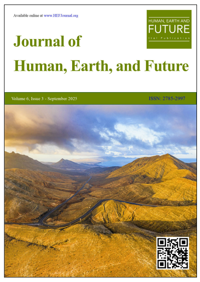
Available online at www.HEFJournal.org

Journal of Human, Earth, and Future

ISSN: 2785-2997

Vol. 6, No. 3, September, 2025



Designing a Multistage Flood Control Channel for Sediment and Flow Management in Coastal Areas

Tiny Mananoma [1*], Jeffry S. F. Sumarauw [1], Roski R. I. Legrans [1], Yosua A. Ratu [1]

[1] *Civil Engineering Department, Universitas Sam Ratulangi, Manado, 95115, Indonesia*.

Received 16 December 2024; Revised 21 May 2025; Accepted 11 June 2025; Published 01 September 2025

Abstract

Flow and sediment are the two main parameters that significantly influence the flood. Flooding results in riverbed degradation, adversely affecting the construction of the river and the environment. Therefore, it is essential to engineer the profile of the flood control channel in the selected area of Likupang Pulisan Beach. This research seeks to develop a design that mitigates the adverse effects caused by flooding and sediment movement, resulting in geological and ecological disasters. The amount of rainfall and watershed characteristics become input data in the HEC-HMS application to obtain the amount of planned flood discharge. Measurement and mapping of river geometry were conducted. This data is used in the HEC-RAS application, which will simulate flow conditions in the field in real time. From the analysis of the flood control channel profile engineering, the dimensions of a multi-stage trapezium channel with top width (La) = 10 m, bottom width (Lb) = 1 m, and height (h) = 3 m were obtained, which can drain a flood discharge of 36.5 m^3/s. The novelty of this research is the design of a multilevel channel profile that is implemented in a tourist area with the aim of flood control.

Keywords: Likupang; Pulisan; Floods; Erosion; Sedimentation.

1. Introduction

The phenomena of flooding, erosion, and sedimentation are problems in a river [1, 2]. The two main parameters that significantly affect the flood phenomenon are flow and sediment [3, 4]. The flood phenomena and sediment movement lead to either aggradation or degradation of the riverbed, negatively impacting river construction and the surrounding environment [5]. Floods can change the morphology of the river [6].

River morphology refers to changes in the shape and size of the river cross section, which includes longitudinal and transverse cross sections of the river caused by erosion and sedimentation phenomena. Efforts to maintain equilibrium or balanced/stable conditions in the river are very difficult to do given the nature and characteristics of the river itself [7]. The condition of the watershed has a huge impact and influence on the occurrence of flow and sediment transport processes in the river. Hydraulic slope and the amount of flow discharge are dynamic characteristics that always change according to time and place [8]. Departing from this theory, although it is not easy, a challenging idea was chosen, namely engineering flood control channel profiles to form equilibrium or stable conditions in selected river channels in the Likupang Pulisan Beach Special Economic Zone.

Special economic zones are regions with unique labor, immigration, taxation, licensing, and customs regulations. By creating places that are advantageous and prepared to receive industrial, export, and import activity as well as high-

* Corresponding author: tiny.mananoma@unsrat.ac.id

http://dx.doi.org/10.28991/HEF-2025-06-03-011

value economic activities, Special Economic Zones are meant to create investment opportunities. The purpose of the Indonesian government program known as the Special Economic Zone is to improve the economy in certain areas [9].

According to Indonesian Government Regulation No. 84 of 2019, the Likupang Special Economic Zone is located in Tanjung Pulisan. It is bordered by the Sulawesi Sea to the north, Kinunang Village in East Likupang District to the east, Pulisan Village in East Likupang District to the south, and the Sulawesi Sea and Marinsow Village to the west. There are various types of topography in this area, ranging from plains to slopes to hills. There are several village settlements around the Special Economic Zone. By establishing Tanjung Pulisan as a Special Economic Zone, the surrounding villages have a strategic position to develop village tourism. Pulisan Beach in Pulisan Village has simple beach conditions with a narrow coastline. Pulisan Beach is a sloping white sand beach. Pulisan Beach is designated as a super priority tourism destination of particular importance because it is protected by a headland, which makes it unique [10].

The selected river section that is the location of this study is part of the Pulisan River flow. River section data was taken along 880 m across the Likupang Tourism Special Economic Zone precisely at Pulisan Beach. The urgency of this research is due to the fact that Pulisan Beach is one of the super priority tourist destinations, so infrastructure readiness is needed.

Flood control analysis involves several stages in the planning of flood control buildings. First, a study of existing conditions is undertaken to determine that the analysis is appropriate for usage. The quantity of rainfall and watershed parameters are fed into the HEC-HMS application (Center for Hydrological Engineering Hydrological Modeling Systems, US Army Corps of Engineers) to calculate the amount of planned flood discharge. The flood control buildings are then planned using the HEC-RAS program, which includes flood analysis and routing. The Hydraulics Model is designed to calculate the water level elevation in the river and its surroundings during a flood. To examine the river hydraulics model, the HEC-RAS program package from the Hydrologic Engineering Center (HEC) of the US Army Corps of Engineers was used. This program package makes it possible to analyze river flow under unsteady flow conditions and also makes it possible to calculate the hydraulic profile of the river water level concerning lateral flow and stage hydrograph [10, 11].

The novelty of this research is the design of a multilevel channel profile that is implemented in a tourist area with the aim of flood control.

2. Material and Methods

2.1. Study Area

The research location can be seen in Figure 1. The research location is in Pulisan village, East Likupang sub-district, North Minahasa Regency, North Sulawesi Province, Indonesia. The research site is located at 1°40'55"N 125°08'52" E in the Pulisan watershed located in Likupang,

Pulisan River is located in the Pulisan River Watershed in Likupag, North Minahasa Regency, North Sulawesi Province, Indonesia, with a total watershed area of 3.25 km^2 and has 9 tributaries that flow into the main Pulisan River [12]. The selected river section that is the location of this study is part of the Pulisan River flow. River section data was taken along 880 m across the Likupang Tourism Special Economic Zone precisely at Pulisan Beach. The Pulisan Watershed and selected river segments can be seen in Figure 2.

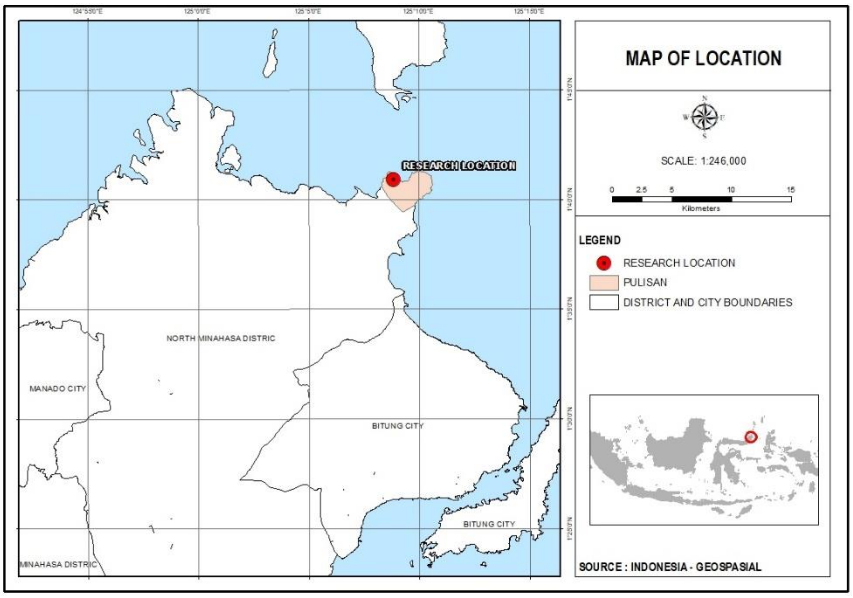


Figure 1. Map of research location

The data used in this research is secondary data. Secondary data was obtained from data and reports sourced from relevant agencies, including rainfall data and Pulisan River Watershed data from the North Sulawesi River Basin Center. A survey of existing conditions was conducted to ensure the suitability of the analysis to be used. The amount of rainfall and watershed characteristics become input data in the HEC HMS application to obtain the amount of planned flood discharge. Measurement and mapping of river geometry were conducted. This data is used in the HEC RAS application, which will simulate flow conditions in the field in real time.

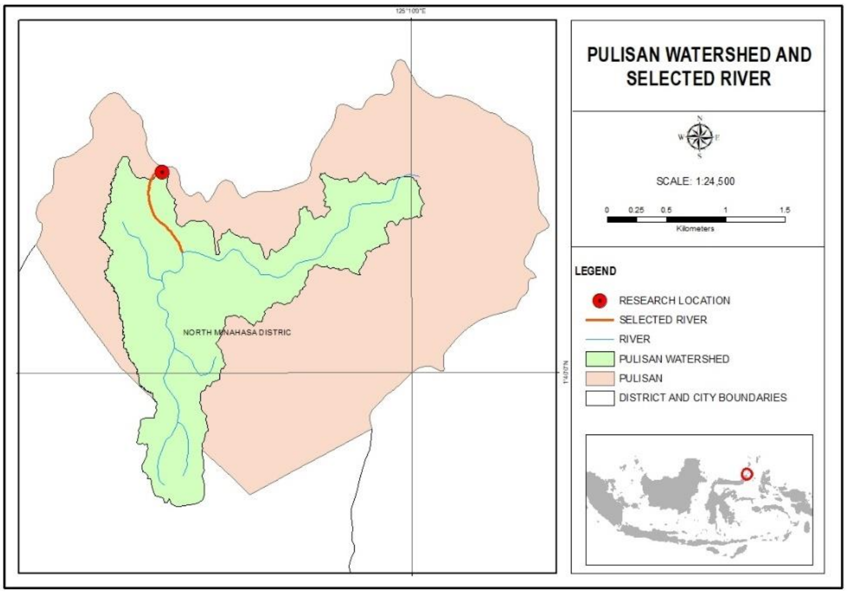


Figure 2. Pulisan watershed and selected river

2.2. Concept of Sediment Transport in Rivers

Bed load sediments are coarse particles that move along the entire riverbed [13, 14]. The movement of particles on the riverbed indicates the presence of sediment bed load; this movement can shift, roll, or jump, but it never leaves the riverbed. This movement can sometimes be up to a certain distance marked by the mixing of the particle grains moving downstream [14, 15]. The sediment transport scheme can be seen in Figure 3.

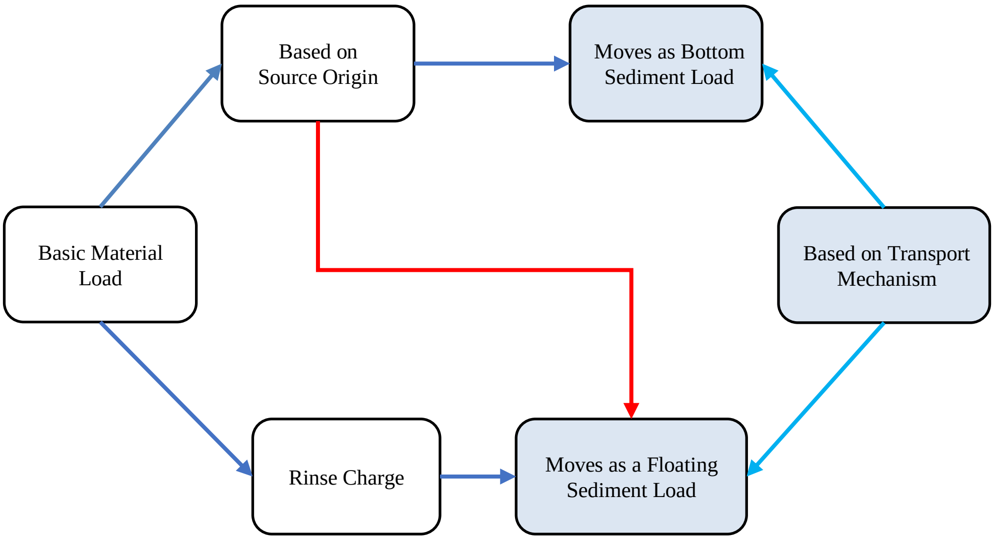


Figure 3. Sediment transport scheme

Various equations for estimating bottom sediment transport have been developed; however, their application for field investigations still needs further study [16].

- Meyer Peter dan Muller

$$\frac{q^{2/3}}{D} - 9.57\left[\frac{\gamma_s-\gamma}{\gamma}\right]^{-10/9} = \frac{0{,}462(\gamma_s-\gamma)^{4/3}}{\gamma^{2/3}D}\left[\left\{\frac{\gamma_s-\gamma}{\gamma_s}\right\}qb\right]^{2/3} \tag{1}$$

- Van Rijn

$$qb = \frac{0.053\, T^{2,1}[(s-1)g]^{1/2} D_{50}{}^{3/2}}{D^{1/3}} \quad (2)$$

- Einstein

$$\phi = \frac{q_b}{\gamma_s}\left(\frac{\gamma}{(\gamma_s-\gamma)gd35^3}\right)^{1/2} \quad (3)$$

- Frijlink

$$q_b = \phi d_{50}\sqrt{g\mu RS} \quad (4)$$

Natural flow is generally not fixed; this is due to the hydraulic geometric shape of the channel, uneven rivers in the field, the presence of plants on the channel cliff, the existence of water buildings, changes in the channel bottom, and other factors [17].

A river is a network of naturally produced grooves on the earth's surface that range in size from small upstream to huge downstream. Rainwater that falls on the earth's surface evaporates, with the majority of it flowing in the form of little grooves, then medium grooves, and finally one large or main groove. Thus, it can be claimed that the river serves to accommodate rainwater and drain it into the sea [18].

A watershed is an area in which all water flows into a specific river. This area is often confined by topographic boundaries, which means it is determined based on surface flow rather than subsurface water because the groundwater level always changes depending on the season and degree of use [9].

Plan flood discharge is the maximum discharge in a river with a certain return period [19]. Data needed to determine the planned flood discharge include rainfall data, catchment area, and land cover data [18]. The return period is defined as the hypothetical time in which the discharge or rain of a certain magnitude will be equaled or exceeded once in a certain time [20].

2.3. SCS CN Model as A Unit for Estimating the Magnitude of The Plan Flood Discharge

The Soil Conservation Service Curve Number (SCS CN) model is a hydrological instrument that analyzes watershed characteristics to forecast floods. The model predicts the maximum soil storage capacity by taking into account land use patterns and soil moisture levels (measured by rainfall five days previously), which is an important element in influencing runoff. The CN coefficient, a constant in the model, plays an important role in this calculation [21]. The equation of the SCS CN model based on the rainfall depth analysis is as follows:

$$Q = \frac{(P-Ia)^2}{((P-Ia)+S)} \qquad \text{for } P > 0.2\ S \quad (5)$$

$$Q = 0 \qquad \text{for } P < 0.2\ S \quad (6)$$

where: Q: Discharge (m^3/s); P: Accumulation of rainfall (mm); S: Maximum storage capacity after run-off happened (mm); Ia: Initial abstraction (mm), Ia: Can be estimated by using the empirical formula:

$$I_a = 0.2\ S \quad (7)$$

By missing the Ia as the independent parameter, and distributing it into the Equations 5 and 6, so there is obtained the formulation as follows:

$$Q = \frac{(P-0{,}2S)^2}{(P+0{,}8S)} \quad (8)$$

The parameter of S accommodates the relation between land use and soil type through the equation as follows, where CN is in the range of 0-100.

$$S = 1000/CN - 10 \quad (9)$$

2.4. HEC HMS as the Flood Simulator by Using Spatial Distribution

The Hydrologic Engineering Center's Hydrologic Modeling System (HEC HMS) is software that was developed by the US Department of Agriculture in 1992 and is designed to simulate the complete rainfall-runoff process for a watershed with a dendritic shape. The HEC HMS model includes meteorology, a watershed model, control specifications, and input data [22, 23]. The HEC HMS model is a process-based physical model with parameters that can be estimated directly from field data and remote sensing data. In several regions, it has been used to model continuous and event-based hydrological systems of gauged and ungauged dendritic watershed systems [24].

2.5. Concept of Flood Control

Rain flow modeling in the HEC HMS computer program uses the HSS Soil Conservation Services method for water loss with the SCS Curve Number (CN). For baseflow, use the recession method. Calibration is a process where the calculated value is compared with the value of field observations. HSS SCS Parameter Calibration needs to be done to find the optimized HSS SCS parameter value by comparing HEC HHMS simulation results with measured discharge data. Calibration was carried out in the research location watershed with measured discharge data in the field. Water level analysis using the HEC RAS computer program requires input data, namely river cross section, channel characteristics for Manning's n coefficient value, and flood discharge data for lasting flow calculations [25]. The Center for Hydrological Engineers uses the HEC-RAS software to analyze rivers. It specializes in modeling and recreating water in both natural waterways such as rivers and artificial channels such as canals and sewers. It can calculate the movement of sediments and chemical pollutants in a stream, as well as water levels and velocity in rivers and industrial courses such as canals and sewers.

3. Results and Discussion

3.1. Simulation of Flood Characteristic

From the Time of Concentration (Tc) analysis of each sub watershed, it was found that the Tc of almost all sub watersheds exceeded 1 hour. Even then, it does not take into account the travel time on the land. The requirement for a small watershed is TC <= 1 hour. It can be concluded that all sub watersheds are not small watersheds. The flood discharge analysis will use the method for medium watersheds (Table 1). The method chosen is the Synthetic Unit Hydrograph (SUH) SCS. The SUH-SCS method is a very frequently used method around the world.

Table 1. Plan flood discharge

Recurrence	Plan Flood Discharge (m^3/second)
Q2	17.2
Q5	22.8
Q10	28.1
Q25	36.5

3.2. Simulation of Flood Characteristic

The stages of hydraulic analysis are: first, inventory data on the characteristics of watersheds and sub-watersheds; then, inventory of river geometry data, namely the measurement of cross and long sections of the river channel in the sub-watershed; then, inventory of the magnitude of the planned flood discharge in each sub-watershed; and after that, analyze the capacity of the river channel with the help of the HEC RAS model; and last, analyze the dimensions of the best hydraulic cross section in the river channel.

From the data inventory of watershed and sub-watershed characteristics, river geometry data, namely the measurement of cross and long sections of river flow in the sub-watershed, as well as data on the planned flood discharge in each sub watershed in Table 2, then simulate the capacity of the flood control channel using the HEC RAS model as shown in Figures 4 and 5. Furthermore, from the simulation results as shown in Figures 6 and 7, the best cross section that is suitable for the selected location as a tourism area is determined.

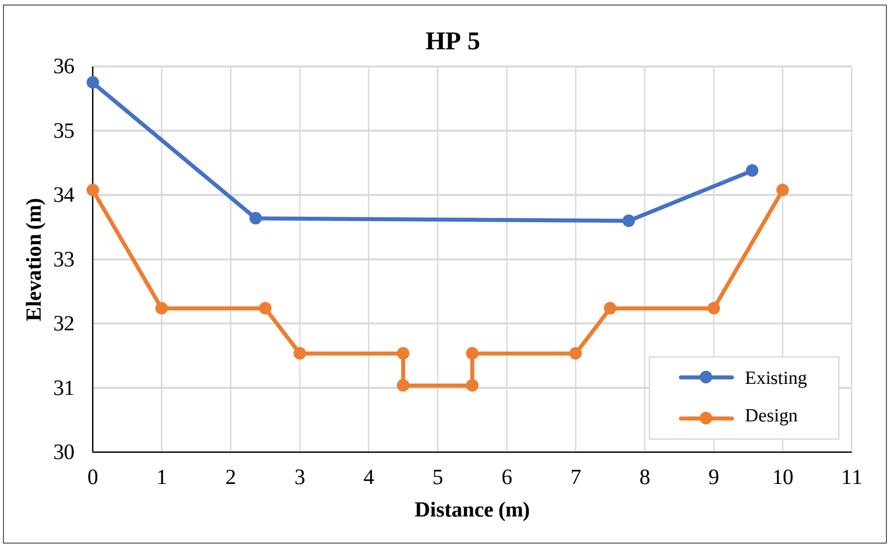


Figure 4. Transverse profile plan of the flood control channel (upstream)

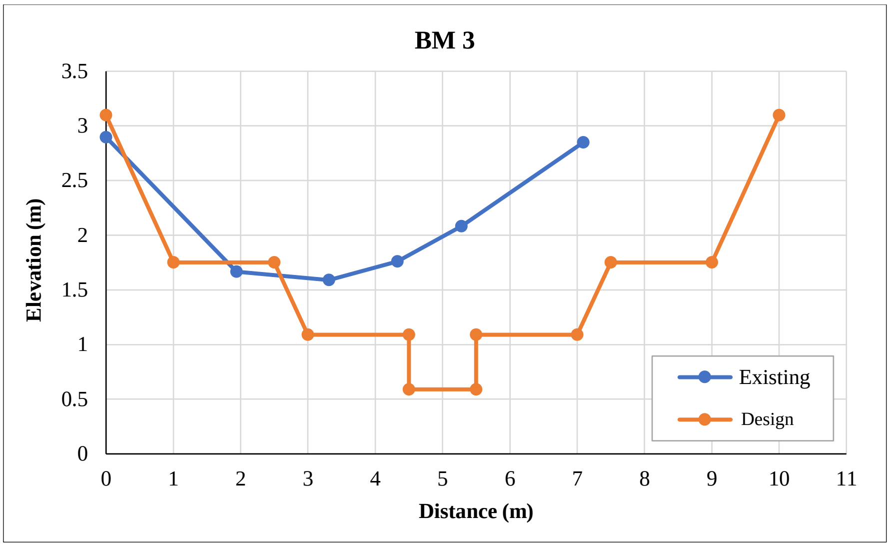


Figure 5. Transverse profile plans of the flood control channel (downstream)

Table 2. Face elevation at planned flood discharge

River Sta.	ID Sta.		Distance (m)			Min Ch El (m)	W.S. Elev (m)	LOB Elev (m)	ROB Elev (m)	Velocity (m/s)	L. Freeboard (m)	R. Freeboard (m)
52	HP	5	0	+	768	31.04	33.51	34.08	34.08	2.47	0.57	0.57
51	K	56	0	+	726	30.8	32.85	33.44	33.44	3.34	0.59	0.59
50	HP	6	0	+	706	30.5	32.55	33.06	33.06	3.33	0.51	0.51
49	K	57	0	+	684	30	32.57	33.04	33.04	2.34	0.47	0.47
48	HP	7	0	+	655	29.94	32.29	32.82	32.82	2.69	0.53	0.53
47	K	58	0	+	635	29.8	31.83	32.38	32.38	3.39	0.55	0.55
46	HP	8	0	+	611	28.51	30.07	30.64	30.64	5.52	0.57	0.57
45	K	59	0	+	569	26.48	28.19	28.7	28.7	4.59	0.51	0.51
44	HP	9	0	+	545	20.72	21.94	22.5	22.5	9.62	0.56	0.56
43	K	60	0	+	522	19.45	21.02	21.6	21.6	5.45	0.58	0.58
42	K	61	0	+	497	14.22	15.49	16.09	16.09	8.57	0.6	0.6
41	K	62	0	+	471	11.84	13.36	13.86	13.86	5.75	0.5	0.5
40	K	63	0	+	445	10.16	11.76	12.3	12.3	5.22	0.54	0.54
39	K	64	0	+	420	8.01	9.51	10.02	10.02	5.92	0.51	0.51
38	K	65	0	+	415	7.7	9.25	9.82	9.82	5.57	0.57	0.57
37	K	66	0	+	390	6.79	8.57	9.1	9.1	4.23	0.53	0.53
36	K	67	0	+	365	3.22	4.45	5.04	5.04	7.88	0.59	0.59
35	K	68	0	+	343	2.46	4.98	5.54	5.54	2.42	0.59	0.59
34	K	69	0	+	318	2.3	4.84	5.43	5.43	2.38	0.59	0.59
33	K	70	0	+	292	2.02	4.77	4.32	5.32	2.12	0.55	0.55
32	K	71	0	+	262	2.03	4.56	5.13	5.13	2.4	0.57	0.57
31	K	72	0	+	247	1.91	4.49	5	5	2.33	0.51	0.51
30	K	73	0	+	242	1.88	4.47	5	5	2.32	0.53	0.53
29	K	74	0	+	237	1.71	4.48	4.99	4.99	2.1	0.51	0.51
28	K	75	0	+	232	1.66	4.47	5.05	5.05	2.06	0.58	0.58
27	K	76	0	+	227	1.53	4.47	5.01	5.01	1.93	0.54	0.54
26	K	77	0	+	222	1.75	4.37	4.96	4.96	2.28	0.59	0.59
25	K	78	0	+	217	1.5	4.4	4.91	4.91	1.97	0.51	0.51
24	K	79	0	+	212	1.38	4.4	4.9	4.9	1.86	0.5	0.5
23	K	80	0	+	207	1.31	4.39	4.99	4.99	1.81	0.6	0.6
22	K	81	0	+	197	1.47	4.32	4.9	4.9	2.03	0.58	0.58
21	K	82	0	+	191	1.5	4.28	4.88	4.88	2.09	0.6	0.6
20	K	83	0	+	186	1.5	4.26	4.77	4.77	2.11	0.51	0.51

19	K	84	0	+	181	1.5	4.23	4.82	4.82	2.15	0.59	0.59
18	K	85	0	+	176	1.3	4.25	4.75	4.75	1.92	0.5	0.5
17	K	87	0	+	166	1.21	4.23	4.73	4.73	1.87	0.5	0.5
16	K	88	0	+	161	1.5	4.11	4.62	4.62	2.28	0.51	0.51
15	K	89	0	+	156	1.4	4.11	4.61	4.61	2.17	0.5	0.5
14	K	90	0	+	151	1.3	4.1	4.69	4.69	2.07	0.59	0.59
13	K	91	0	+	146	1.3	4.08	4.59	4.59	2.09	0.51	0.51
12	K	92	0	+	139	1	4.1	4.65	4.65	1.8	0.55	0.55
11	K	93	0	+	134	0.82	4.11	4.66	4.66	1.66	0.55	0.55
10	K	94	0	+	129	0.65	4.11	4.63	4.63	1.55	0.52	0.52
9	K	95	0	+	124	1.25	3.97	4.57	4.57	2.16	0.6	0.6
8	K	96	0	+	119	1.45	3.8	4.37	4.37	2.69	0.57	0.57
7	K	97	0	+	114	1.33	3.8	4.38	4.38	2.47	0.58	0.58
6	L	6	0	+	109	1.23	3.8	4.32	4.32	2.35	0.52	0.52
5	L	5	0	+	82	1.14	3.61	4.13	4.13	2.47	0.52	0.52
4	L	4	0	+	60	1	3.48	4	4	2.47	0.52	0.52
3	L	3	0	+	44	0.98	3.26	3.83	3.83	2.81	0.57	0.57
2	L	2	0	+	25	0.81	3.09	3.62	3.62	2.82	0.53	0.53
1	BM	3	0	+	0	0.59	2.6	3.1	3.1	3.38	0.5	0.5

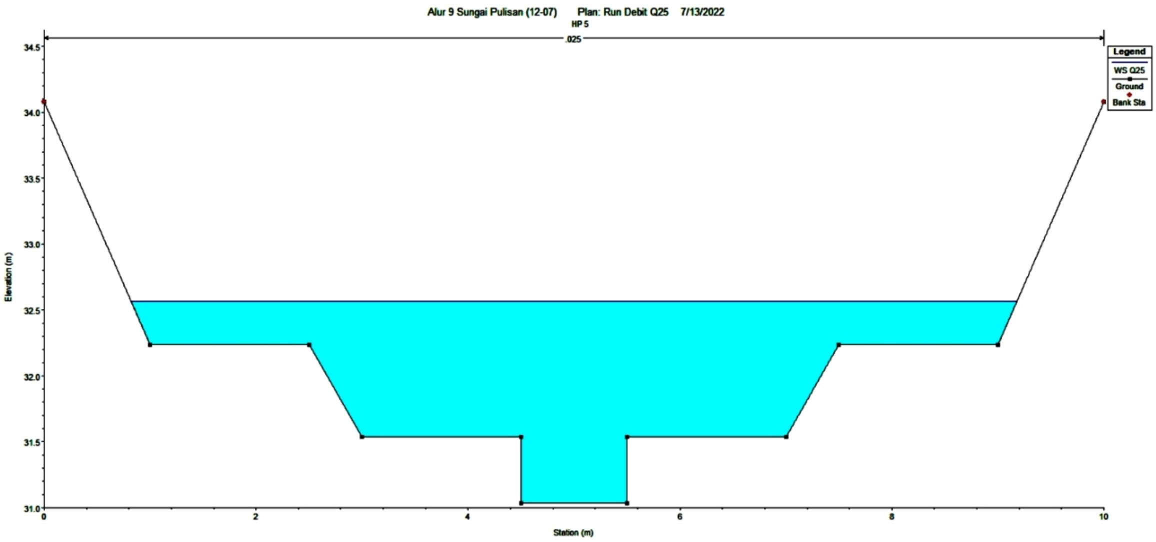


Figure 6. Running result transverse profile of upstream water level elevation (HP 5)

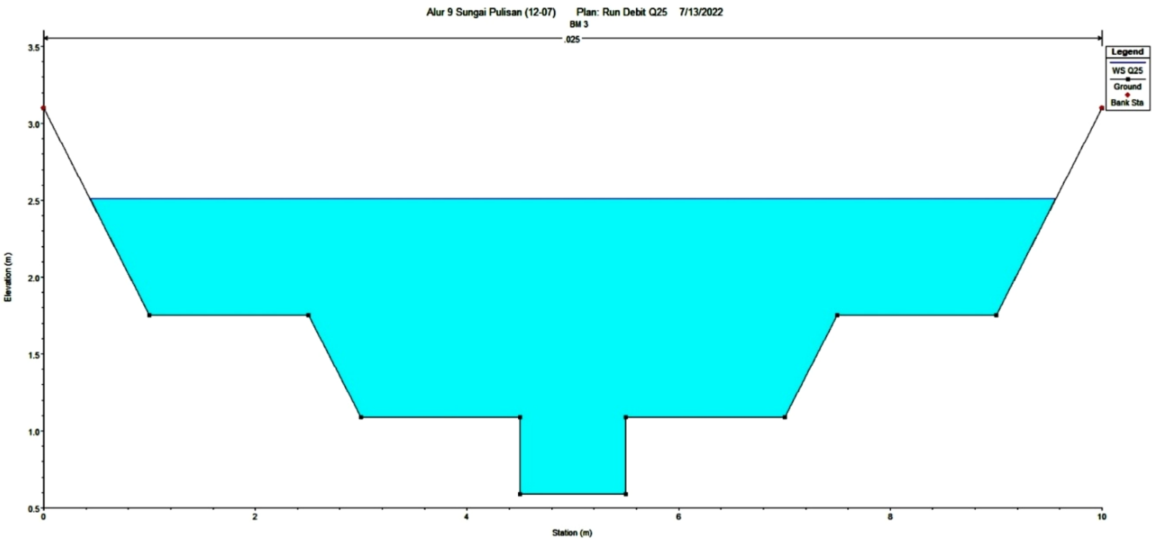


Figure 7. Running result transverse profile of water level elevation downstream (BM 3)

4. Conclusion

After simulating and evaluating several types of flood control channel cross-sections along with their hydraulic dimensions, the multi-stage cross-section was ultimately selected as the most appropriate design. This type of channel offers multiple functional advantages. In particular, it is well-suited for a tourism area because, during periods of low discharge, the side spaces remain available for recreational purposes such as tourism or sports activities. This multifunctional use makes the channel not only a hydraulic structure but also an asset to the community.

In addition, the stepped geometry of the multi-stage channel provides greater resilience against sedimentation, facilitating regular maintenance and minimizing the need for extensive dredging or corrective works. When subjected to large discharge flows, such as the Q25 design flood, the channel continues to perform safely and effectively, maintaining stability with a minimum freeboard height of 0.5 m. This ensures that the structure can handle both routine and extreme hydrological conditions.

To sustain these benefits over time, it is essential to establish a program of regular inspection, operation, and maintenance. Such measures will ensure that the channel continues to function at its intended capacity and aligns with the original design plan. In this way, the multi-stage channel represents not only a technically sound solution but also a sustainable and community-friendly approach to flood control in sensitive or multifunctional landscapes.

5. Declarations

5.1. Author Contributions

Conceptualization, T.M.; methodology, T.M.; software, J.S.F.S.; validation, T.M., J.S.F.S., and Y.A.R.; formal analysis, T.M.; investigation, T.M.; resources, T.M.; data curation, Y.A.R.; writing—original draft preparation, J.S.F.S.; writing—review and editing, T.M.; visualization, R.R.I.L.; supervision, T.M.; project administration, R.R.I.L.; funding acquisition, T.M. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

5.4. Acknowledgments

The authors sincerely thank the North Sulawesi Watershed Area Center (BWS) and the National Disaster Management Agency (BNPB), for providing data.

5.5. Institutional Review Board Statement

Not applicable.

5.6. Informed Consent Statement

Not applicable.

5.7. Declaration of Competing Interest

The authors declare that there are no conflicts of interest concerning the publication of this manuscript. Furthermore, all ethical considerations, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

6. References

[1] Wahab, N. A., Kamarudin, M. K. A., Toriman, M. E., Juahir, H., Ata, F. M., Ghazali, A., Samah, M. A. A., Azinuddin, M., Khairuldin, W. M. K. F. W., & Hoe, L. I. (2022). The assessment of sedimentation and water quality status for river catchment management in Kenyir Lake Basin. Desalination and Water Treatment, 269, 93–105. doi:10.5004/dwt.2022.28674.

[2] Mase, L. Z. (2020). Slope Stability and Erosion-Sedimentation Analyses along Sub-watershed of Muara Bangkahulu River in Bengkulu City, Indonesia. E3S Web of Conferences, 148. doi:10.1051/e3sconf/202014803002.

[3] Listia, V., Munirwansyah, M., Azmeri, A., & Yulianur, A. (2023). An Investigation of Hydro-morphology Contributory Factors in Flooding and Sedimentation Problems on the Krueng Buloh River, Indonesia. The Open Civil Engineering Journal, 17(1), 1–13. doi:10.2174/18741495-v17-2306070-2022-83.

[4] Hu, J., Zhao, G., Mu, X., Hörmann, G., Tian, P., Gao, P., & Sun, W. (2020). Effect of soil and water conservation measures on regime-based suspended sediment load during floods. Sustainable Cities and Society, 55, 102044. doi:10.1016/j.scs.2020.102044.

[5] Gibson, S., & Shelley, J. (2020). Flood disturbance, recovery, and inter-flood incision on a large sand-bed river. Geomorphology, 351, 106973. doi:10.1016/j.geomorph.2019.106973.

[6] Fernandes, M. R., Aguiar, F. C., Martins, M. J., Rivaes, R., & Ferreira, M. T. (2020). Long-term human-generated alterations of Tagus River: Effects of hydrological regulation and land-use changes in distinct river zones. Catena, 188, 104466. doi:10.1016/j.catena.2020.104466.

[7] Mananoma, T. (2009). The effect of sediment supply to the damage of infrastructures. International Conference on Sustainable Development for Water and Waste Water Treatment, Yogyakarta, Indonesia.

[8] Tiny, M., Swingly Frans, S. J., & Rolans Izack, L. R. (2021). Study of Sediment Material Utilization for Morphology Stability of Bobuatan River. International Journal of Civil Engineering, 8(10), 14–22. doi:10.14445/23488352/ijce-v8i10p103.

[9] Makal, A. P., Mananoma, T., & Sumarauw, J. S. (2020). Analysis of Flood Discharge and Water Level of Kawangkoan River in Kawangkoan Village, Kalawat Sub-district, North Minahasa Regency. Jurnal Sipil Statik, 8(3), 283-292.

[10] Firmansyah, A. (2021). Descriptive Analysis of Tourism Potential in Villages Surrounding the Likupang Special Economic Zone (KEK). Jurnal Pariwisata Terapan, 5(2), 160-173. doi:10.22146/jpt.55822.

[11] Abbass, Z. D., Maatooq, J. S., & Al-Mukhtar, M. M. (2024). Investigating the Hydraulic Behaviours of an Alluvial Meandering River Reach between Two Barrages. Civil Engineering Journal, 10(05), 1561-1576. doi:10.28991/CEJ-2024-010-05-013.

[12] Auwyanto, K. H., Mananoma, T., & Sumarauw, J. S. (2024). Study of the Effectiveness of Gully Plugs in Controlling Runoff in the Upstream Area of the Pulisan Watershed. EDUSAINTEK: Jurnal Pendidikan, Sains dan Teknologi, 11(1), 143-158.

[13] Fitriadin, A. A., Ikhsan, J. U., & Harsanto, P. (2017). Morphology analysis in middle-downstream area of Progo River due to the debris flow. AIP Conference Proceedings, 1855(1), 040016. doi:10.1063/1.4985512.

[14] Mananoma, T., Sudjarwadi, & Legono, D. (2005). Prediction of Sediment Transport in Rivers for Water Damage Control. Pertemuan Ilmiah Tahunan HATHI XXII, Yogyakarta, Indonesia. Available online: http://repo.unsrat.ac.id/28/1/Prediksi_Transport_Sedimen_(HATHI%2CYogya_2005)_.pdf (accessed on August 2025).

[15] Mananoma, T., Legono, D., & Rahardjo, A. (2006). Torrential River Management to Control Watershed Damage. UNSRAT Repository, 1-8. Available online: http://repo.unsrat.ac.id/id/eprint/17 (accessed on August 2025).

[16] Yang, C. T. (1996). Sediment Transport: Theory and Practice. McGraw-Hill Book Company, Ohio, United States.

[17] El-Baradei, S. A., El-Abd, M., & Hazem, N. (2024). Estimate of Power Output from Hydraulic Jumps Generated Downstream from Barrages. Journal of Human, Earth, and Future, 5(1), 72–84. doi:10.28991/HEF-2024-05-01-06.

[18] Isa, M., Sumarauw, J. S., & Hendratta, L. A. (2020). Analysis of Flood Discharge and Water Level of the Marisa River, West Limboto District, Gorontalo Regency. Jurnal Sipil Statik, 8(4), 591-600.

[19] Sondak, S. W., Tangkudung, H., & Hendratta, L. A. (2019). Analysis of flood discharge and water level of the Girian River in Bitung City. Jurnal sipil statik, 7(12), 1681-1688.

[20] Triatmodjo, B. (2008). Applied Hydrology Yogyakarta. Beta Offset, Java, Indonesia.

[21] Soulis, K. X., & Valiantzas, J. D. (2012). SCS-CN parameter determination using rainfall-runoff data in heterogeneous watersheds-the two-CN system approach. Hydrology and Earth System Sciences, 16(3), 1001–1015. doi:10.5194/hess-16-1001-2012.

[22] Wijaya, T., & Wijayanti, Y. (2024). Flood Mapping Using HEC-RAS and HEC-HMS: A Case Study of Upper Citarum River at Dayeuhkolot District, Bandung Regency, West Java. IOP Conference Series: Earth and Environmental Science, 1324(1), 012103. doi:10.1088/1755-1315/1324/1/012103.

[23] Ikhwali, M. F., Pawattana, C., Nur, S., Azhari, B., Ikhsan, M., Aida, N., & Silvia, C. S. (2022). Reviews, challenges, and prospects of the application of Hydrologic Engineering Center-Hydrologic Modelling System (HEC-HMS) model in Indonesia. Engineering and Applied Science Research, 49(5), 669–680. doi:10.14456/easr.2022.65.

[24] Hussain, F., Wu, R. S., & Yu, K. C. (2021). Application of physically based semi-distributed HEC-HMS model for flow simulation in tributary catchments of Kaohsiung area Taiwan. Journal of Marine Science and Technology (Taiwan), 29(1), 42–62. doi:10.51400/2709-6998.1003.

[25] Fajar, M. M., Sumarauw, J. S. F., & Mananoma, T. Potential Analysis and Flood Control in Pulisan River with the Eco-Hydraulic Concept. Tekno, 20(80), 107–118. doi:10.35793/jts.v20i80.43026.