ISSN (*Online*) 2620-7222
ISSN (*Print*) 2503-2399

Available online at
https://jurnalteknik.unisla.ac.id/index.php/CVL

https://doi.org/10.30736/cvl.v2i2

Hydrological and Hydraulic Modelling of Sekolo River Diversion for Coal Mining Activities

Wahyu Gendam Prakoso[1*], Dinta Anindy Ismiralda[2]
[1*]*Civil Engineering Department, Faculty of Engineering, Pakuan University, Bogor*
[2] *Geological Engineering Department, Faculty of Engineering, Pakuan University, Bogor*
Email : [1] wahyugendamprakoso@unpak.ac.id . [2]dintaanindyismiralda@unpak.ac.id*

ARTICLE INFO

Article History :
Article entry : 02-02-2024
Article revised : 02-13-2024
Article received : 03-15-2024

Keywords :
Hydrological, Hydraulic, Modelling, River Diversion

IEEE Style in citing this article :
W. G. Prakoso and D. A. Ismiralda, "Hydrological and Hydraulic Modelling of Sekolo River Diversion for Coal Mining Activities", *civilla*, vol. 9, no. 1, pp. 47–60, Mar. 2024.

ABSTRACT

A Hydrological and hydraulic modeling of the proposed diversion of the Sekolo River for coal mining purposes will provide an overview and technical information on the proposed river realignment and identify potential impacts on the use of the Sekolo River. It is being carried out for River extension to maintain river sustainability and functionality. Sekolo River watershed modeling utilizes a combination of hydrological analysis and open-channel hydraulic modeling using HEC-HMS and HEC-RAS software. To meet the area criterion (volume), the dimensions of the diversion channel are planned with B = 15 m. H = 1.5 m; m = 1.5; L = 1253 m. These dimensions make the volume of the diversion approximately the same as the existing river. Hydraulic simulation results showed that the flood level would not rise downstream of the diversion channel. The upstream (Q25) peak flow rate is 41.90 m3/s, while the downstream peak flow rate after diversion is increased by 0.02% compared to the existing flow rate. After introducing the diversion channel, the difference in flood peak arrival time (Tp) will be 3 minutes earlier than before the diversion.

1. Introduction

Open coal mining areas are typically located in remote and natural settings, allowing for the presence of rivers and other watercourses (creeks) in those areas. Mine development often involves crossing river channels, not only concerning coal conservation but also about environmental protection and safety aspects (geotechnical)[1]. River diversion is usually the last option chosen because, fundamentally, coal mining contractors prefer alternative options over river channel relocation [2].

This study encompasses hydrological and hydraulic modeling of the planned river flow diversion for Sekolo River for coal mining activities. The research aims to provide an overview and technical consideration ofthe proposed river channel relocation and to identify potential impacts on the utilization of the former Sekolo River while preserving the river's sustainability and function.

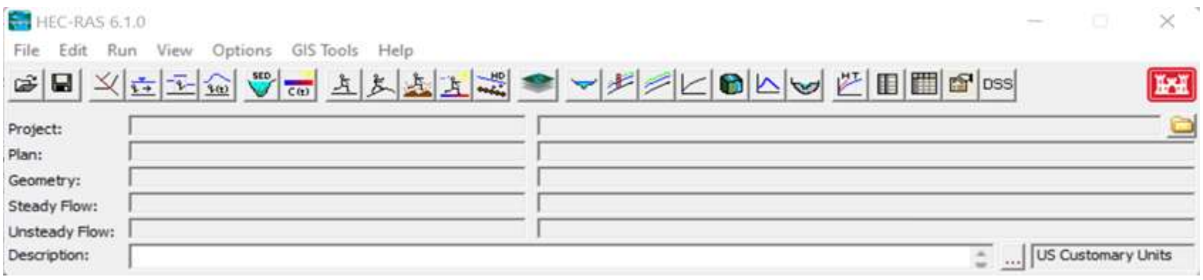
2. Research Method

Modeling the relocation of Sekolo River flow using a combination of hydrological analysis and open-channel hydraulic modeling. Hydrological modeling is conducted by transforming rainfall into runoff using the HEC-HMS model [2]. The HEC-HMS model is a computer program designed to calculate rainfall transformation and routing processes in a watershed system [3][4]. This software is developed by the Hydrologic Engineering Centre (HEC) of the US Army Corps of Engineers. Hydrological Analysis consists of:

1. Rainfall Runoff Analysis.
2. Flood Discharge Analysis

The numerical/mathematical model approach HEC-RAS was created and developed by the Hydraulic Engineering Center, a division of the Institute for Water Resources (IWR), U.S. Army Corps of Engineers. This program is a part of the Next Generation (NextGen) development of the Hydrologic Engineering software. HEC-RAS Version 6.1.0 essentially consists of three one-dimensional hydraulic analysis components:

1. Simulation of one-dimensional steady flow.
2. Simulation of one-dimensional unsteady flow.
3. Calculation of sediment movement transport.



Source: HEC- USACE, 2023

Figure 1. Graphical User Interface Display of HEC-RAS

3. Description and Technical

In river planning, to estimate the design flood hydrograph using the unit hydrograph method, it is necessary to first determine the temporal distribution of rainfall with a specific interval. Since hourly rainfall data is not available, the Genta/PSA007 method is used for rainfall distribution, assuming the duration of rainfall in the study area [6].

Rainfall-runoff transformation is a process of converting rainfall into actual flow; rainfall flows from upstream to downstream until the control point as surface runoff, eventually becoming runoff. In this transformation process, a rule (regulation/model) reflecting the watershed characteristics is needed to understand the conversion of rainfall into runoff [7].

Modeling in HEC-RAS involves the representation of geometric data and geometric calculations, as well as iterative hydraulic calculations. The fundamental calculation procedure is based on solving the one-dimensional energy conservation equations. Energy loss is evaluated through friction (Manning's equation) and contraction or expansion. Momentum equations are used in situations where the water surface profile changes rapidly. This involves calculations for mixed flow areas, hydraulic structure calculations, and evaluating profiles in interconnected or branched rivers. The flowchart and research stages can be seen in Figure 2.

The hydraulic planning of river diversion must consider the dimensions of the cross-sectional and longitudinal profiles to effectively convey the planned discharge during specific recurrence intervals. Overflow must be prevented in the diversion channel. Additionally, attention should be given to the river flow velocity, which should not be too high to avoid erosion on the riverbed and banks, posing a threat to existing water structures [1].

For river diversion planning, the riverbanks are equipped with embankments designed to withstand the water level resulting from a 25-year recurrence interval flood. Embankments along the river are crucial and essential structures in safeguarding lives and properties from inundation caused by floods. Embankments are primarily constructed using earth fill construction, as they are continuous structures with significant length and require a substantial volume of fill material [8].

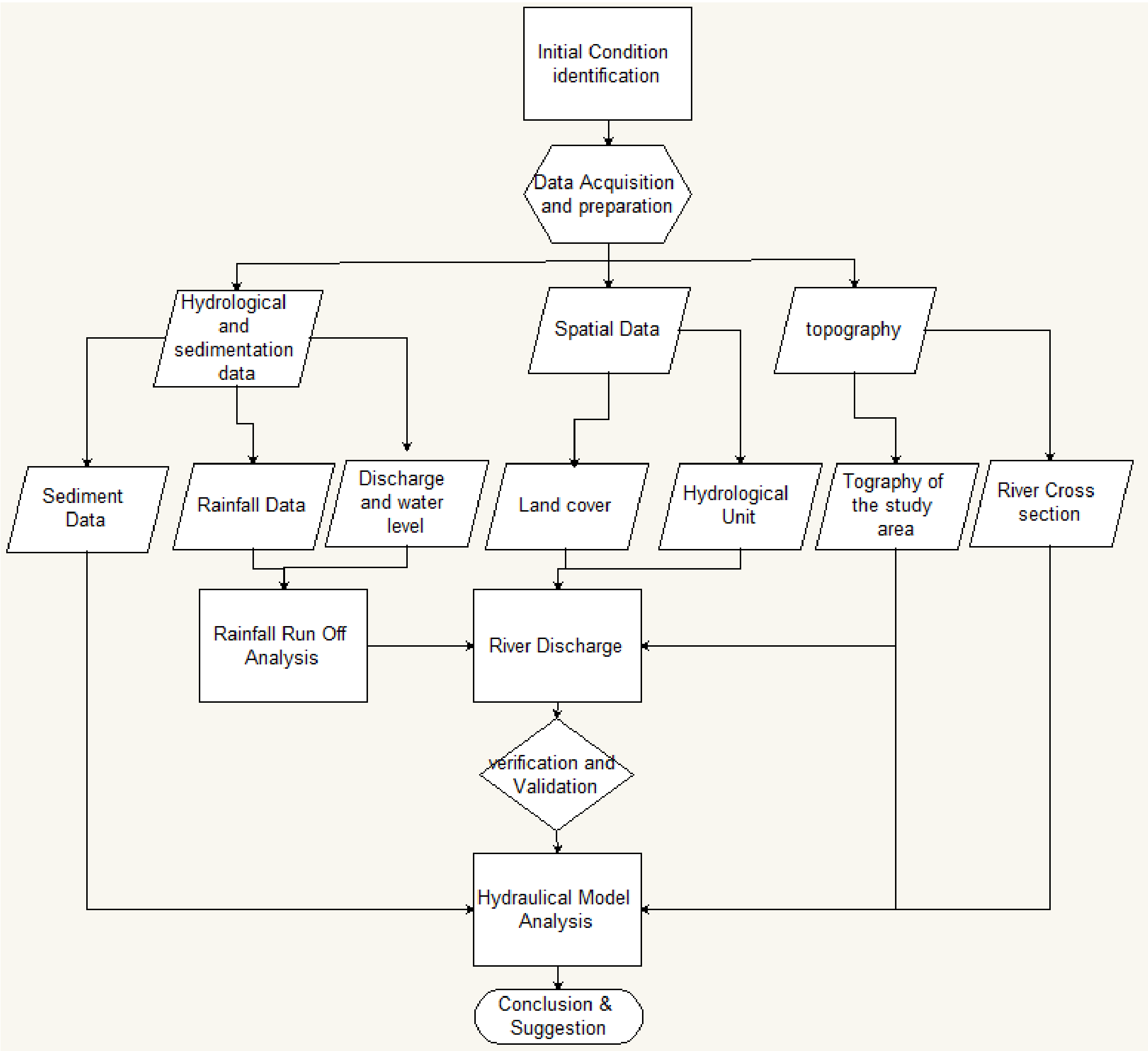
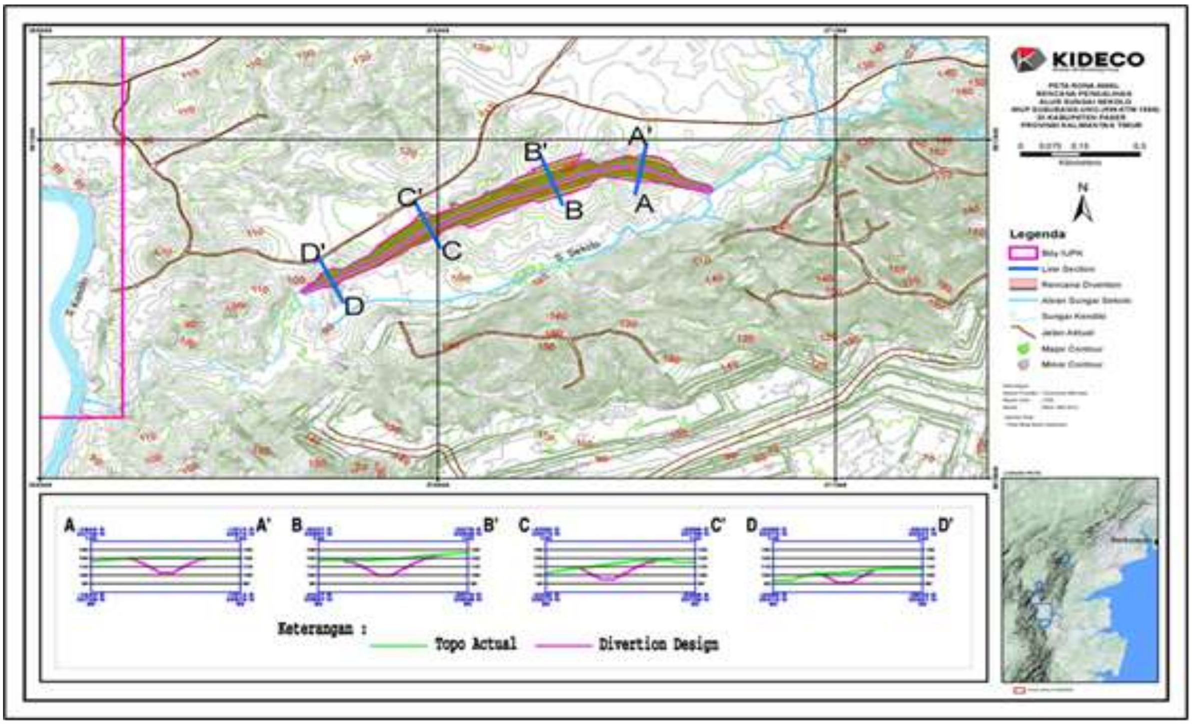


Figure 2. Flowchart of the Modeling Method and Stages

4. Results and Discussions

Almost all rivers in the study area flow into the Kendilo River. The Sekolo River also flows into the Kendilo River, which is a first-order river. The pattern of the Kandilo River network follows a one-way network rule, where branches and tributaries flow into the main river, forming a trellis dendritic flow pattern. This pattern is commonly found in areas with sedimentary layers in folded mountain regions (trellis) and areas with widespread distribution of similar rocks, besides being covered by extensive sediment and situated in a horizontal plane in lowland areas (dendritic). There are 11 Sub-Watersheds in Kandilo, namely: Upper Kandilo Sub-Watershed (including the Sekolo River), Kuaro Sub-Watershed, Komam Sub-Watershed, Kesungai Sub-Watershed, Setiu Sub-Watershed, Samurangau Sub-Watershed, Biu Sub-Watershed, Samu Sub-Watershed, Seratai Sub-Watershed, Pasir Sub-Watershed, and Suliliran Sub-Watershed.

The river diversion plan based on the design of the Sekolo Baru River Cross-Section Plan can be seen in Figure 3. The design for altering the Sekolo River flow adheres to the planning criteria outlined in the Ministry of Public Works and Housing Regulation Number 21 of 2020 (PERMEN PUPR No. 21/2020) concerning River Channel Diversion. To achieve an efficient design, the cross-section shape of the new river flow utilizes a trapezoidal profile.



Source: KIDECO, 2021

Figure 3. Diverting flow Planning of the Sekolo River

Design for the alteration of the Sekolo River using a trapezoidal cross-section model with initial dimensions of a riverbed width of 2 meters, a single-step height of 4 meters, a step width of 2.5 meters, and a single slope inclination of 30°.

Table 1. River Geometry Changes of Sekolo River

Description	Existing	Planning
Overall Geometric		
River lenght (km)	4,29	3,91
Geometrical Changes		
River Lenght (km)	1,50	1,13
Bottom Inlet (ML)	105,7	105.6
Bottom Outlet (ML)	90,00	90.00
Average Top Widht (m)	1,25	10
Water Level (m)	0,5	1,56
River Grade (%)	1,33%	1,38%

Source: LAPI-ITB (2022).

As hourly rainfall data is unavailable, the Genta/PSA007 method is employed to determine rainfall distribution, assuming that the rainfall event lasts for 6 hours. The following is the planned rainfall distribution for the Sekolo River Watershed.

Table 2. Hourly Rainfaal Distribution of Sekolo River Watershed

Hour	Distribution	Hourly Rainfall (mm/ hour)					
	%	R_2	R_5	R_{10}	R_{25}	R_{50}	R_{100}
1	1	0.66	0.94	1.13	1.36	1.53	1.71
2	6	3.98	5.65	6.76	8.16	9.20	10.23
3	24	15.91	22.61	27.05	32.65	36.81	40.94
4	54	35.80	50.87	60.86	73.47	82.83	92.11
5	12	7.95	11.31	13.52	16.33	18.41	20.47
6	3	1.99	2.83	3.38	4.08	4.60	5.12
Netto Rainfall (mm/day)		66.29	94.21	112.70	136.05	152.38	170.58

Source: LAPI-ITB (2022). (Procesed)

With the assistance of the HEC-HMS program, flood hydrographs will be analyzed for each watershed for return periods of 2, 5, 10, 25, 50, and 1000 years, which serve as references for design. A summary of the flood study is presented in the form of hydrographs and peak discharge or maximum flood, as depicted in Figure 4.

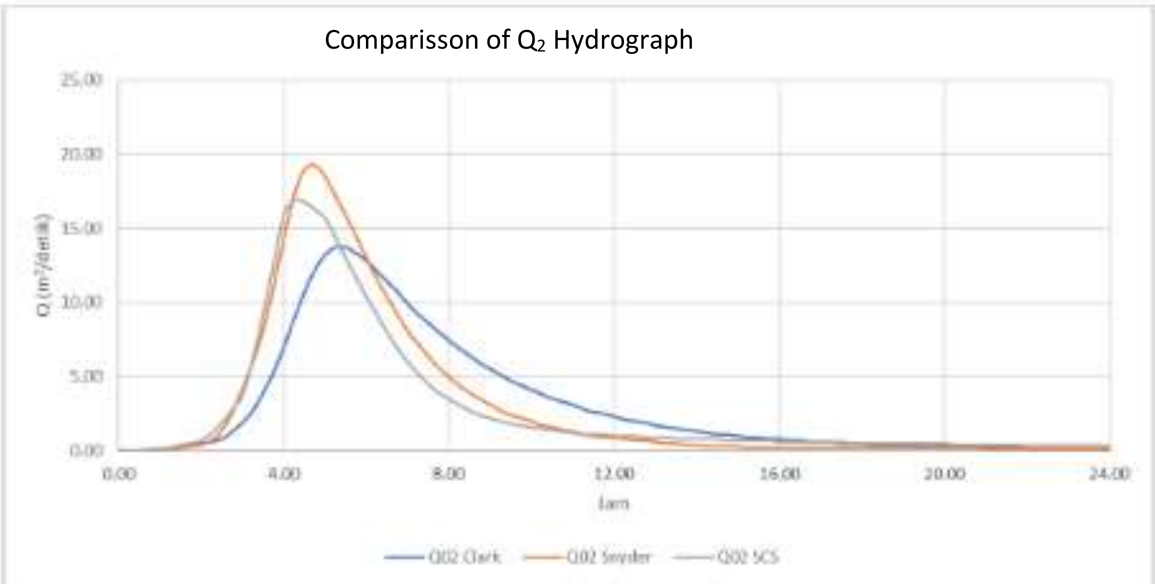
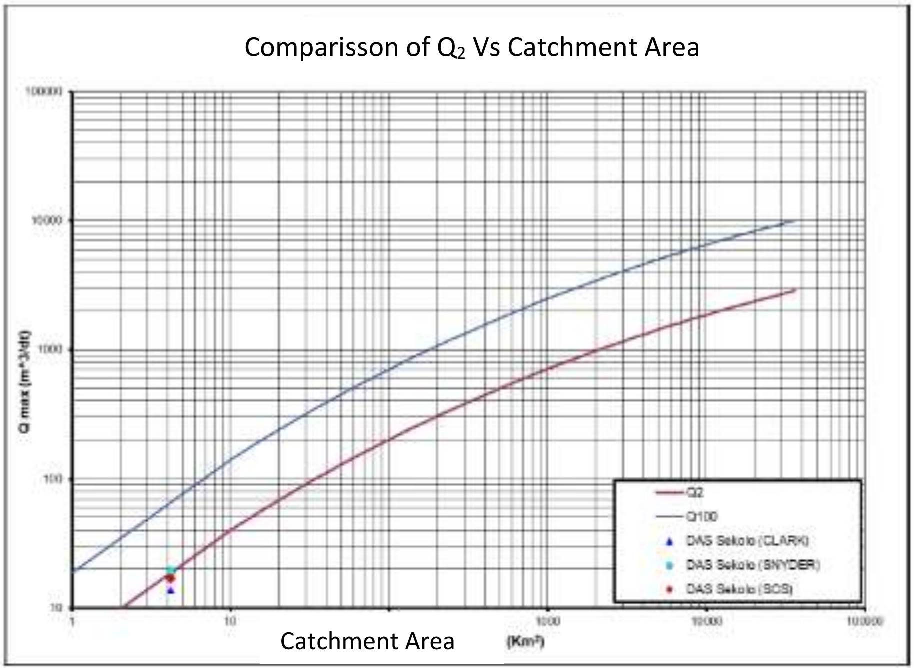


Figure 4. Flood hydrograph Q2 using the SCS, Snyder, and Clark methods in the Sekolo Watershed.

Based on the flood discharge analysis with HEC HMS, it was found that the Snyder and SCS methods yield similar hydrograph shapes and peak discharges. Therefore, it can be considered reasonable to treat both methods as aligned. However, to determine the method to be used, a comparison will be made with the Creager Q2 curve. The results of the Creager curve analysis in the Sekolo Watershed can be seen in Figure 5.



Source : Ewea et al, 2020; Ewea et al, 2017; Chavez et al, 2017; Lima et al , 2017; Vogel et al, 2007 (processed)

Figure 5. Creager Curve of the Sekolo Watershed.

Based on the curve graph above, it can be concluded that the SCS method provides results that are most similar to the Creager curve. Therefore, the SCS method will be chosen for the analysis of planned flood discharge in the Sekolo Watershed.

After analyzing of the 2-year return period flood discharge compared to the Creager curve, it is concluded that the SCS method is the most suitable for use in the Sekolo Watershed. Based on these analysis results, a summary of the peak flood discharges for various return periods in the Sekolo Watershed has been compiled in Table 3.

Table 3. Summary of Peak Flood Discharge in Sekolo River Watershed

Peak Discharge (m^3/s)					
Q_2	Q_5	Q_{10}	Q_{25}	Q_{50}	Q_{100}
16.86	26.68	33.36	41.90	48.28	54.63

Following the results of the hydrological analysis, the planning of river cross-section dimensions is carried out by considering the magnitude of the discharge originating from its watershed flowing through the river. Based on design criteria, hydraulic planning for the cross-section in the initial stage is performed using the steady flow condition approach employing Manning's equation. In designing this Cross Section, the current topographical conditions will be taken into account. The planning of the dimensions of the Cross Section in the Sekolo River will consider several important factors. Firstly, the 25-year return period flood discharge will be the basis for determining the spillway dimensions. Additionally, the length and area of the spillway must be at least equal to or greater than the river reach to be diverted. If this length criterion is not met, the use of retention ponds and/or other water storage facilities may be necessary as compensation.

The main key to modeling in HEC-RAS is the use of geometric data representation and repetitive geometry and hydraulic calculations. The basis of the calculation procedure used is grounded on solving the one-dimensional energy conservation equation. Energy loss is evaluated through friction (Manning's equation) and contraction or expansion. Momentum equation is applied in situations where the water surface profile changes rapidly. This involves calculations of mixed flow areas, hydraulic structure calculations, and evaluating profiles in interconnected or branching rivers. The simulation scenarios to be conducted are seen in Table 4.

Table 4. Simulation Scenario for Hydraulic Modeling

Scenario	Description
Q_2 and Q_{25}	• Existing Sekolo River • Flood Water Level , Flood Routing
Q_{25}	• Sekolo River Diversion • Flood Water Level , Flood Routing

Source: Karama et al, 2022; LAPI-ITB, 2022; Bachri et al, 2022; Nugroho et al , 2020

The river data to be input includes both the existing river cross section and the river polyline. The distance between cross-sections at each station varies. Cross-sections with wider spacing are found in the straight river flow, while cross-sections with closer spacing are in the meandering river flow.

Source: LAPI-ITB, 2022

Figure 6. Sekolo River Diversion Layout Plan

One of the required input data for hydraulic simulation is river geometry, in the form of cross-sectional profiles of the river. Typical cross-sectional profiles of the existing river and the river diversion to be simulated can be seen in Figure 7. A Manning coefficient of 0.028 is used for the diversion design and 0.035 for the existing river. Flow simulation in the main Sekolo River is conducted under steady conditions to observe the floodwater surface elevation, flow velocity, erosion potential, and sedimentation.

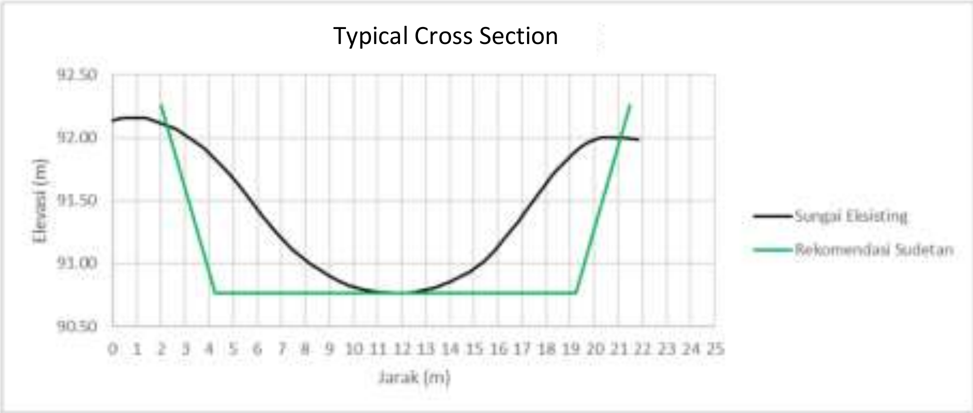


Figure 7. Typical Cross Section of the Sekolo River Diversion

The comparison of downstream water surface elevations for existing conditions and after the diversion can be seen in Figure 8 and Figure 9. Based on the simulation results, there is a 0.2% increase in water surface elevation compared to the existing conditions.

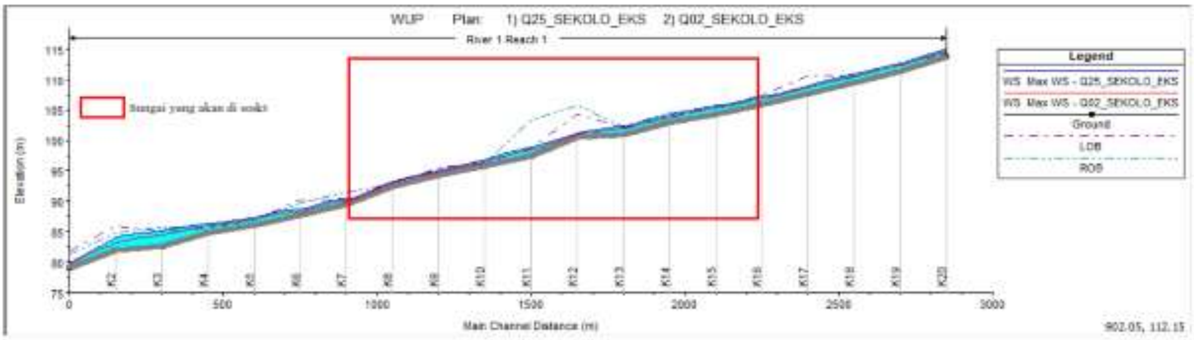


Figure 8. Longitudinal Section of the Simulation Results for the Existing Sekolo River

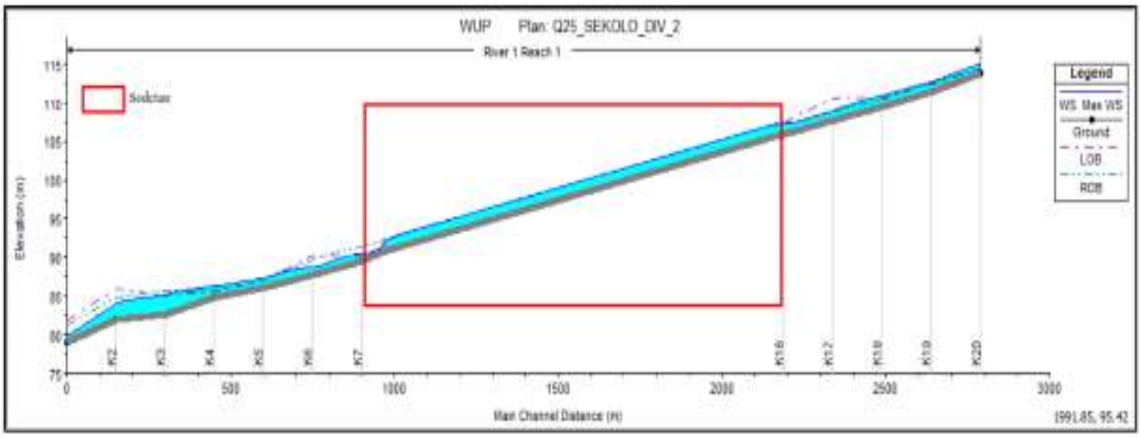


Figure 9. Longitudinal Section of the Simulation Results for the Sekolo River Diversion

The flood propagation can be observed through the difference in peak flood times downstream, before and after the diversion. The peak flood times are depicted in the hydrograph in Figure 10. In terms of minutes, there is a difference in the peak flood times upstream between existing conditions and after the spillway installation. The peak flood time for the existing river is 4 hours and 29 minutes, while the peak flood time after the river diversion is 4 hours and 32 minutes. In terms of minutes, there is a 3-minute difference in the arrival time of the flood. The arrival time of the original river flood is 14 minutes, while the arrival time after the diversion is 17 minutes. Relatively, the change in flood propagation time after the river diversion is not significant.

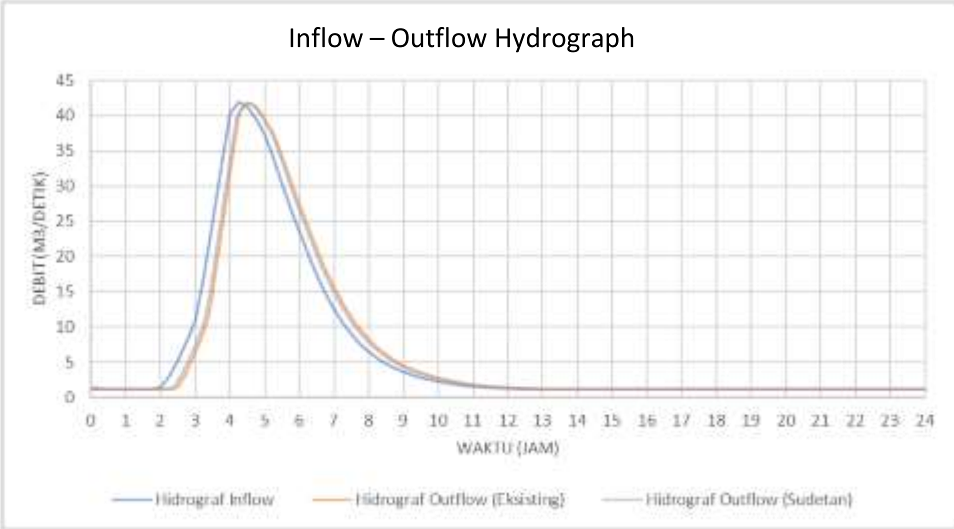


Figure 10. Inflow – Outflow Hydrograph Comparison of the Sekolo River Diversion

The summary of hydraulic simulation results for the Sekolo River Diversion is presented in Table 5.

The flow velocity at the upstream section of the spillway under existing conditions is 3.74 m/s, and after the diversion, it decreases to 2.82 m/s. Downstream, the flow velocity under existing conditions is 2.92 m/s, and after the diversion, the flow velocity remains unchanged. Referring to the permissible flow velocity standards, the allowed value for soil material is 0.7 m/s. From these data, it is evident that under existing conditions, erosion has occurred, indicating that the flow velocity exceeds the permissible limit.

From the simulation results, it can be concluded that under existing conditions, both upstream and downstream, erosion has occurred. Additionally, the change in flow velocity after the diversion indicates a decrease of 24.6% upstream and no change downstream. Erosion will occur if the flow velocity exceeds the critical velocity of sediment particles. Conversely, sedimentation will occur when the flow velocity is less than the critical velocity of sediment particles.

According to measurement data, the average d_{50} value for the Sekolo River at the spillway is 0.45 mm. When examined using the Hjulstrom diagram in Figure 10, the critical velocity or permissible limit obtained for deposited sediment particles is less than 0.029 m/s, while particle initiation occurs within the range of 0.029 - 0.26 m/s, and particles undergo erosion at speeds above 0.26 m/s.

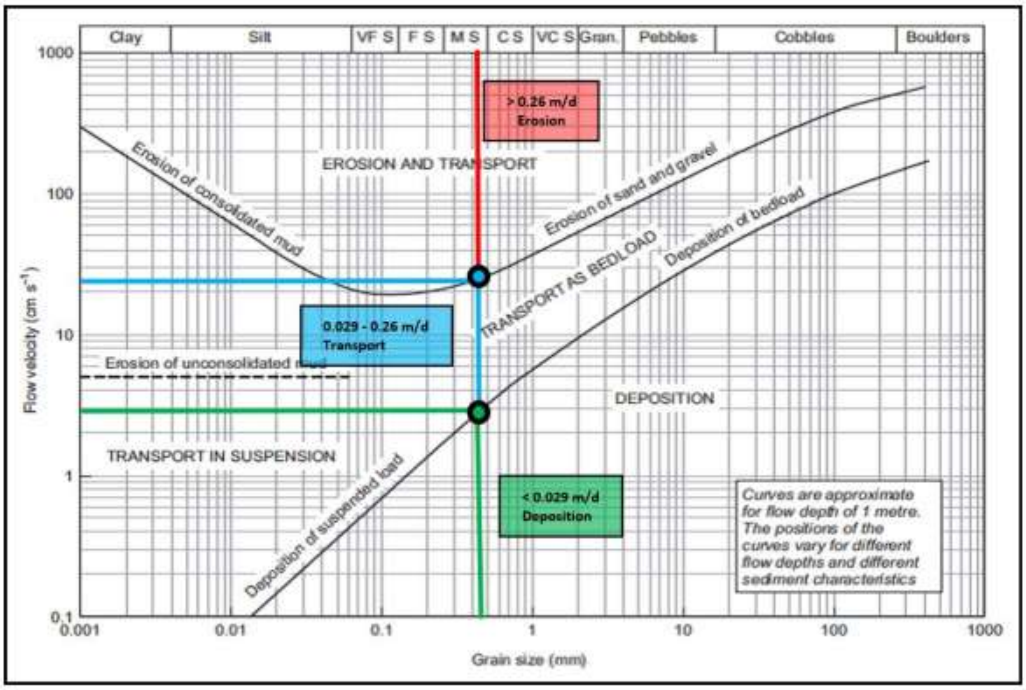
Table 5. Summary of hydraulic Modelling

No	Description		River Condition		Remarks
			Existing	Diversion Design	
1.	River Lenght (L)		1238.00	1253.00	m
2.	Typical Dimension	Botom widht (B)	14.00	15.00	m
		Depth (H)	1.50	1.50	m
		Embankment Slope (m)	2.00	1.50	
		Top widht (T)	20.00	19.50	m

3.	Channel Average Slope (S_0)	1.21	1.31	%
4.	Manning Coef (n)	0.035	0.028	
5.	Q_{25}	41.9	41.9	m^3/s
6.	Time to peak (t_p)	4 hour 29 minute	4 hour 32 minute	
7.	Flow time	14	17	minute
8.	Flow velocity	3.3	4.11	m/s
9.	Flood water level	+110.926	+110.926	
10.	River Bankfull Capacity(x 1000)	27.54	28.19	m^3

In the Sekolo River, measurement data indicates that for normal flow velocity conditions, the flow velocity is 0.1 m/s. If the relationship between the bed sediment particles and flow velocity is analyzed using the Hjulström diagram, no sediment deposition occurs when the flow discharge is in normal conditions.

However, if we refer to the simulation results that show flow velocities above 0.26 m/s, especially during flood conditions, erosion will occur both upstream and downstream of the diversion, both under existing conditions and after the diversion. Nevertheless, the impact of the diversion process itself does not have a significant effect on the changes in riverbed erosion from existing conditions. This is evident from the reduction in flow velocity of about 24.6% upstream, which occurs after the spillway installation.



Source: Miedema, 2010; Miedema, 2013; Corcoran et al, 2016; LAPI-ITB, 2022

Figure 11. Critical/Permissible Velocity for Channel Bed Material (existing-Diversion) of the Sekolo River

5. Conclusion and Suggestion

5.1 Conclusion

Conclusions from the hydrological and hydraulic analysis of the Sekolo River Diversion are as follows:

1. Hydrological Analysis: a. The planned river diversion is located in the Kendilo River Basin. Based on the river order (order), the location of the river to be diverted falls under

orders 2 and 3. b. Rainfall analysis is conducted for various return periods, namely 2, 5, 10, 25, 50, and 100 years. The results are compared with rainfall data from the Ministry of Public Works and Housing isohyetal maps and are deemed within a reasonable range. c. Flood discharge analysis is performed using the HECHMS software. This analysis employs 3-unit hydrograph methods due to the absence of streamflow observation stations for calibration. d. The results of planned flood discharge analysis show a similarity in the hydrograph shapes between the SCS and Snyder methods. e. Based on the Creager curve, the SCS method is chosen as it closely approximates the discharge values from the Creager curve. f. The planned flood discharge used for hydraulic analysis is Q_{25}.

2. The results of hydraulic simulation for the existing river conditions and the Sekolo River diversion for each location are as follows: a. To meet area (volume) criteria, diversion dimensions are planned with B = 15 m; H = 1.5 m; m = 1.5; L = 1253 m. With these dimensions, the diversion has approximately the same volume as the existing river. b. Hydraulic simulation results show no increase in floodwater surface elevation downstream of the diversion. c. The peak discharge upstream (Q_{25}) is 41.90 m^3/s, while the peak discharge downstream after the diversion increases by 0.02% compared to the existing river. d. After the diversion, the peak flood arrival time (Tp) difference becomes 3 minutes earlier compared to before the diversion.

5.1 Suggestion

Improved model accuracy requires detailed topographic observation data, field measurements of flow and water surface, as well as maximum daily rainfall data at the study location with a sufficient length of adequate data.

References

[1] Narendranathan, S, Stipcevich, Rastogi, S. A case study: assessing the impacts of open cut coal mining on the Maryvale Field (Yallourn) Open Cut and Morwell River Diversion through the use of finite element modelling, Slope Stability 2020: Proceedings of the 2020 International Symposium on Slope Stability in Open Pit Mining and Civil Engineering, Australian Centre for Geomechanics, Perth, pp. 849-862, https://doi.org/10.36487/ACG_repo/2025_55 , 2020.

[2] Hydrologic Engineering Center – United States Army Corps of Engineers [HEC-USACE] . HEC-RAS *River Analysis System Manual. (https://www.hec.usace.army.mil/software/hec-ras/features.aspx, 15 November 2023).*

[3] Flatley, Alissa, Rutherfurd, Ian. Rules of reengagement: integrating geomorphology into river diversion designs. Proceeding of 10 th Australian Stream Management Conference 2020. Kingscliff, New South Wales (NSW), Australia, https://www.researchgate.net/publication/353702271_Rules_of_reengagement_integrating_geomorphology_into_river_diversion_designs ,2021

[4] Peker, ˙I.B.; Gülbaz, S.; Demir, V.; Orhan, O.; Beden, N. Integration of HEC-RAS and HEC-HMS with GIS in Flood Modeling and Flood Hazard Mapping. Sustainability 2024, 16, 1226. https://doi.org/10.3390/su16031226. 2024.

[5] Uca, Lamada, M, Arfan A, Haris, NA. Flood Modelling Using Integration of Multi-data Analysis and HEC-RAS Model in Mata Allo River, Sulawesi. E3S Web Conf. Volume 400, International Conference on Sciences, Mathematics, and Education (ICoSMEd 2022).

[6] Setiawan, A, Taufik, M, Larasati, NA. Analisis Hidrologi Penentuan Debit Banjir

Bendung Tegalduren Kabupaten Purworejo. Jurnal Surya Beton, Volume 6, Nomor 2. 2022

[7] Ata, F, Toriman, ME, Desa, SM, San, LY, Kamarudin, MKA. Development Of Hydrological Modelling Using HEC-HMS And HEC-RAS For Flood Hazard Mapping At Junjung River Catchment. PLANNING MALAYSIA: Journal of the Malaysian Institute of Planners,VOLUME 21 ISSUE 6, Page 116 – 129. 2023

[8] Idfi, G, Rahayuningsih, T, Suryoputro, N. Diversion canal to decrease flooding at Kemuning river, Sampang district. IOP Conf. Series: Materials Science and Engineering 930 (012073). 4th International Conference on Civil Engineering Research (ICCER). 2020

[9] Sukmajati , EI, Kusuma, MSB, Hatmoko, W, Farid, M, Natasaputra , S. Kajian Model Matematik Efektivitas Normalisasi Sungai Terhadap Penurunan Risiko Banjir Studi Kasus : Sungai Tikala, Kota Manado. 2022

[10] KIDECO. *Feasibility Study* WIUPK Roto Samurangau dan WIUPK Susubang Uko. 2021.

[11] LAPI-ITB. Kajian Rencana Teknik Tambang WIUPK Susubang Uko. 2022

[12] Ewea, HA, Al-Amri, NS, Elfeki, AM. Analysis of maximum flood records in the arid environment of Saudi Arabia. GEOMATICS, NATURAL HAZARDS AND RISK, VOL. 11, NO. 1,pp. 1743–1759. 2020.

[13] Ewea, HA, Elfeki, AM, Al- Amri, NS. Development of intensity–duration–frequency curves for the Kingdom of Saudi Arabia. GEOMATICS, NATURAL HAZARDS AND RISK, VOL. 8, NO. 2,pp. 570–584. 2017.

[14] Chavez, LG, Studart, TMC, Campos, JNB, Filho, FAS. Regional envelope curves for the state of Ceará: a tool for verification of hydrological dam safety. Revista Brasileira de Recursos Hídricos, Brazilian Journal of Water Resources. http://dx.doi.org/10.1590/2318-0331.021720160062 , 2017.

[15] Lima, GD, Marcellini, SS, Neill, CR, Salla, MR. Preliminary estimate of floods discharge in Brazil using Creager envelope curves. Revista Brasileira de Recursos Hídricos, Brazilian Journal of Water Resources. https://doi.org/10.1590/2318-0331.011716078 , 2017.

[16] Vogel, RM, Matalas, RC, England, JF, Castellarin, A. An assessment of exceedance probabilities of envelope curves. WATER RESOURCES RESEARCH, VOL. 43, W07403, doi:10.1029/2006WR005586, 2007.

[17] Karamma, R, Badaruddin, S, Mustamin, R, Saing , Z. Flood Modelling due to Dam Failure Using HEC-RAS 2D with GIS Overlay: Case Study of Karalloe Dam in South Sulawesi Province Indonesia. Civil Engineering and Architecture 10(7): 2833-2846, 2022

[18] Bachri, S, Aldianto, YE, Sumarmi, Kresno, SBU, Naufal, M. Flood Modelling Of Badeng River Using HEC-RAS In Singojuruh Sub District, Banyuwangi Regency, East Java, Indonesia. Jurnal Geografi Vol 13 No. 1.2021

[19] Nugroho, J, Soekarno, I, Harlan, D. Model of Ciliwung River Flood Diversion Tunnel Using HEC RAS Software. MATEC Web of Conferences 147, 03001. 2018

[20] Miedema, SA. Constructing The Shields Curve, A New Theoretical Approach And Its Applications. WODCON XIX, Beijing China, September 2010.

[21] Miedema, SA. Constructing The Shields Curve Part C: Cohesion By Silt, Hjulstrom, Sundborg. Proceedings of the ASME 2013 32nd International Conference on Ocean, Offshore and Arctic Engineering OMAE2013,June 9-14, 2013.

[22] Corcoran, MK, Sharp, MK, Wibowo, JL, Ellithy, G. Evaluating the mechanisms of erosion for coarse-grained materials. E3S Web of Conferences 7. FLOODrisk 2016 - 3rd European Conference on Flood Risk Management. 2016

This page is intentionally left blank