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STRUCTURAL FLOOD CONTROL MODEL BASED ON ECO-HYDRAULIC IN SMALL WATERSHEDS (CASE STUDY OF THE AKELAKA-HALMAHERA RIVER)

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ABSTRACT

Various factors, such as the physical condition of the area, nature, and humans, influence the phenomenon of flooding. Thus, the flood control application model will differ in each region. The application of flood control structurally lowers the flood water level significantly, but it changes the ecosystem around the river. The eco-hydraulic concept is a new paradigm in watershed management to reduce the impact of floods while still paying attention to river ecosystems. This study aims to integrate structural methods with eco-hydraulic concepts in flood control in small-scale watersheds. The locus is the Akelaka watershed on Halmahera Island. Watershed morphometric analysis using the ArcGIS application, hydrological analysis for five and 25-year return floods, and hydraulics testing using the HecRAS application are used. The application of this concept uses vegetation on river slopes after normalization. The results showed that flood control which combined normalization, eco-hydraulic and structural ideas in Akelaka village, showed excellent results. The potential for inundation is reduced by up to 93% for a five-year return period flood discharge and 89% for a 25-year return period flood discharge.

Keywords: flood control, structural, eco-hydraulic, Hec-RAS.

1. INTRODUCTION

Floods are natural disasters that occur all over the world. Every year, the frequency and amplitude have increased. It is inextricably linked to land-use changes due to population growth and global climate change. CRED and UNISDR annual reports show that floods accounted for 43.4% of all-natural disasters between 1998 and 2017. (CRED, 2018). Meanwhile, in Indonesia, the National Disaster Management Agency reported that the number of flood events in 2022 was 1,524, accounting for 43.1% of all natural disaster events.

The Akelaka River is the main river in the Akelaka Watershed in the South Oba District of Tidore City. Floods caused by the Akelaka River overflow inundated 1,243 houses in Koli Village, Kosa Village, Trans SP I Area, and Trans SP 2 Area, as well as the Kahoho Irrigation Area, covering an area of 650 ha, as shown in Figure-1. The inundation height caused by the Akelaka river overflow ranged between 0.4 and 0.7 meters. Flood problems in the Akelaka Watershed are caused by a combination of factors, including high rainfall, watershed morphometric conditions, river profiles, and changes in land use (Sahdar *et al*., 2022).

Structural efforts have long been a practical flood control solution in various countries because they can quickly reduce flooding in an area (Yevjevich, 1994). (Heidari, 2009). However, structural flood control efforts are still relatively expensive in planning, construction, maintenance, and building time (Kryzanowski *et al*., 2013). Furthermore, this traditional method impacts river ecosystem quality (Kingsford, 2011), such as decreased land fertility, land use change, land subsidence, changes in river morphology, and potential ecological changes (Petry, 2002). It is also explained that changing river flow regimes will result in inhibition, damming, over-abstraction, the spread of invasive species, over-harvesting of water, and the effects of water pollution. However, the main threat to the rivers and wetlands is the sustainability of water resources, which will be exacerbated by future climate change (Kingsford, 2011).

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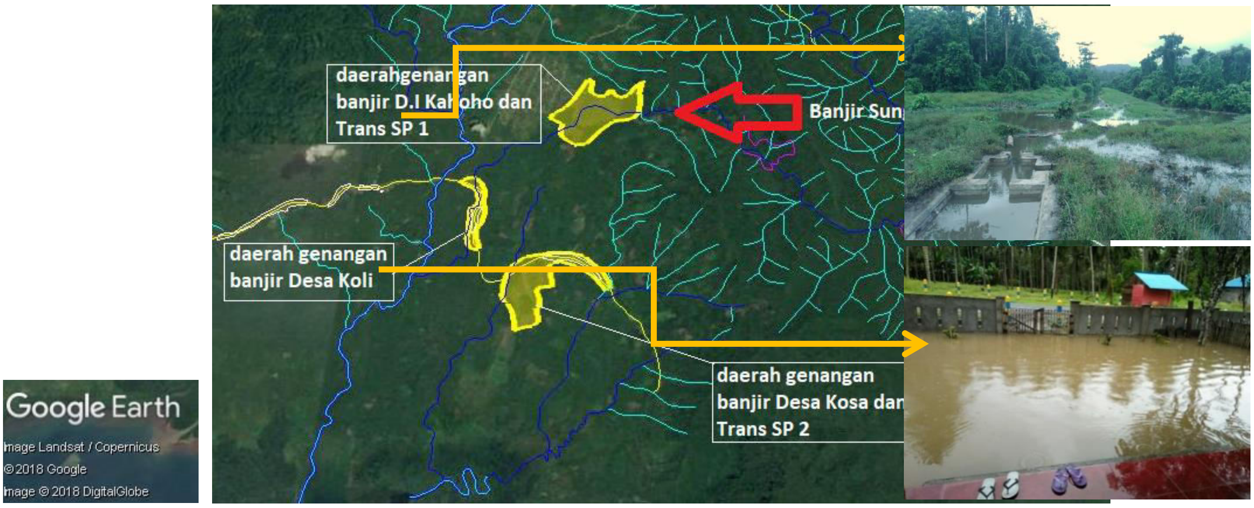

Figure-1. Distribution of flood inundation in 2017.

River ecosystems are extraordinarily complex and dynamic. Discharge fluctuations strongly influence biotic and abiotic components' characteristics, interactions, and development each season (Knighton, 1998). The ecological approach in engineering is becoming a new paradigm in various fields, in line with the growing awareness of environmental sustainability. It is thought to have a long-term impact on life. Elliott (2014). Eco-hydraulic engineering takes into account river ecosystems. The eco-hydraulic concept is based on the idea that flow strength significantly impacts ecological systems (Wilkes *et al*., 2013).

Floodplain management necessitates a policy foundation for related parties to determine the best control model for a given area. The simulation approach and mapping of the distribution of floods provide a solid foundation for understanding the flooding characteristics in a given area (Rauf *et al*., 2021). Hec-RAS is one application that has been widely used in simulating flood behavior. Many studies have used Hec-RAS in flood modeling, including Tigris River flood analysis (Ogras & Onen, 2020), Akelaka River flood hazard assessment (Rauf *et al*., 2021), and Flood risk in urban areas (Madhur *et al*., 2021).

This research uses an eco-hydraulic approach to examine the impact of structural efforts on flood behavior in the Akelaka watershed. The effect of flooding is determined by the area and height of the inundation, as determined by simulation and mapping results obtained with the Hec-RAS application.

2. RESEARCH METHOD

2.1 Research Location

This study takes place in the Akelaka sub-watershed, part of the AkeTayawi watershed, which covers an area of 403.67 km^2. The Akelaka watershed is astronomically located at coordinates 0° 09 09.01 - 0°28 17.01 North Latitude and 127° 36 14.01 - 127° 47 40.60 East Longitude, as shown in Figure-2.

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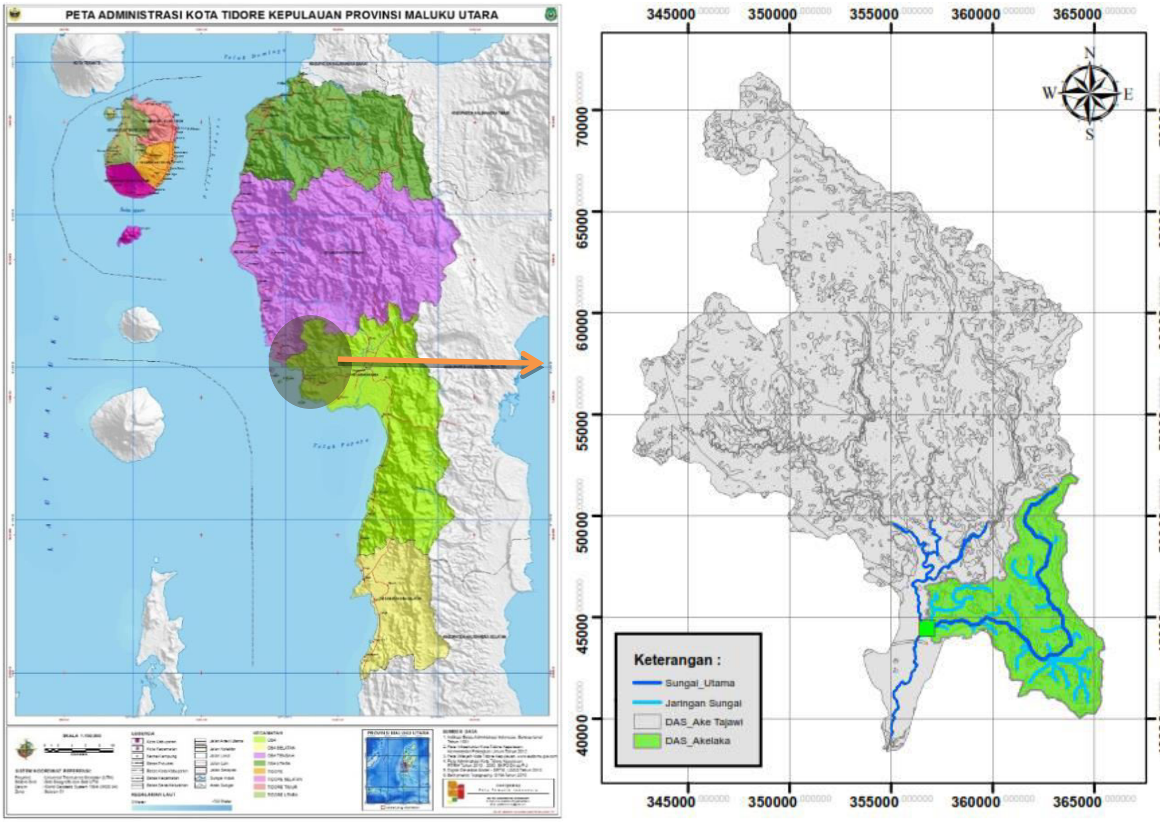

Figure-2. Akelaka sub-watershed in Ake Tayawi watershed (Source: BPDAS North Maluku, 2020).

3. DATA AND ANALYSIS TECHNIQUES

The primary data for this study came from field measurements of flow velocity, existing river section geometry, and area topography. Secondary data comes from various agencies and previous research: digital elevation model data (Digital Elevation Model, DEM), maps of land cover types, and a 13-year data series of maximum daily rainfall.

This research has three stages of analysis: GIS-based river morphometric, hydrological, and hydraulics analysis. Each step is explained in detail below:

a) The first stage of this research is the extraction of the sub-DAS and Akelaka River to determine their morphometric properties. Researchers use Digital Elevation Model data to interpret the characteristics of a site based on morphometric parameters (Loebis *et al*., 1993).
b) The following stage is to conduct a hydrological analysis using a statistical approach, referring to the steps described by Triatmodjo (2008). This analysis aims to obtain a rainfall forecast with a return period of 5 years and 25 years. The Nakayasu HSS model is used in the discharge analysis because it better describes flood characteristics than other methods (Safarina *et al*., 2011). (Sarminingsih, 2018).
c) The final stage of the research analysis is flow hydraulics analysis using Hec-RAS ver. 5.0.7. This application's flood simulation process includes: river geometry imitation and flow imitation stages. Geometry imitation is based on field measurements, where the river's topography is modeled in the Hec-RAS application, while the hydrological analysis results are the input parameters for flow imitation.

The simulation results based on the existing flow conditions are the foundation for every flood control effort in the Akelaka watershed. The trial and error method with various flood control methods was used to find a model with negligible flood impact. Meanwhile, the impact magnitude is determined by the area and height of the inundation caused by each effort.

The structural approach used in this study consisted of improving the river's transverse and longitudinal geometry and building flood protection embankments and retention ponds. Meanwhile, the eco-hydraulic principle used in this study is using vegetation to increase river flow side resistance, which affects the decrease in flow velocity. A survey conducted in 2001 by Sepriady and Maryono found that on river slopes reinforced with concrete, average flow velocity increased by 50% compared to natural channels with vegetation-covered channel walls (Maryono, 2008). As a result, the value of the channel roughness coefficient is used as a variable to examine its impact on flood reduction. Chow (1985) compiled Manning roughness values for various materials and floodplains, with Manning coefficient values ranging from 0.035 to 0.06 for canal cross-sections with vegetation slopes.

4. RESULTS AND DISCUSSIONS

4.1 Morphometric Characteristics of Akelaka Sub-watershed

Figure-3a depicts the Akelaka sub-watershed as extracted by a GIS-based application. Previous research results show its morphometric parameters. The Akelaka River is 19.951 kilometres long from its highest point to its confluence with the AkeTayawi River. The Akelaka Watershed has a total area of 45.72 km^2 and a slope ranging from 2% to 40%. The Akelaka River has an Order of 4, a Branching Index of 4.68, and a Density Index of 1.25 km/km^2.The results show that the flood characteristics of the Akelaka sub-watershed have a slow and steady increase and decrease in flood water level. It is due to the presence of hard-resistant rocks. As a result, the surface runoff that occurs will be more significant.

The Akelakariver has two junctions, as shown by the flow direction in Figure-3b. At junction 1, the flow from upstream is divided into three orders: Akelaka 1, Akelakan 2, and Akelaka Downstream 1. Junction 2 is the intersection of Akelaka 1 and Akelaka 2. The discharge from the upstream of the river will be divided into sections Akelaka 1, Akelaka 2, and Akelaka Downstream, with percentages of 33%, 25%, and 42% based on the results of measuring the flow velocity and river geometry.

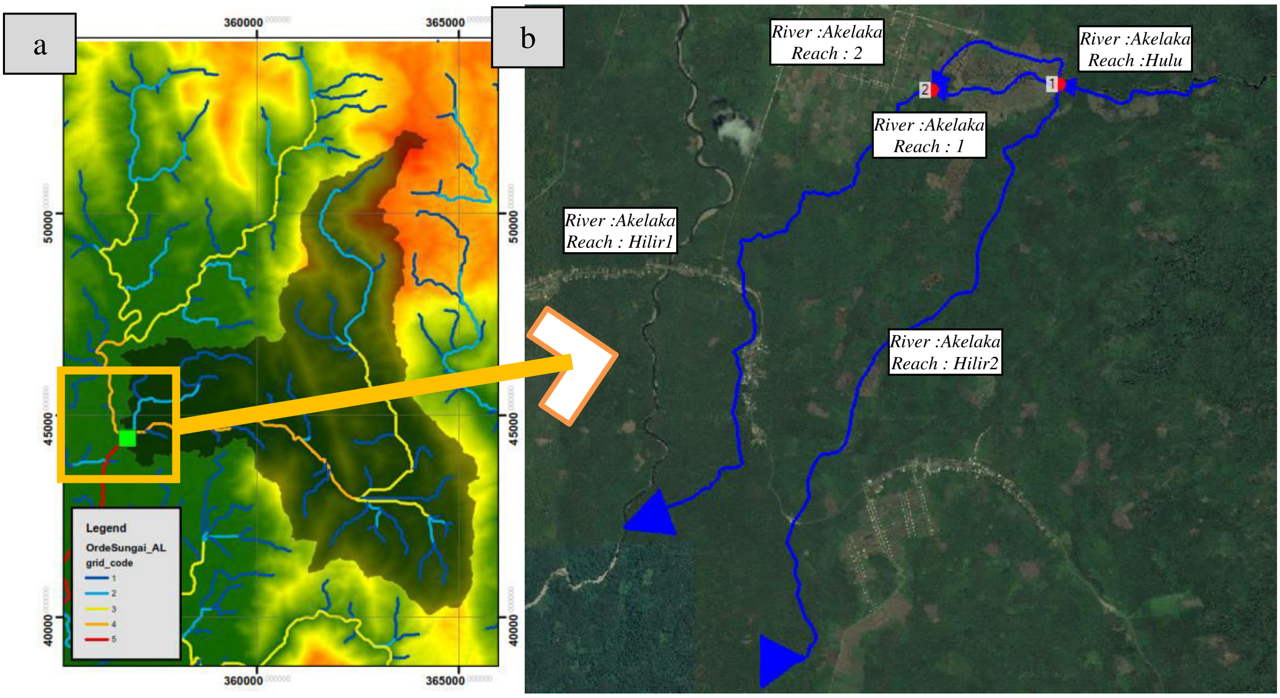

Figure-3. Akelaka watershed and Akelakariver flow pattern.

4.2 Hydrology Analysis

a. Planned Rainfall

The planned rainfall in this study was carried out using four rainfall distribution models: the Normal Distribution Model, the Log Normal Distribution Model, the Gumbel Distribution Model, and the Pearson Log Distribution Model. Statistical parameter tests and data consistency tests using the Chi-Square Test and Smirnov-Kolmogorov Test were carried out to determine the rainfall design used in the return period of flood discharge analysis. The results of the design rainfall frequency analysis are shown in Table-1.

Table-1. The results of the analysis of the maximum rainfall distribution.

Return Period (T)	Normal	Log-Normal	Gumbel	Pearson
2	87.38	83.15	71.53	80.91
5	111.15	109.88	96.62	110.25
10	123.61	127.16	113.22	126.25
25	135.72	146.57	134.21	145.26

The results of the parametric test show that the Pearson Log Distribution Model meets the requirements, where the slope coefficient (Cs)≠ 0. The fit test using the Chi-Square and Smirnov-Kolmogorov tests shows that the

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Pearson III Log Distribution Model also meets the statistical requirements, where the calculated Chi value is 2.00 < 5.991 (Critical Chi value for DK value = 2, at the degree of confidence (α) = 5%). At the same time, the Smirnov-Kolmogorov method test shows thatΔ_{max} Smirnov - Kolmogorov for the amount of data (n) of 13 will obtain a α value of 0.368, where this value is greater than the Smirnov - Kolmogorov Δ_{count} value of 0.155. Thus, for determining flood discharge with a return period of 5 and 25 years, the design rainfall is 110.25 mm and 145.26 mm, respectively.

The duration of the rain strongly influences the estimation of the magnitude of the peak flood discharge, where the value of the duration of the rain must be at least the same as the time of concentration (Westphal, 2001). The duration of the rain can be taken as 3 hours or multiples of that. Rain duration in Indonesia is typically 6 hours. Table-2 shows the results of calculating the rainfall distribution for the Akelaka sub-watershed for 6 hours using the Mononobe equation.

Table-2. Planned rainfall with a duration of 6 hours.

Effective rain (hour)		1	2	3	4	5	6
R2 (mm)	80.91	44.53	11.57	8.12	6.46	5.46	4.77
R5 (mm)	110.25	60.67	15.77	11.06	8.81	7.44	6.50
R10 (mm)	126.25	69.48	18.06	12.67	10.08	8.52	7.44
R25 (mm)	145.26	79.94	20.78	14.58	11.60	9.80	8.56

b. Repeated Flood Discharge

The Nakayasu synthetic hydrograph calculates the return period of flood discharge. Thus, the peak flood discharge (Qp) with a rain duration of 6 hours for return periods of 2, 5, 10, and 25 years is 56,636 m^3/s, 76, 987 m^3/s, 88,091 m^3/s, and 101.279 m^3/sec, respectively. Meanwhile, as shown in Figure-4, the hours leading up to the flood's peak were 2.8 hours.

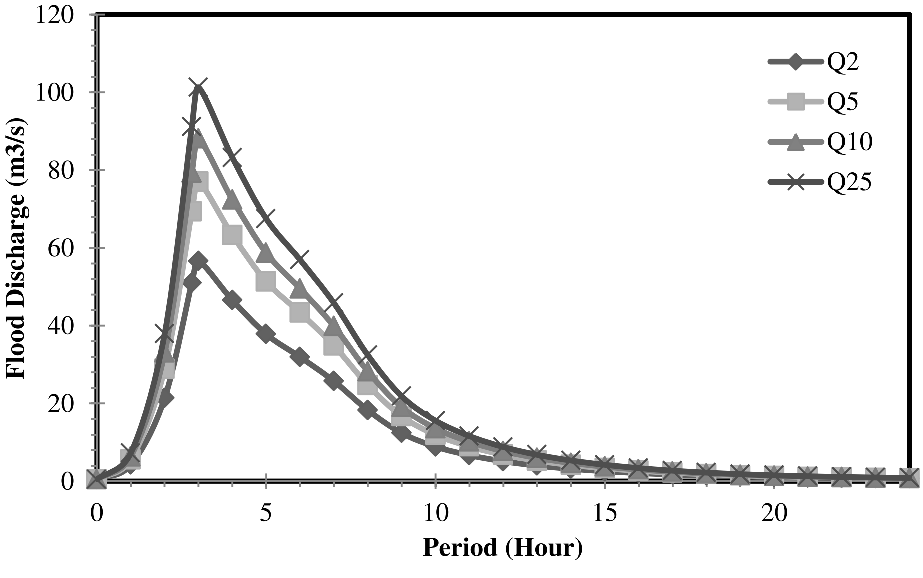

Figure-4. Flood hydrograph of the Akelaka sub-watershed.

c. The hydraulics of the Akelaka River

4.3 Flood Characteristics for Existing Conditions

The HecRASver 5.0.7 application was used to analyze distribution patterns and inundation height as parameters for measuring the effectiveness of flood control efforts. The Akelaka sub-watershed flood distribution simulation employs a flood discharge with a return period of 5 years and 25 years.

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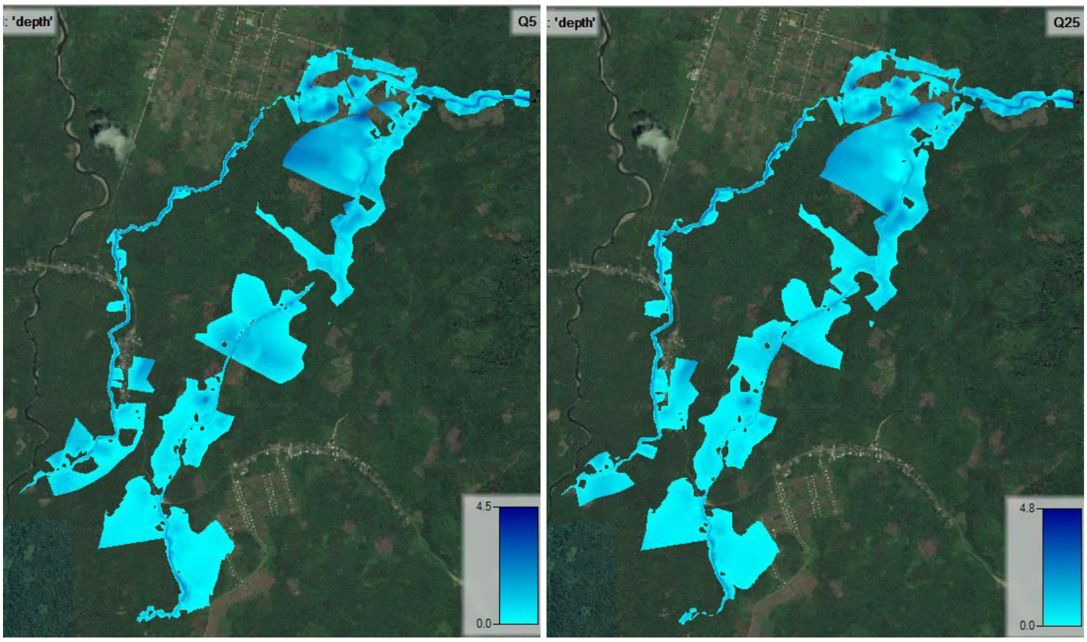

Figure-5. Simulation of the distribution of flood inundation with a return period of (a) 5 years (b) 25 years.

Figure-5 depicts the distribution of floods in the Akelaka sub-watershed under current conditions. Floods with return periods of 5 to 25 years have the potential to cause inundation in Koli Village, Kosa Village, Trans SP1 Village, and Trans SP2 Village, according to the data. There is a potential inundation of 22.531 ha at the Q5 flood discharge of 76.987 m^3/s, with a maximum inundation height of 4.4 m. The Q25 flood discharge can potentially cause inundation in residential and irrigation areas, covering an area of 23.084 ha with a maximum inundation height of 4.6 m. Overflow in almost all sections of the river flow indicated that the Akelaka River's capacity could no longer accommodate the flood discharge during this return period. Furthermore, the longitudinal profile of the channel base is not compliant. As a result, efforts to control must begin with improving river geometry or normalization.

4.4 Normalization of the Akelaka River

Adjusting the longitudinal slope of the river bed and enlarging the channel cross-section are two ways to improve channel geometry. It is carried out in various ways, considering each stream's junctions to improve the slope of the river bed. Meanwhile, a trapezoidal channel's economic cross-section size is when the water surface's width is twice the length of the channel's sloping side (Triatmodjo, 2003). In other words, the angle formed by the inclined plane of the track to the horizontal is 60°.

The Hec-RAS application simulation results show that normalization efforts reduce the impact of flooding in residential areas, particularly on the 5-year return period discharge. Meanwhile, settlements in Koli village are still potentially affected by the 25-day return period. Furthermore, the potential for overflow and inundation is concentrated in the Akelaka Upstream section in the downstream area, along the Akelaka 1 and Akelaka 2 sections, and in the Akelaka Downstream 1 section upstream. Because it serves as agricultural land, this condition cannot be separated from the surrounding lower topography.

The estimated inundation height caused by the 5-year return period discharge is 3.20 m in agricultural areas, with a potential inundation area of 4.618 ha. Compared to the situation before normalization efforts, this value shows an 84% reduction in inundation. The estimated maximum elevation of the flood water level occurs in the agricultural land of residents with a height of 3.80 m, with an inundation area of 8.974 ha, for the return discharge of 25 years.

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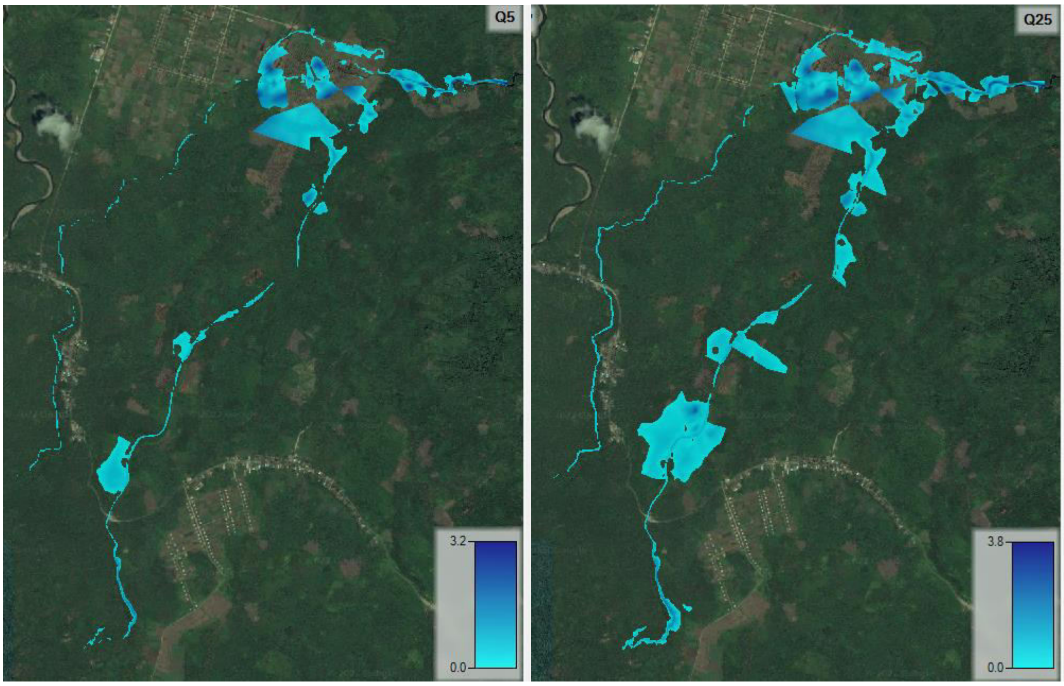

Figure-6. Akelaka watershed flood distribution model after normalization.

4.5 Flood Distribution with Eco-hydraulic Approach

Manning's roughness coefficient of 0.35 was used in this study. It is presumptively based on using grass and natural plants with a height of 4-6 inches as reinforcement (Chow, 1985). As illustrated in Figure-7, using normalization in conjunction with the eco-hydraulic concept in flood control in the Akelaka Watershed has a relatively positive impact.

The flood inundation area for the 5-year and 25-year return period discharges is 7,634 ha and 12,611 ha, respectively, according to the Hec-RAS simulation results. This effort reduced the size of flood inundation in the study location by 74% for a 5-year flood discharge and 58% for a 25-year flood discharge compared to the existing river conditions. The maximum inundation height caused by each planned release may occur in agricultural land areas with water level elevations of 3.4 m and 3.9 m for Q5 and Q25, respectively.

Compared to land channels without vegetation, the eco-hydraulic concept raises the water level and flood inundation area. It is because vegetation slows the flow, increasing the frictional force between the channel cross-section and the water flow. However, this application is deemed critical for preserving the ecosystem in each river segment.

The simulation results show that despite efforts to normalize and normalize with the eco-hydraulic approach, flooding in the Akelaka watershed remains uncontrollable. As a result, other structural approaches expected to have a greater impact on potential flood reduction, particularly for the 25-year return period flood discharge, must be considered.

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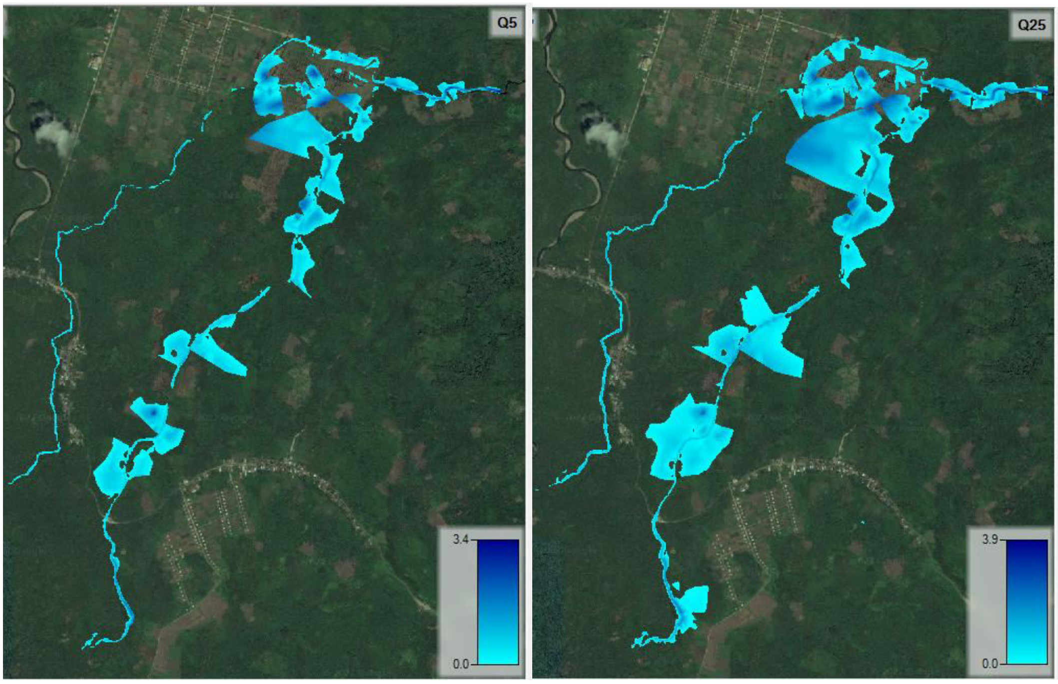

Figure-7. Akelaka watershed flood distribution model after normalization.

4.6 Structural Efforts to Flood the Akelaka Sub-watershed

Previous simulation results show that flood inundation is still possible in the Akelaka sub-watershed. As a result, flood control necessitates structural efforts, particularly to anticipate flooding caused by flood discharges with a 25-year return period.

Retention ponds and flood embankments are used to apply structural efforts. The planned retention pond is located at junction one and has dimensions of 100 m, 85 m, and 4.5 m, with a storage volume of 38,250 m^3. This structure contains a gate that controls the discharge on the Akelaka 1, Akelaka 2, and AkelakaHilir 1 sections. The flood dam will be built on the AkelakaHilir 1 section, with a height ranging from 0.50 m to 2.50 m. It is done while keeping future changes in land use in mind.

According to the simulation results, the addition of structural efforts has a significant impact on flood control. Figure-7 depicts the simulation results of potential overflow, where there is still the possibility of flooding at several points in the Akelaka 1, Akelaka 2, and Akelaka H1 sections. At the fifth anniversary, flood inundation's potential area and height in the lowland watershed is 1.56 ha, with the maximum water level elevation at 3.40 m. The area and height of the flood water level for the 25-year flood discharge are 2.52 ha and 3.90 m, respectively.

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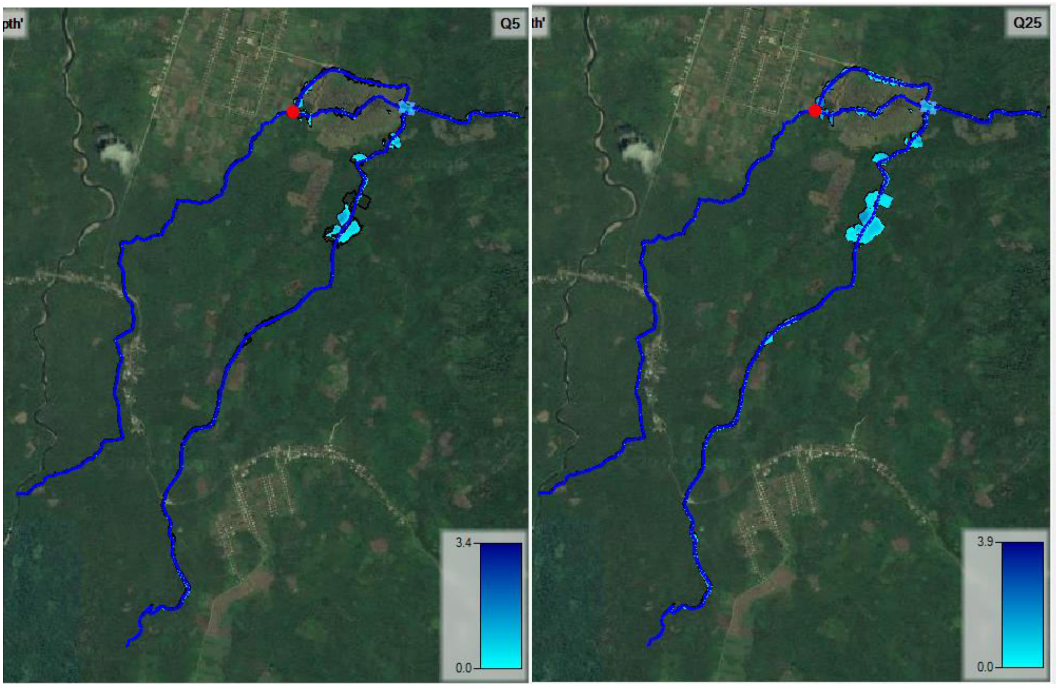

Figure-8. Akelaka watershed flood distribution model after normalization.

4.7 Comparison of Flood Distribution in the Akelaka Sub-watershed

Table-3 displays the flow hydraulics analysis and simulation results in the Akelaka sub-watershed. It demonstrates that flood control, which combines normalization, eco-hydraulic, and structural concepts, produces very good results. The potential for inundation caused by Akelaka river overflow can be reduced by up to 93% for a five-year return period flood discharge and 89% for a 25-year return period flood discharge.

Table-3. Results of the HecRAS simulation on flood modeling in the akelaka sub-watershed.

Flood Discharge	Flood Area (ha)				Inundation Height (m)			
	Existing	Normalization	Normalization+ Eco-hydraulic	Normalization + Eco-hydraulic + Structural	Exising	Normalization	Normalization + Eco-hydraulic	Normalization + Eco-hydraulic + Structural
Q_5	22.531	4.618	7.634	1.56	4.4	3.2	3.4	3.4
Q_{25}	23.083	8.974	12.611	2.52	4.9	3.8	3.9	3.9

5. CONCLUSIONS

From the results of the analysis and simulation of flood control in the Akelaka watershed, it can be concluded that:

a) The Hec-RAS application can provide a good picture of the distribution of floods in the Akelaka Watershed by modeling the distribution of floods. Normalizing the river geometry will significantly reduce surges in the Akelaka sub-watershed.
b) The eco-hydraulic approach to flood control in the Akelaka Watershed, which uses vegetation on riverbanks, increases the area and height of the inundation. It is due to the increased frictional force between the flow plane and the river cross-section, which slows the flow.
c) Because the cross sections of the river on each segment are still unable to accommodate flood discharges that may occur, especially during the 25-year return period floods, structural flood control measures in the Akelaka watershed are required. Construction of river embankments and retention ponds equipped with incoming and outgoing discharge regulators are among the structural efforts planned.

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