2.1. Location

Sukamahi dam located in the Cisukabiru Watershed, upper Ciliwung, West Java Indonesia.

2.2. Data and Software

Data and Softwares which are used in the study can be seen in Table 1.

Table 1. Data and softwares.

Data	Source	Note	Software	Version
DEM	SRTM		ArcGIS	10.1
River Polyline	SRTM, RBI		HEC-RAS	
Raingauge	BBWS, BMKG		Xrisk	4.06
Discharge	BBWS		MS Excell	2010
River Profile	BBWS			

The HEC RAS system contains several river analysis components especially for unsteady flow water surface. The unsteady flow water surface analysis can be used to perform subcritical, supercritical and mix flow regime on the dam break with overtopping scenario. Xrisk model analyzes the consequences from a flood event caused by dam break with overtopping scenario. It calculates damages to structures and contents and estimates the potential of fatalities.

2.3. Flow Chart

Working flow of the study which is followed by cause and consequences of the dam safety (see [9] and [10]) can be illustrated in Figure 1. Risk assessment procedures and consequences of dam safety used in this study can be illustrated in Figure 1 (b) (restrictions on the cause of dam failure due to overtopping)

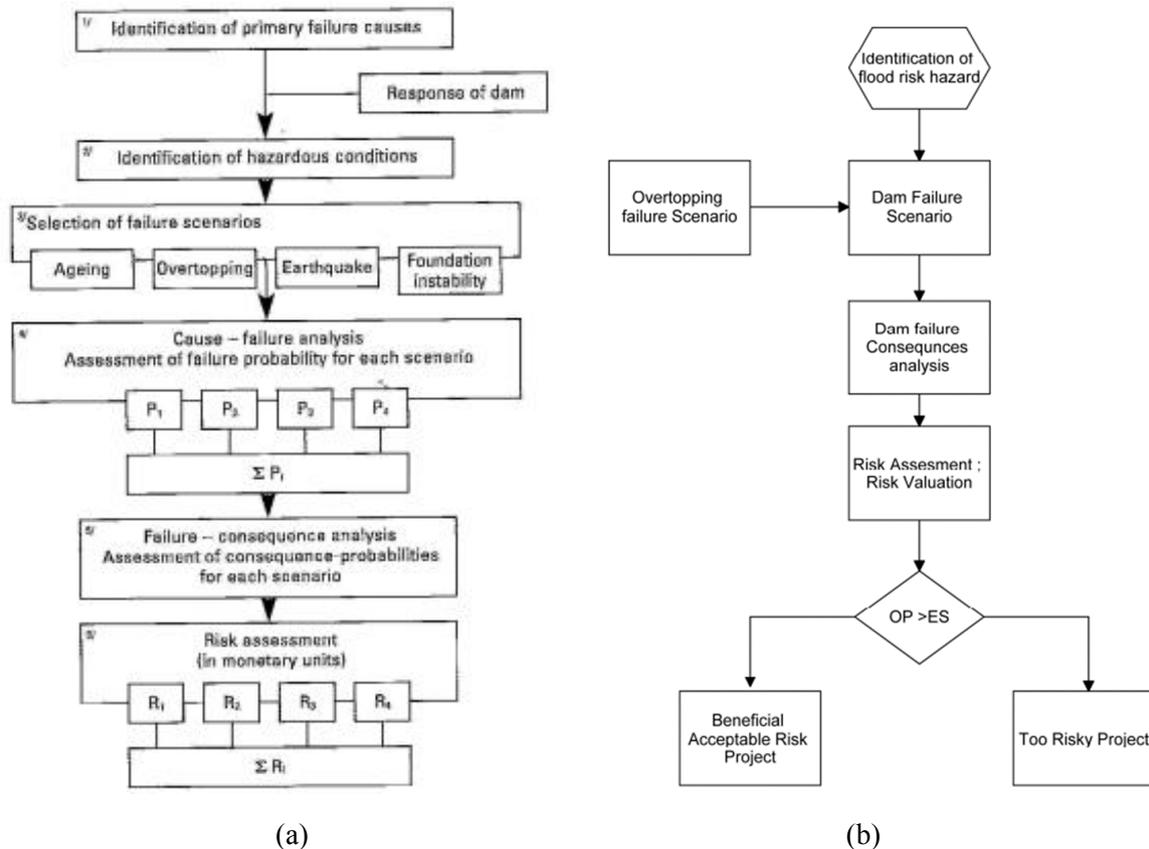


Figure 1. Research Flow Chart (a) ; Risk assessment procedures and consequences of dam safety used in this study (b).

3. Results/Discussion

3.1. FloodRisk Analysis on the Detailed Engineering Design and Operation Plan of Sukamahi Dam

The Sukamahi dam is planned to control the Ciliwung River flood. The main difficulty in controlling floods is the relatively small volume of Sukamahi Dam reservoirs. Flood reduction by utilizing a reservoir above a spillway such as a dam is generally not possible, because the resulting flood reduction will be very small. The engineering operation is carried out by applying the concept of dry dam, where at the beginning of the rainy season the reservoir water level is at a low elevation so that at the beginning of the flood, the flood discharge could flow freely through the tunnel.

The operational plan for controlling the flood of the Ciliwung River in the Sukamahi dam can be described as follows:

- 1) Changing the river flow pattern which under existing conditions it flows through the natural river channel with an average river width of 13-15 m, into a controlled flow by creating a dam where water is flowed through the tunnel.
- 2) Discharge capacity through the tunnel will be smaller than the natural river, so the water flowing downstream to the Katulampa dam will be decreased.
- 3) The function of the dam is to hold the rising water level as the discharge out flow through the tunnel is smaller than the inflow discharge.
- 4) The dam is equipped with a spillway, so if the flood discharge is large enough, then the reservoir surface rises and the water flows through the spillway. The debit that comes downstream of the dam is the total discharge that flows through the tunnel and through the overflow.

5) For the safety of the dam, the height of the dam is determined based on the search for flood discharge of 1000 years return period and the discharge is controlled by PMF discharge.

Sukamahi dam located at the Cisukabiru river which is a tributary of the Ciliwung River, the Sukamahi dam watershed area is 15.86 km², the main river length is ± 15 km, with an average river slope of 0.037 or 3.7 % (Figure 2).

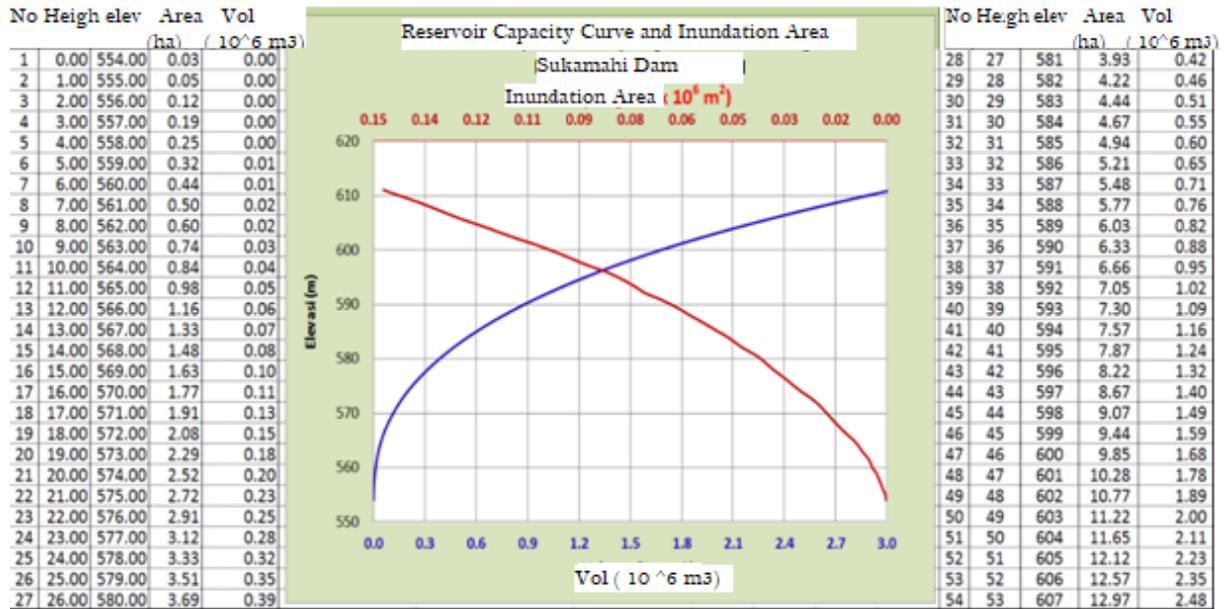


Figure 2. The storage capacity and the area of the Sukamahi Dam [3, 7].

Sukamahi tunnel building has a diameter of 3 m with a horseshoe shape. Considering that the flood discharge in Sukamahi dam is relatively small and in order to reduce it, the diameter of the tunnel is reduced to 1.6 m. The capacity of the Sukamahi dam tunnel with variations in the upstream water level is shown in Figure 3.

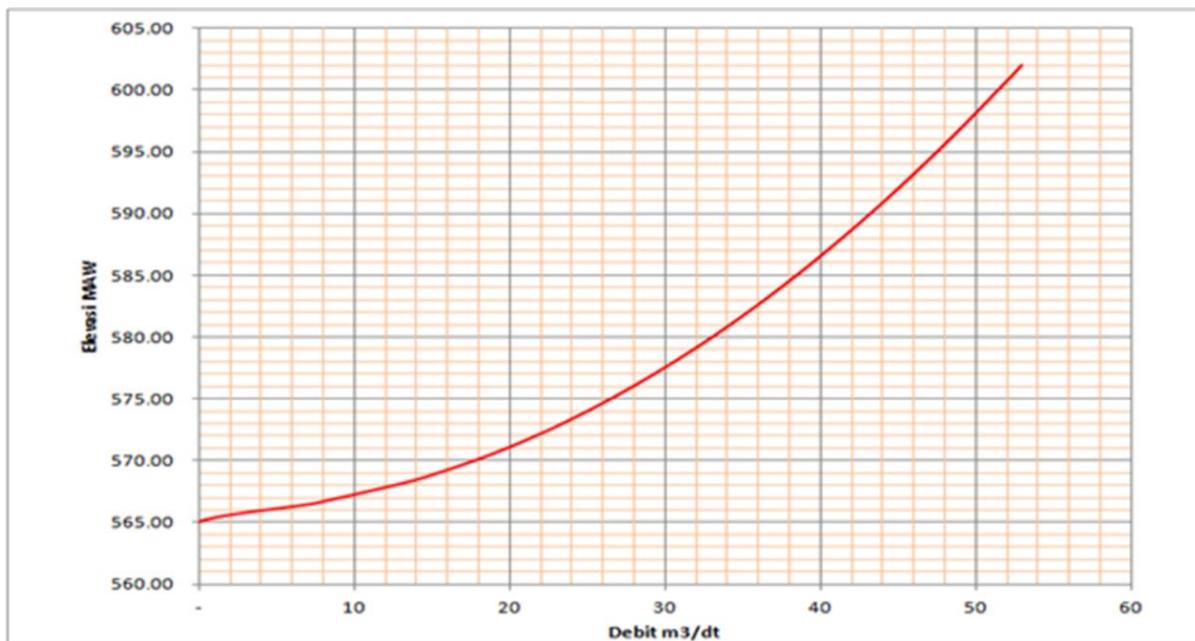


Figure 3. The discharge capacity of the Sukamahi dam tunnel [3, 7].

The overflow elevation at Sukamahi Dam is planned + 596 m, with a storage capacity of 1.32 million m³. With an 80% probability inflow debit of 8.15 m³/sec, the Sukamahi dam will be full in 1.87 day (Figure 4).

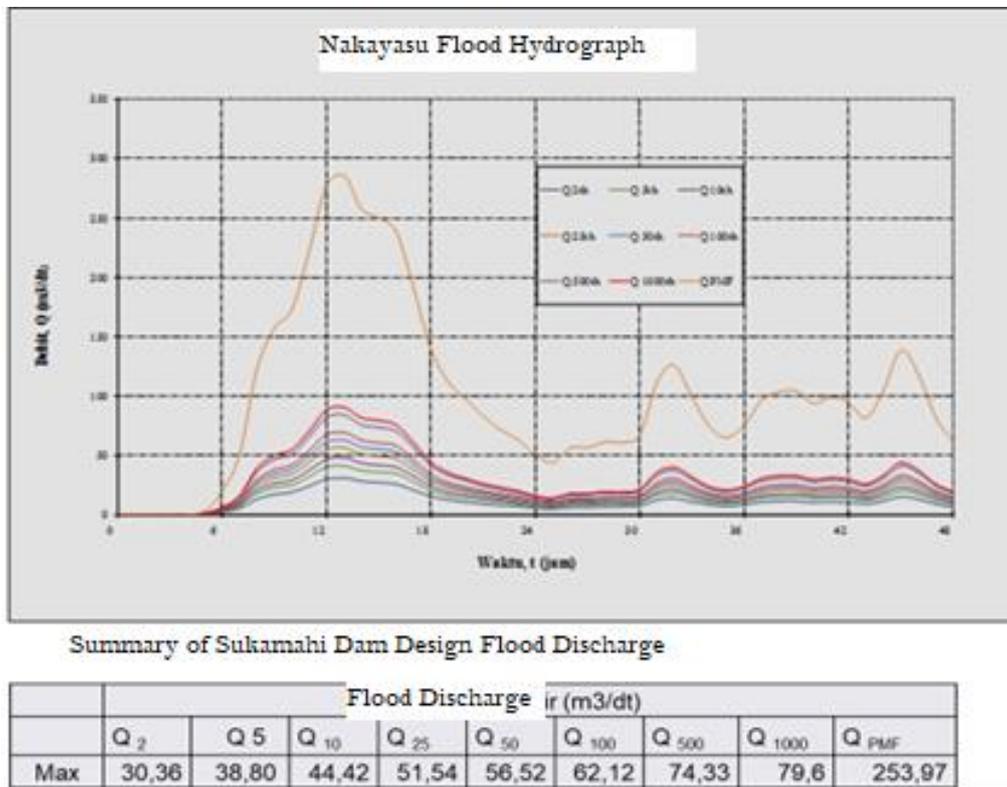


Figure 4. Sukamahi Dam Flood Discharge (Nakayasu) [3, 7].

Based on hourly data on the AWLR Katulampa and AWLR Cibogo in the period 2004 - 2013, the Ciawidam and Sukamahidam discharge patterns were computed as follows in Table 2.

Table2. Sukamahi Dam Flood Event 2004 - 2013.

No.	Flood Event	Flood Discharge (m ³ /s)	
		Ciawi	Sukamahi
1.	18 Jan 2004	73.19	13.12
2.	18 Jan 2005	119.34	21.39
3.	23 Jan 2006	100.63	18.03
4.	03 Feb 2007	360.91	64.68
5.	12 Maret 2008	125.96	22.57
6.	13 Jan 2009	117.72	21.10
7.	12 Feb 2010	218.19	39.10
8.	17 Nov 2011	78.31	14.03
9.	13 Dec 2012	103.63	18.57
10.	04 Maret 2013	253.34	45.40

In order to reach an optimal flood reduction, then the initial reservoir water level is in a low condition, where water flows freely through the tunnel. Flood control is optimized at a 50-years return period. At a debit above 50 years the flood control function will decrease (see Table 3).

Table 3. Flood Routing Sukamahi Dam Tunnel Discharge [3, 7].

No.	Return Period (years)	Inflow	Outflow	Reduction	Inflow	Outflow	Reduction	Peak	Peak Time	
		Ciawi (m ³ /s)	Ciawi (m ³ /s)	Ciawi (m ³ /s)	Sukamahi (m ³ /s)	Sukamahi (m ³ /s)	Sukamahi (m ³ /s)	Reduction (m ³ /s)	Ciawi	Sukamahi
1.	2	184.70	163.19	21.51	30.36	28.46	1.90	23.42	1.50	3.50
2.	5	242.87	199.70	43.17	38.80	35.32	3.48	46.65	3.00	6.00
3.	10	281.60	219.70	61.90	44.42	39.42	5.00	66.90	3.50	6.50
4.	25	330.72	240.81	89.90	51.54	43.99	7.55	97.46	4.00	7.00
5.	50	365.00	253.40	111.60	56.52	42.99	13.53	125.13	4.00	4.00
6.	100	403.60	340.47	63.13	62.12	55.72	6.40	69.53	3.00	6.00
7.	1000	524	519.61	4.49	79.60	78.93	0.66	5.15	0.00	0.50
8.	PMF	1,242.96	1,228.10	14.86	253.97	252.50	1.47	16.32	0.00	0.00

3.2. Sukamahi Dam Failure Risk Analysis Due to Excessive Overflow Capacity

Based on the flood design and Sukamahi dam operation plan, it can be seen that the Sukamahi dam has a high vulnerability to the danger of overflow capacity and dodging tunnels. If there is a failure in the tunnel when an extreme rain occurs that causes the peak of flood discharge which exceeds Q_{50} , it can potentially harm the Sukamahi dam, especially from the aspect of failure due to overtopping.

According to the Dam Risk Assessment Guidelines issued by the Ministry of Public Works in 2011 there are 2 (two) methods that can be used to conduct a risk assessment of dams namely the event tree method and a fault tree method. In this study a risk assessment of the failure of the Sukamahi dam was carried out according to the event tree method because a fault tree is more suitable to describe the failure process of the reliability of overflow doors while the overflow of Sukamahi dam is not equipped with the gate. In addition, the event tree method can map the dam failure mechanism starting from the emergence of the problem as a path of identification of the dam component failure model. While the fault tree method works by tracing different pathways as a cause of dam failure from the peak event (top event) refers to similar research [1][4]. In spillway buildings, hazard identification is limited to the adequacy of capacity and the adequacy of high levels of overflow and high capacity is based on the Volume III Rock Fill Dam Planning Guide Ministry of Public Works, 1999, which is a minimum height of 0.75 m.

Based on detailed data of the Sukamahi dam engineering design, the peak elevation of the Sukamahi dam is set at El. 601,000 m. Basic elevation of El foundation excavations is 551,000 m, so the height of the dam is equal to El. 601,000 m - El. 551,000 m which is 50 m. Free board in Q Pmf is 0.75 m and Q 1000 is 1,605 m. Then the response of the emergency time of the overflow failure and the tunnel will be relatively short in flood events with extreme discharges (see Table 4).

Table 4. Free Board Height and Peak Elevation of the Dam Required by the Sukamahi Dam Operation on Flood Control [3, 7].

Condition	Normal Water Level (H1) (m)	Q_{1000} Water Level (m)	Q_{PMF} Water Level (m)
H_w	0.753	0.705	-
$\frac{3}{4} H_w$	0.565	0.529	-
H_s	0.002	0.001	-
H_r	0.619	0.575	-
H_e	0.241	-	-
H_u	1.000	0.500	-
Free Board Height	2.427	1.605	0.750
Water Level Elevation	El 596.50	El 592.40	El 599.87
Crest Elevation	El 548.927	El 594.003	El 600.617

Identification of overflow building failure models based on the event tree method for determining the value of the probability of risk of each loading status at the lower limit interval based on the Probability Mapping Scheme [5] (see Figure 5).

Incremental population at risk (PAR)	Severity of damage and loss							
	Negligible		Minor		Medium		Major	
2 ≤ PAR ≤ 10		0.5x10 ⁻⁴	Significant	0.5x10 ⁻⁴	Significant	1.0x10 ⁻⁴	High C	1.0x10 ⁻⁵
	Low		Significant		Significant		High C	
10 < PAR ≤ 100		0.5x10 ⁻⁴		1.0x10 ⁻⁴		1.0x10 ⁻⁴		C
		0.5x10 ⁻⁴	Significant	1.0x10 ⁻⁴		1.0x10 ⁻⁴		1.0x10 ⁻⁵
		1.0x10 ⁻⁴		1.0x10 ⁻⁴	C	High C	C	High B
100 < PAR ≤ 1000	If in this region, go to the next highest severity of Damage and Loss category for the same PAR				A		A	High B
					A	High A		High A
					A		A	High A
PAR > 1000	If in this region, go to the next highest severity of Damage and Loss category for the same PAR						PMF	PMF
							Extreme	
							PMF	PMF

Where

- A = PMP design flood
- B = PMP design flood or 10⁻⁶, whichever is the smaller flood event
- C = PMP design flood or 10⁻⁵ whichever is the smaller flood event

Note that the probability of the probable maximum precipitation (PMP) design flood is a function of the catchment area.

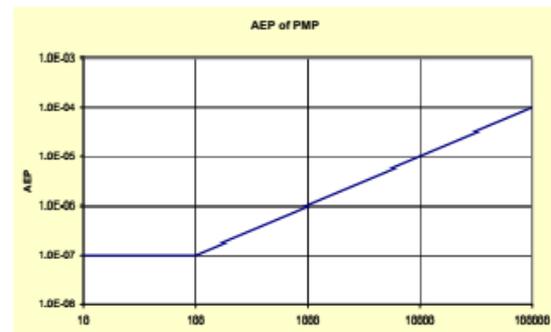


Figure 5. Required Range of Acceptable Flood Capacities for different hazard categories [5].

The catchment area of Sukamahi Dam is 15.86 km² with AEP of 1 X 10⁻⁷ so that it is taken as the AEP (annual exceedance probability). The framework of this analysis can be seen in Figure 6.

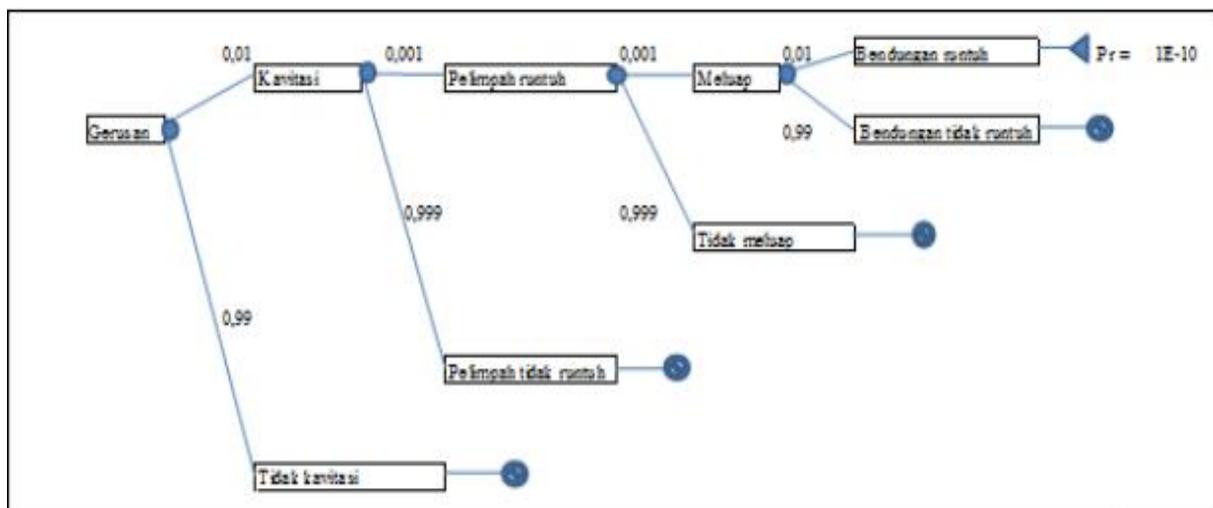


Figure 6. Tree Analysis of Spillover Events on the Potential of Overflow 1x10⁻⁷[4].

3.3. Risk Analysis Inundated Area in the Sukamahi Dam failure scenario

Simulation results using HEC RAS Software was described as follows. In the case of the Sukamahidam collapse due to overtopping, the maximum runoff discharge that occurs is $11,867.172 \text{ m}^3 / \text{s}$ at hours to ± 0.29 or 1,044 seconds when the process collapses. At 1,116 hours there was an increase in runoff discharge due to the inflow discharge (QPMF) into the reservoir. From the analysis of Sukamahi dam collapse simulation for overtopping case scenario for simulation time 31.248 hours or 1,302 days, the total accumulation of inundation area is 3,312.667 Ha and the total volume of inundation is $49.226.749,5 \text{ m}^3$ (see Figure 7). These results are in line with similar studies on the analysis of flooded areas and flood behavior in Ciawi dam failure simulations [10].

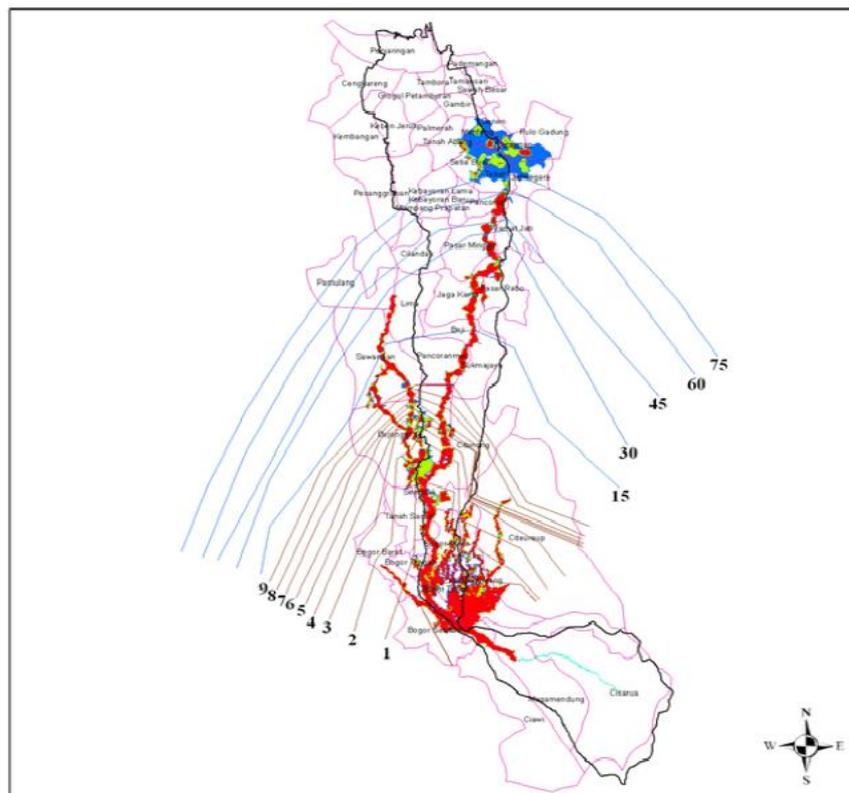


Figure 7. Map of contour of flood flow propagation in case of overtopping of Sukamahi Dam [10].

3.4. Economic Valuation Method of Option Value and Option Price on Risk Increasing Sukamahi Dam Construction Project

Economic valuation which is used to calculate the value of benefits based on the choice of option. The benefits of the Sukamahi Dam development project will obtain flood control expressed as an option value with No dam failure, but because dam development will also bears higher potential loss due to dam failure so option value with failure possibilities is needed, which is stated as option value with dam failure. Another option is to leave the existing condition stated as the status quo. The value of the benefits obtained are compared with the required cost expressed as the option price.

Economic valuation methods of value and option price options on Sukamahi dam construction project are carried out with some limitations of the simulation values as follows:

- The affected area of the Ciliwung watershed is 10,000 ha
- It is assumed that the asset value of the land is as large as Rp. 5,000,000, - / Ha
- Pay off value is determined based on the difference in the area of flooded land in each event scenario. If there is a maximum protection of 10,000 Ha, then the value of the benefit is $\text{IDR } 5,000,000 / \text{ha} \times 10,000 \text{ Ha} = \text{IDR } 50 \text{ Billion}$

A summary of the option price calculation on Sukamahi Dam construction project based on the over mentioned limitation can be seen in Table 5.

Table 5. Economic Valuation for the option price on Sukamahi Dam construction project.

Contingencies	Sukamahi Dam Construction	Status quo	Probability	ES (Expected Surplus)
Flood No. dam failure	10.000	6.000	0.999999	89,999.91
Flood with dam failure	1.000	3.000	0.000001	
EV	10000	6000.024		
Variance	810	90.002016		

Source: (Analysis, 2018)

Based on the option price analysis vs. Option value with a risk averse scenario, risk takers and normal risk as a whole result in $OP < ES$ so that if viewed from the point of view of the value of the benefit to the risk, the benefit value of the flood reduction obtained by the construction of Sukamahi dam is 35% Q_{50} is relatively less when compared to the risk dam failure value that might occur even with relatively small opportunities.

4. Conclusion

In conclusion, it was found that valuation of the risk value of the benefits of flood control Sukamahi dam construction on the dam failure scenario gives a negative value with the $OP < ES$ value so that the risk value is greater than the value of the benefit.

Further approach may be performed in order to deal with the primary limitations inherent in the hydrological and statistical analyses, particularly in the assessment of flood-affected asset values in flooded areas and modeling of inundated areas and flood behavior in Sukamahi dam failure with more precise hydrometry and river hydraulics data.

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