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Hydraulic Analysis of Dredging Impacts in Downstream Reach of the Tulang Bawang River

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***Abstract*—The Tulang Bawang river is one of the largest rivers in Lampung Province, Indonesia, transporting humans and goods. Changes in upstream land use, climate, and sedimentation are silting the riverbed and disrupting transportation. To this end, investors and government agencies have submitted various proposals to carry out sand mining downstream to assist the local government in revitalizing transportation. However, some government and community assets are likely to be affected in the upstream part that is planned to be dredged. Therefore, this study aimed to conduct a modeling scenario of riverbed dredging in the lower reaches of the Tulang Bawang River from the estuary to 11.8 km upstream. It also aimed to review the impact on the environment, especially the impact of flooding and sedimentation by 17.8 km upstream, using the HEC-RAS software. The scenarios of upstream and downstream boundary conditions were used to determine the significance of the impact. The results showed that dredging would cause water level elevation to drop upstream and sediment deposition along the river section dredged. However, the decrease in river water level was insignificant for the upstream assets and beneficial for reducing flood inundation. The result of sedimentation analysis shows that river dredging leads to morphological changes and may have an environmental impact. Therefore, effective environmental management for dredging needs to be applied to minimize the environmental impact.**

***Keywords*— Dredging; flood; sedimentation; environment.**

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I. INTRODUCTION

Rivers are natural resources that sustain living things [1]–[5]. Moreover, it serves as a waterway to oceans and affects the development of humans and culture by playing an essential role as a means of transportation [6]–[9]. Dredging is often necessary to restore the functions of rivers in terms of increasing the reduced capacity due to sedimentation [10]–[16]. Some people believe that river dredging negatively impacts the environment [17], [18], while others think otherwise [19], [20].

The discourse of dredging also echoes when discussing the Tulang Bawang River, located in Lampung Province, Indonesia. Based on the watershed pattern, this river has an area of 9814.30 km^2 and a length of 753.5 km. It is spread over several regencies: Way Kanan, North Lampung, West Tulang Bawang, and Tulang Bawang. The average annual rainfall in this watershed is greater than 2,500 mm. This river has a continuous annual flow in the rainy and dry seasons. It has an average width of 180 m and a depth of 40 m (Fig. 1).

The current condition of the Tulang Bawang River estuary is almost similar to that of others on the East Coast of Lampung Province, which has been experiencing siltation [21]. Apart from erosion in upstream, other causes of siltation include the confluence of east and west winds that carry sand and mud from the high seas, resulting in accumulation and sedimentation in river mouths.

Several important assets concern the government; therefore, dredging must be carried out to keep the assets' functioning and existence unharmed. A Dipasena shrimp pond is located approximately 17.8 km from the mouth of the Tulang Bawang River (Fig. 1). It was once the favorite spot of the largest shrimp exporters, although there has been a vacuum in recent times. This pond was handed over to the government in 2021. Furthermore, two swamp irrigation systems, namely Rawa Jitu and Rawa Pitu, utilize this river. In Lampung Province, the largest swamp region used for paddy fields is in Tulang Bawang Regency.

At the estuary of the Tulang Bawang River, Kuala Teladas Village, there is a docking (Fig. 2). There are seven piers on the Tulang Bawang river, namely Menggala, Gedong Aji, Bina Bumi, Gunung Tapa, Rawajitu, Teladas, and Kuala Teladas (Fig. 1). Menggala Pier, once served the Menggala–Merak transportation using a speed boat, connecting Sumatera and Java islands. However, this mode of transportation has remained non-operational for a long time because it was extremely expensive. In addition, there have been conflicts with the residents on the outskirts of the Tulang Bawang River because of the current generated. This speedboat interferes with the development of fish in the community's cages. Nevertheless, the existence of several plantation companies, ponds, or fisheries creates the potential for river transportation revitalization, especially for conveying goods.

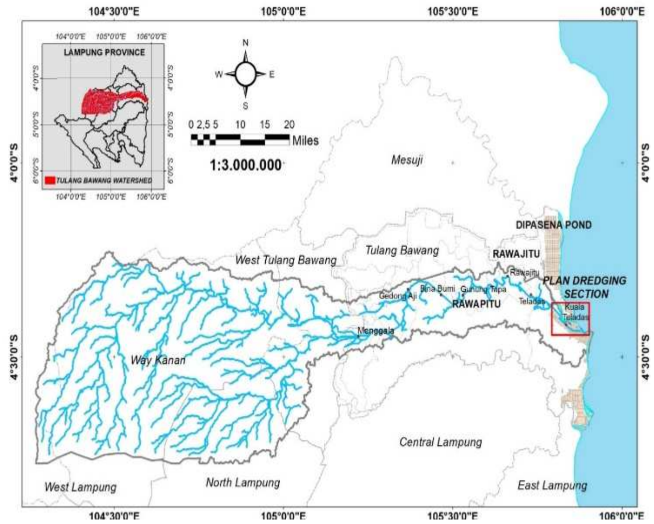

Fig. 1 Tulang Bawang River Basin

Recently, the Indonesian government implemented a flexible policy granting permits to investors and government agencies, such as the department of transportation, to carry out their business activities in the country in the context of accelerating development. One of the efforts is the submission of technical recommendations from the authorities, which is a requirement to obtain a permit for sand mining activities. Notably, dredging activities deepen the riverbed while creating opportunities for river transportation [22]–[24], which is also one of the Lampung regional government's agendas. However, a lot needs to be initially studied regarding the environmental impact, especially strategic businesses upstream. The existence of several reactivated plantation companies, fisheries, swamp irrigation systems, and Dipasena ponds emphasizes the potential for revitalizing river transportation, especially for the conveyance of goods.

The objectives of this study are to conduct a modeling scenario of riverbed dredging in the lower reaches of the Tulang Bawang River from the estuary to 11.8 km upstream. It also aimed to review the impact of dredging on the environment, especially flooding and sedimentation, by 17.8 km upstream to Dipasena shrimp pond and further upstream to Rawajitu and Rawapitu swampland areas. This study used some scenarios of upstream and downstream boundary conditions to determine the significance of the impact.


Fig. 2 The pier located at Kuala Teladas at the estuary of the Tulang Bawang River

II. Materials and Method

Primary and secondary data obtained from field measurements and previous studies were utilized. Primary data included bathymetry measurements of the Tulang Bawang River along a stretch of 11.8 km from the estuary. Meanwhile, situational and tidal surveys were carried out to determine the minimum and maximum water level elevations used to determine boundary conditions downstream. Secondary data included bathymetry measurements of the Tulang Bawang River from a distance of 12–17.8 km downstream. Similarly, tidal information for one year were generated using the WX-TIDE software.

The discharges measured daily from 1986 to 2000 were used for data analysis. Afterward, there was no measurement available in subsequent years. Based on the available information, the average, minimum, and maximum discharges were 545 m^3/s, 52 m^3/s, and 3334 m^3/s, respectively. The hydrological analysis included the analysis of design flood discharges and drought discharges.

Frequency analysis is used to determine the design of flood discharge. The aim is to examine the relationship between the extreme events' magnitude and the occurrence frequency using a probability distribution. The design flood discharge for a certain return period is calculated based on the selected distribution type (Normal Distribution, Log-Normal, Log Pearson Type III, or Gumbel).

Drought discharge analysis determined water availability or dependable discharge depending on the available data. This study acquired the daily discharge data within a fairly lengthy recording period, followed by the Flow Duration Curve (FDC). The FDC was obtained by sorting the discharge data from the largest to the smallest. This was followed by calculating the probability of each data based on the data series. The dependable discharge was calculated based on the desired probability, further converted into a return period, *T*. Drought discharge for return period *T* was obtained using Equation 1:

$$\mathbf{T} = \frac{1}{(1-P(X\geq x))} = \frac{1}{P(X<x)} \quad (1)$$

T denotes the number of years showing the failure probability at a discharge < x m^3/s, which occurs at an average of once in T years, while P is the probability.

Numerical simulation was carried out to describe the conditions of existing and planned channels and determine the river's hydraulic flow behavioral phenomenon. Furthermore, the HEC-RAS modeling program [25]–[30] was used to determine the hydraulic analysis, which included examining the water level elevation, dredging plan, and sedimentation under several boundary conditions. This was carried out to investigate the water level and sediment in the longitudinal direction. The scenario in Setting 3 boundary conditions is as follows:

- A: upstream flooding and low downstream tide.
- B: upstream flooding and downstream high tide.
- C: upstream drought and low downstream tide.

The upstream and downstream boundary conditions are the discharge and water level elevation, respectively.

The flow scheme of the Tulang Bawang River from the river mouth to 17.8 km upstream, i.e., the Dipasena shrimp pond, is shown in Figure 3. The cross-sectional data of the river and its stationing position concerning the estuary at certain coordinates and elevations were taken from the BenchMark based on measurements made in the field. Peg 0 depicts an estuary elevation of +15.00 m. The 15 m datum is the Mean Sea Level that facilitates the HEC-RAS modeling.

A hydraulic analysis was carried out to understand the impact of dredging on the river. However, the cross-sectional input data was used to investigate the water level along the river, assuming the sediment dredging would be carried out later. The part of the Tulang Bawang River to be dredged along an 11.8-km stretch with the number of cross-sections measured on the field is 114 pieces. Figure 3 shows the longitudinal cross-sections of the river upstream, and figure 4 shows the middle part to be dredged at 5.4 km from the estuary.

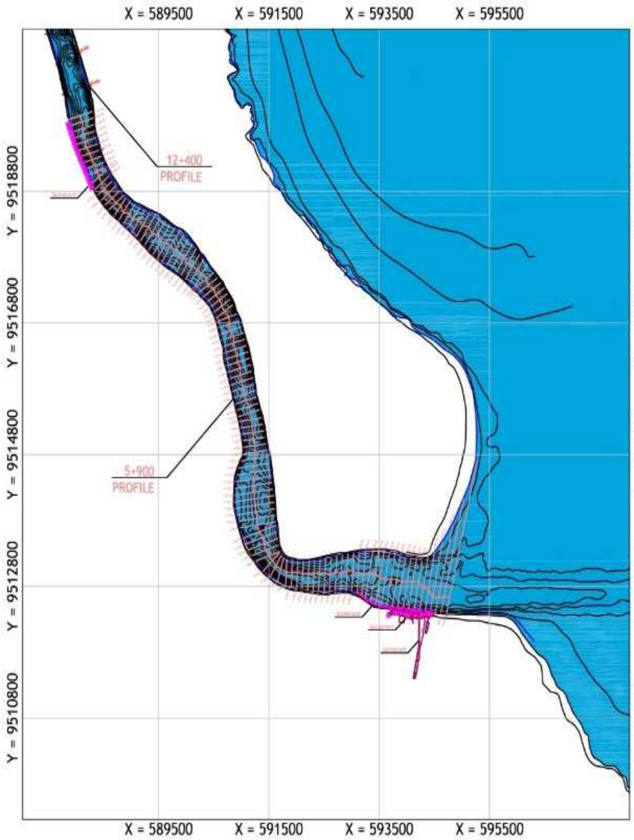

Fig. 3 Longitudinal cross-section of the dredged river section

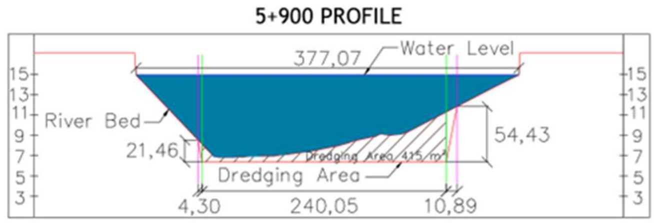

Fig. 4 Cross-section of the planned dredged section at a distance of 5.9 km from the estuary

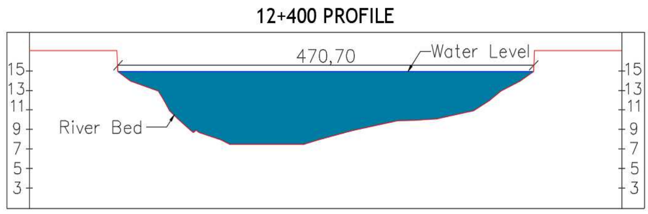

Fig. 5 Cross-section of the Tulang Bawang River along the stretch from 11.8 km (estuary) to 17.8 km (Dipasena) that is not considered to be dredged

The cross-section of the river that was not dredged, at a distance of 11.8 to 17.8 km from the estuary, is represented by Figure 5. This constitutes the secondary data, with a less frequent density than the section planned to be dredged. Figure 6 shows a longitudinal cross-section of the riverbed from the estuary to 17.8 km, at the existing condition and after the planned dredging.

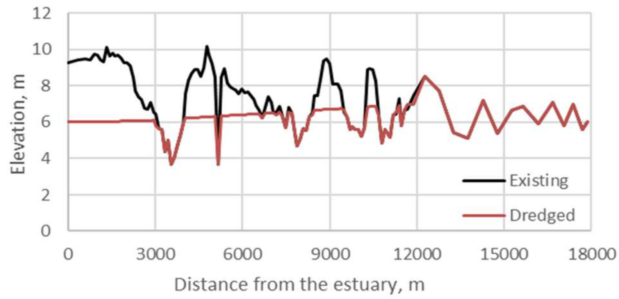

Fig. 6 Longitudinal cross-section of the riverbed in terms of the existing condition and dredging target

For sedimentation analysis, the geometric data used is similar to the water level analysis. In addition, the sediment data section required several input parameters, namely the equations used and the grain size gradation. The applied equations are Toffaleti as a sediment transport function, Thomas (Ex5) for the sorting process, and the Ruby method used to obtain the Fall Velocity. Figure 7 shows the grain size gradation obtained from the laboratory analysis of sediment extraction at that location. A flow chart of the research stages systematically presented in Figure 8.

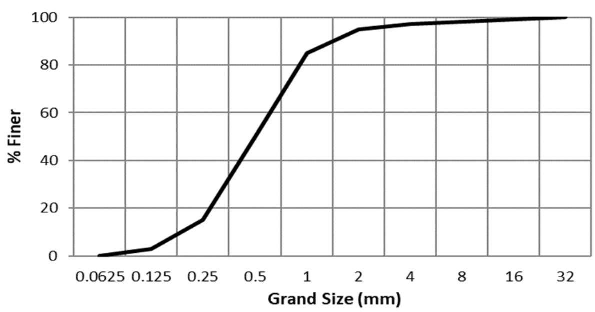

Fig. 7 Gradation of sediment grain size

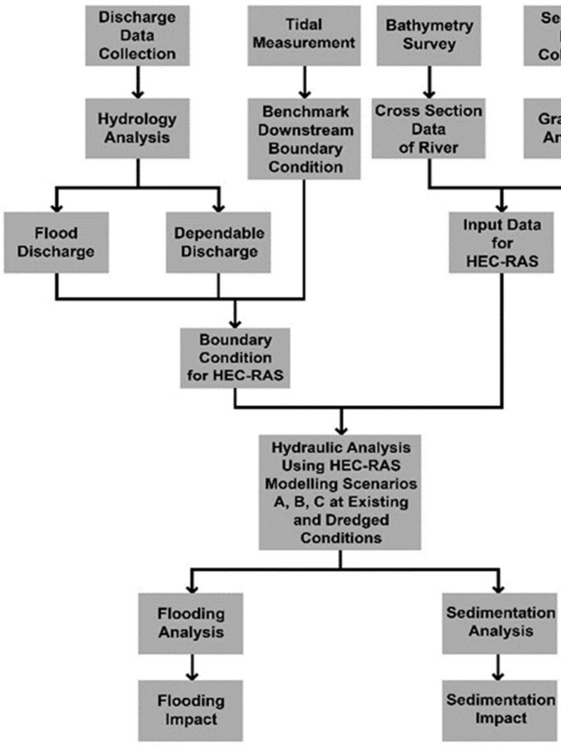

Fig. 8 Systematic of the research stage

III. Results and Discussion

A. Impact of Water Elevation Changes

Downstream boundary conditions is determined based on tidal measurement from June 18 to July 1, 2020, and WX TIDE predictions with data generation for 1 year. The datum used is 15 m, which is assumed to be the MSL (Mean Sea Level elevation) and obtained from the results of the analysis using WX TIDE for 1 year. The analysis results showed that the highest and lowest tide elevations (HWS and LWS) are 15.97 m and 14.14 m, respectively.

The upstream boundary experiences a discharge with a return period of 2, 10, and 25 years, which was obtained by calculating the frequency analysis of the flood conditions. Meanwhile, for dry conditions, the drought discharge was calculated using Formula 1. For downstream boundary conditions, the water level was used. Downstream flooding means the highest tide elevation was applied, while downstream drought means the lowest low tide was used to calculate the downstream low tides. The calculated results of each boundary condition are shown in Table 1.

TABLE I
UPSTREAM AND DOWNSTREAM BOUNDARY CONDITIONS FOR EACH SCENARIO

Boundary Condition	UPSTREAM			UPSTREAM
	Design Discharge (m^3/s)			Water Level Elevation
	2 years	10 years	25 years	(m)
A	1931.4	4253.2	6069.2	14.14
B	1931.4	4253.2	6069.2	15.97
C	474.07	190.92	53.93	15.97

TABLE II
SCENARIO A, B, AND C MODELING RESULTS FOR WATER LEVEL ELEVATION

Modeling Scenario	Return Period (year)								
	A			B			C		
	2	10	25	2	10	25	2	10	25
Existing condition (m)	15.2	17.0	18.2	16.3	17.5	18.6	16	15.97	15.97
After dredging (m)	14.8	16.3	17.4	16.2	17.1	17.9	15.99	15.97	15.97
Elevation Drop (m)	0.4	0.69	0.8	0.1	0.3	0.6	0.01	0	0

The Water Level Modeling Scenario results shown in Table 2 indicate that the upstream water level elevation is 17.8 km from the estuary. Table 2 shows the water level elevation simulation results following the upstream and downstream boundary conditions presented in Table 1. However, the differences in the existing water level elevation before and after dredging were reported for each boundary condition scenario.

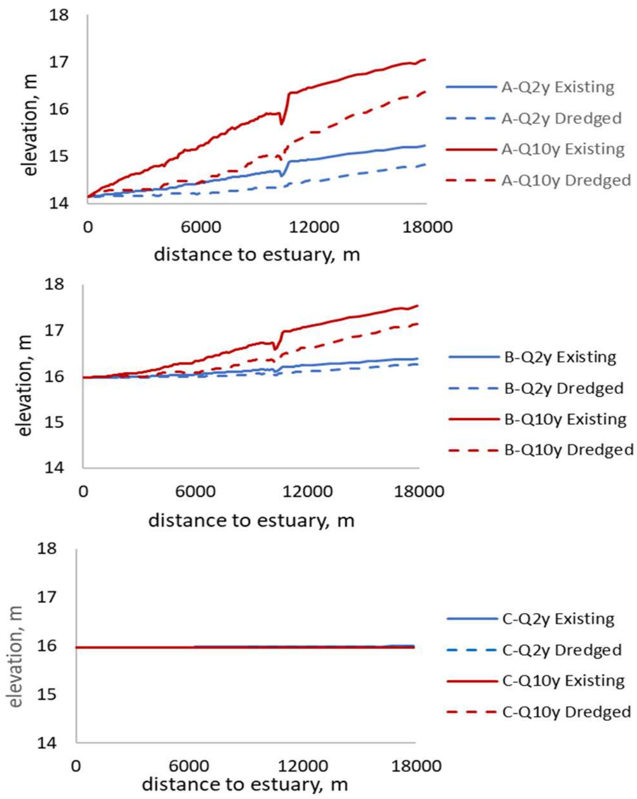

Fig. 9 Water level elevation of the Tulang Bawang River from 17.8 km to the estuary before and after dredging concerning 2 and 10-year return periods in boundary condition scenario A, B and C

Based on the scenario analysis results of boundary conditions A, when the downstream floods recede, there is a decrease in the water level upstream from 0.4 m to 0.8 m for a return period of 2 to 25 years. For the same return period, water level drops using scenario A are larger than those using scenario B.

The scenario analysis results of boundary conditions B (upstream flooding and downstream tides) show that when there is a flood in the upstream and tide in the downstream, the flow propagation in the upstream becomes smaller when dredged. This is similar to scenario A in the upstream and lower parts of the flood and low tide, respectively. Simulation B shows how tides in the estuary spread upstream, and dredging reduces flood propagation's effect upstream. Meanwhile, when the upstream was flooded within a return period of 2 years, the difference before and after dredging became 0.13 m, and the decrease in elevation rose with increasing flood returns. During the 25th return period, the difference in water level before and after dredging was 0.65 m.

Dredging sediment from riverbeds increases the flow capacity of the channels. As shown in this study, as the impact of dredging, the water level decreases (Figure 9). This result is in line with the stakeholders' and policymakers' point of view that dredging is often the most appropriate flood-reduction measure [22], [24]. The part of the Tulang Bawang River studied here inundates some villages when it floods. Dredging the lower portion of the rivers thus reduces the impact of flooding on communities located on the banks of rivers.

Based on the result obtained from scenario C, water from downstream moves upstream during the drought period at the upstream and high tide downstream. However, no elevation difference results with and without dredging on the water level upstream. Even for a higher return period (25 years), as presented in Table 2, dredging has no impact on the water level upstream. Condition C has the maximum chance for seawater intrusion in the upstream direction. Under existing conditions, seawater intrusion occurred along a stretch of 80 km from the Menggala area [31]. The intrusion increases when there is an increase in the upstream base elevation because the energy grade is affected under these conditions. Therefore, based on the analysis results, the effect of dredging on seawater intrusion is insignificant and, therefore, considered safe.

As salt intrusion is not much upstream, it may be said that the swamp irrigation areas, Rawa Jitu and Rawa Pitu will not be affected by saltwater. The irrigation areas produce paddy rice in large quantities every year. The swamp irrigation areas exhibit good water management and prevent saltwater from invading the paddy fields. As this study shows, dredging causes a drop in the water elevation at a point upstream of the planned dredge area; a drop of 13 cm was observed in the water level for a 2-year return period. The situation was analyzed using the boundary condition of the extreme situation. Considering the water level drop in a regular situation would not be much help, as it would be much less than that in an extreme situation.

In addition, the Rawajitu and Rawapitu swamp irrigation areas are located 27 km and 45 km from the estuary, which lessens the effect of elevation on water drop even more. While for the Dipasena shrimp pond, this has an insignificant effect because it draws water supply from the sea with intakes that are not connected to the Tulang Bawang River. The part of the Dipasena Shrimp Farm connected to the river is the outlet. Therefore, the decrease in water level elevation is stated to have an insignificant effect on the pond. It is beneficial for the main drain Dipasena, which is connected to the Tulang Bawang River, to have water elevation drop.

B. Impact of Riverbed Changes and Sedimentation

The sedimentation process in the Tulang Bawang River based on the three scenarios is shown in Fig. 10. Simulation for a period of one-year results in aggradation and deposition along the river both before and after dredging. Scenarios A and B showed significant changes in the Tulang Bawang Riverbed, while the changes observed in scenario C were incredibly minimal.

In addition to scenarios A to C for boundary conditions, each simulation was carried out in 2 scenarios before and after dredging. In total, six scenarios were recorded. Furthermore, for each of these scenarios, the cumulative sediment was analyzed in three sections: 1) a section of the Tulang Bawang River from the Dipasena downstream to the upstream planned to be dredged (17.8 km–11.8 km from the estuary); 2) a part of the dredged riverbed (11.8 km–0 km); and 3) from the Dipasena downstream to the estuary (17.8 km–0 km). To further analyze the sedimentation process in each segment, the cumulative reviewed are sediments in (In), (out), and (all). This represents the sum of incoming and outgoing sediments. The analysis results are shown in detail in Table 3.

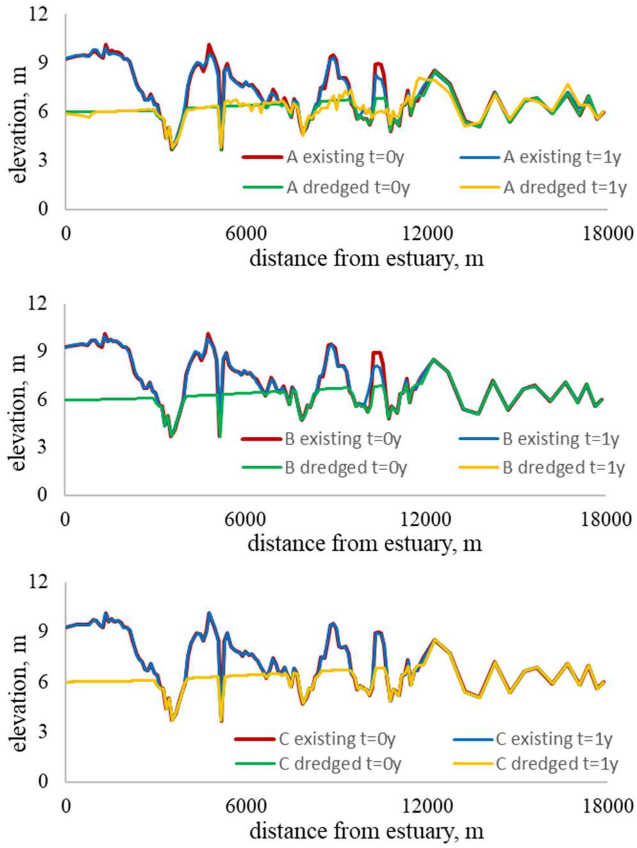

Fig 10 Riverbed elevation at existing and dredged conditions for scenarios A, B and C

Dredging in tidal rivers, as in the Tulang Bawang River, may push sediments up the rivers [28], potentially increasing the risk associated with floods. Besides, dredging in scenario A showed that cumulative sediment has the largest deposition compared to the other scenarios. In addition, scenario B showed that when dredging was carried out, the riverbed upstream of the dredged section experienced erosion (sediment Out is greater than In). This needs to be paid attention to if dredging will be carried out in the future. Both scenarios A and B showed a higher sedimentation value in circumstances where no dredging was conducted. Meanwhile, scenario C showed an even smaller sedimentation impact after dredging.

TABLE III
CUMULATIVE SEDIMENT (IN, OUT, AND ALL) (IN 10^3 M^3) FOR VARIOUS SCENARIOS ON 3 RIVER SECTIONS

Distance from estuary (km)		Difference of Cumulative Sediment (10^3 m^3) of existing to dredged conditions		
		A	B	C
In	17.8 - 11.8	3354.2	270.8	-5.4
	11.8 - 0	-150.3	-2852.2	-59.8
	17.8 - 0	3203.9	-2581.4	-65.1
Out	17.8 - 11.8	3344.0	320.5	-5.1
	11.8 - 0	-476.4	-2927.9	-67.7
	17.8 - 0	2867.6	-2607.4	-56.5
All	17.8 - 11.8	10.2	-49.7	-0.3
	11.8 - 0	325.9	75.7	-0.2
	17.8 - 0	336.2	25.9	-0.5

The result of sedimentation analysis shows that river dredging leads to morphological changes. Dredging activities occur both in developed and developing countries such as Indonesia and may have an environmental impact [32]–[34]. Especially in a developing country, effective environmental management for dredging needs to be implemented to minimize the environmental impact such as technologies applied in some countries [35].

IV. CONCLUSION

River dredging leads to long- and short-term morphological changes. In the case of the downstream dredging plan in the Tulang Bawang River, the results of this study indicate that, after the process was carried out, changes in the water level elevation had an insignificant effect on valuable assets in the upstream section. Water elevation drop will benefit the Dipasena shrimp pond as the part connected to the Tulang Bawang River is the main drain. Changes in water level elevation may insignificantly affect the swampland irrigation areas. The dredging process will increase cumulative sediment deposited at the dredged section. Further study needs to be conducted to have a minimum impact on dredging activities upstream and in the dredged section.

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REFERENCES

[1] S. Janjua, I. Hassan, S. Muhammad, S. Ahmed, and A. Ahmed, "Water management in Pakistan's Indus Basin: challenges and opportunities," *Water Policy*, vol. 23, no. 6, pp. 1329–1343, 2021, doi: 10.2166/wp.2021.068.

[2] C. R. Ortloff, "Inka hydraulic engineering at Tipon Roya Compound (Peru)," *Water*, vol. 14, no. 1, pp. 1–27, 2022, doi: https://doi.org/10.3390/w14010102.

[3] A. Kothari and S. Bajpai, "Rivers and Human Rights: We are the River, the River is Us?," *Econ. Polit. Wkly.*, vol. 52, no. 35, pp. 1–17, 2017.

[4] B. Wang, J. Wan, and Y. Zhu, "River chief system: an institutional analysis to address watershed governance in China," *Water Policy*, vol. 23, no. 6, pp. 1435–1444, 2021, doi: 10.2166/wp.2021.113.

[5] I. G. A. P. Eryani, I. W. Runa, and M. W. Jayantari, "Water potential management and arrangement of river estuary area for the mitigation of the climate change in Bali," *Int. J. Adv. Sci. Eng. Inf. Technol.*, vol. 9, no. 3, pp. 849–854, 2019, doi: 10.18517/ijaseit.9.3.8224.

[6] E. Helal, H. Elsersawy, E. Hamed, and F. S. Abdelhaleem, "Sustainability of a navigation channel in the Nile River: A case study in Egypt," *River Res. Appl.*, vol. 36, no. 9, pp. 1817–1827, 2020, doi: 10.1002/rra.3717.

[7] Z. Horvat, M. Horvat, F. Majer, and D. Koch, "Hydraulic analysis of a meander on the Danube River using a 2D flow model," *Environ. Monit. Assess.*, vol. 192, no. 2, 2020, doi: 10.1007/s10661-020-8074-z.

[8] A. J. Paarlberg, M. Guerrero, F. Huthoff, and M. Re, "Optimizing dredge-and-dump activities for river navigability using a hydro-morphodynamic model," *Water*, vol. 7, no. 7, pp. 3943–3962, 2015, doi: 10.3390/w7073943.

[9] M. Guerrero, M. Re, L. D. D. Kazimierski, Á. N. Menéndez, and R. Ugarelli, "Effect of climate change on navigation channel dredging of the Parana River," *Int. J. River Basin Manag.*, vol. 11, no. 4, pp. 439–448, 2013, doi: 10.1080/15715124.2013.819005.

[10] G. Brousse *et al.*, "Channel response to sediment replenishment in a large gravel-bed river: The case of the Saint-Sauveur dam in the Buëch River (Southern Alps, France)," *River Res. Appl.*, vol. 36, no. 6, pp. 880–893, 2020, doi: 10.1002/rra.3527.

[11] K. S. Hiemstra, S. van Vuren, F. S. R. Vinke, R. E. Jorissen, and M. Kok, "Assessment of the functional performance of lowland river systems subjected to climate change and large-scale morphological trends," *Int. J. River Basin Manag.*, vol. 18, no. 4, pp. 1–22, 2020, doi: 10.1080/15715124.2020.1790580.

[12] B. Thom, E. Rocheta, C. Steinfeld, N. Harvey, J. Pittock, and P. Cowell, "The role of coastal processes in the management of the mouth of the River Murray, Australia: Present and future challenges," *River Res. Appl.*, vol. 36, no. 4, pp. 656–667, 2020, doi: 10.1002/rra.3551.

[13] B. Hidayat, B. Istijono, Irwan, T. Ophiyandri, and A. Junaidi, "The effects of batang kandis river flood control in padang city-palapa metropolitan urban area," *Int. J. GEOMATE*, vol. 19, no. 71, pp. 9–14, 2020, doi: 10.21660/2020.71.5525.

[14] Y. G. Wang and Y. Chen, "The influence of human activity on variations in basin erosion and runoff-sediment relationship of the Yangtze River," *ISH J. Hydraul. Eng.*, vol. 26, no. 1, pp. 68–77, 2020, doi: 10.1080/09715010.2018.1452646.

[15] D. S. van Maren, T. van Kessel, K. Cronin, and L. Sittoni, "The impact of channel deepening and dredging on estuarine sediment concentration," *Cont. Shelf Res.*, vol. 95, pp. 1–14, 2015, doi: 10.1016/j.csr.2014.12.010.

[16] P. Teatini *et al.*, "Hydrogeological effects of dredging navigable canals through lagoon shallows. A case study in Venice," *Hydrol. Earth Syst. Sci.*, vol. 21, no. 11, pp. 5627–5646, 2017, doi: 10.5194/hess-21-5627-2017.

[17] A. D. Lade and B. Kumar, "Streambed instabilities around a bridge pier in a dredged channel," *River Res. Appl.*, vol. 36, no. 7, pp. 1360–1365, 2020, doi: 10.1002/rra.3629.

[18] M. Bendixen, J. Best, C. Hackney, and L. L. Iversen, "Time is running out for sand," *Nature*, vol. 571, no. 7763, pp. 29–31, 2019, doi: 10.1038/d41586-019-02042-4.

[19] W. S. Smith, F. L. Da Silva, and R. C. Biagioni, "River Dredging: When the Public Power Ignors the Causes, Biodiversity and Science," *Ambient. Soc.*, vol. 22, no. e00571, pp. 1–17, 2019, doi: 10.1590/1809-4422asoc0057r1vu19l1ao.

[20] L. Jing *et al.*, "Dredging project caused short-term positive effects on lake ecosystem health: A five-year follow-up study at the integrated lake ecosystem level," *Sci. Total Environ.*, vol. 686, pp. 753–763, 2019, doi: 10.1016/j.scitotenv.2019.05.133.

[21] G. Žilinskas, R. Janušaitė, D. Jarmalavičius, and D. Pupienis, "The impact of Klaipėda Port entrance channel dredging on the dynamics of coastal zone, Lithuania," *Oceanologia*, vol. 62, no. 4, pp. 489–500, 2020, doi: 10.1016/j.oceano.2020.08.002.

[22] D. K. Ralston, S. Talke, W. R. Geyer, H. A. M. Al-Zubaidi, and C. K. Sommerfield, "Bigger Tides, Less Flooding: Effects of Dredging on Barotropic Dynamics in a Highly Modified Estuary," *J. Geophys. Res. Ocean.*, vol. 124, no. 1, pp. 196–211, 2019, doi: 10.1029/2018JC014313.

[23] G. H. P. Campmans, P. C. Roos, N. R. Van der Sleen, and S. J. M. H. Hulscher, "Modeling tidal sand wave recovery after dredging:effect of different types of dredging strategies," *Coast. Eng.*, vol. 165, p. 103862, 2021, doi: 10.1016/j.coastaleng.2021.103862.

[24] A. Daigneault, P. Brown, and D. Gawith, "Dredging versus hedging: Comparing hard infrastructure to ecosystem-based adaptation to flooding," *Ecol. Econ.*, vol. 122, pp. 25–35, 2016, doi: 10.1016/j.ecolecon.2015.11.023.

[25] A. Urzică *et al.*, "Using 2D HEC-RAS modeling and embankment dam break scenario for assessing the flood control capacity of a multireservoir system (Ne Romania)," *Water*, vol. 13, no. 1, pp. 1–28, 2021, doi: 10.3390/w13010057.

[26] S. Malik and S. C. Pal, "Application of 2D numerical simulation for rating curve development and inundation area mapping: a case study of monsoon dominated Dwarkeswar river," *Int. J. River Basin Manag.*, vol. 19, no. 4, pp. 553–563, 2021, doi: 10.1080/15715124.2020.1738447.

[27] A. Amini, J. Bahrami, and A. Miraki, "Effects of dam break on downstream dam and lands using GIS and Hec Ras: a decision basis for the safe operation of two successive dams," *Int. J. River Basin Manag.*, vol. 19, pp. 1–12, 2021, doi: 10.1080/15715124.2021.1901728.

[28] A. Sathya, S. G. Thampi, and N. R. Chithra, "Development of a framework for sand auditing of the Chaliyar River basin, Kerala, India using HEC-HMS and HEC-RAS model coupling," *Int. J. River Basin Manag.*, vol. 19, pp. 1–14, 2021, doi: 10.1080/15715124.2021.1909604.

[29] A. Kalra; N. Joshi, S. Baral, and S. N. Pradhan, "Coupled 1D and 2D HEC-RAS Floodplain Modeling of Pecos River in New Mexico," 2021, *World Environmental and Water Resources Congress 2021*, doi: https://doi.org/10.1061/9780784483466.016.

[30] L. Milanesi and M. Pilotti, "Coupling Flood Propagatiom Modeling and Building Collapse in Flash Flood Studies," *J. Hydraul. Eng.*, vol. 147, no. 12, 2021, doi: https://doi.org/10.1061/(ASCE)HY.1943-7900.0001941.

[31] Directorate General of Water Resources Development, Ed., *Southern Sumatera Water Resources Development Tulang Bawang and Mesuji River Basins*. Jakarta: Ministry of Public Works Republic of Indonesia, 1989.

[32] C. R. Esposito, I. Y. Georgiou, and K M Straub, "Flow Loss in Deltaic Distributaries: Impacts on Channel Hydraulics, Morphology, and Stability," *Water Resour. Res.*, vol. 56, no. e2019WR026463, pp. 1–18, 2020, doi: https://doi.org/10.1029/2019WR026463.

[33] J-S Chou and Y-C Chiu, "Identifying critical risk factors and responses of river dredging projects for knowledge management within organisation," *J. Flood Risk Manag.*, vol. 14, no. e12690., pp. 1–16, 2021, doi: https://doi.org/10.1111/jfr3.12690.

[34] L. Koehnken, M. S. Rintoul, M. Goichot, D. Tickner, A-C Loftus, and M. C. Acreman, "Impacts of riverine sand mining on freshwater ecosystems: A review of the scientific evidence and guidance for future research," *River Res. Appl.*, vol. 36, pp. 362–370, 2020.

[35] A. Bianchini, F. Cento, A. Guzzini, M. Pellegrini, and C. Saccani, "Sediment management in coastal infrastructures: Techno-economic and environmental impact assessment of alternative technologies to dredging," *J. Environ. Manage.*, vol. 248, no. January, p. 109332, 2019, doi: 10.1016/j.jenvman.2019.109332.