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Study of the Effectiveness of Flood Control Concepts in the Molibagu River, South Bolaang Mongondow Regency

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ABSTRACT

Flooding in Molibagu Village in 2020 caused significant damage and losses to residents living near the Molibagu River. One of the primary causes was heavy rainfall, which increased the river's flow discharge. This research aims to analyze flood discharge and water levels in the Molibagu River to reduce flood risks and identify effective flood control strategies. Several scenarios were evaluated, including river normalization, construction of embankments, and a combination of both. The study area, the Molibagu Watershed, spans 38.7 km². Secondary rainfall data from 2008 to 2022 was obtained from the Sulawesi I River Basin Office (BWSS-I) through ARR-MRG Kosinggolan Matayangan and MRG Bolangaso Molibagu rainfall stations. The HEC-HMS software was used to determine and calibrate the hydrological parameters required to calculate peak discharge (17.5 m³/s) and design flood discharges for multiple return periods. These results were then integrated into the HEC-RAS software to simulate water surface elevation and inundation areas. Three flood control scenarios were modeled using RAS Mapper to visualize the effectiveness of each approach. The findings indicate that the normalization scenario (Scenario 2) is more effective in reducing water levels and mitigating flood overflow compared to levee construction. However, at 50- and 100-year return periods, normalization alone is insufficient to reduce flood discharge, necessitating a combination of normalization and embankments (Scenario 3). This research provides valuable insights for policymakers and stakeholders in planning integrated flood control measures in the Molibagu River region.

INTRODUCTION

The Molibagu River is one of the main rivers that traverses *Bolaang Mongondow Selatan* Regency in *Bolaang Uki* District. Administratively, the Molibagu River flows through four villages: *Molibagu*, *Toluaya*, *Soguo*, and *Popodu*. Heavy rainfall has caused the *Salongo*, Molibagu, and *Tolondadu* rivers to overflow, leading to flash floods in mid-2020 across three districts: *Bolaang Uki*, *Helumo*, and *Tomini* (Jansen, Jansen, & Hendratta, 2017; Kairupan, Mananoma, & Sumarauw, 2017). The impact of the flooding damaged residential areas, roads, and several bridges, with some houses inundated by water levels ranging from 50 to 150 cm (Lengkey, Mananoma, & Sumarauw, 2019).

To control flooding caused by the overflow of the Molibagu River, structural measures are needed in addition to non-structural efforts to reduce flood disaster risks (Lalamentik, Sumarauw, & Hendratta, 2021; Manoppo, Mananoma, & Sumarauw, 2022). The selection of flood control structures must consider the effectiveness of the river's capacity, as well as the long-term benefits, costs, and potential drawbacks (Makal, Mananoma, & Sumarauw, 2020; Makahinsade, Mananoma, & Sumarauw, 2020). This study aims to conduct a hydrological and hydraulic approach to flood control along the Molibagu River. Several flood control scenarios will be designed and evaluated for their effectiveness to be implemented in the field as a preventive measure against future floods (Isa, Sumarauw, & Hendratta, 2020).

Rahman et al. (2019) conducted a study on flood mitigation in small watersheds in Indonesia using HEC-RAS modeling to simulate water levels under various rainfall intensities. Their findings demonstrated that levee construction could reduce peak water surface elevation by 15–20%. However, this study only focused on hydraulic modeling without considering upstream hydrological inflows or rainfall-runoff dynamics, which limited its accuracy under extreme conditions (Madhatillah, 2020). Similarly, Sulaiman and Pratiwi (2021) analyzed flood mitigation in the *Luna* River region using normalization and embankments, showing that normalization alone decreased inundation by 30%, while the addition of embankments provided only marginal improvements. Despite these insights, their research did not apply an integrated hydrology–hydraulic approach and lacked scenario testing across different flood return periods (Limpong, Mananoma, & Sumarauw, 2022; Mamahit, Mananoma, & Sumarauw, 2022).

Addressing these gaps, this study combines HEC-HMS for rainfall-runoff modeling with HEC-RAS for hydraulic simulations to evaluate three flood control scenarios—normalization, embankments, and a combination of both—on the Molibagu River. The objective of this research is to identify the most effective scenario to enhance the river's capacity and mitigate flooding. The benefits include providing practical recommendations and technical guidance for flood control planning in *Bolaang Mongondow Selatan*, ultimately improving community resilience against future flood events.

This research aims to identify the most effective scenario among several alternatives, including river normalization and the addition of embankments on the left and right sides of the river, for flood control efforts. The benefit of this research is to provide information regarding the most effective scenario for flood control. Based on the research topic, the researcher intends to explain that the implementation of flood control scenarios—such as the construction of embankments and river normalization—can improve the river's capacity and effectively control flooding in the Molibagu River.

METHOD

The Molibagu River Basin, located in the *Bolaang Uki* District, *South Bolaang Mongondow* Regency, *North Sulawesi* Province, has a river length of 448 meters and a riverbed width ranging from 30 meters to 60 meters. The research location is situated at the Molibagu River, with coordinates 0°23'40.412"N and 124°58'47.987"E. The study period is six months, from November 2023 to May 2024. Secondary data refers to technical data relevant to this research, which has been obtained from related institutions, published materials, and reports from individuals with relevant information. The data used in the study includes the topographic map of Molibagu obtained from the *Geospatial Information Agency*, the Molibagu River Basin map created using *Google Earth Pro*, maximum daily rainfall data from the *Sulawesi I River Basin Center*, discharge data from the *Sulawesi I River Basin Center*, and river cross-section data of Molibagu obtained from the *Sulawesi I River Basin Center*.

The methodology used in this study includes problem identification, which involves identifying the issues occurring at the research site. A literature review was conducted to gain knowledge and theoretical foundations for the research. Data collection was carried out to gather information about the general conditions at the site, as well as the necessary data, both primary and secondary. This was followed by the analysis of the collected data. Finally, the results are presented and discussed to provide insight into the effectiveness of the proposed flood control measures.

RESULTS AND DISCUSSION

The total maximum daily rainfall data for the Molibagu watershed (DAS Molibagu), obtained from the hydrology unit of the Sulawesi I River Basin Authority (BWSS-I) at the ARR-MRG Kosinggolan Matayangan and MRG Bolangaso Molibagu stations, provides maximum daily rainfall data over a 15-year period. The rainfall stations influencing the Molibagu watershed were identified, and their data were used for analysis. Using the regional analysis method, the Molibagu River's average discharge in 2009 was calculated as 1.062 m³/s. This calculated average discharge was then input into the HEC-HMS software as initial discharge data.

Watershed Parameter Calibration Using HEC-HMS

The calibration parameters obtained were used to determine the design flood discharge for various return periods.

1) **Basin Model Manager → Subbasin Creation Tool (sub-watershed).**
2) Inputting watershed parameters such as area, curve number, lag time, initial discharge, recession constant, and threshold ratio. The **SCS Curve Number** was used as the loss method, and **SCS Unit Hydrograph** was applied as the transform method.
3) Streamflow and rainfall data were entered into the **Time-series Data** component, using data from the Kosinggolan-Matayangan and Bolangaso-Molibagu rainfall stations (2009) and measured discharge from the Molibagu River (2009).
4) All rainfall stations were included in the **Meteorologic Models** component to calculate design rainfall, and the percentage influence of each station was determined using the gage weight approach.
5) The time and interval for discharge calculations were set using **Control Specifications.**
6) The Molibagu watershed was selected for calibration. Parameters such as baseflow, lag time, recession constant, curve number, and ratio to peak were adjusted. Default HEC-HMS parameter limits were applied.

Since this is a flood discharge analysis based on watershed area comparisons, only peak discharge data were considered. If the peak discharge approximates or matches the observed discharge, the analysis proceeds.

Flood Discharge Simulation Using HEC-HMS

In flood discharge calculations, the calibrated sub-watershed parameters were used. The steps include:

1) **Basin Model Manager → Subbasin Creation Tool (sub-watershed).**
2) Using calibrated parameters: watershed area, curve number, lag time, initial discharge, recession constant, and threshold ratio. **SCS Curve Number** was used as the loss method, and **SCS Unit Hydrograph** as the transform method.
3) Adding **Time-Series Data** for rainfall to calculate Q5, Q10, Q25, Q50, and Q100, adjusting rainfall units, duration, and time intervals.
4) **Meteorologic components** were adjusted based on return periods since rainfall data was already averaged.
5) **Control specifications** were set to determine calculation start and end times based on planned rainfall events.

After all components were completed, the design flood discharges for return periods of 5, 10, 25, 50, and 100 years were obtained.

5-Year Return Period: Peak discharge = 89.4 m³/s.

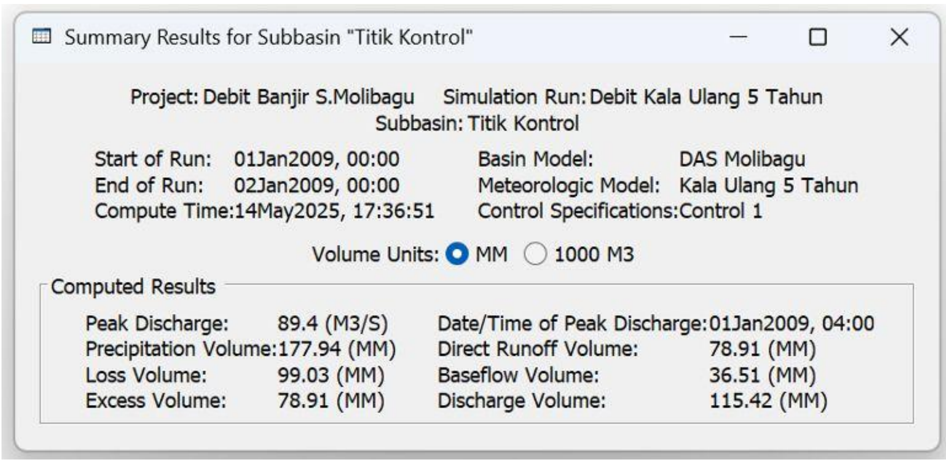

Figure 1. Summary of 5-Year Return Period Results

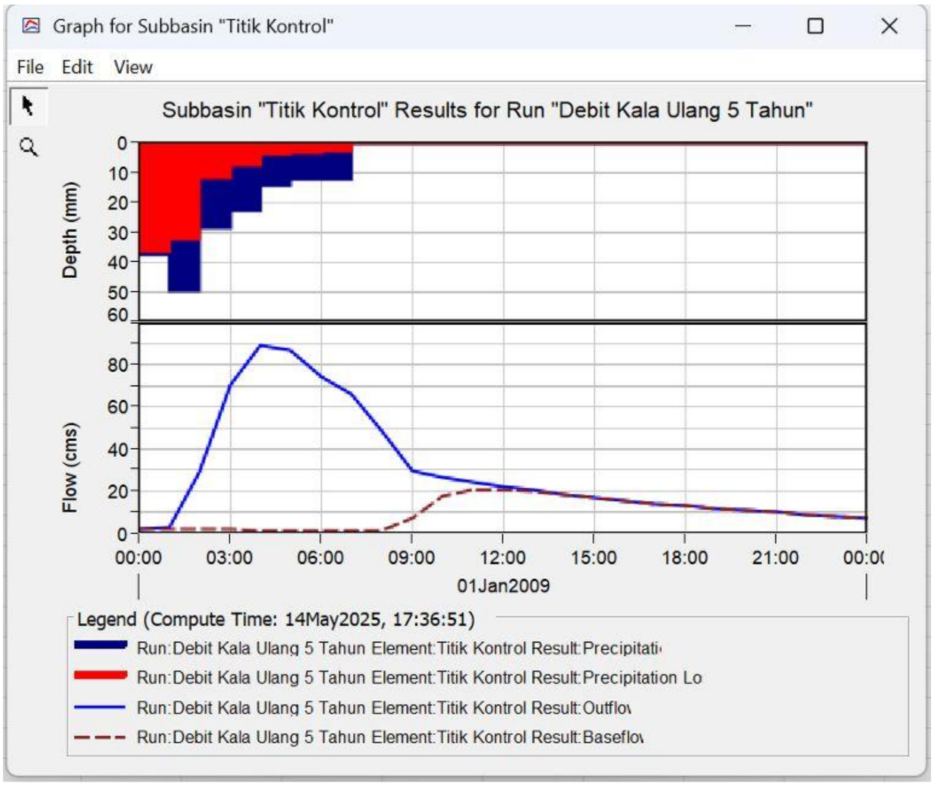

Figure 2. Hydrograph of Discharge for 5-Year Return Period

The results of the design flood discharge analysis for return periods of 10, 25, 50, and 100 years are shown in the table below:

Table 1. Design Flood Discharge for Various Return Periods

Return Period	Q_{10}	Q_{25}	Q_{50}	Q_{100}
Peak Discharge (m^3/det)	138,1	219,8	297,1	389,6

Hydraulic Analysis Using HEC-RAS

Flood inundation modeling for the existing condition was performed using HEC-RAS version 6.4.1 (version 6 or above is recommended) to identify locations of flood overflow along the river and inundation patterns for various return period discharges.

2D Flood Modeling Using HEC-RAS:

a. Projection Data

1) Determine the UTM (Universal Transverse Mercator) zone of the watershed under study.
2) The Molibagu watershed lies in Zone 51N. From https://spatialreference.org/, the projection (.PRJ) data is obtained to define the geometry coordinates on the map.

3) Open **RAS Mapper** in HEC-RAS and set the projection according to the UTM zone of the Molibagu watershed (Siban, Sumarauw, & Supit, 2023).

b. Topographic Data

1) The DEMNAS (National Digital Elevation Model) from the Geospatial Information Agency is combined with cross-section measurements of the Molibagu River using **Global Mapper**. The DEM used is sheet number 2316-244.
2) Create a **New RAS Terrain** combining field survey data and DEMNAS.

c. Land Cover Data

1) Assign Manning's roughness coefficient (n) values according to the Molibagu River characteristics: 0.04 for the main channel, 0.035 for the left overbank (LOB), and 0.03 for the right overbank (ROB).
2) In the map layers, **Create a New RAS Layer** and select **Land Cover Layer**, then manually classify land cover types (if shapefiles are unavailable).

d. Domain Setup

1) Create the 2D flow area perimeter slightly larger than the study area, with grid/cell size DX = 1 and DY = 1 for better representation.
2) Boundary condition lines are drawn perpendicular to the flow direction at the upstream and downstream ends but outside the 2D flow area.

e. Flow Simulation

1) Flow simulation uses unsteady flow data to model 2D flood events.
2) The downstream boundary condition is set as normal depth based on the energy slope due to friction, using average water surface slope data from the cross-sections.
3) The upstream boundary condition uses a **flow hydrograph** derived from SCS (Soil Conservation Service) design flood discharge for 5, 10, 25, 50, and 100-year return periods.

Table 2. Simulation Results of Flood Hydrograph for Various Return Periods

Time	Return Period				
(hours)	5	10	25	50	100
0	2,1	2,1	2,1	2,1	2,1
1	2,9	5,9	13,6	23,2	36,8
2	28,6	51,5	95,9	142,4	202,3
3	70,9	117	198	277,2	374,3
4	89,4	138,1	219,8	297,1	389,6
5	87	129,2	198,1	262,1	337,7
6	74	107,2	160,7	209,6	267,2
7	65,7	93,4	137,6	177,7	224,8
8	48,9	68,8	100,4	129	162,4
9	29,2	44,6	70,2	94,2	122,9
10	26,6	40,7	64,1	86	112,2
11	24,3	37,1	58,5	78,5	102,4

Time	Return Period				
(hours)	5	10	25	50	100
12	22,2	33,9	53,4	71,7	93,5
13	20,3	30,9	48,7	65,4	85,3
14	18,5	28,2	44,5	59,7	77,9
15	16,9	25,8	40,6	54,5	71,1
16	15,4	23,5	37	49,7	64,8
17	14	21,5	33,8	45,4	59,2
18	12,8	19,6	30,8	41,4	54
19	11,7	17,9	28,2	37,8	49,3
20	10,7	16,3	25,7	34,5	45
21	9,7	14,9	23,5	31,5	41,1
22	8,9	13,6	21,4	28,8	37,5
23	8,1	12,4	19,6	26,2	34,2
0	7,4	11,3	17,8	24	31,2

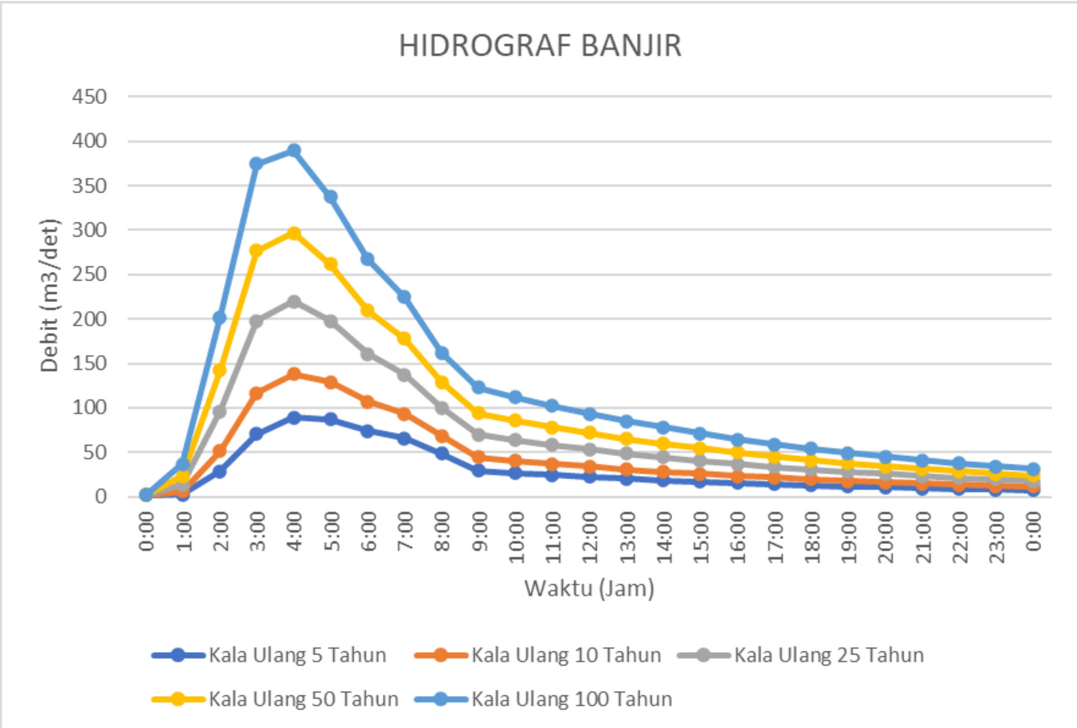

Figure 3. Flood Hydrograph of the Molibagu Watershed

Based on the flood hydrograph graph above, it shows the relationship between discharge and time at the upstream boundary of the river (Oroh, Supit, & Sumarauw, 2023; Sakudu, Sumarauw, & Mananoma, 2023). From these data, the flow routing results indicate changes in discharge at the upstream boundary and constant water levels at the downstream boundary (Nadia, Mananoma, & Tangkudung, 2019; Welliang, Sumarauw, & Mananoma, 2019).

Flow Simulation & Run

In the Computation Settings, the calculation time step used is 6 seconds, with 5 minutes for the Hydrograph Output Interval and 5 minutes for the Detailed Output Interval (Supit, 2013; Sumarauw, 2017a). This setting ensures that detailed calculations and hydrograph coordinate data are recorded and saved every five minutes, even though the time step is 6 seconds. The 6-second interval was chosen considering the significant increase in discharge from 2.9 m³/s in the 2nd hour to 28 m³/s in the 3rd hour (Sumarauw, 2013; Sumarauw, 2017b). The computation settings significantly influence the model's stability and the simulation time, depending on the length or shortness of the time interval being simulated (Sumarauw, 2017c; Sumarauw, 2018; Poli, Sumarauw, & Mananoma, 2019).

CONCLUSION

The HEC-RAS 2D simulation shows that each cross-section of the *Molibagu* River cannot accommodate the design flood discharges for return periods of 5 years (89.4 m³/s), 10 years (138.1 m³/s), 25 years (219.8 m³/s), 50 years (297.1 m³/s), and 100 years (389.6 m³/s). To address this, three flood control scenarios were applied. Scenario 1 (*Levees*): For the 5-year return period, *levees* at two locations (396 m long, 1–1.2 m high, 2 m wide) reduced inundation by 6,977 m². For the 10-year return period, *levees* at three locations (573 m long, 1.2–1.4 m high) reduced 12,890 m². For the 25-year return period, *levees* at four locations (759 m long, 1.2–2.4 m high) reduced 44,118 m². Scenario 2 (*River Normalization*): For the 5-year return period, widening the river (20 m top width, 40 m bottom width) reduced 11,753 m². For 10 years, increasing width to 30 m/50 m reduced 15,221 m². For 25 years, widening to 35 m/50 m reduced 42,484 m². Scenario 3 (*Combination*): For the 50-year return period, combining *levees* (from Scenario 1) and normalization (from Scenario 2) reduced 63,500 m². For the 100-year return period, the combination reduced 77,485 m². Thus, the combined use of *levees* and normalization effectively reduced flood discharges compared to pre-treatment conditions. Scenario 2 (*normalization*) is more effective in lowering water levels and controlling floods than *levees* alone. However, for 50- and 100-year return periods, only a combination of Scenarios 1 and 2 can accommodate all design flood discharges, eliminating inundation entirely.

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