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Analysis of the Partition Method in Reservoirs to Enhance Operation and Maintenance Efficiency at the Mengkoang Reservoir

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Abstract

Dams are essential water resources infrastructures that play a significant role in supplying water for various purposes, including agricultural and plantation irrigation. One of the primary factors affecting reservoir performance and service life is sedimentation. Mengkoang Reservoir, which serves as a water source for agricultural and plantation irrigation in the vicinity of Lape Village, experiences sedimentation problems that result in sediment accumulation within water conveyance channels, disruption of irrigation distribution, and reduction of reservoir storage capacity. This study aims to analyze sedimentation characteristics and evaluate the effectiveness of check structures (skat) as a sediment control measure in Mengkoang Reservoir. The research methodology involved the collection of geographical, geological, and climatological data to characterize the study area, followed by hydrological and hydraulic analyses to determine rainfall, discharge, and sedimentation rates. Furthermore, numerical simulations were conducted using HEC-RAS 2D to model flow patterns and sediment transport under different check structure scenarios. The simulation results indicate that a concrete check structure is capable of retaining up to 80% of incoming sediment; however, it generates a relatively greater backwater effect. In contrast, a gabion check structure retains approximately 65% of sediment while producing a lower backwater impact. Sedimentation analysis revealed an annual sedimentation rate of 1,838 tons/year under existing conditions, which decreased to 1,541 tons/year following the implementation of the check structure system. These findings demonstrate that the application of check structures is effective in reducing sedimentation rates in Mengkoang Reservoir. The selection of construction materials should consider the trade-off between sediment retention efficiency and the hydraulic impacts generated by backwater effects.

Keywords: *sedimentation, reservoir, dam, HEC-RAS 2D, check structure, sediment control.*

Abstrak

Bendungan merupakan infrastruktur sumber daya air yang berperan penting dalam penyediaan air untuk berbagai kebutuhan, termasuk irigasi pertanian dan perkebunan. Salah satu permasalahan utama yang memengaruhi kinerja dan umur layanan waduk adalah sedimentasi. Waduk Mengkoang yang berfungsi sebagai sumber air irigasi bagi lahan pertanian dan perkebunan di sekitar Desa Lape mengalami permasalahan sedimentasi yang menyebabkan penumpukan material pada saluran air, mengganggu distribusi irigasi, serta mengurangi kapasitas tampungan waduk. Penelitian ini bertujuan menganalisis karakteristik sedimentasi serta mengevaluasi efektivitas penerapan skat sebagai upaya pengendalian sedimen di Waduk

Mengkoang. Metode penelitian meliputi pengumpulan data geografis, geologis, dan klimatologis untuk mengidentifikasi kondisi daerah studi, dilanjutkan dengan analisis hidrologi dan hidraulika guna menentukan curah hujan, debit aliran, dan laju sedimentasi. Selanjutnya, pemodelan dilakukan menggunakan perangkat lunak HEC-RAS 2D untuk mensimulasikan pola aliran dan distribusi sedimen pada berbagai skenario penerapan skat. Hasil pemodelan menunjukkan bahwa skat berbahan beton mampu menahan sedimentasi hingga 80%, namun menghasilkan efek backwater yang relatif lebih besar. Sementara itu, skat berbahan bronjong mampu menahan sekitar 65% sedimentasi dengan dampak backwater yang lebih rendah. Hasil analisis sedimentasi menunjukkan laju sedimentasi pada kondisi eksisting sebesar 1.838 ton/tahun, yang berkurang menjadi 1.541 ton/tahun setelah penerapan sistem skat. Temuan ini menunjukkan bahwa penerapan skat efektif dalam mengurangi laju sedimentasi di Waduk Mengkoang, dengan pemilihan material yang perlu mempertimbangkan keseimbangan antara efektivitas penahanan sedimen dan dampak hidraulik yang ditimbulkan.

Kata kunci: *sedimentasi, waduk, bendungan, HEC-RAS 2D, skat, pengendalian sedimen*

INTRODUCTION

Dams constitute one of the most important water resources infrastructures extensively developed in Indonesia. As hydraulic structures, dams function to impound river water within reservoirs and serve multiple purposes, including hydropower generation, flood mitigation, irrigation supply, and tourism development. In addition to hydraulic design considerations, sedimentation represents a critical factor that must be addressed during dam planning and management. An inevitable consequence of river water impoundment is the accumulation of sediments transported by streamflow. These sediments are generally classified into two categories: suspended load, consisting of fine colloidal particles transported within the water column, and bed load, comprising coarser particles that move along the riverbed under the influence of flowing water. (Soedibyo, 1987).

The planning and design of a dam are inherently linked to the projected service life of its reservoir. Consequently, reservoir planning must incorporate estimates of the volume of sediment expected to accumulate throughout the reservoir's operational lifespan. Accurate prediction of sediment inflow is essential to ensure that storage capacity, operational performance, and reservoir functionality can be maintained over the intended design life. (Achsan, Bisri, & Suharyanto, 2015). The service life of a reservoir is primarily determined by the duration required for sediment to occupy the dead storage capacity (Mukti, 2019). Reservoir sedimentation generally originates from watershed and riverbank erosion processes occurring throughout the drainage network. Sediment particles transported by streamflow are eventually deposited within the reservoir, leading to a gradual reduction in storage capacity and potentially affecting reservoir performance and sustainability. (Wulandari, 2007).

The storage capacity of a reservoir gradually decreases over time as a result of continuous sediment accumulation. The deposition of incoming sediments alters both the surface area and storage volume of the reservoir, thereby reducing its effective capacity and potentially impairing its operational performance. (Issa, Al-Ansari, Sherwany, & Knutsson, 2015). Furthermore, the reduction in effective reservoir storage capacity caused by sedimentation can significantly impair the reservoir’s functional benefits. As sediment accumulates, the available storage volume decreases, thereby reducing the reservoir’s ability to fulfill its intended purposes, including water supply, irrigation, flood control, and other operational functions. (Soewarno & Syariman, 2008).

Understanding the spatial distribution of sediment deposition within a reservoir is essential for developing appropriate sediment management strategies. Knowledge of sediment distribution patterns enables the identification of effective mitigation measures aimed at reducing sedimentation rates and minimizing sediment accumulation within the reservoir, thereby enhancing reservoir performance and prolonging its operational lifespan. (Vitta Pratiwi, 2017). Therefore, hydrodynamic modeling is required to analyze sediment distribution patterns within the reservoir and to support the development of effective sediment management strategies. One of the reservoirs currently affected by sedimentation is Mengkoang Dam, which is administratively located in Lape Village, Lape Lopok District, Sumbawa Regency, Indonesia. Geographically, the dam is situated at coordinates 117°37′52.2″ E and 8°38′37.9″ S. The site can be accessed by four-wheeled vehicles and is located approximately 50 km from Sumbawa Besar City. A detailed map of the Mengkoang Dam location is presented in Figure X (Sediment Control and Dam Area Management Plan for Sumbawa I, 2020).

Figure 1. Location Map of Mengkoang DAM

Mengkoang Reservoir serves as a primary water source for agricultural and plantation irrigation in the communities surrounding Lape Village. In addition, the reservoir provides raw water to meet the domestic water demands of local residents. In the upstream section of the reservoir, the surrounding hills on both sides act as natural catchment features that enhance the reservoir's water storage capacity. The upstream area remains predominantly covered by forest vegetation, with no significant agricultural activities or residential settlements present within the catchment area (Sediment Control and Dam Area Management Plan for Sumbawa I, 2020).

River sedimentation significantly affects reservoir functionality and operational performance. Therefore, sediment-related issues must be addressed promptly, as excessive sediment accumulation within dam waterways can obstruct irrigation flows, reduce hydraulic efficiency, and shorten the service life of the reservoir. Although mitigation efforts, including channel rehabilitation and sediment management measures, have been implemented, sediment deposits remain dispersed throughout several areas of the reservoir. The widespread distribution of sediment accumulation complicates maintenance and operational activities, resulting in increased management challenges and potential impacts on local communities, infrastructure, and the surrounding environment. Consequently, effective and sustainable solutions are required to address these sedimentation issues and enhance the operational efficiency of reservoir infrastructure systems.

Based on the aforementioned background, this study proposes a novel approach to sediment management by analyzing reservoir sediment storage through the implementation of a Skat system combined with an open-channel configuration. The proposed sediment retention structure is designed to concentrate sediment deposition within a designated area, thereby facilitating sediment removal operations while reducing maintenance costs and operational time requirements. This approach is expected to improve the efficiency of reservoir operation and maintenance activities while enhancing the long-term sustainability of reservoir performance.

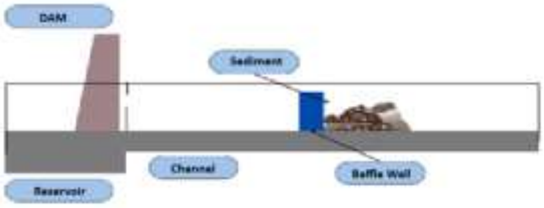


Figure 2. Schematic Illustration of the Skat Method

METHOD

The implementation of this thesis research consisted of several stages designed to achieve the research objectives. These stages are illustrated in the flowchart below.

Figure 3. Research Methodology Flowchart A

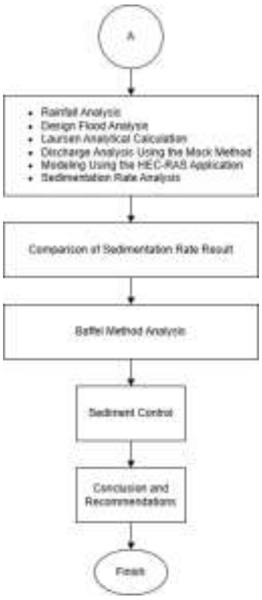


Figure 4. Research Methodology Flowchart (Part B)

RESULTS AND DISCUSSION

TOPOGRAPHY

In general, the Mengkoang Dam catchment area is characterized by lowland terrain with moderately hilly topographic features. Approximately 50.1% of the catchment area is located at elevations ranging from 50 to 150 m above mean sea level (amsl), while 42.7% lies between 150 and 300 m amsl, and the remaining 7.3% is situated at elevations between 300 and 395 m amsl. These characteristics indicate that the majority of the Mengkoang Dam catchment area consists of lowland terrain with elevations below 300 m amsl. The topographic conditions and elevation distribution of the catchment area are presented in Figure 5.

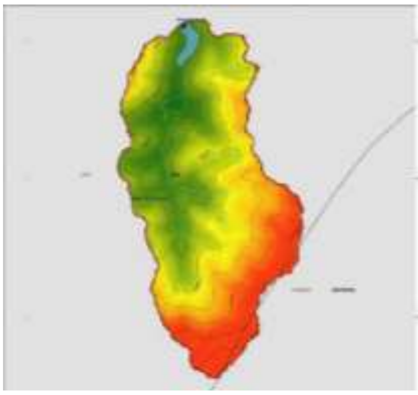


Figure 2. Topographic Elevation Map of the Mengkoang Dam Catchment Area

Based on land slope characteristics, the Mengkoang Dam catchment area is predominantly characterized by steep terrain. The slope classification indicates that 3.6% of the catchment area consists of flat land with slopes ranging from 0–8%, 7.1% comprises gently sloping land (8–15%), 13.6% is classified as moderately steep (15–25%), 46.8% as steep (25–45%), and 28.9% as very steep with slopes exceeding 45%. These results demonstrate that the catchment area is largely dominated by steep to very steep topography, which may contribute to increased surface runoff and erosion potential. The spatial distribution of land slopes within the Mengkoang Dam catchment area is presented in Figure 6.

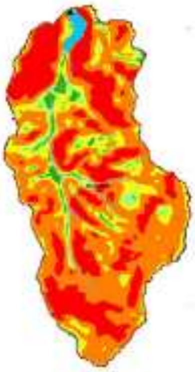


Figure 3. Spatial Distribution of Land Slope Classes in the Mengkoang Dam Catchment Area

BATHYMETRY

Bathymetric data were obtained from the Operation Permit Preparation and Approval Study (PPIO) of Mengkoang Dam conducted in 2019. Based on the bathymetric survey results, the maximum reservoir depth was estimated to be approximately 8 m below the Normal Water Level (NWL). The bathymetric characteristics and depth distribution of the reservoir are illustrated in the bathymetric map presented in Figure 7.

Figure 4. Peta Batimetri Dam Mengkoang

CATCHMENT AREA DELINEATION AND ADMINISTRATIVE BOUNDARY

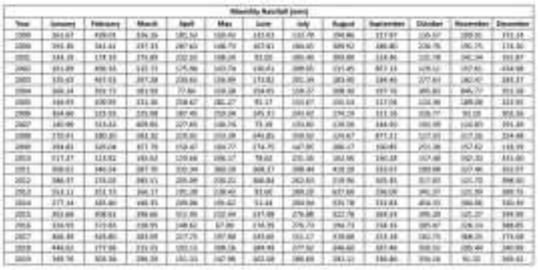
Mengkoang Dam has a catchment area of approximately 216.5 ha, representing the drainage area of the Mengkoang River system, with the dam serving as the downstream outlet of the watershed. The reservoir impoundment formed by Mengkoang Dam covers an area of approximately 2.4 ha, equivalent to about 1.1% of the total catchment area. In addition, the main river channel within the watershed extends for approximately 2.386 km. The catchment boundary was delineated using topographic data based on watershed divides and ridge lines that direct surface runoff toward the Mengkoang River system. A satellite image of the Mengkoang Dam catchment area is presented in Figure 8.

Figure 5. Delineated Catchment Area of Mengkoang Dam

CATCHMENT AREA RAINFALL

No rainfall gauging station is located within the Mengkoang Dam catchment area. Therefore, rainfall data were obtained from stations situated outside the catchment boundary but within a distance of less than 10 km from the study area. The nearest rainfall monitoring station is the Lape Manual Rainfall Gauge (MRG), located approximately 2.79 km from the proposed dam site. Consequently, data from this station were considered representative for the hydrological analysis of the Mengkoang Dam catchment area.

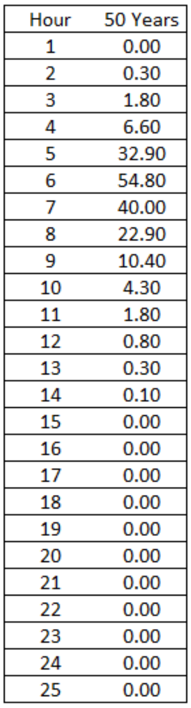
Table 1. Monthly Rainfall Distribution (mm)



DESIGN FLOOD ANALYSIS

To estimate the 50-year return period design flood within the Mengkoang catchment area, the Hydrologic Engineering Center–Hydrologic Modeling System (HEC-HMS) was employed to simulate the reservoir inflow discharge. The model inputs consisted of short-duration design rainfall corresponding to a return period of 50 years (Tr = 50 years), watershed characteristics, including catchment area, and the Curve Number (CN) parameter representing land use and soil hydrologic conditions.

Table 2. Q50 Design Flood Hydrograph of the Mengkoang Catchment Area



Hour	50 Years
1	0.00
2	0.30
3	1.80
4	6.60
5	32.90
6	54.80
7	40.00
8	22.90
9	10.40
10	4.30
11	1.80
12	0.80
13	0.30
14	0.10
15	0.00
16	0.00
17	0.00
18	0.00
19	0.00
20	0.00
21	0.00
22	0.00
23	0.00
24	0.00
25	0.00

Following model calibration, inflow discharges corresponding to reliability levels of 50%, 80%, and 90% were obtained and subsequently used as reservoir inflow data. The differences in water availability among the three reliability levels are illustrated in the following figure.

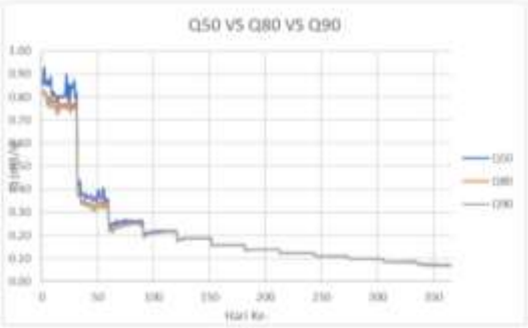


Figure 6 Water Availability Estimated Using the F.J. Mock Method at 50%, 80%, and 90% Reliability Levels

SOIL EROSION ANALYSIS USING THE USLE METHOD

The rainfall erosivity analysis for Sumbawa I Reservoir was conducted using rainfall data obtained from the Sultan Muhammad Kaharuddin Meteorological Station (BMKG), located at longitude 117.41336 and latitude −8.48845. The dataset consisted of daily rainfall records collected over a 31-year period, from January 1990 to December 2021. As shown in Figure 10, maximum rainfall generally occurs between September and March, during which erosion and sediment transport processes are most active. The results of the rainfall erosivity analysis are presented in Table 3, which summarizes the erosivity characteristics of the Sumbawa I Reservoir catchment area.

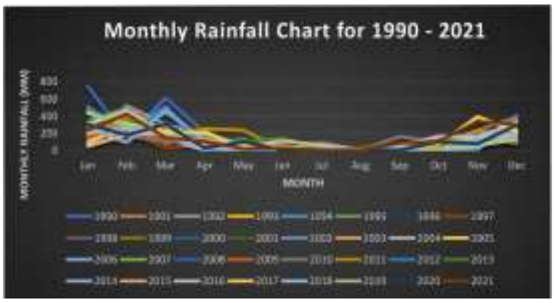


Figure 7. Monthly Rainfall Distribution from 1990 to 2020

The rainfall erosivity data for 2015 were excluded from the analysis due to incomplete records resulting from the absence of rainfall measurements between May and August 2015. Consequently, the 2015 dataset was not incorporated into the estimation of soil erosion and sediment yield. The soil erodibility factor (K) represents the susceptibility of soil particles to detachment and transport by the kinetic energy of rainfall and surface runoff. This parameter reflects the inherent resistance of soil to erosion and is influenced by soil properties such as texture, structure, permeability, and organic matter content. (Asdak, 1995).

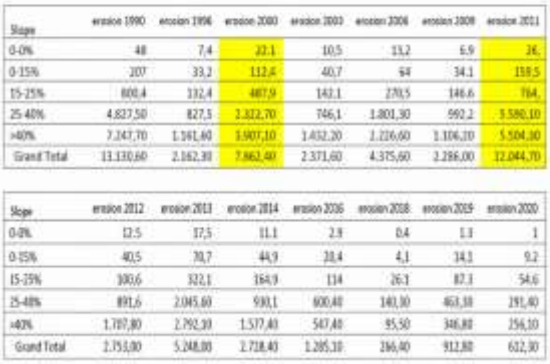
Table 3. Rainfall Erosivity Factor (R) in the Mengkoang Reservoir Catchment Area

No	Year	R (K/j/Ha)	No	Year	R (K/j/Ha)
1	1990	1,261	17	2006	283
2	1991	167	18	2007	241
3	1992	502	19	2008	306
4	1993	193	20	2009	140
5	1994	543	21	2010	632
6	1995	628	22	2011	295
7	1996	184	23	2012	378
8	1997	184	24	2013	421
9	1998	296	25	2014	314
10	1999	269	26	2015	73
11	2000	441	27	2016	479
12	2001	85	28	2017	620
13	2002	502	29	2018	128
14	2003	317	30	2019	421
15	2004	126	31	2020	245

Source: Sediment Control and Dam Area Management Plan for Sumbawa I (2020).

Based on the analysis results, the estimated soil erosion within the Mengkoang Reservoir catchment area from 1990 to 2020 is presented in the following table. The highest erosion rates were recorded in 2000 and 2011, exceeding 12,000 tons/year and 7,000 tons/year, respectively. The magnitude of soil erosion in the Mengkoang catchment area in 2020 was primarily influenced by steep slope conditions, reduced vegetation canopy cover during the dry season, and the presence of previously degraded and erosion-prone soils.

Table 4. Estimated Soil Erosion Based on the USLE Method



Slope	erosion 1990	erosion 1996	erosion 2000	erosion 2003	erosion 2006	erosion 2009	erosion 2011
0-0%	48	7,4	22,1	10,5	13,2	6,9	26,
0-15%	207	33,2	112,4	40,7	64	34,1	138,5
15-25%	800,4	132,4	487,9	142,1	270,5	146,6	784,
25-40%	4.827,50	827,5	2.322,70	746,1	1.801,30	992,2	3.580,10
>40%	7.247,70	1.161,40	3.907,10	1.432,20	2.226,60	1.106,20	5.504,30
Grand Total	13.130,60	2.162,30	7.862,40	2.371,60	4.375,60	2.286,00	12.044,70

Slope	erosion 2012	erosion 2013	erosion 2014	erosion 2016	erosion 2018	erosion 2019	erosion 2020
0-0%	12,5	17,5	11,1	2,9	0,4	1,3	1
0-15%	40,5	70,7	44,9	20,4	4,1	14,1	9,2
15-25%	100,6	322,1	164,9	114	26,1	87,3	54,6
25-40%	891,6	2.045,60	930,1	600,40	140,30	463,30	291,40
>40%	1.707,80	2.792,30	1.577,40	547,40	95,50	346,80	256,10
Grand Total	2.753,00	5.248,00	2.728,40	1.285,10	266,40	912,80	632,30

MODELING RESULTS

The sediment input data used in the numerical modeling consisted of sediment gradation characteristics and sediment transport rates derived from the soil erosion analysis. A total of three sampling locations were established within the Mengkoang Dam area to characterize the spatial distribution of sediment gradation. The sediment gradation data from these sampling points were subsequently interpolated using the Thiessen Polygon method to represent sediment distribution throughout the reservoir. The locations of the bed sediment sampling points used in this study are presented in Figure 11.

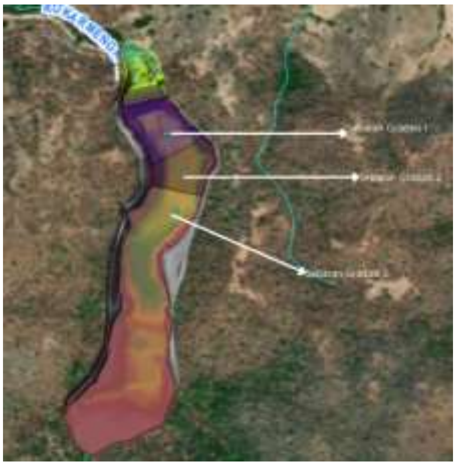


Figure 8. Thiessen Polygon of Sediment Gradation Distribution

Sediment deposition in both 2020 and 2024 was predominantly concentrated in the upstream section of the reservoir. In 2020, the catchment area was characterized by relatively dense vegetation cover, with extensive green areas and abundant riparian vegetation along the Mengkoang River. However, by 2024, noticeable land cover changes had occurred, as indicated by the conversion of vegetated areas into sparsely covered or exposed land surfaces. This transformation is reflected by the increase in brown-colored areas on the land cover map, suggesting a reduction in tree cover and vegetation density within the surrounding catchment area. Such land cover degradation may contribute to increased soil erosion and sediment delivery to the reservoir.

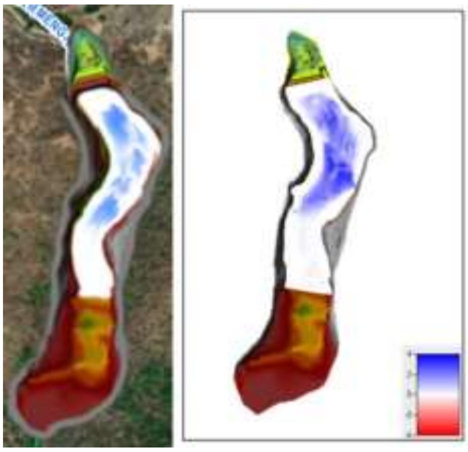


Figure 9. Sediment Distribution in 2020 and 2024

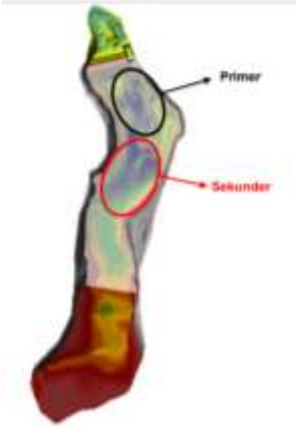


Figure 10. Sediment Distribution Before Baffle Installation

In this simulation, a spillway structure was incorporated into the model to prevent flow velocities in the downstream reach from approaching zero. The simulation results differed from those of the initial model configuration, where no significant sediment deposition was observed in the downstream reach. Instead, sediment accumulation became concentrated in the upstream section of the reservoir.

A second simulation scenario was subsequently developed by incorporating the spillway geometry based on the design specifications reported in the technical documentation. The spillway parameters consisted of a crest width of 22.00 m, a crest elevation of +251.00 m, and a crest height of 8.00 m. The spillway was represented in the model by modifying the dam embankment elevation to match the spillway crest elevation (+251.00 m) over a station length corresponding to the spillway width of 22 m.

Figure 11. Sediment Distribution with Concrete Skat Structures

The performance of the Skat system in Mengkoang Reservoir was evaluated using three different structural heights. The simulation results indicate that a Skat height equivalent to one-quarter of the channel depth reduced sediment accumulation by approximately 80%, while heights of one-third and one-half of the channel depth achieved sediment reduction efficiencies of approximately 82% and 86%, respectively. Although the concrete Skat structure demonstrated a high capacity for sediment retention, it also generated substantial backwater effects, resulting in the inundation of several upstream areas. These findings suggest that, despite its effectiveness in trapping sediment, the hydraulic impacts of the concrete Skat structure must be carefully considered in reservoir management and design.

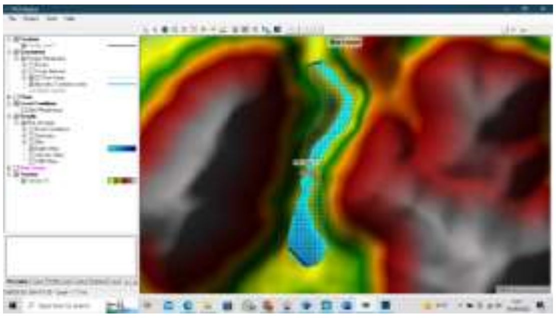


Figure 12. Backwater Effects Induced by the Concrete Skat Structure

Figure 13. Gabion Skat Structure

The construction of Skat structures extending from the reservoir bed of Mengkoang Dam was found to significantly reduce the amount of sediment entering the reservoir. In addition to structural measures, vegetation restoration within the upstream watershed plays a crucial role in mitigating sedimentation by reducing soil erosion at its source. Improved vegetation cover enhances slope stability, decreases surface runoff, and limits sediment transport into the reservoir system.

Based on the simulation results, the combined implementation of Skat structures and watershed vegetation restoration was capable of reducing sediment inflow to the reservoir by approximately 80%, 82%, and 86% under the evaluated scenarios. Sediment removal and maintenance activities were assumed to be conducted annually, with accumulated sediment extracted once every year to maintain the effectiveness of the sediment management system.

CONCLUSIONS

1. The highest sedimentation rate in Mengkoang Reservoir was estimated at 1,837.64 tons/year. Sediment deposition was distributed across multiple locations within the reservoir, thereby increasing the complexity of dredging and maintenance operations. To address this issue, the Skat method is recommended as a sediment management strategy to concentrate sediment deposition within designated areas, thereby facilitating sediment removal activities and improving operational efficiency.
2. The implementation of the Skat system in Mengkoang Reservoir was proposed at the narrowest section of the river channel in order to minimize construction costs. The concrete Skat structure demonstrated substantial sediment retention performance, reducing sediment accumulation by approximately 80%, 82%, and 86% for Skat heights equivalent to one-quarter, one-third, and one-half of the river depth, respectively. The corresponding sediment retention capacities were estimated at 1,783.43 tons/year, 1,809.93 tons/year, and 1,870.21 tons/year. However, the concrete Skat generated significant backwater effects, which reduced flow conveyance from upstream to downstream and resulted in the inundation of several agricultural areas. In contrast, the

gabion Skat structure, evaluated at a height equivalent to one-quarter of the river depth, achieved a sediment reduction efficiency of approximately 65%, corresponding to a retained sediment volume of 1,540.66 tons/year. Although a portion of the sediment was able to pass through and accumulate outside the Skat structure, the gabion system did not generate significant backwater effects because water could flow through the voids within the gabion material. Therefore, the gabion Skat is recommended as the most suitable alternative for Mengkoang Reservoir, as it effectively reduces sediment accumulation while minimizing hydraulic impacts. Furthermore, annual dredging operations are considered sufficient to maintain the effectiveness of the proposed sediment management system.

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