

## A STUDY ON THE OPTIMIZATION OF DREDGING ALIGNMENT AND PERFORMANCE OF BANK PROTECTION WORKS ALONG TETULIA RIVER AT BAKERGANJ AND BAUPHAL UPAZILLAS

M. Shahabuddin<sup>1\*</sup>, A. K. M. Ashrafuzzaman<sup>1</sup>, O. A. Maimun<sup>1</sup>, B. Roy<sup>1</sup>, M. A. H. Podder<sup>1</sup>, M. Tofiquzzaman<sup>1</sup>, M. K. Eusufzai<sup>2</sup> and P. Kanungoe<sup>1</sup>

### Abstract

This paper presents the results for finalization of the proposed dredging alignment & its design and performance of the revetment for bank protection work in the Tetulia River at Bakerganj and Bauphal upazillas using scale modeling. The model is an overall distorted morphological model having horizontal scale 1:600 and vertical scale 1:80. The main purpose of this model is to provide decision support for determining of suitable and optimal dredging alignment and to investigate the efficacy of the proposed bank protection work to ensure a stable river course facilitating smooth navigation. The river reaches of about 50 km of Tetulia River and about 10 km of Karkhana River have been reproduced in this study. Different application test runs were conducted with different test scenarios (introducing revetment & dredged channel) using different discharges (ebb & flood) conditions. A 7 km revetment is proposed at the right bank of Tetulia River and 0.5 km at the left bank of Karkhana River. Model study shows it works well and is recommended. Dredged channel alignment is optimized along the left side channel of Char Durgapasha at a shallow depth. The longitudinal bed slope of the dredged channel is 4 cm km<sup>-1</sup>. The bottom width of the dredged channel is considered as 120 m. Total volume of material to be dredged under this test condition is around 10,26,685 m<sup>3</sup>. The recommended length of dredged channel is 2,534 km having bottom width 120 m, bottom level -9.0 mPWD, longitudinal bottom slope 4.0 cm km<sup>-1</sup> and side slope 1:3. The volume of dredged material is 10,26,685 m<sup>3</sup> for dredged channel section of recommended dredging option. About 56% of the dredged volume, or approximately 574,944 m<sup>3</sup>, was used to fill up the dredged channel. To maintain the channel's usability, maintenance dredging once a year for two years is recommended.

**Keywords:** Application, Bank Protection Work, Discharge, Dredging, Dumping, Maintenance, Offtake, Performance, Revetment, Scenarios.

### Introduction

At present the vast area from Dhulia Launch ghat area in Bauphal upazilla of Patuakhali district to Durgapasha area in Bakerganj upazilla of Barisal district are facing severe bank erosion. In fact, unabated right bank erosion at this river stretch has been taking place over the last four decades as can be seen from the available historical satellite images. In the seventies of the 20<sup>th</sup> century, the river at the erosion prone area used to be a single-channel river with a few small sized chars in the middle of the channel. However, with the passage of time these small sized chars grew in size causing changes in flow pattern and consequent braid-dominance with anabranches. A number of consequences have been visible including reduced flow depths, over-flow of banks and bank erosion. Such issues are constituted by sediment transport and deposition characteristics along the river bed (RRI, 2021). This study is done for the protection of area about 7.5 km from Dhulia Launch ghat area under Bauphal upazilla of Patuakhali district to Durgapasha area under Bakerganj upazilla of Barishal district from the erosion of Tetulia River with provision of dredging in the Tetulia River. It aims to divert the flow from the eroding bank to the center of the channel thus reducing bank erosion. It is very important to select a suitable dredging alignment that would be sustainable and would bring benefit in terms of reduction of near bank flow velocity. The overall objective of the physical model study is to fix suitable alignment of dredging of the Tetulia River at Dhulia-Durgapasha and determine suitable location for dredged material disposal and type, dimension and orientation of river training works for stabilizing the river bank (RRI, 2022b). The location map of the study area is shown in Fig.1.

Physical model is employed to investigate the performance of different options and strategies of dredging and dredged material disposal, sustainability of dredged channel and

hydraulic and morphological impacts of dredging. As such, present initiative is taken in order to obtain necessary physical modeling support for effective and sustainable dredging of the Tetulia River at the project site where the river has been experiencing large right bank erosion. The model can be used as a decision support tool for fixation of dredging alignment and design of bank protection work.

Tetulia River is a channel in the Meghna Estuary region of Bangladesh where the constant process of erosion and deposition takes place due to the complex interactions between large river discharge and sediment load, tidal forces, waves, storm surges etc. In fact, interactions among these factors together with their seasonal occurrence, variation and dominance over one another shape the morphology of the Meghna estuary. The distribution of discharge, sediment and water level in the different channels of the Meghna estuary including the Tetulia River are governed by river discharge, the tide and the wind speed. Karkhana River, on the other hand, is a distributary of the Tetulia River. The flow and sediment distribution in the Karkhana River as a percentage of discharge and sediment load of the Tetulia River is influenced by the hydraulic and morphological developments of the parent river at its off-take.

Due to unabated bank erosion in the study area many people have lost their homesteads and cultivable lands. Damaged properties include educational institutions, religious places, private and public infrastructures, communication systems etc. In fact, river erosion has changed the life pattern of many people of the study area. Losing livelihood many people were compelled to look for alternative sources of income. People are taking shelter in nearby rural areas, khashlands etc. losing homesteads and most of the affected people are being migrated to urban and sub-urban areas. Enough initiatives are not taken for the resettlement of the displaced people. Only small percentage of displaced population has been resettled in the char land. The char land of the Tetulia River is also

<sup>1</sup> Hydraulic Research Directorate, River Research Institute, Faridpur-7800, Bangladesh.

\* Corresponding Author (E-mail: [mshahabuddin@rri.gov.bd](mailto:mshahabuddin@rri.gov.bd))

<sup>2</sup> Dhaka Laboratory, River Research Institute, Dhaka-1205, Bangladesh.

susceptible to erosion. Since most of the people in the study area are dependent on agriculture loss of homesteads and cultivable lands due to bank erosion takes a heavy toll on these people's livelihoods forcing internal migration.

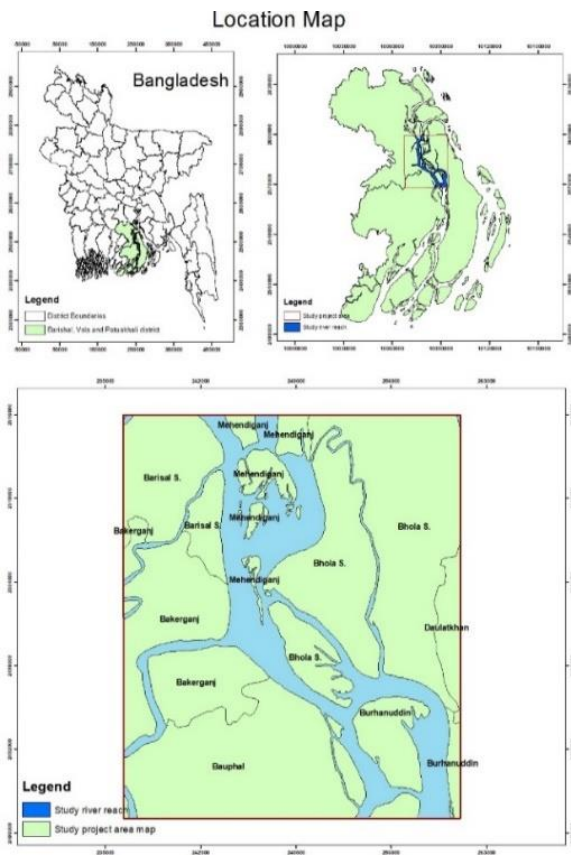


Fig.1. Location map of the study area.

The present bank erosion situation in the study area is visible from Fig. 2. At present there is no planned bank protection work in the erosion prone area of the Tetulia and Karkhana Rivers. Along the erosion prone stretch of the Tetulia River from Durgapasha to Dhulia only a small stretch of the bank has been stabilized by implementing hard material protection using cement concrete blocks in order to protect the Dighirpar Launch Terminal (Fig. 3). Geobag protection measure has also been implemented up to a certain extent beyond this hard material protection works both upstream and downstream (Fig. 4). Scattered and piecemeal geobag protection works are also noticeable elsewhere along the erosion prone bank (RRI, 2023).

Dredging has been proven as an effective process to control the deposited sediment to prevent flooding and make a pathway for the main channel flow (Gob et al., 2005; Zinger et al., 2011). The process also allows us to further solve engineering problems related to sedimentation and erosion in rivers, estuaries, and coastal seas (Van Rijn, 2005). A better prediction of erosion-sedimentation scenarios is inevitable to justify the long-term effectiveness of dredging, which could further promote the design strategies based on qualitative and quantitative analysis. Prediction of accurate scour depth and deposition of the braided river is methodologically very challenging because of the variation in simple path-length distribution resulting in over-scouring (Kasprak et al., 2019).



Fig. 2. Present right bank erosion situation of the Tetulia River in the upstream of Dhulia Launch Ghat area.



Fig. 3. Existing hard material protection (CC block) works at Dighirpar Launch Terminal.



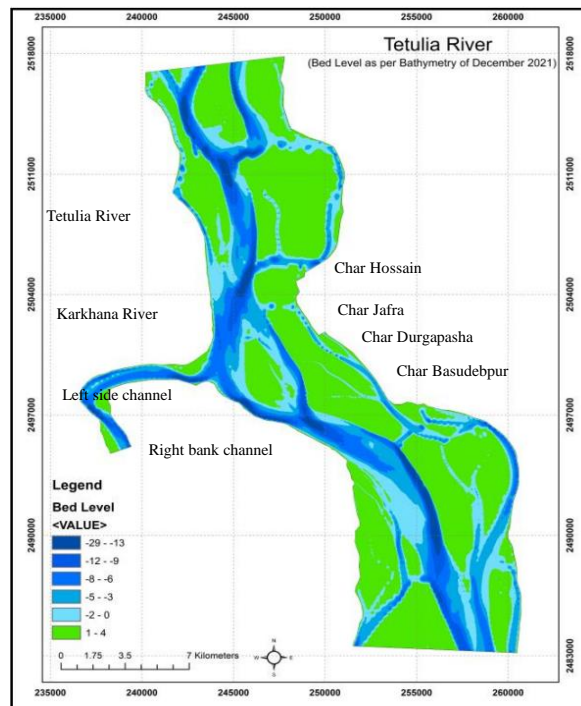
Fig. 4. Existing geobag protection works in the upstream of Dighirpar Launch Terminal.

The principal estuarine channels, proceeding from west to east are the Raymangal, Malancha, Bara Panga, Marjhata, Bangara, Haringhata or Baleswar, Ramnabad-Tetulia, Shahbazpur of Lower Meghna (Rob, 2012). Tetulia River originates from the Lower Meghna River at north of Bhola district. The river flows through Tetulia, Nimdi, Kalaiya and Purbamunia and ends up to the Bay of Bengal as the Buragouranga channel at Rangopaldi of Galachipa upazilla under Patuakhali district. It used to flow with a strong or rapid current. However, hydrodynamics of flow has been changed in recent years due to formation of many sand bars. The river separates Bhola island from the

main land. The Ramnabad Island is located at the west bank of the river. An offshoot of the Meghna River from Shahbajpur meets the Tetulia River. The total length of the river is about 84 km and the average width is 6 km (Chowdhury, 2012).

## Methodology

An overall distorted morphological model was constructed which included a river stretch covering around 40 km of Tetulia River and also another river stretch covering around 10km of Karkhana River from its offtake with Tetulia River. The overall objective of the physical model study was to fix a suitable alignment for dredging of the Tetulia River at Dhulia-Durgapasha and determine a suitable location for dredged material disposal and the type, dimension, and orientation of river training works for stabilizing the river bank. The specific objectives of the overall distorted morphological model were to quantify the optimum dredging alignment and section of the dredged channel in the Tetulia River, the hydraulic performance of the dredged channel, to investigate the hydraulic and morphological effects of dredging, the impact on flow pattern, bank erosion phenomena, and other associated features, and to devise suitable types, placement, dimensions, and orientation of river training works to ensure a stable river course. The initial bathymetry of the model in prototype value is shown in **Fig. 5**.



**Fig. 5.** Initial bathymetry of the model in prototype value.

The sustainability and effectiveness of any river dredging project depended on how intelligently it was planned and designed. Back-filling of the dredged channel was a natural tendency. However, it was important to quantify the best-suited alignment for maximizing the benefit and lengthening the sustainability of the initiative. Therefore, morphological physical modeling was a useful tool to be employed before dredging activities. This allowed observation of the overall morphological developments in response to dredging, leading to a more informed approach.

The effect of dredging on river morphology could be predicted by this model, and potentially effective dredging strategies could have been devised. It was shown that in some cases, dredged channel silted up with sediment within a single monsoon season. Therefore, successful and sustainable river dredging involved a number of issues that needed to be well-understood and addressed during the dredge planning and design phases (RRI, 2022a)

These issues involved various morphological changes, such as the formation of shoals, islands, and chars, the meandering tendency of the river, the effect of construction hydraulic structures, damages to the banks, the effect of afforestation/deforestation, and even tectonic occurrences. Prior to preparing a dredge plan and design, some of these issues could have been addressed through modeling. Additionally, post-dredge monitoring of these issues could have been supplemented by model studies, as required, to allow for timely corrective measures to maintain the river's morphology and check for local erosion damage. Suitable river training works would have also been necessary to ensure the long-term sustainability and cost-effectiveness of the protection efforts.

Physical modeling could have been used as an important tool to assist in developing an optimal dredge plan. Additionally, it could have been employed for post-dredge monitoring and the design of optimal bank protection works to combat riverbank erosion. This model would have allowed prediction of the dredging's effects on surrounding areas, both upstream and downstream, facilitating the development of effective dredging strategies.

The RRI open air model bed with dimensions of 100m × 80m had been used to reproduce the overall distorted morphological model. The model itself was a sand bed morphological model. It had been constructed based on selected geometric scales. Because it was a distorted model, vertical and horizontal scales of the model had been selected as 80 and 600 respectively for construction. The construction of the model involved a series of tasks. In addition to selecting the geometric scale ratios, the model bed had been prepared through several steps. These included uprooting the grass, dismantling any previous structures in the selected area, and disposing of any debris. The old sand from the model bed had been removed and replaced with new fine sand with the required median size. Additionally, the necessary model construction materials had been procured, and bathymetric and bank line data had been collected.

The model design adhered to established scale laws and conditions for river scale models. In this regard, recent development in the theories of the physical processes of the large alluvial rivers was considered during scaling and design of the models. The model was investigated on a mobile bed. The hydraulic similarity was established in the model to a distorted scale. The design ensured that the model fulfilled both flow and sediment transport criteria simultaneously. This meant the water velocity in the model exceeded the critical velocity required to initiate sediment movement. This design choice was made because, for velocities exceeding the critical point, the dimensions of any resulting scour (erosion) are primarily determined by the flow direction and the geometry of any structures present.

In this physical model, various types of instrument and facilities were needed such as, sharp-crested weir for measuring flow, point gauge for measuring water level, 3-D

current meter for measuring velocity, high resolution camera for taking video and photographic view of model, stopwatch for taking instant time and plastic-coloured balls (floats) for tracing flow path of flowing water. The discharge in the model was measured using sharp-crested weir at the inflow section using Rebeck's formula. Model velocity was quantified by current meter.

Water slope was determined by analyzing water level measurements from various point gauges installed in the model. Flow lines of the stream were identified by dropping colored balls from a calibration section and observing their path to the end of the model. A stopwatch was used to calculate the surface velocity of the flow. Data from the physical model was then analyzed to interpret the test results. The initial bathymetry (December 2011) of the model was reproduced based on field survey data collected for this study. Calibration of the model was achieved using prototype water levels, flow velocities, and sediment transport data. Sediment feeding in the model was done artificially to maintain sediment balance. This process was conducted manually by observing the formation of bed forms. Continuous monitoring of the model bed was performed by taking soundings (depth measurements) (RRI, 2023).

The rate of sediment feeding for a particular model discharge was typically determined first using sediment transport formulas or relationships proposed by various researchers. In this specific model, the formula developed by Engelund and Hansen (1967) was initially used to establish the sediment feeding rate. However, this initial rate required calibration. Calibration involved taking measurements of bed levels along several cross-sections located at different points in the model at regular time intervals. The goal of calibration was to achieve a condition where the bed level remained relatively constant. This meant that the amount of sediment fed into the model should equal the amount transported out, achieving a state of sediment equilibrium.

*Model Calibration*

Model calibration is done in existing condition of the river to ensure that the model is able to reproduce the flow condition, morphological behavior and sediment transport in the field. The model is calibrated for single discharge (estimated) and verified with another single discharge (measured). The model layout is shown in Fig. 6.

Velocity distribution in the model at the sections where discharge has been measured in the field is compared with the field measurements at the same sections. In this regard, depth averaged flow velocities are measured in the model and compared with prototype measurements. Discharge distribution into the Karkhana River in the model and prototype as a percentage of the total discharge (upstream of the off-take) of the Tetulia River has also been compared.

The measurements during the calibration include water levels, bed levels, point velocities, float tracks and discharges. Calibration of water surface slope aims to achieve a dynamic equilibrium in water surface slope in the model. Calibration of discharge distribution aims to achieve a more or less constant discharge through the Karkhana River as a percentage of total discharge of the Tetulia upstream. At the end of the calibration test the discharge through the Karkhana River is found to be as about 25% of the Tetulia River. It is to be noted here that variable discharges in the Karkhana River have been measured at different times during the

calibration test. This variation in the Karkhana discharge has been occurred with the developments in the Tetulia bed in response to the imposed conditions for sediment transport similar to that in the prototype. Calibration of sediment transport depends on the reliable field data of the same.

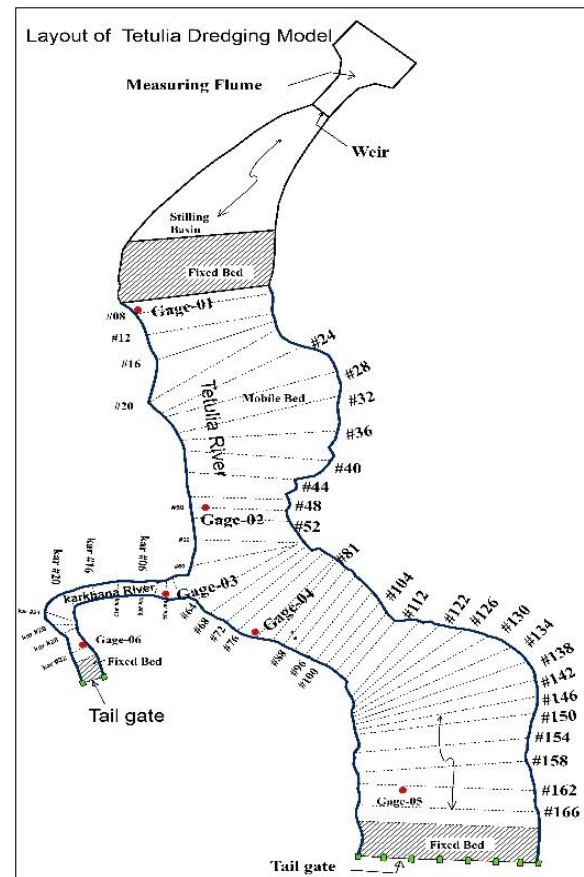


Fig. 6. Layout of the Model.

During calibration test sediment was fed manually at the inflow section of the model. Initially the rate of sediment feeding has been determined using Engelund and Hansen model. However, at the end of the test the calculated rate has been verified and it is found that equilibrium sediment transport rate in the model is  $0.054 \text{ m}^3 \text{ h}^{-1}$  for estimated channel forming discharge. It is to be noted here that some deviations around this value is caused by bed forms that migrate through the model. The sediment transport could not be compared as the sediment transport measurements in the prototype for the considered discharge is not available. Moreover, the sediment transport in the model is very difficult to compare with the prototype measurements as the model has some scale effects in reproduction of the magnitude and direction of sediment transport. The necessary measurements taken during the calibration test have been processed and analyzed. The scales of the different basic and derived parameters have been determined based on the calibration test results. Table 1 presents the characteristics parameters of the dominating processes for the overall morphological model after calibration. It is to be noted here that scales of water depth and velocity vary at different locations of the model signifying the presence of scale effects. However, the range of variation is less. The scale factors presented in this table correspond to a representative section somewhat upstream of the Karkhana River off-take.

During the calibration test the model is allowed to adjust its water surface slope and bed slope. Water levels at six prefixed gauge stations have been recorded at certain time interval and plotted to see the development of water level slope with time. The water level slope is found to vary within 0.0010 - 0.0020 and the equilibrium water level slope is 0.0015. However, still water surface slope may vary from

stretch to stretch and there is a control of daily tidal water level fluctuation on slope. Calibration of morphology requires historical bathymetric data, which is not available with RRI. Calibration of morphology has, therefore, been concentrated on achieving an equilibrium condition in the model bed configuration similar to the initial bathymetry of the model.

**Table 1.** Characteristic hydraulic and morphological parameters of the calibrated model (At upstream cross-section CS50 of the Tetulia River).

Basic and Derived Parameters	Prototype Data	Model Data	Scale Factor
Cross-sectional area (A) in m <sup>2</sup>	20800	0.43	48372
Average depth (h) in m	7.30	0.089	82
Water Width (W) in m	2850	4.75	600
Slope (i)	0.000015	0.0015	0.01
Median diameter (D <sub>50</sub> ) in m	0.00008	0.000108	0.74
Relative density (Δ)	1.65000	1.6500	1
Shields parameter (θ)	0.83	0.75	1.11
Average Velocity (V) in m s <sup>-1</sup>	0.93	0.19	4.9
Chezy (C) in m <sup>1/2</sup> s <sup>-1</sup>	88	25	3.55
Froude number (Fr)	0.11	0.20	0.55
Discharge (Q) in m <sup>3</sup> s <sup>-1</sup>	19200	0.82	235006
Friction velocity (U*) in m s <sup>-1</sup>	0.0328	0.0362	0.91
Non-dimensional particle parameter (D*)	2.02	2.73	0.74
Critical Shields parameter for motion (θ <sub>cm</sub> )	0.094	0.077	1.22
Fall velocity (w <sub>s</sub> ) in m s <sup>-1</sup>	0.00576	0.0105	0.549
Critical friction velocity (U* <sub>c</sub> ) in m s <sup>-1</sup>	0.0184	0.0209	0.8789
Critical Shields parameter for suspension (θ <sub>crs</sub> )	0.10884	0.0932	1.1684
Critical velocity for motion (U <sub>cm</sub> ) in m s <sup>-1</sup>	0.33300	0.2136	1.5587415
Critical velocity for suspension (U <sub>crs</sub> ) in m s <sup>-1</sup>	0.35828	0.2353	1.52295701
Critical depth (h <sub>cr</sub> ) in m	0.958	0.0111	86.55
Rouse parameter (w <sub>s</sub> /kU*)	0.439	0.725	0.606
U*/w <sub>s</sub>	5.695	3.45	1.65
Reynolds number (Re)	6789000	16910	401
Reynolds particle parameter (R*)	2.622	3.91	0.671
Reynolds critical particle parameter (R* <sub>c</sub> )	1.472	2.26	0.66
Sediment Transport, s (m <sup>2</sup> s <sup>-1</sup> )	0.00007	0.000003	23.33
Sediment Transport, S (m <sup>3</sup> s <sup>-1</sup> )	0.2	0.0000143	14000
1D celerity (m s <sup>-1</sup> )	0.00005	0.0002	0.28
1D time scale (days)	8932	4.6	1941
Aspect ratio	390.41	53.37	7.32
Flow adaptation length (λ <sub>w</sub> ) in m	2938.84	2.84	1036.6
f(θ)	0.266	1.04	0.256
Mode of oscillation	1.0	1.0	1.0
Adaptation length for sediment transport (λ <sub>s</sub> ) in m	30068	26.72	1125.18
Interaction parameter (I <sub>p</sub> )	10.23	9.426	1.08

#### Application Tests

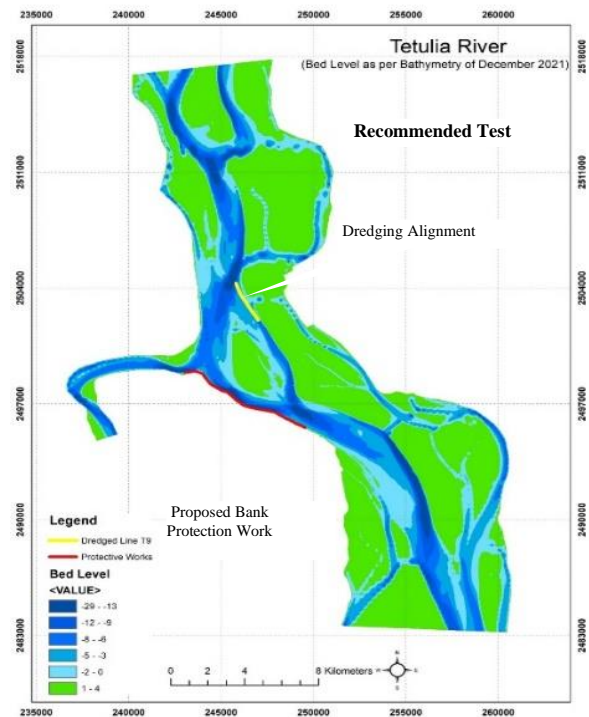
After calibration of the model, tests are carried out for different discharges in base and intervention conditions.

Calibration of the model is considered as test T0. Besides 9 (nine) tests including base run have been anticipated. The discharge measurement in the river was carried out in the second week of September, 2021 when the Tetulia River was

in spate. There is no discharge gauge station anywhere on the Tetulia river to have the historical discharge record and carry out flood frequency analysis for determining probable discharges and compare the measured discharge with probable discharges. However, it appears from the information obtained through the available literature review that the measured discharge of the Tetulia River ( $25,513 \text{ m}^3 \text{ s}^{-1}$  in the upstream of the Karkhana River off-take) is a high discharge for the Tetulia River and is not one that may be termed as channel forming discharge. Therefore, based on available cross-section data and water surface slope a discharge of  $19,200 \text{ m}^3 \text{ s}^{-1}$  has been estimated and is considered as channel forming discharge. Base run is considered for measured discharge as well as estimated channel forming discharge.

Six application tests (T2, T3, T4, T5, T7 & T9) have been conducted with six different alignments of the dredged channel both in the left and right-side channels of the Tetulia River. These two channels are divided by char land (Char Laxmipur and Char Durgapasha). Same design section has been considered for four alternative alignments of the dredged channel (T2, T3, T4 & T5) where the design bed level is considered to be  $-9.0 \text{ mPWD}$  at the start and  $-10.0 \text{ mPWD}$  at the end of the dredged channel, bottom width  $150 \text{ m}$  (for test T5, bottom width  $175 \text{ m}$ ) with a side slope of 1:3.

*Recommended Test*



**Fig. 7.** The alignment of the proposed short dredged channel and bank protection work.

Test T9 is the recommended application test, which is conducted for dominant discharge of  $19200 \text{ m}^3 \text{ s}^{-1}$  as for other application tests. In this test the length of dredging is reduced to  $2.534 \text{ km}$ . Besides, the location and alignment of the dredged channel are also changed. The length of proposed bank protection works is kept the same ( $7.5 \text{ km}$ ). Out of  $7.5 \text{ km}$ ,  $7 \text{ km}$  is for the protection of right bank of Tetulia River

and  $0.5 \text{ km}$  is for the protection of left bank of Karkhana River from its offtake.

The alignment of the recommended dredged channel has been fixed along the left side channel of Char Durgapasha at a relatively shallow depth (**Fig. 7**). The bottom elevation of dredged channel at the starting point, middle point and end point is  $-8.946 \text{ mPWD}$ ,  $-9.000 \text{ mPWD}$  and  $-9.047 \text{ mPWD}$  respectively. The side slope of the dredged channel is 1:3. The longitudinal bed slope of the dredged channel is  $4 \text{ cm.km}^{-1}$  as per suggestion by Field Engineer of BWDB. The bottom width of the dredged channel is considered as  $120 \text{ m}$ . Total volume of material to be dredged under this test condition is around  $10,26,685 \text{ m}^3$ .

The bank protective works consists of geobag bags and CC blocks. The geobags are placed in the bottom layer of protective work and CC blocks in the top layer. The length of launching apron is  $45 \text{ m}$ . The volume of geobag dumping is  $35 \text{ m}^3 \text{ m}^{-1}$  and also the CC block dumping over geobag is  $35 \text{ m}^3 \text{ m}^{-1}$ . Since the model is distorted the reproduction of CC blocks and geo bags in the model is qualitative to some extent.

**Results and Discussion**

The near right bank velocity along the erosion prone bank (Durgapasha-Dhulia-Mathbaria) stretch of the river) is measured and it is found that at the end of the test the velocity is found to vary from  $0.33 \text{ m s}^{-1}$  to  $0.96 \text{ m s}^{-1}$ . The flow velocity along the end of launching apron of protective works has been measured starting from the off-take mouth and is found to vary between  $0.54 \text{ m s}^{-1}$  and  $1.59 \text{ m s}^{-1}$ . The maximum velocity occurs at cross-section number CS 86 of the Tetulia River.

The measured model discharge at the end of the test indicates that about 22% of the total discharge of the Tetulia River in the upstream of the Karkhana River off-take finds its way into the Karkhana River. Of the remaining 78% of the total discharge about 61% passes through the right bank channel in the erosion prone area, 35% through the left side channel adjacent to the Char Durgapasha and 4% through the relatively smaller left bank channel.

Change in bed level with time within the dredged channel has been measured at some preselected sections. In the upstream part the dredged channel the rate of filling up is found to be higher compared to its downstream part. At the end of the test final bed level at some preselected points along the dredged channel have been recorded. The initial bed elevation at these points over the dredged bed is known. Based on initial and final bed level data the thickness of deposition at each point has been estimated. On the other hand, percentage of filling up dredged channel has been estimated based on final bed level and initial bed level in pre dredged condition. The variation in the thickness of deposition along the dredged channel has been measured. It is noticeable that maximum thickness of deposition is  $3.66 \text{ m}$ . However, for the entire dredged channel the average thickness of deposition is estimated to be approximately  $1.81 \text{ m}$ .

Disposal or dumping of dredged material at a suitable location with minimal adverse environmental impacts is a very important issue to be addressed. For the proposed dredging in test T9 there is scope for dumping the dredged material on the charlands (Char Hossain and Char Jafra) situated on left side of the dredged channel. There are

vegetation (trees), sparse human settlements (guchhagram) and other infrastructures (cyclone center, road, etc.) on these charlands. The dredged material may be dumped on these charlands for raising land elevation and reclaiming land without causing any negative environmental impact or social conflict. Details of the dumping areas are given in **Table 2**. The scour/deposition around the end of the launching apron of proposed bank protection works is measured and the net maximum scour is found 8.40 m at cross-section number CS 72 in the Tetulia River. The bed level in the left side channel where the dredging is considered under test T9 has undergone change with time compared to the initial condition. The same happened in other locations too where the flow pattern is changed due to dredging. The bed level for the cross-sections situated within the proposed bank protection work under test T9 at the right bank of Tetulia River has undergone somewhat change with time compared to the initial condition.

**Table 2.** Details of the likely dumping areas of dredged material.

Areas where dredged material to be dumped				
Dumping areas	Length (m)	Width (m)	Height (m)	Approximate distance from CL of dredging alignment, m
1 (Char Hossain)	600	300	3	1200
2 (Char Jafra)	600	267	3	650

## Conclusions

From Dhulia to Durgapasha, the near right bank velocity is high enough to cause bank erosion when tested with flood discharge condition. Bank erosion may continue at this area if appropriate bank protection measures are not taken immediately. Maximum velocity in the left side channel of Char Durgapasha remains below  $1.5 \text{ m s}^{-1}$  and the same in the left bank channel is found to be below  $1.0 \text{ m s}^{-1}$  under flood discharge. For dominant discharge the percentage of flow through the Karkhana River is 23%. Of the remaining 77% flow 68% passes through the right bank channel, 28% through the left side (of Char Durgapasha) channel and 4% through the left bank channel. Under different test conditions (with dredging and bank protection works) and for dominant discharge the percentage of flow through the left side channel (of Char Durgapasha) is increased by 2%, 9%, 12%, 11% and 7% in tests T3, T4, T5, T7 and T9 respectively compared to base condition.

Sustainability of the dredged channel in the right bank channel is less due to relatively quick filling up of the upstream part of the dredged channel. Complex flow pattern in the immediate upstream of the off-take is responsible for such quick filling up of the dredged channel. Such complex flow pattern is caused by occurrence of flow separation near the off-take. Dredging in the left side channel of Char Durgapasha could be a relatively better solution although it may also involve substantial maintenance dredging. As a result of dredging in the left side channel the overall average bed level of this channel may decrease to some extent

although a large percentage of the dredged channel (56% in test T9) may get filled up within a year.

For all test conditions with dredging noticeable flow velocity along the dredged channel occurs in the beginning. However, with the passage of time the dredged channel gets gradually silted up with a corresponding fall in the magnitude of flow velocity. The upstream portion of dredged channel gets silted up earlier than the downstream portion. The proposed bank protection works introduced at the right bank is found to work well as found from the model study. Special care should be taken at CS72 where bed level is -29.16mPWD, 138m away from right bank. In this case, geo-bags/CC blocks should be kept ready for emergency dumping. The protective structures (combination of CC blocks over geo-bags) are effective to protect the erosion prone area from Dhulia to Durgapasha.

recommended test for dredging alignment where length of the dredged channel is 2534 m. If the proposed dredging along the left side channel is intended it will ensure the stability of the bank protection work by reducing the flow through the right bank channel and thereby, reducing the near bank flow velocity. But the dredged channel is mostly found to be silted up. The model results indicate that the average percentage of filling up of the dredged channel is about 56% in one year. However, the cross-sectional area of the left side channel where dredging will be carried out is likely to be increased as a whole due to dredging.

Total volume of material to be dredged for recommended dredging alignment and dredged channel section is  $10,26,685 \text{ m}^3$ . The volume of filling up of the dredged channel is found about  $5,74,944 \text{ m}^3$ . For test T9 conditions the maximum thickness of deposition is 3.66m and the average thickness of deposition after one year is 1.81m. The maximum scour around the end of launching apron in test T9 is about 8.4 m at the end of test and it occurs at cross-section number 72 (CS72) about 2.53km downstream of the Karkhana off-take mouth along the Tetulia River. The suitable locations for dumping the dredged material are Char Hossain and Char Jafra situated on the left side of the dredged channel.

## Recommendations

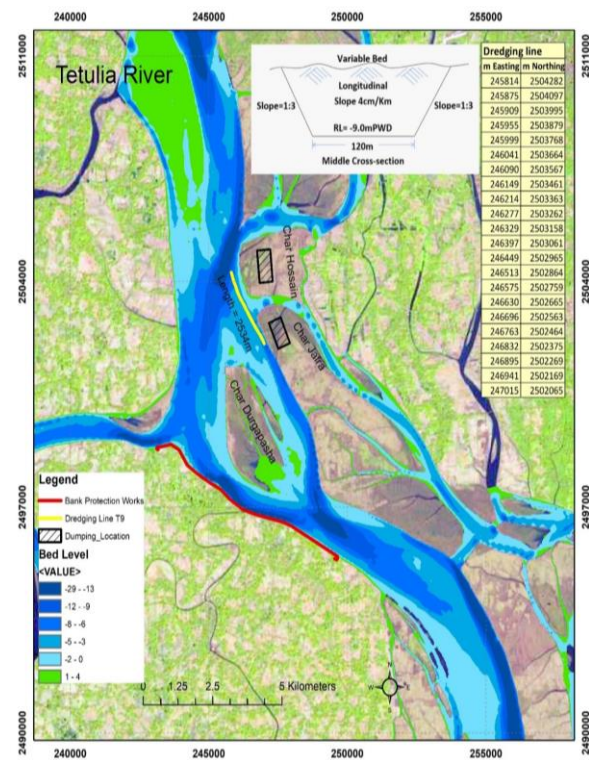
The bank protection work (7.0 km is for the protection of right bank of Tetulia River and 0.5 km is for the protection of left bank of Karkhana River from its offtake) proposed by BWDB tested in different tests work well and it is recommended to implement in the field. There should be provision for keeping adequate geo-bags/CC blocks ready for emergency dumping.

Bank protection work and dredging considered under test T9 are the recommended interventions to achieve the project objectives in terms of erosion protection as it provides better results from technical and economical point of view. The recommended length of dredged channel is 2.534 km in the left side channel having bottom width 120m, bottom level -9.0 mPWD, longitudinal bottom slope  $4 \text{ cm km}^{-1}$  and side slope 1:3. The position (Easting, Northing) of centreline of the recommended dredged channel is given in the report.

The implementation of the recommended bank protection works and dredging in the field may be carried out immediately for the protection of the erosion prone Dhulia-Durgapasha area and to prevent further bank erosion in the coming year. Substantial left bank erosion in the Karkhana River beyond the termination of the proposed bank protection

work has been observed during model tests. Based on the model results it is suggested to provide bank protection work on the left bank of the Karkhana River for a length of about 1.5km from its off-take.

Some right bank erosion in the Tetulia River beyond the termination of the proposed bank protection work has also been observed during model tests. Based on the model results it is suggested to provide bank protection work on the right bank of the Tetulia River for a length of about 1.0 km from its termination. The depth of suggested dredged channel may get reduced considerably after one year despite the fact that overall cross-sectional area of the left side channel where the dredging is suggested will be increased. In order to keep the dredged channel active maintenance dredging is suggested for two years with frequency of once in a year.



**Fig. 8.** Detailed layout of the recommended dredged channel section and bank protection work and potential suitable locations for dumping the dredged material.

Monitoring of the developments in the dredged channel is suggested for taking decision as to maintenance dredging. Cross-section survey along the dredged channel at some preselected locations before dredging, after dredging and

during post monsoon period is needed for this purpose. Bank protection work alignment, dredging alignment, dredged channel section and dredged material dumping locations as shown in **Fig. 8** may be considered.

## References

Chowdhury, M. H. (2012). Tetulia River, Banglapedia: National Encyclopedia of Bangladesh (Second ed.). Asiatic Society of Bangladesh.

Engelund, F. and Hansen, E. (1967). A Monograph on Sediment Transport in Alluvial Streams. *Teknisk Forlag*, Copenhagen, 62 p.

Gob, F., Houbrechts, G., Hiver, J. and Petit, F. (2005). River Dredging, Channel Dynamics and Bedload Transport in an Incised Meandering River (the River Semois, Belgium). *River Res. Appl.* 21, 791-804. <https://doi.org/10.1002/rra.883>

Kasprak, A., Brasington, J., Hafen, K., Williams, R. D. and Wheaton, J. M. (2019). Modelling Braided River Morphodynamics Using a Particle Travel Length Framework. *Earth Surf. Dyn.* 7, 247-274. <https://doi.org/10.5194/esurf-7-247-2019>

Rob, M. A. (2012). Ganges-Padma River System. Banglapedia: National Encyclopedia of Bangladesh (Second ed.). Asiatic Society of Bangladesh.

RRI (2021). Physical Modeling Study for Dredging and Bank Protection Works along Tetulia River at Bakerganj and Bauphal Upazillas under Barishal and Patuakhali Districts, Inception Report, October 2021.

RRI (2022a). Annual Report of River Research Institute, July 2021- June 2022, River Research Institute, Ministry of Water Resources Government of the People’s Republic of Bangladesh.

RRI (2022b). Physical Modeling Study for Dredging and Bank Protection Works along Tetulia River at Bakerganj and Bauphal Upazillas under Barishal and Patuakhali Districts, Revised Interim Report, May 2022.

RRI (2023). Physical Modeling Study for Dredging and Bank Protection Works along Tetulia River at Bakerganj and Bauphal Upazillas under Barishal and Patuakhali Districts, Final Report, February 2023.

Van Rijn, L. C. (2005). Principles of Sedimentation and Erosion Engineering in Rivers, Estuaries and Coastal Seas Including Mathematical Modelling Package (Toolkit on CD-ROM). Aqua Publications.