

# Analysis of flood propagation and its impact on Negeri Lima Village due to the failure of Way Ela Dam

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**Abstract.** Way Ela dam is a dam to be built in the Negeri Lima village. In the negeri lima village there was also a dam that formed naturally by landslide due to high rainfall on 13 July 2012. A year after it was formed, on 25 July 2013 flooding occurred due to an extreme rainfall that caused the failure of the natural dam. The event of the failure on 2012 generated flood that severely damaged houses and various public facilities to negeri lima village down toward to the coast. As a result of this event, a small-scale reservoir is formed. The Government plans to utilize the established reservoir to build the new Way Ela Dam. This study was conducted to analyze floods with scenarios in the event of a failure in the new Way Ela Dam. The overland flow is simulate with two dimensional numerical model HEC-RAS v.5. Determining strategies for mitigation needs to be assessed comprehensively, by simulating disaster scenarios on the dam, analyzing the impacts and then planning recommendations for disaster risk. The results are expected to be a reference for mitigation plans for the new Way Ela Dam.

## 1 Introduction

Way Ela Dam is a dam to be built in the Negeri Lima village. In the negeri lima village there was also a dam that formed naturally by landslide due to high rainfall on 13 July 2012 [1]. A year after it was formed, on 25 July 2013 flooding occurred due to an extreme rainfall that caused the failure of the natural dam. The event of the failure on 2012 generated flood that severely damaged houses and various public facilities to negeri lima village down toward to the coast. As a result of this event, a small-scale reservoir is formed.

The Government plans to utilize the established reservoir to build the new Way Ela Dam. Based on regulation in Indonesia mention that during construction of the dam, each dam must prepare a plan for emergency action [2]. This study was conducted to analyze floods due to dam break scenarios in the new Way Ela Dam which can be used as a guide or input in the preparation of emergency action plan documents.

Dam Break flows can be analyzed by analytical, numerical and experimental method. The numerical model itself has been carried out with finite difference in 1D [3] and finite volume [4]. The numerical model 1d for dam break has not been able to accurately determine the flood propagation due to the dam failure. US Crops Army's Hydrology Engineering center's River Analysis System (HEC-RAS) simulation model is a numerical

model with a free license that has been widely used to simulate flood propagation. Starting from v.5, the model is capable for determining water depth, discharge, inundation area, and flood wave velocity & flood arrival time in two dimensions. The model was developed based on the full 2D St. Venant equations, solved using a finite difference scheme. The model is powerful, robust and accurate. The model was applied for simulating Way Ela Natural Dam Failure [5] Ujjani Dam Break [6] and Montecello Dam Breach [7] with a good result.

In this study, the analysis of flood propagation due to dam break scenario of Way Ela Dam is conducted in order to predict the flood inundation, flood depth and flood arrival time on the negeri lima village so that it can be anticipate and reduce the human-economic losses. The modeling is based on the Probable Maximum Flood and the DEM (Digital Elevation Model) data from measurement 1m x 1m. A two-dimensional (2D) numerical model, HEC-RAS v.5.0.5, is used to simulate the overland flow. The dam break itself is simulated by using HEC-HMSv.4.2.1 with four scenarios as follows: 1) Overtopping; 2) Top Piping; 3) Middle Piping; 4) Bottom Piping.

## 2 Materials and methods

Analyzing of failure of dam in this study will be carried out in two steps. 1) Analysis of outflow hydrograph from

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the dam break. 2) The outflow from the breach must be routed through the downstream of Way Ela Dam to determine the impact of the flood at Negeri Lima Village.

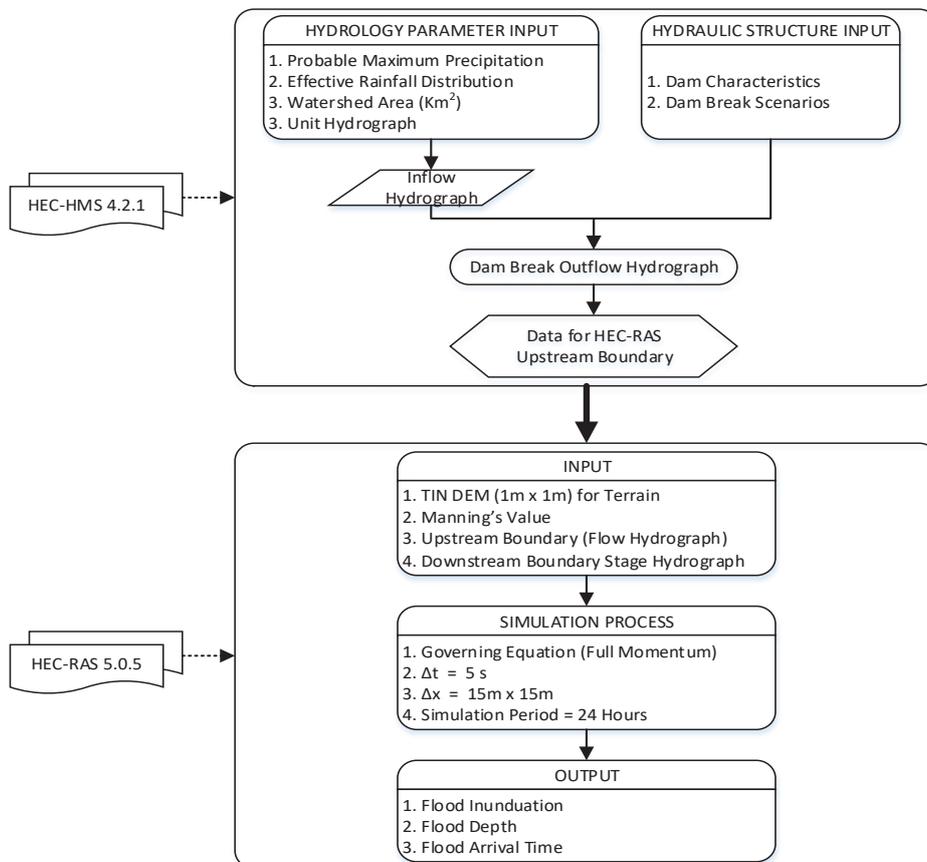


Fig.1. Scheme of methodology

### 2.1. Study area

Refer to [5] Way Ela Dam is located in Negeri Lima Village, Leihitu District, Ambon Island. The village had a mean elevation between 0-700 m above sea level. The main River are the Way Ela River which in 2012 dammed to form a natural dam due to avalanches.

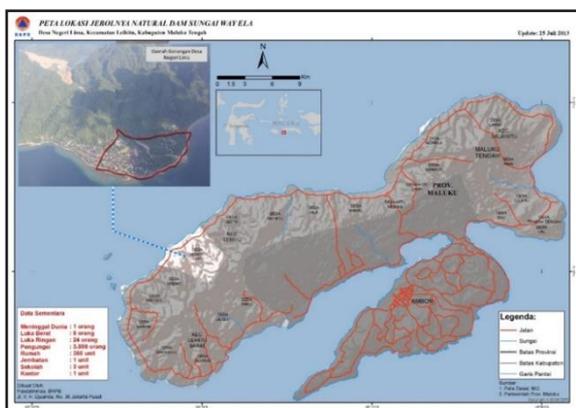


Fig. 2. Study area. BNPB [1]

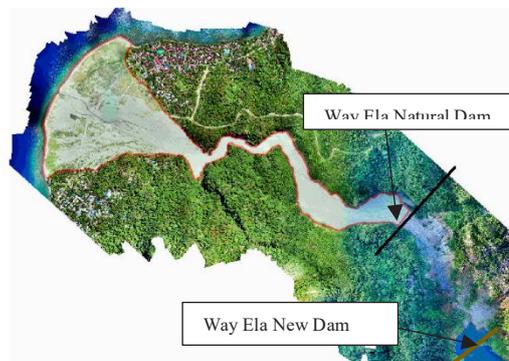


Fig. 3. Orthophoto of inundation image after the Way Ela Natural dam failure.

### 2.2 Data used

The data collected for the study includes the daily rainfall data for the past 32 years (1981 – 2013) from the Indonesia Meteorological department. The Topography data for digital elevation model is based on topographic measurement. The distance between contours is 1m.

### 2.3 Probable maximum precipitation

Probable maximum precipitation (PMP) is a theoretical concept that is widely used by hydrologists to arrive at estimates for probable maximum flood (PMF) that find use in planning, design and risk assessment of high-hazard hydrological structures such as flood control dams upstream of populated areas. [8]

Probable Maximum Precipitation in this study is analyzed using Hersfield Method refer to [9] (SNI 7746-2012).

### 2.4 Reservoir routing

Reservoir routing was calculated using HEC-HMS 4.2.1 to estimate the amount of discharge when the dam failed. There are two main parameters used as the input for reservoir routing, Inflow Hydrograph from Way Ela River watershed and Hydraulic Structure of Way Ela Dam. The output from this reservoir routing is the outflow discharge due the failure of Way Ela Dam. The Inflow Hydrograph can be obtain from hydrology parameter of Way Ela watershed.

**Table 1.** HEC-HMS data used

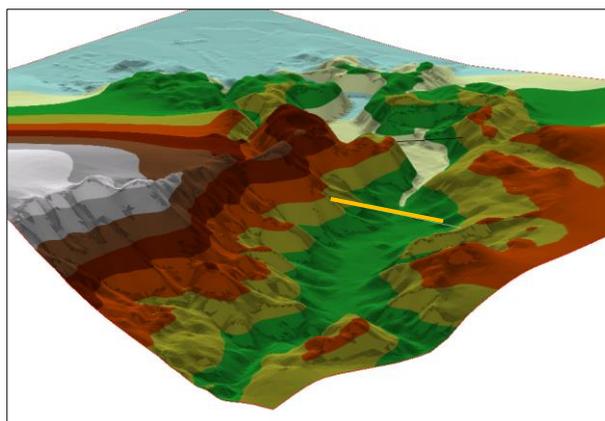
Data	Values
Watershed Area (km <sup>2</sup> )	10.7
River Length (km)	5.1
Land Cover (Runoff Coefficient)	0.5
Inflow Hydrograph	Figure 4
Dam Top Elevation (m)	+ 193
Dam Top Length (m)	490
Normal Water Level (m)	+ 190

#### 2.4.1 Inflow

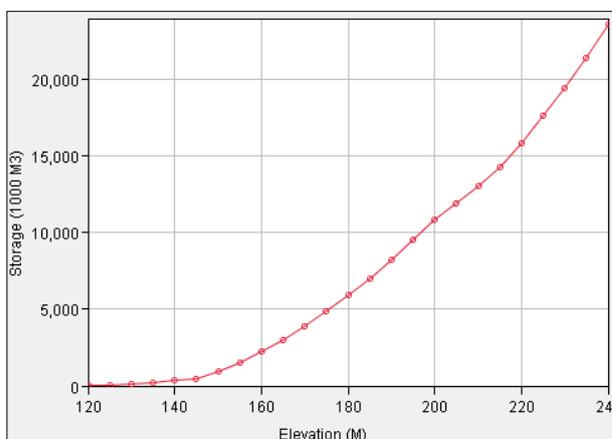
The inflow of the reservoir was calculated using probable maximum precipitation as a design rainfall. Three unit hydrograph method is used to obtain the inflow hydrograph from Way Ela river watershed. 1) Nakayasu, 2) Snyder-Alexeyev 3) SCS. Each method is calibrate using *Creager's* method is a kind of estimation of specific flood and this method provided nonlinear equations based on relationship between the drainage area and PMF in order to calculate the PMF of multipurpose dams over medium-sized [10] . The characteristic of the watershed area as given in table 1.

#### 2.4.2 Reservoir bathymetry

Reservoir Bathymetry of the Way Ela Dam was analyzed based on topography data the result is given in figure 5 and figure 6.



**Fig. 5.** 3D view at the study location after the Way Ela Natural dam failure.



**Fig. 6.** Way Ela dam reservoir bathymetry

#### 2.4.4 Dam failure scenario

**Table 2.** Dam break parameter for overtopping scenario

Overtopping	
Top Elevation (m)	193
Bottom Elevation (m)	120
Bottom Width	73
Left Slope (xH : 1V)	1
Right Slope (xH : 1V)	1
Development Time (HR)	0.5
Trigger Elevation (m)	193

**Table 3.** Dam break parameter for piping scenario

Piping			
	Top	Middle	Bottom
Top Elevation (m)	193	193	193
Bottom Elevation (m)	120	120	120
Bottom Width	73	73	73
Left Slope (xH : 1V)	1	1	1
Right Slope (xH : 1V)	1	1	1
Piping Elevation (m)	171	151	121
Development Time (HR)	0.5	0.5	0.5
Trigger Elevation (m)	193	193	193

### 2.5 Flood propagation model

The two dimensional flood propagation was modeled using HEC-RAS v5. The HEC-RAS v5 solves the full 2D Saint Venant equations [11] :

Continuity Equation

$$\frac{\partial \zeta}{\partial \tau} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = 0 \quad (1)$$

Momentum Equation :

$$\begin{aligned} \frac{\partial p}{\partial \tau} + \frac{\partial}{\partial x} \left( \frac{p^2}{h} \right) + \frac{\partial}{\partial x} \left( \frac{pq}{h} \right) = \\ - \frac{n^2 pg \sqrt{p^2 + q^2}}{h^2} - gh \frac{\partial \zeta}{\partial \tau} \\ + pf + \frac{\partial}{\partial x} (h \tau_{xx}) + \frac{\partial}{\partial y} (h \tau_{xy}) \end{aligned} \quad (2)$$

where h is the water depth (m), p and q are the specific flow in the x and y directions (m<sup>2</sup>/s), is the surface elevation (m), g is the acceleration due to gravity (m/s), n is the Manning resistance, ρ is the water density (kg/m<sup>3</sup>), xx, yy and xy are the components of the effective shear stress and f is the Coriolis (1/s). The manning roughness is estimated for each type of land cover as given in the table and figure below.

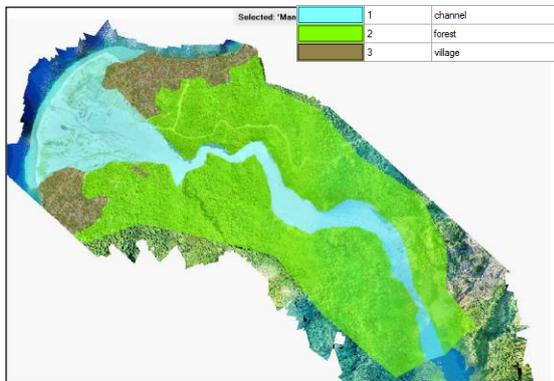


Fig. 7. Manning distribution map “n”

Table 4. Manning’s Roughness

Land Cover	Manning’s n
Forest	0.03
Channel/Coastal	0.025
Village	0.172

Source : Kotani, et. al. [12], chow [13], Gibson [14]

In order to ensure the stability of the model, the time step was estimated according to the Courant-Friedrichs-Lewy condition :

$$Cr = \frac{c\Delta t}{\Delta x} = \frac{\sqrt{gh}\Delta t}{\Delta x} \leq 1 \quad (3)$$

Table 4. Input data for flood propagation model

Data	Values
Outflow Hydrograph (Upstream Boundary)	From Reservoir Routing
Stage Hydrograph (Downstream Boundary)	0
Terrain	15 m × 15 m
Land Cover (manning’s n)	Table 4
Δt [s]	5
Δx [m]	15
Simulation Period (hours)	20

## 3 Results and discussions

### 3.1 Maximum precipitation

The estimated of one day weighted PMP of Way Ela watershed are presented in table 5.

Table 5. Analysis of probable maximum precipitation

No	Years	Maximum Precipitation (m)	No	Tahun	Maximum Precipitation (m)
1	1981	232	15	1995	179
2	1982	140	16	1996	231
3	1983	135	17	1997	97
4	1984	431	18	1998	162
5	1985	151	19	2004	130
6	1986	70	20	2005	101
7	1987	113	21	2006	166
8	1988	455	22	2007	263
9	1989	233	23	2008	170
10	1990	307	24	2009	97
11	1991	145	25	2010	224
12	1992	106	26	2011	188
13	1993	150	27	2012	360
14	1994	133	28	2013	432
<b>Average</b>		=	200.04		
<b>Sd</b>		=	107.23		
<b>km from chart</b>		=	12.00		
<b>Sn-m</b>		=	94.87		
<b>Xn-m</b>		=	190.59		
<b>f1 from chart</b>		=	0.99		
<b>f2 from chart</b>		=	1.02		
<b>f3 from chart</b>		=	1.01		
<b>f4 from chart</b>		=	1.05		
<b>Xp</b>		=	200.60		
<b>Sp</b>		=	113.51		
<b>PMP Hersfield</b>		=	1765.84		

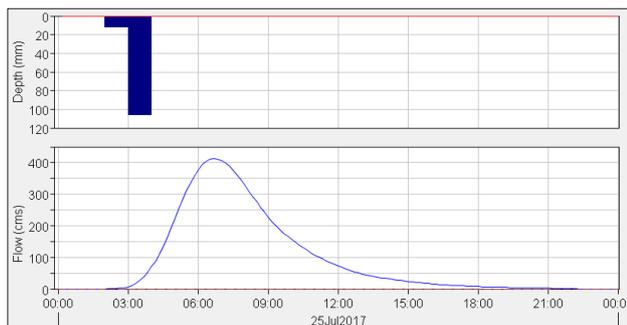
### 3.2 Maximum flood (inflow)

Inflow hydrograph of Probable Maximum Flood is analyzed used design rainfall from Probabale Maximum Precipitation. In this study analysis was carried out using three Unit Hydrograph method, which would be calibrated by the Creager’s method to determine which hydrograph method would be used. Analysis for Creager’s Method can be seen in table 6.

**Table 6.** Analysis of Creager’s method for inflow hydrograph

Unit Hydrograph Method	QPMF (m <sup>3</sup> /dt)	QPMF Creager for Maluku			Concl usions
Q <sub>PMF</sub> Snyder Alexeyev	900.23	212.98	-	425.97	NOT OK
Q <sub>PMF</sub> Nakayasu	1077.98	212.98	-	425.97	NOT OK
Q <sub>PMF</sub> SCS	406.28	212.98	-	425.97	OK

Based on table 6 the SCS method is chosen, the inflow hydrograph for SCS method given in the figure 8



**Fig. 8.** Q<sub>PMF</sub> SCS Inflow Hydrograph

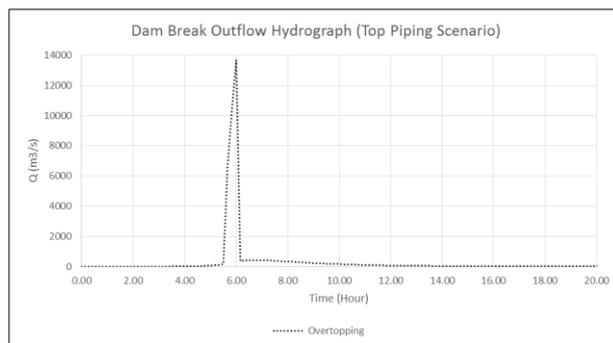
### 3.3 Reservoir routing (outflow)

Outflow from dam failure is simulated used HEC-HMS.. Inflow Hydrograph was analyzed using the Synder-Alexeyev Synthetic Unit Hydrograph. The result of this routing process will be shown by table 7.

**Table 7.** Peak discharge of outflow hydrograph

Dam Break Scenarios	Q <sub>peak</sub> (m <sup>3</sup> /s)
Overtopping	9280.20
Top Piping	13697.80
Middle Piping	9319.30
Bottom Piping	12429.30

The outflow hydrograph for top piping dam break scenario shown by figure 9.



**Fig. 9.** Outflow hydrograph for top piping dam break

### 3.4 Dam break flood propagation

#### 3.4.1 Flood inundation area and depth

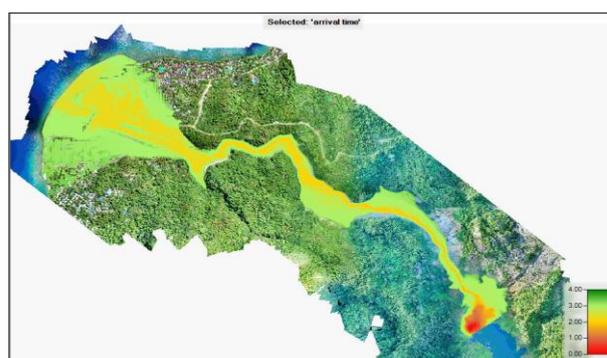
Time requirement to execute this model for 1 day simulation period is 2 hours.



**Fig. 10.** Flood depth map

Figure 10 shows the maximum depth of flood inundation. The maximum depth in the village area are between 0.2 - 1.5 m, the depth of flood in the upstream near the dam is 4-20 m, and in the middle of the channel, the depth flood inundation is quite high 4-24 m due to its topographic condition which is a cliff. The area of Negeri Lima Village affected by flood inundation is 2.82 ha.

#### 3.4.2 Flood arrival time



**Fig. 11.** Flood arrival time map

Figure 11 shows that the arrival time of the flood caused by the dam break of Way Ela Dam it will reach the village between 2-3 hours started from the breach occurred.

### 3 Conclusions

The Analysis of flood propagation due to dam break of Way Ela Dam is carried out using HEC-RAS 5.0.5 numerical model. The Probable Maximum Precipitation is found out to be 1,765.84 mm and the corresponding flood from the dam break flow is 13,697.80 m<sup>3</sup>/s from top piping dam break scenario. The total time of travel of dam break flood wave to Negeri Lima Village is found out to be 2 – 3 hours. The flood water depth in Negeri Lima Village is up to 1.5 m and the area of Negeri Lima Village affected by flood inundation is 2.82 ha.

These information are very important for determining strategies for mitigation that needs to be assessed comprehensively, by simulating disaster scenarios on the dam, analyzing the impacts and then planning recommendations for disaster risk. These results are expected to be a reference for mitigation plans for the new Way Ela dam.

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