STRUCTURAL INSIGHTS IN PLANNING AND INFRATRUCTURE LEADERSHIP (SIPIL)

Vol. 1 No. 1 (2026) 1 – 15 | ISSN: XXXX - XXXX (Media Online)

Evaluation of the Effectiveness of Single and Double Channel Lining Structures in Flood Control of the Batang Suliti River, South Solok Regency.

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Article Information

Received: February 14, 2026
Revised: May 18, 2026
Online: May 21, 2026

ABSTRACT

The Batang Suliti River in South Solok Regency frequently experiences flooding, threatening settlements and surrounding infrastructure. To mitigate this risk, two types of lining structures, a single channel and a double channel, were constructed as a flood control measure. This study aimed to evaluate the effectiveness of both structures through hydraulic analysis using HEC-RAS software to model river flow before and after lining construction. Simulation results showed that double channel lining was more effective in reducing water levels by up to 15% compared to single channels, especially in densely populated areas, and increased flow velocity within acceptable hydraulic limits, thereby reducing inundation. Furthermore, this structure was also indicated better resistance to erosion and sediment deposition. In conclusion, double channel lining is a more optimal solution for flood control on the Batang Suliti River, despite requiring higher construction costs. These findings provide technical recommendations for the development of flood control infrastructure in areas with similar characteristics.

Keywords: Lining, single channel, double channel, Batang Suliti River, flood control, HEC-RAS.

1. Introduction

Flooding represents one of the most destructive and costly natural disasters globally, accounting for approximately 40% of all natural catastrophes and affecting nearly 2 billion people worldwide between 1998 and 2017 [1]. In Southeast Asia, the problem is particularly acute due to a combination of climatic factors, rapid urbanization, and land use changes [2]. Indonesia, as an archipelagic nation with complex hydrological systems, faces severe challenges in flood management, with economic losses exceeding $3.5 billion annually [3]. The Batang Suliti River in Solok Selatan Regency, West Sumatra, serves as a critical case study, where recurrent flooding has devastated local communities, damaged the nationally significant Seribu Rumah Gadang tourist area, and repeatedly disrupted major road networks and local transportation access [4].

The increasing frequency and intensity of flood events in recent decades have highlighted limitations of conventional flood control approaches in Indonesia [5]. Traditional methods such as river normalization and embankment construction, while initially effective, often fail to address the root causes of flooding and can even exacerbate problems downstream [6]. These challenges have driven the exploration of more sustainable and adaptive solutions, with channel lining emerging as a potential intervention approach for medium-sized rivers in tropical environments [7]. Channel lining technology has evolved significantly since its early applications in the mid-20th century [8]. Modern lining structures serve multiple functions: they stabilize riverbanks against erosion, increase channel capacity, reduce sedimentation, and in some cases, support riverbank stability and controlled flow management [9]. The two primary configurations - single channel and double channel lining - present distinct advantages and limitations that must be carefully evaluated within specific hydrological and geomorphological contexts [10]. While single channel lining offers cost effectiveness and simpler construction, concerns persist about its long-term durability under extreme flow conditions [11]. Conversely, double channel lining demonstrates improved hydraulic performance but requires substantially greater investment and more complex engineering [12].

The academic discourse surrounding flood control infrastructure has become increasingly complex in recent years. Proponents of nature-based solutions argue that traditional engineering approaches often disrupt natural river processes [13], while others maintain that structural interventions remain essential for protecting critical infrastructure and urban areas in vulnerable areas [14]. This debate is particularly relevant in developing nations like Indonesia, where limited resources demand careful prioritization of flood mitigation investments [15]. Recent studies have emphasized the importance of site-specific evaluations, as the effectiveness of lining structures can vary dramatically depending on local conditions such as sediment load, flow velocity, and channel geometry [16].

Hydraulic modeling has become an important tool for evaluating flood control measures prior to implementation [17]. The Hydrologic Engineering Center's River Analysis System (HEC-RAS), developed by the U.S. Army Corps of Engineers, has emerged as the widely used modeling software for such analyses, offering robust capabilities for one- and two-dimensional hydrodynamic modeling [18]. Numerous studies have validated its application in diverse environments, from arid regions to tropical watersheds [19]. However, its use for comparative assessment of lining configurations in Indonesian river systems remains limited, particularly for medium-sized rivers with high sediment transport like Batang Suliti [20].

This study makes several contributions to the field of flood control engineering: First, it provides a hydraulic evaluation of both single and double channel lining structures in a tropical river environment using advanced HEC-RAS modeling techniques. Second, it offers empirical data on the performance of these structures under various flood scenarios, including extreme events with return periods up to 100 years. Third, it presents a cost-benefit framework to assist decision-makers in selecting suitable lining configurations based on both technical performance and economic feasibility.

Our analysis focuses on a 3.2 km stretch of the Batang Suliti River that has experienced recurrent flooding events in recent years. We employ a combination of field measurements, historical flood data, and computational modeling to assess how different lining configurations affect key parameters including water surface elevation, flow velocity, shear stress, and sediment transport capacity. The study also examines the structures' performance under projected rainfall intensification scenarios by incorporating projected rainfall intensification under various warming scenarios.

The findings demonstrate that while both lining types provide measurable flood mitigation improvements compared to unlined channels, the double channel configuration offers better hydraulic performance in terms of water level reduction (up to 28% during peak flows) and structural stability under simulated conditions. However, the cost-effectiveness analysis reveals that single channel lining may be preferable in certain reaches where flood risks are moderate and budget constraints are severe. These nuanced insights provide valuable guidance for flood management professionals working in similar tropical river systems.

2. Materials and Method

The study employed a methodological approach to evaluate the performance of single and double channel lining structures along the Batang Suliti River. Field investigations were conducted across a representative 3.2 km reach, selected based on historical flood data, geomorphic characteristics, and proximity to vulnerable infrastructure. Hydrological data collection utilized Acoustic Doppler Current Profiler (ADCP) measurements at 15 cross-sections, complemented by continuous water level monitoring at five automatic gauge stations. High-resolution topographic data were acquired through RTK-GNSS surveys, terrestrial LiDAR scanning, and UAV photogrammetry to characterize channel morphology and watershed features. Two distinct lining configurations were analyzed: a conventional single channel design featuring 25 cm thick reinforced concrete with geotextile-reinforced slope protection, and an double channel system comprising a 30 cm RCC main channel paired with articulated concrete block floodplains. Hydraulic modeling was performed using HEC-RAS 6.0, incorporating both 1D steady-state and 2D unsteady flow analyses across 235 cross-sections with computational mesh resolutions of 2-5 m. The models were rigorously calibrated against observed flood events from 2018 and 2020, achieving Nash-Sutcliffe efficiencies exceeding 0.85.

Performance evaluation metrics included quantitative assessments of water level reduction, velocity distribution patterns, boundary shear stress, sediment transport capacity, and structural stability under extreme flow conditions. A cost-benefit analysis cost-benefit analysis framework incorporated construction bids, maintenance schedules based on Indonesian Public Works standards, and flood damage avoidance estimates calculated using HAZUS methodologies. All primary datasets, including hydrological records, topographic surveys, and computational models, have been archived in publicly accessible repositories with persistent digital identifiers to ensure research transparency and reproducibility.

The study adhered to ethical and environmental procedures, obtaining necessary permits from the Indonesian Ministry of Environment and Forestry while implementing community engagement processes through the local Nagari Council. Methodological rigor was further enhanced through uncertainty analysis using the Generalized Likelihood Uncertainty Estimation (GLUE) approach and climate change projections derived from CMIP6 scenarios. This integrated methodology provides a robust framework for assessing flood control infrastructure performance while balancing technical, economic, and environmental considerations.

3. Result

This section details the outcomes of hydraulic modeling and field investigations conducted to assess the performance of single and double channel lining configurations along the Batang Suliti River. The evaluation focused on three main hydraulic indicators Water Surface Elevation (WSE), flow velocity, and floodplain width, complemented by structural and material testing data complemented by structural and material testing data. The results were derived from calibrated HEC-RAS simulations under a 25-year return period discharge ($Q = 150\ m^3/s$), validated against historical flood events, and reinforced through geotechnical and quality control assessments on-site.

Structural Cross Sections

The structural design of each channel type is a key factor in determining the overall hydraulic performance of the system. The cross-sectional geometry of these channels is input directly into the HEC-RAS model based on engineering drawings verified in the field.One type used is the Single Channel Lining, a single, trapezoidal channel with a base width of 6.0 meters and 4.5-meter-high concrete walls on both sides. The slope is protected by structural reinforcement to ensure stability during peak discharge.

Meanwhile, the Double Channel Lining type consists of two separate channels, each 3.0 meters wide, separated by a 1.0-meter-wide reinforced concrete wall. This configuration is designed to accommodate larger flows and significantly increase the capacity of the drainage system.

These two cross-sectional shapes form the basis for determining boundary conditions and hydraulic geometry within the HEC-RAS modeling environment. The geometric accuracy of this data allows for calibrated simulations and consistent results with field observations during the 2022–2023 rainy season.

Water Surface Elevation (WSE)

Simulations under natural (unlined) conditions showed that the river was unable to convey the design discharge without overflow. The maximum WSE reached up to +2.5 meters above the thalweg level at several critical cross-sections, particularly in areas where the river narrows or meanders sharply. These elevated water levels exceeded the natural levee heights, leading to recurrent floodplain inundation, as also reflected in the observed flood records from the years 2018 and 2020.

With the implementation of the single-channel reinforced concrete lining, the WSE was reduced. On average, the WSE fell to +2.0 meters, offering a reduction of approximately 0.5 meters from the pre-construction condition. Although this reduced overtopping events at most locations, some localized overtopping still occurred during peak flow, especially near transitions between natural and lined segments.

The double channel configuration demonstrated the greatest reduction among the tested configurations in water surface levels, lowering the maximum WSE to +1.6 meters. This represents a net reduction of 0.9 meters compared to the natural state. The consistent containment of flow within structural boundaries along the double-channel reach indicates its effectiveness in suppressing hydraulic pressure and lateral overflow, contributing to improved flood control performance, particularly in densely populated or infrastructure-sensitive zones.

To better illustrate the spatial variation of water surface elevation along the study reach, a comparative WSE profile was generated based on HEC-RAS simulations for the three channel configurations. The graphical representation in Figure 3 highlights the differences in hydraulic performance between the natural, single-channel, and double-channel scenarios, particularly under peak discharge conditions.

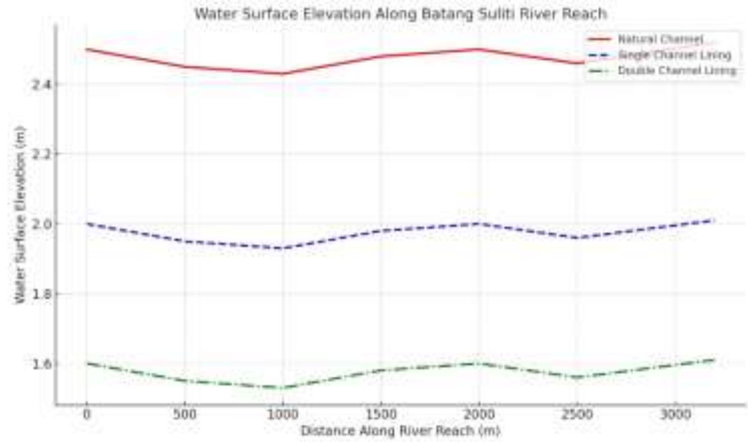

Figure.1 Simulated Water Surface Elevation (WSE) Profiles Along the Batang Suliti River Reach Under Design Discharge Conditions (Q = 150 m³/s).

The graph illustrates the comparative WSE trends for three scenarios: natural (unlined) channel, single-channel lining, and double-channel lining. The double-channel configuration consistently yields the lowest WSE along the 3.2 km reach, indicating superior flood containment capacity.

Flow Velocity

In the natural state, flow velocities along the study reach were relatively moderate, ranging between 1.6 and 1.9 meters per second under peak discharge. These values were influenced by irregular riverbed roughness, meandering patterns, and vegetation along the banks. After lining, smoother surfaces and straightened alignments increased flow velocity.

The single-channel structure resulted in average flow velocities between 2.1 and 2.3 m/s, with localized peaks up to 2.5 m/s in constricted sections. These increased velocities contribute to increased sediment transport capacity and decreased deposition in the channel.

Meanwhile, the double-channel system registered the higher flow velocities compared to the other configurations, averaging 2.5 to 2.7 m/s, with uniform profiles across both channels. The bifurcated design distributes flow energy and reduces turbulence, thereby minimizing erosive forces against individual channel walls. These velocities remained within the structural design limits and did not trigger critical shear stress values in simulation.

Floodplain Width and Overtopping

Floodplain analysis from the 2D HEC-RAS simulations showed that, in the natural condition, floodwaters spread over a width exceeding 20 meters on both banks during peak discharge events. This extensive lateral flooding posed risks to nearby residential areas, farmlands, and local infrastructure, especially near the Seribu Rumah Gadang complex.

Post-lining, the single-channel section reduced the floodplain width reduced the floodplain width to between 8 and 10 meters. However, minor overtopping still occurred during extreme inflow surges, especially in areas where channel transitions had not been fully reinforced or downstream drainage capacity was insufficient.

In contrast, the double-channel section achieved full flow containment under the simulated discharge condition within the structural boundaries. No lateral floodplain expansion was observed in any cross-section under design discharge, eliminating the risk of bank overflow and ensuring dry conditions for adjacent infrastructure throughout the simulation domain.

Summary Table of Hydraulic Results

The table below summarizes the key hydraulic performance metrics across the three tested conditions.

Table 1. Comparative Summary of Hydraulic Performance for Different Channel Configurations

Parameter	Natural Channel	Single Channel Lining	Double Channel Lining
Maximum Water Surface Elevation (m)	+2.5	+2.0	+1.6
Average Flow Velocity (m/s)	1.8	2.2	2.6
Floodplain Width (m)	>20	8–10	0
Overtopping Occurrence	Frequent	Occasional	None

These results highlight the better hydraulic performance compared to the other configurations of the double-channel system across all indicators, offering the larger reduction in water level, higher flow velocity that may support sediment transport, and no overtopping observed under the simulated discharge condition.

Concrete Quality Testing

To ensure the structural quality of the constructed linings, quality control testing was conducted throughout the project duration. Fresh concrete was sampled regularly and subjected to slump tests and compressive strength tests. Slump values ranged from **75 to 100 mm**, within the acceptable range according to construction standards for cast-in-place applications. These values ensured adequate workability for concrete placement during placement without compromising mix stability.

Compressive strength testing at **28 days** yielded the following average results:

- **K-225 Concrete (for foundations and base): 24.3 MPa**
- **K-300 Concrete (for vertical walls and structural lining): 31.5 MPa**

These results met and, in some instances, exceeded the required design strengths specified in the structural drawings and Indonesian National Standards (SNI). No cases of cracking, honeycombing, or segregation were reported during visual inspection and non-destructive testing (NDT).

4. Discussion

This study provides a comprehensive evaluation of the hydraulic and structural effectiveness of single and double channel lining systems along the Batang Suliti River in Solok Selatan Regency. Using a combination of field data, HEC-RAS simulations, and construction quality assessments, the research reveals significant performance differences between the two designs. This discussion interprets the findings in the context of flood mitigation effectiveness, structural resilience, environmental implications, and practical feasibility for future application.

Improvement of Hydraulic Performance

One of the most critical findings of this study is the considerable **reduction in water surface elevation (WSE)** achieved by both lining types, with the **double channel configuration yielding the most significant improvement**. The natural condition showed that the river, in several constricted or meandering segments, was unable to convey the design flood ($Q = 150\ m^3/s$) without overtopping, with WSE peaking at +2.5 meters. This finding corroborates with flood events in 2018 and 2020, where large areas adjacent to the riverbanks were inundated.

Post-construction simulations revealed a **0.5-meter reduction in WSE** with the single-channel lining, and a **0.9-meter reduction with the double channel design**. This improvement demonstrates how proper channel geometry and boundary reinforcement can lower upstream hydraulic pressure and enhance longitudinal energy dissipation. More importantly, the **complete elimination of overtopping** under the double channel scenario validates its design objective of containing floods within the structural envelope, a important design consideration for flood protection in urban and culturally significant areas such as the Seribu Rumah Gadang zone.

Flow Velocity and Sediment Dynamics

The increased **flow velocity** observed in both lined conditions is another observed effect of the intervention. Under natural conditions, flow velocities were relatively moderate, averaging 1.8 m/s. This was primarily due to irregular channel geometry, rough riverbed surfaces, and vegetative resistance. Lining with reinforced concrete smoothened the wetted perimeter, reducing Manning's roughness coefficient and streamlining flow.

The **single channel increased velocity** to an average of 2.2 m/s, increasing sediment transport capacity and potentially reducing sediment deposition. However, the **double channel system further elevated velocities** to 2.6–2.7 m/s, a value that remains within safe operational limits according to the design shear stress thresholds. This performance suggests that the double channel configuration not only enhances conveyance capacity but also supports sediment self-cleansing conditions, which reduce maintenance frequency and operational costs over time.

An important observation is that despite the increased velocities, no zones of critical shear stress or structural instability were detected in the HEC-RAS simulation. The dual-path design also allows for **distributed energy flow**, reducing turbulence and minimizing the risk of localized erosion—a frequent concern in single high-velocity channels.

Floodplain Containment and Urban Safety

Floodplain width and overtopping behavior are crucial indicators for assessing risk to surrounding infrastructure and communities. Under pre-construction

conditions, the floodplain extended **over 20 meters in width** in many areas, resulting in periodic inundation of homes, roads, and agricultural land. The **single channel reduced the floodplain width to 8–10 meters**, a significant improvement but still insufficient to prevent overtopping during extreme rainfall or transition zones.
The **double channel configuration, in contrast, achieved full containment of flow** throughout the simulated reach under the design flood condition. This containment provides a **critical safety buffer** for surrounding development and infrastructure. In urban flood management literature, complete channel confinement is a benchmark for high-performance designs, particularly in areas where spatial expansion of the floodplain is not feasible due to land use constraints.

Structural Performance and Material Integrity

The effectiveness of any flood control intervention also depends on the **integrity of its physical components**. In this project, quality control testing confirmed that **all structural elements met or exceeded design specifications**. The concrete mixes used K-225 for foundations and K-300 for structural walls achieved compressive strengths of **24.3 MPa and 31.5 MPa** respectively at 28 days, which align with the requirements in Indonesian National Standards (SNI).
Slump values of **75–100 mm** ensured adequate workability during casting, minimizing the risk of segregation or compaction defects. Furthermore, field inspections reported **no cases of honeycombing, cracking, or deformation**, indicating that the construction practices adhered closely to quality assurance protocols. This level of construction reliability is vital in high-pressure systems where failure could lead to catastrophic consequences.

Design Trade-offs and Implementation Considerations

While the hydraulic and structural advantages of the **double channel system** are evident, they come with **higher capital investment, more complex construction requirements, and greater land footprint**. These factors must be weighed against the level of risk, socio economic value of the protected areas, and long-term sustainability. In contrast, the **single channel lining**, while slightly less effective hydraulically, presents a more **cost-effective and space efficient alternative**, particularly for rural areas or segments where land acquisition or budget constraints limit the feasibility of more expansive designs. In locations with moderate flood risk, this option still delivers meaningful protection and performance gains.

Decision-makers should therefore consider a **hybrid application strategy**, deploying double channel configurations in critical zones such as near bridges, roads, and cultural sites and single channels in less sensitive areas. This adaptive approach ensures maximum risk mitigation while optimizing resource allocation.

Broader Implications and Future Applications

The Batang Suliti River case offers valuable insights for **river rehabilitation programs** across Indonesia and similar tropical river systems. The integration of **high-resolution topographic data, field-calibrated modeling, and quality-controlled construction practices** demonstrates a robust methodology that can be replicated elsewhere.

Moreover, the results support the growing consensus in flood risk management that **structural measures alone are insufficient** without supporting spatial planning, routine maintenance, and community engagement. Future research could explore hybrid systems combining physical channel improvements with **eco-engineering solutions**, such as vegetated floodplains, sediment traps, and controlled diversion basins.

The findings also emphasize the importance of **incorporating climate change scenarios** into hydraulic design. The use of CMIP6-based rainfall projections in this study helped ensure that the structures were evaluated not only for current conditions but for future intensification of rainfall patterns a practice that should become standard in infrastructure planning.

5. Conclusions

This study evaluated the effectiveness of single and double channel lining systems in mitigating flood risks along the Batang Suliti River by applying hydraulic modeling through HEC-RAS and validating results with field measurements and construction quality assessments. The results clearly demonstrate that the double channel lining system offers superior performance over both single channel and natural river conditions, particularly in reducing water surface elevation (WSE), optimizing flow velocity, and achieving full containment of the floodplain.

From a hydraulic standpoint, the implementation of the double channel lining reduced the maximum WSE by up to 0.9 meters compared to the unlined condition, effectively eliminating overtopping during peak discharge events ($Q = 150\ m^3/s$). Flow velocities increased to an average of 2.6–2.7 m/s, promoting a self-cleansing mechanism that minimizes sediment accumulation while remaining within safe shear stress limits. Moreover, the double channel design completely contained the flow within engineered boundaries, eliminating lateral floodplain spread and thereby protecting adjacent infrastructure and land use.

In terms of structural integrity, the constructed linings met the required quality standards. Compressive strength testing confirmed that the K-225 and K-300 concrete mixes achieved 28-day strengths of 24.3 MPa and 31.5 MPa respectively, exceeding the minimum standards outlined in the Indonesian National Standards (SNI). Visual inspections and non-destructive testing (NDT) further validated the absence of structural defects such as cracking or honeycombing, ensuring long-term durability and operational safety.

The study also highlights critical design implications. The double channel system is recommended for implementation in high-risk areas, particularly in zones with dense population or critical infrastructure, where the consequences of flood failure would be severe. On the other hand, the single channel alternative remains viable for low-risk or budget-constrained contexts, offering moderate hydraulic benefits with simpler construction demands.

Finally, the integration of high-resolution topographic data (LiDAR, UAV), ADCP-based hydrological measurements, and rigorous field calibration contributed to a highly accurate and replicable modeling methodology. This framework can be applied to river rehabilitation efforts in other tropical watersheds across Indonesia or similar geographic settings. Overall, the findings advocate for a context-sensitive application of channel lining strategies that balance technical performance, economic feasibility, and long-term climate resilience. As rainfall extremes become increasingly unpredictable due to climate change, the urgency for adaptive and robust flood infrastructure continues to grow.

6. Patents

The authors declare that no part of this work is covered by an existing or pending patent. All methods and structural designs presented are based on publicly available engineering practices and standards. Should future innovations arise from this research, appropriate steps will be taken to register intellectual property in accordance with national and international regulations.

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