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RESEARCH ARTICLE
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Eco-Hydraulic Cross-Section Engineering for Flood Management of Kinunang River in Likupang Priority Tourism Area, Indonesia

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Abstract:

Introduction: This study aimed to apply flood management at Kinunang River, focusing on evaluating and designing the most suitable river channel geometry that will effectively mitigate destruction due to moderate to extreme flood events. Kinunang is a river located within the Likupang Special Economic Zone for ecotourism. Consequently, the river area's precondition is flood-free, and any developments herein should adhere to eco-friendly and aesthetic principles.

Methods: Hydrological analysis of local rainfall data was carried out using HEC-HMS to predict the amount of flood discharge. Hydraulic analysis using HEC-RAS was applied to predict channel storage capacity, to simulate flow profile, and to assess the flow speed with the intention of minimizing scouring. Eco-hydraulic property of the designed channel cross-section was examined by simulating the effect of placing 3 different plants along the channel.

Results: Re-dimensioning of the river cross-section resulted in a multi-stage trapezoid channel with an upper width (La), lower width (Lb), and depth (h) of 2 m, respectively. The use of vetiver grass was able to reduce the flow velocity by 29%.

Discussion: The multi-stage trapezoidal cross-section was selected because it can drain the design flood discharge and facilitate the use of plants to meet the eco-hydraulic property. Vetiver grass was chosen due to its maximum amount of velocity reduction.

Conclusion: The Kinunang River does indeed require channel re-dimensioning. A multi-stage trapezoid channel and the planting of vetiver grass will diminish the impact of the design flood, prevent river bank erosion, and display an attractive green river bank.

Keywords: Kinunang River, Flood management, Eco-hydraulic cross-section engineering, Aesthetic principles, Flood discharge, River channel geometry.

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1. INTRODUCTION

Kinunang River is a tributary of Pulisan River located in the Likupang area, North Sulawesi Province. It resides within the Likupang Special Economic Zone (SEZ), which is one of the 5 super-priority destinations in Indonesian tourism. This unique SEZ is designed to support economic development, especially focused on the tourism sector in North Sulawesi. As a Tourism SEZ, there is a prerequisite for any river within the SEZ to be flood-free, and all kinds of infrastructures must adhere to principles that may uphold sustainable environment conservation. Every endeavour should apply aesthetic principles that will demonstrate the natural beauty of nature and the synchronized man-made environment.

Unfortunately, in 2019 Kinunang River was flooded. This event posed serious questions as to how to prevent such a natural disaster from recurring in the future. Preliminary field survey of the river catchment showed the erosion-prone cliff material of the river banks. A quick desk study revealed that hydrodynamic data of the river flow were lacking. There was no specific analysis carried out on the flow regime, and no flooding or inundation data were recorded in previous years.

This study, hence, undertook all necessary activities to come up with a solution to sustainably implement the flood management initiative in the Kinunang River and catchment. These included performing a hydrological evaluation of the river catchment and hydraulic simulation of existing channel and flow properties. The specific objective of this study is to obtain a cross-sectional design by applying eco-hydraulic principles to cope with flooding in the Kinunang River with a 25-year return period, reducing the flow velocity in the river by selecting the right vegetation construction.

Considering that the Kinunang River area is a tourist area, the flood control system should consider the application of the eco-hydraulic principle. This concept is an integral part of integrated water resources management, and the approach is also environmentally friendly [1]. Some studies documented that eco-hydraulic designs may offer protection from erosion of riverbanks by means of the installation of riparian buffer strips or planting vegetation on riverbanks [2, 3].

The use of Eco-Hydraulics for cliff protection, both preventive and after damage has occurred, still needs to be popularized. In modern times, Eco-Engineering (Eco-Hydraulics) has become popular in several countries [4-8]. Various research results show that with this method, several advantages are obtained, such as controlling or retaining floods, preserving ecology, increasing resistance to erosion, reducing flow velocity at a relatively low cost (compared to permanent concrete or masonry construction), and providing inexpensive maintenance costs [9, 10]. The application of the Eco-Hydraulic concept in the form of using vetiver grass can reduce the flow velocity [2, 11-13]. This is corroborated by the results of research showing that eco-hydraulics strongly support the realization of a green environment, providing cool, conservational, and beautiful effects [14].

2. MATERIALS AND METHODS

2.1. Research Location

Kinunang River is located in Likupang, North Minahasa Regency, North Sulawesi Province. The research location is at 1°40'46 “N 125°08'47” E, as shown in Fig. (**1**).

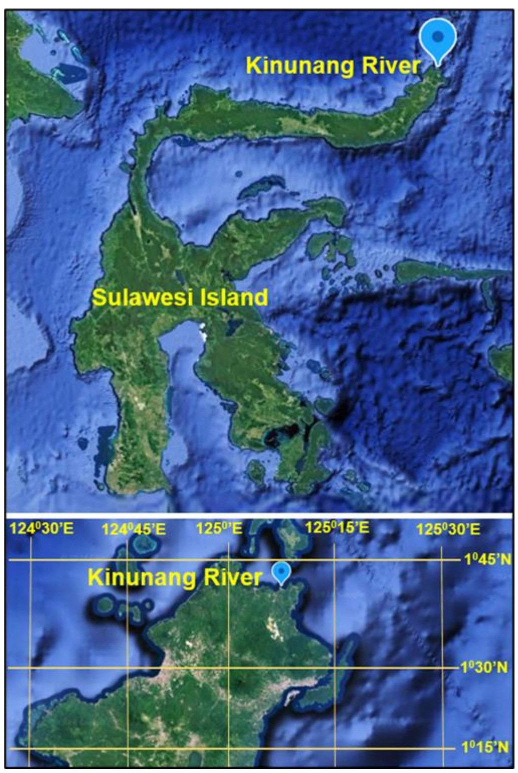

Fig. (1). Research location map.

2.2. Watershed Analysis

Watershed analysis was conducted to determine the area of the Kinunang watershed. The watershed area was analyzed using DEM data. The Kinunang watershed area is 3.25 km^2, as shown in Fig. (2).

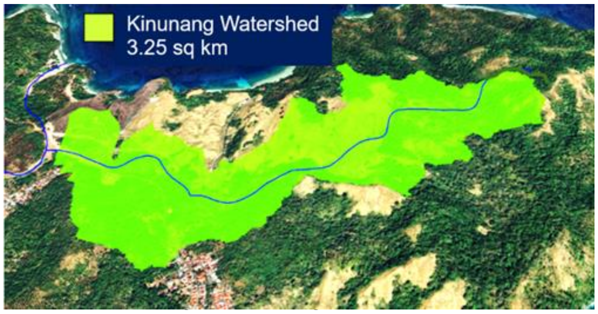

Fig. (2). Kinunang watershed.
Source: Google Earth and analysis results.

2.3. Analysis of Watershed Average Rainfall

There are two rain gauging stations around the watershed, namely Maen Climatology Station and Araren-Pinenek MRG Station. The location of the two rain gauges in relation to the Kinunang watershed and the Thiessen Polygon is shown in Fig. (3).

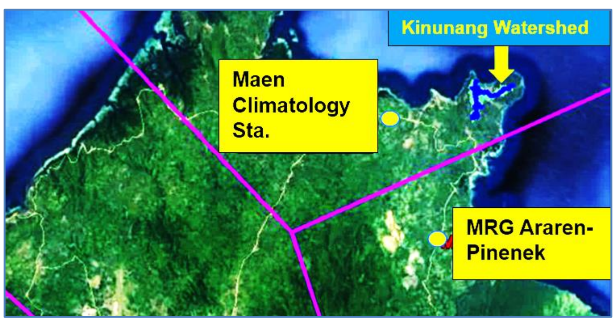

Fig. (3). Rain station location and thiessen polygon.

Analysis of watershed average rainfall using the Thiessen Polygon method using the following equation (1) [15-17]:

$$R = \frac{R1.A1+R2.A2+\cdots+Rn.An}{A1+A2+\cdots+An} \quad (1)$$

Where:

R = average rainfall of the watershed

$R1, R2, Rn$ = rainfall recorded at stations 1, 2, n

$A1, A2, An$ = area of influence of the station 1, 2, n.

The Thiessen polygon image is shown in Fig. (3).

From the Thiessen polygon analysis, it is found that the particularly influential rainfall station in the watershed is Maen Climatology Station. Rain data recorded at Maen Climatology Station is available for only 15 years. The average rainfall of the watershed will use data from the Maen station for all years collected at the Maen Climatology Station, while rainfall data of missing years collected at the Maen Climatology Station will utilize data from the MRG Araren-Pinenek station. The results of the analysis of average watershed rainfall are shown in Table 1.

2.4. Frequency Analysis of Rainfall Data

Frequency analysis is used to obtain the amount of rainfall. There are 4 frequency distributions commonly used in hydrological analysis [15, 18].

[1] Normal Distribution
[2] Log Normal Distribution
[3] Gumbel Type I Distribution
[4] Log Pearson Type-III Distribution

2.4.1. Criteria for Initial Selection Of Distribution Type Suitability Based on Statistical Parameters

The type of data distribution can be determined from the statistical parameters of the data itself. The statistical parameters of the data to be seen are: Coefficient of Skewness (Cs), Coefficient of Kurtosis (Ck), and Coefficient of Variation (Cv) [4, 16, 19].

Distribution selection requirements:

- Normal distribution type, if Cs ≈ 0, Ck ≈ 3
- Log-Normal distribution type, if Cs ≈ Cv3 + 3 Cv, or Ck = Cv8+ 6Cv6 + 15Cv4 + 16Cv2 + 3
- Gumbel distribution type if Cs ≈ 1.14, or Ck ≈ 5.40
- If the above three (3) criteria are not met, then the suitable distribution type is the log Pearson-III distribution.

From the distribution of selection requirements, the conclusion is presented in Table 2. The analysis presented in Table 2 concludes that the distribution of data tends to follow the Log Pearson Type-III distribution. Therefore, the rainfall plan will be calculated using the Log Pearson Type-III distribution.

2.4.2. Distribution Log Pearson Type-III

Equation for the Log Pearson Type-III distribution:

$$\log X = \overline{\log X} + K_{TR,CS}.S_{\log X}$$

Where:

Log XTR = log rainfall series

Log X bar = average of log series data

Slog = standard deviation of log series data

KTR, Cs = frequency factor.

The rainfall design is shown in Table 3.

2.5. Converting Daily to Hourly Rainfall Design

Rainfall design results of the analysis in the form of daily rainfall in Table 3 will be converted into hourly rainfall design. Converting daily rainfall into hourly rainfall uses the hourly rain pattern of the nearest area, namely Manado and its surroundings [20-22]. The rain pattern is shown in Table 4.

Using the hourly rainfall distribution pattern, the daily rainfall is converted to hourly rainfall, and the results are shown in Table 5.

2.6. Model Calibration

The first step was to calibrate the HEC-HMS parameters. Calibration aims to compare the calculated discharge with the measured discharge. Selected discharge measurement results for 1 specific year. By entering the selected rainfall data and parameter values that fall within the required range, the discharge is calculated with the assistance of HEC-HMS tools. Furthermore, the calculated discharge is compared with the measured discharge. If the calculated discharge has a significant difference from the measured discharge, the entered parameter values must be altered to produce a calculated discharge value with a slight difference from the measured discharge. The calculated discharge has a close value to the measurement discharge, which means the parameter values used are appropriate for the watershed. Furthermore, the discharge for other years can be calculated using the calibrated parameter values.

Table 1. Watershed average rainfall.

No.	Year	Watershed Average Rainfall (mm)
1	2002	188,2
2	2003	137,2
3	2004	102,3
4	2005	97,6
5	2006	95,8
6	2007	96,9
7	2008	71,9
8	2009	65,0
9	2010	68,0
10	2011	108,0
11	2012	83,0
12	2013	138,0
13	2014	126,5
14	2015	80,0
15	2016	65,5
16	2017	112,0
17	2018	76,0
18	2019	87,0
19	2020	80,0
20	2021	124,5
21	2022	139,5
22	2023	120,2

Table 2. Data statistical parameter requirements.

Distribution	Data		Condition		Conclusion
	Cs	Ck	Cs	Ck	
Normal	0,959	1,494	0	3	Unsatisfied
Log Normal			1,1124	5,278	Unsatisfied
Gumbel			1,14	5,4	Unsatisfied
Log Pearsson III			In addition to the 3 conditions		Compliant

Table 3. Rainfall design.

Return Period (Year)	Daily Rainfall (mm)
25	172,01

Table 4. Hourly rain pattern of manado and surrounding areas [20].

Hour To	1	2	3	4	5	6	7	8
% rain distribution	54	22	8	6	3	1	3	3

Table 5. Hourly rainfall plan.

Recurrence Time	Rain Plan	Hourly Rainfall Plan (mm)							
		Hour to							
		1	2	3	4	5	6	7	8
25	172,01	92,89	37,84	13,76	10,32	5,16	1,72	5,16	5,16

2.7. Discharge Data

There is no measured discharge data available in the Kinunang River. For rivers where measurement discharge data is not available, discharge data can be estimated from the discharge data of nearby rivers that have similar characteristics to each other. The method used is the watershed area comparison method. This method is very commonly used in areas where no river discharge measurement data is available. This method requires measured discharge data of the reference river, the watershed area of the reference river, and the watershed area of the destination river.

Watershed area comparison method using the following equation (2):

$$Q2 = \frac{A2}{A1} x\, Q1 \qquad (2)$$

Where:

Q2 = approximate discharge of destination river (m^3/s)

Q1 = Measured discharge of reference river (m^3/s)

A2 = Watershed area of destination river (km^2)

A1 = Watershed area of reference river (km^2)

To estimate the Kinunang River discharge data, the nearest river with similar characteristics, the Likupang River, was selected. The two rivers are only 1 km apart. By using the watershed area comparison method, the estimated discharge data in the Kinunang River can be estimated from the Likupang River discharge data. The watershed area comparison is shown in Table **6**.

Using the watershed area comparison method, the estimated discharge of the Kinunang River was obtained as shown in Table **7**.

The 2019 watershed average rainfall data was typed into HEC HMS. The calculated discharge was compared to the estimated discharge of the Kinunang River in 2019, then calibrated. One of the parameters calibrated is Curve Number (CN) [23, 25]. Calibration results are shown in Fig. (**4**), and calibration parameters are presented in Table **8**.

Since the analysis is a flood discharge analysis, the calibration is emphasized on the amount of peak discharge. From the calibration results, it was found that the calculated peak discharge and the measured peak discharge were close to the same value of 3.32 m^3/s. It can be concluded that the parameters used are appropriate for the Kinunang watershed and can be used to calculate the discharge for the specified rainfall plan.

2.8. Flood Discharge Simulation

The rainfall-flow modelling in the software of HEC-HMS [26-28] uses the method of SCS (Soil Conservation Service) Synthetic Unit Hydrograph (SUH), and the water losses are determined using the SCS Curve Number (CN). The baseflow was analyzed using the recession method. Calibration is a process in which the analysis result is compared with the field observation results. The calibration of the SCS-SUH parameter needs to be carried out by finding the optimal SCS-SUH parameter and comparing it with the simulation result of HEC-HMS by the measured discharge data. The calibration is carried out in the watershed, which is the research location, by the measurable discharge data in the field. The analysis of water level depth uses the software of HEC-RAS, and the input data are needed, such as river section, channel characteristics for the Manning coefficient (n), and the design flood data for the analysis of the eternal flow.

2.9. Water Level Analysis

HEC-RAS 5.0.7 software is used to analyze the water level. Input data includes the existing river geometry data in the form of cross and long sections, riverbed slope (S), channel roughness (Manning's n coefficient value), and the designed flood discharge [29, 30]. There are 41 cross sections selected along the Kinunang River. The characteristics of the Kinunang River channel are shown in Table **9**. The upstream and downstream of existing cross-section data are shown in Fig. (**5**).

3. RESULT AND DISCUSSION

3.1. Existing Cross-section

A 25-year return period flood discharge of 24.5 m^3/s was simulated at the existing cross-section. The results of the water level simulation with the input of the 25-year return period flood discharge at the existing cross section are shown in Fig. (**6**). The results show that all existing cross sections of the Kinunang River are no longer able to accommodate flood discharge with a 25-year return period flood discharge. Therefore, it is necessary to re-dimension the cross-section.

The results showed that all cross-sections overflowed, and the river was unable to accommodate the existing discharge. The river cross-section needs to be re-dimensioned.

3.2. Redimensioning the Cross-section

Based on the analysis results of the flood control channel profile design, the new dimension is a multi-stage

Table 6. Comparison of watershed area.

Watershed	Area (km^2)
Kinunang	3,2546
Likupang at the discharge measurement point	69

Table 7. Estimated discharge of Kinunang river.

Day	Discharge (m^3/s)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nop	Dec
1	0,200	0,889	0,132	0,132	0,222	0,088	0,055	0,049	0,038	0,033	0,042	0,042
2	0,365	0,324	0,119	0,255	0,179	0,086	0,053	0,049	0,038	0,032	0,046	0,046
3	0,217	0,517	0,183	0,465	0,146	0,081	0,053	0,049	0,038	0,032	0,042	0,053
4	0,509	0,911	0,136	0,465	0,123	0,076	0,051	0,048	0,038	0,032	0,041	0,086
5	0,187	0,720	0,116	0,365	0,099	0,072	0,051	0,048	0,038	0,036	0,039	0,126
6	0,255	0,999	0,107	0,204	0,175	0,069	0,049	0,048	0,038	0,036	0,039	0,149
7	0,208	0,563	0,105	0,417	0,153	0,149	0,048	0,046	0,036	0,035	0,039	0,200
8	0,265	0,302	0,153	1,180	0,126	0,139	0,048	0,046	0,036	0,036	0,038	0,213
9	0,208	0,196	0,129	0,858	0,110	0,132	0,149	0,046	0,036	0,038	0,038	0,222
10	0,378	0,156	0,123	0,555	0,105	0,126	0,132	0,044	0,036	0,038	0,038	0,175
11	0,494	0,291	0,110	0,911	0,099	0,119	0,129	0,044	0,036	0,036	0,036	0,231
12	0,588	0,204	0,119	0,787	0,096	0,107	0,119	0,042	0,036	0,039	0,036	0,191
13	1,870	0,291	0,110	0,313	0,245	0,105	0,107	0,042	0,036	0,036	0,035	0,164
14	1,755	0,231	0,105	0,191	0,217	0,099	0,099	0,042	0,036	0,035	0,035	0,222
15	2,133	0,187	0,102	0,365	0,175	0,094	0,187	0,041	0,036	0,039	0,033	0,187
16	1,130	0,353	0,107	0,265	0,196	0,088	0,175	0,041	0,035	0,038	0,033	0,153
17	3,308	0,285	0,222	0,494	0,160	0,083	0,149	0,041	0,035	0,036	0,032	0,250
18	0,710	0,231	0,226	1,218	0,136	0,081	0,126	0,041	0,035	0,035	0,032	0,787
19	0,647	0,175	0,191	0,837	0,129	0,074	0,126	0,039	0,035	0,036	0,031	0,647
20	0,900	0,139	0,149	1,284	0,123	0,072	0,110	0,039	0,035	0,039	0,031	0,889
21	0,479	0,187	0,136	0,889	0,110	0,078	0,105	0,039	0,035	0,035	0,031	0,965
22	0,444	0,191	0,129	1,464	0,099	0,088	0,099	0,039	0,035	0,036	0,029	0,692
23	1,270	0,153	0,116	0,943	0,096	0,083	0,088	0,039	0,035	0,048	0,029	0,405
24	1,046	0,204	0,105	0,647	0,096	0,078	0,078	0,038	0,033	0,048	0,029	0,208
25	1,180	0,307	0,183	0,384	0,091	0,076	0,072	0,038	0,033	0,048	0,027	0,231
26	3,308	0,204	0,164	0,231	0,088	0,072	0,069	0,038	0,033	0,044	0,036	0,200
27	0,943	0,156	0,142	0,226	0,083	0,069	0,061	0,038	0,033	0,041	0,038	0,160
28	1,069	0,132	0,123	0,280	0,105	0,067	0,057	0,038	0,033	0,038	0,041	0,231
29	1,069		0,107	0,472	0,099	0,065	0,055	0,038	0,033	0,035	0,038	0,204
30	1,167		0,102	0,465	0,096	0,061	0,051	0,038	0,033	0,039	0,036	0,149
31	1,338		0,094		0,091		0,049	0,038		0,041		0,136

Table 8. Parameters of calibration results.

Initial Discharge	2,75 m^3/s
Ratio to peak	0,288
Recession Constant	0,88
Curve Number (CN)	77

Table 9. Kinunang river characteristics.

Total Cross Section	Total Length (m)	Riverbed Slope (S)	Elevation (m)	
			Upstream	Downstream
41	595	0,007	35,63	31,29

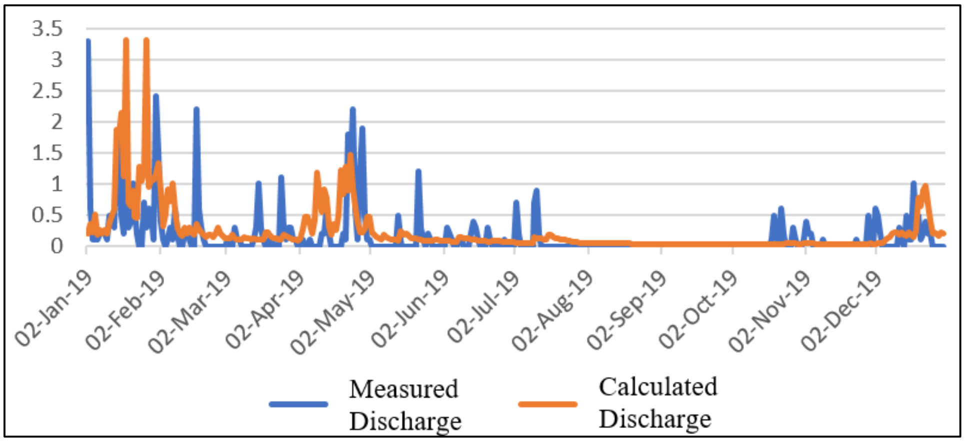

Fig. (4). Measured and calculated the discharge of calibration results.

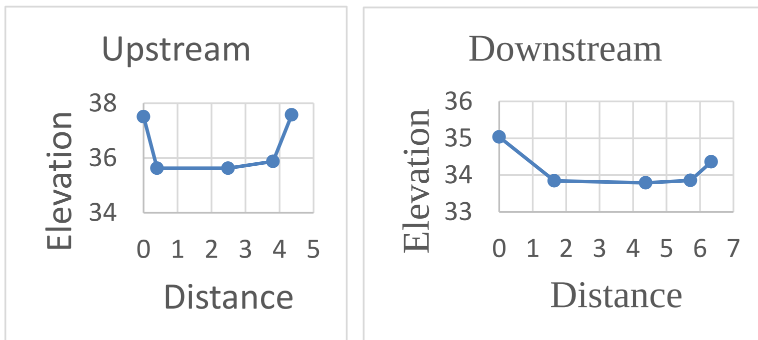

Fig. (5). Existing cross-section data at upstream and downstream.

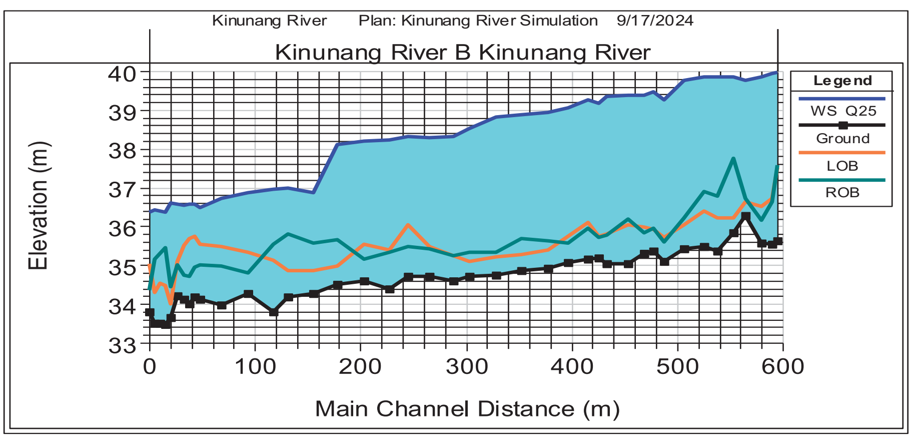

Fig. (6). Water level with plan flood at the existing cross-section.

trapezoid channel with an upper width (La) of 12 m, a lower width (Lb) of 6 m, and a depth (h) of 2 m. This dimension can drain the design flood of 24.5 m^3/s (Q25). Existing and design cross-section images of upstream and downstream are shown in Fig. (7).

A 25-year return period flood discharge was run on the design cross-section. The results showed that the design cross-section was able to convey the planned discharge. Figure. (8) shows the water level that occurs in the design cross-section (cross-section and long section).

3.3. Eco-Hydraulic Design

The next phase is the eco-hydraulic design. The design is carried out by planting 3 types of plants on the riverbanks, namely vetiver grass, shrub grass, and bamboo plants. The design of the cross-section with additional green construction is shown in Fig. (9).

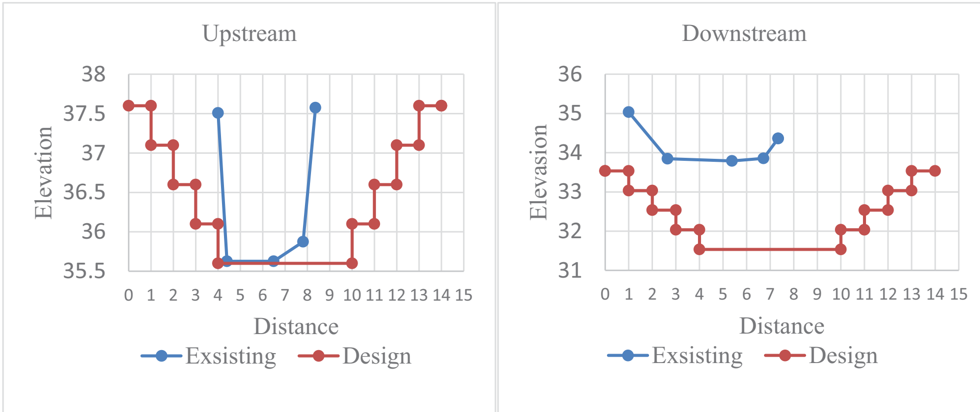

Fig. (7). Existing and design cross-section at the upstream (left) and downstream (right).

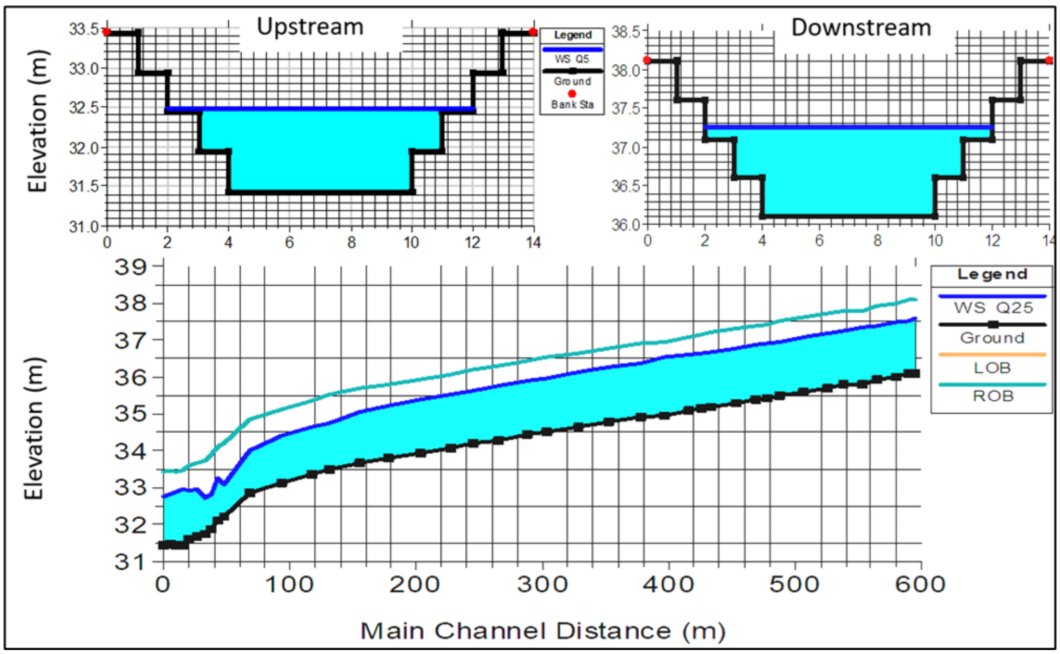

Fig. (8). Water level at the design cross-section, cross-section, and long section.

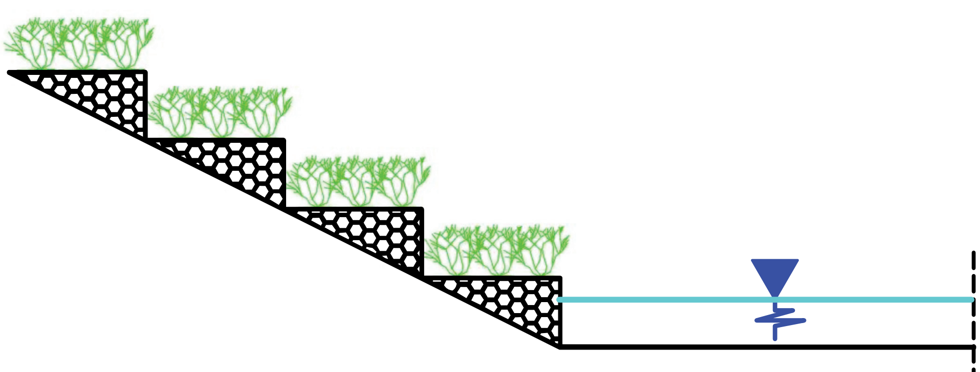

Fig. (9). Eco-Hydraulic design.

Simulation was executed with Manning's roughness (n) value for vetiver grass, shrub grass bamboo plants. These three types of plants were chosen because they were abundant at the site. The simulation results of the water level with each plantation of the 25-year return period flood discharge are shown in Fig. (**10**). The results indicate that all cross sections planted with vetiver grass, shrub grass, and bamboo plants are able to accommodate flood discharge. The highest water table is the one using vetiver grass, followed by bamboo plants, and the lowest is bush grass. This occurs because the roughness level of vetiver grass is the greatest compared to bamboo plants and shrub grass.

The results also show that the flow velocity is different for each type of plant. Cliffs planted with vetiver grass provide the smallest flow velocity, followed by bamboo plants and finally bush grass. This is also due to the roughness of each type of plant. Vetiver grass is the roughest, resulting in the smallest flow velocity. The results of the flow velocity simulation at each cross-section after the installation of vetiver grass, shrub grass, and bamboo plants are presented in Fig. (**11**).

The application of the three types of plants, namely vetiver grass, shrub grass, and bamboo plants, on riverbanks has a different effect on the water level and flow velocity in the river. For water level, vetiver grass provides the highest water level, followed by bamboo plants and shrub grass, but the water level that occurs is still below the riverbank.

For flow velocity, cliffs using vetiver grass provide the smallest velocity, followed by bamboo plants and shrub grass. River cliffs in the Kinunang River consist of material that is easily eroded. To avoid cliff erosion, a relatively small flow velocity is needed. The smaller the flow velocity, the better. With this limitation, vetiver grass was chosen as a cover plant for the Kinunang River cliff. As an application of eco-hydraulic, vetiver grass is superb because it provides a green effect, as well as keeping the flow velocity low, and controlling the flood.

The above results reveal that installing eco-hydraulic in the form of vetiver grass can reduce the flow velocity in the Kinunang River. This is due to the resistance of the grass. The average flow velocity of the existing cross-section plan is 2.32 m/sec. With the green construction, namely vetiver grass vegetation, the average flow velocity becomes 1.64 m/sec. The results show that eco-hydraulic construction in the form of vetiver grass can reduce the flow velocity by 29%. The flow velocity will be greater if there is no vegetation on the riverbank. The vegetation on riverbanks has its function as a component to delay the flow of water to downstream, thus flood energy to downstream can be reduced. By planting vetiver grass, the flow velocity can be reduced, and the cross-sectional dimensions can still accommodate floods with a 25-year return period.

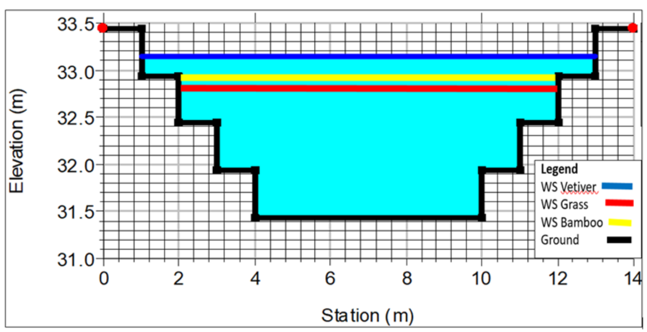

Fig. (10). Water level of cross-section plan with vetiver grass, shrub grass, and bamboo plants at the upstream.

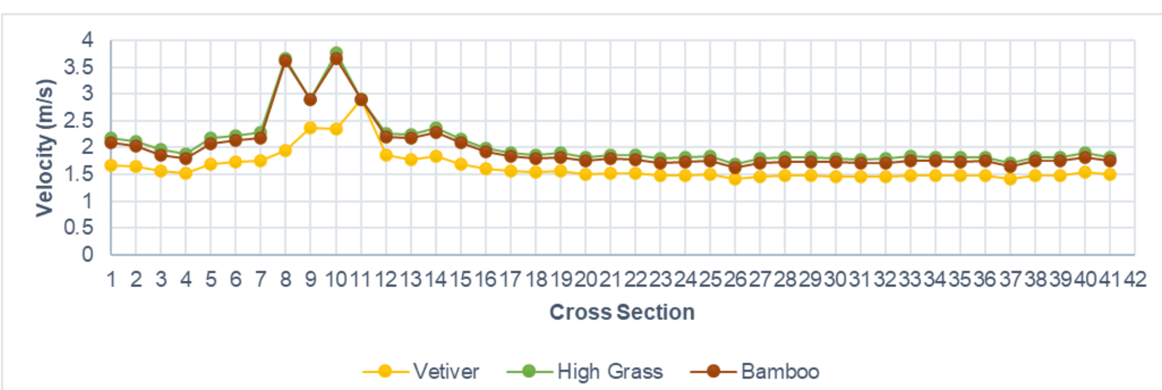

Fig. (11). Vetiver grass, shrub grass, and bamboo plants.

CONCLUSION

The Kinunang River is unable to accommodate the 25-year return period flood discharge of 24.5 m^3/s. Thus, leading to a redimensioning of its cross-section. The analysis shows that the dimension of a multi-stage trapezoid channel with an upper width (La) of 12 m, lower width (Lb) of 6 m, and depth (h) of 2 m that can drain the design flood of 24.5 m3/s. The wet cross-sectional area of 18.1 m2 can accommodate the flood design. Flood control in the Kinunang River manipulates the concept of eco-hydraulics. Application of eco-hydraulics by selecting vetiver grass as a cliff cover plant. The vetiver grass will provide a natural green atmosphere. The vetiver grass also reduces the flow velocity, thus reducing the risk of cliff erosion. Vetiver grass can reduce the velocity by 29%. Redimensioning the cross-section and the application of the eco-hydraulic concept in the form of planting vetiver grass on the Kinunang River will be able to cope with the flood design, minimize the flow velocity, and make it an attractive construction with a green appearance. This is requisite considering the Kinunang River area is a top-priority tourist destination.

AUTHORS' CONTRIBUTIONS

It is hereby acknowledged that all authors have accepted responsibility for the manuscript's content and consented to its submission. They have meticulously reviewed all results and unanimously approved the final version of the manuscript.

LIST OF ABBREVIATIONS

SEZ	=	Likupang Special Economic Zone
Cs	=	Coefficient of Skewness
Ck	=	Coefficient of Kurtosis
SUH	=	Synthetic Unit Hydrograph
CN	=	Curve Number

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

The data and supportive information is available within the article. Cross section data: [Inspire Unsrat] at [https://inspire.unsrat.ac.id/uploads/repository//4cabfed3d802e938dae3378dd9751a2189628dc6.pdf], reference number 1. Rainfall and discharge data: [Inspire Unsrat] at [https:// inspire.unsrat.ac.id/uploads/repository//b1599136620f148864186560e9204c1a50438863.pdf], reference number [2].

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CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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