

Morphological Impact of Bridge Construction on Sunsari Morang Irrigation Intake

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Abstract – In this paper, we present the results of a morphological study revealing the impacts of river intervention during bridge construction phase in Koshi River near Chatara. We demonstrate how such intervention in the river reach resulted in morphological changes that subsequently had an impact on the intake of Sunsari-Morang Irrigation Project (SMIP), located downstream of the bridge. We carried out image analysis to detect the problem and attempted to replicate it using a two-dimensional morphological model (Delft3D). The study revealed how flow and geomorphological feature and processes as well as intervention on these processes lead to adverse impacts on the river system on one hand, and safety and functionality of water infrastructures on the other. The paper demonstrates how a process-based modelling tool can be useful for a rapid assessment of morphological impacts caused by interventions in a highly dynamic and sediment laden river like Koshi.

Keywords – Delft 3D, morphology, Sunsari Morang

I. INTRODUCTION

The Koshi River is the largest river of Nepal (Devkota et al. 2018) and is one of the largest tributaries of Ganges. It has three major tributaries: the Sunkoshi, Arun and Tamur for a confluence near Tribeni which is about 10 km upstream of the intake of Sunsari Morang Irrigation Project (SMIP). The river then flows through a gorge and debouches into a plain area where it becomes braided.

The project has been suffering from the problem of siltation since the very beginning due to which less water than designed has been entering into the system. The intake is located just around 1 km upstream of the area where the Koshi River starts transition from a confined to a braided river. Due to the dynamic nature of the river, aggradation has been occurring in the eastern side near the SMIP intake. The sill level of the SMIP intake is below the bed level of the river (Sunsari Morang Inception Report, 2017) and annual dredging works need to be conducted near the mouth of the SMIP intake as well as in the main canal of the system to divert water into the intake (Durbar 2012). Recent formation of a mid-channel bar near the intake area due to the construction of the Chatara

Bridge 100 m upstream of the existing SMIP intake made the situation even worse. This mid-channel bar created a bifurcation which divided the river into two channels. Majority of the water started to flow towards the right channel, whereas the intake at the left bank received less water. If the process continues, there is the possibility for the intake to get isolated during the low flow period. Before 2014 there was no bar in the middle of the river channel. The mid-channel bar appeared after the construction of the Chatara bridge. During the construction of the Chatara Bridge upstream of the SMIP intake, temporary cofferdams were built in two phases. At first, a cofferdam was constructed on right bank of the Koshi River and in the second phase, another cofferdam was constructed on the left bank of the river. The first cofferdam built on the right bank didn't seem to have noticeable effect in the area. While the second cofferdam built on the left bank has affected the morphology of the river resulting in the formation of the mid-channel bar. It is to be noted that the cofferdam in the left bank was not removed completely after the construction. The replication of formation of mid-channel bar and its effect on the SMIP intake by using a morphological model (Delft3D) is the subject of this study.

II. IMAGE ANALYSIS

Error! Reference source not found. is the google earth images which clearly shows the formation of mid-channel bar after the construction of the cofferdam.



Figure 1: Google earth images showing the evolution of mid-channel bar as an effect of coffer dams

III. NUMERICAL MODELLING

The study of river morphology can be done analytically, through satellite images, ground data analysis, building a physical model and/or using numerical model. In this study, we have used a two-dimensional morphological model, namely Delft3D. The numerical model has been used to study the effect of construction of temporary cofferdams on the formation of the mid-channel bar, and in turn changes in discharge towards the SMIP intake.

A. Model Set-up

This part consists of building a hydrodynamic as well as morphological model which shall represent the study domain. The model developed is expected to have less computational time with reasonable accuracy. The speed for the model to compute the results also depends upon the size of the grid cells. Smaller the grid size, the model takes more simulation time. Also, the speed of the model is dependent upon the number of fraction of the grain size that we input in the model. If more number of fractions is used, the computation time of the model increases.

Different processing tools of Delft3D such as RFGRID, QUICKIN and Graphical user interface (GUI) have been used to build the model. RFGRID is used to generate the grid which is the building blocks of a model whereas QUICKIN is used to create model bathymetry and other spatially varied inputs over the grid. (GUI) Graphical User Interface is used to assign other input parameters to complete the model. In GUI, values for flow discharge time series, boundary conditions in the model domain, sediment transport formula etc. are assigned as inputs.

B. Flow and Sediment Conditions

In the model, it is necessary to assign hydraulic condition at two open boundaries, i.e. upstream and downstream of the model domain. At upstream boundary, we have assigned the time series of flow discharge values as the boundary conditions, whereas at downstream boundary, a rating curve has been assigned. The upstream discharge condition is based on observed data (provided by Department of Hydrology and Meteorology, Nepal). As there is no gauge station in the area where we have defined the downstream boundary in the model. Therefore, a rating curve is derived for the downstream area with the information on the width, roughness of the river (i.e. uniform depths for selected discharges).

In this study, we have simulated the hydraulic conditions before, after and during the construction of cofferdams. Therefore, daily inflow hydrograph of respective period has been used as upstream boundary conditions based on observed data as shown in Figure 2.

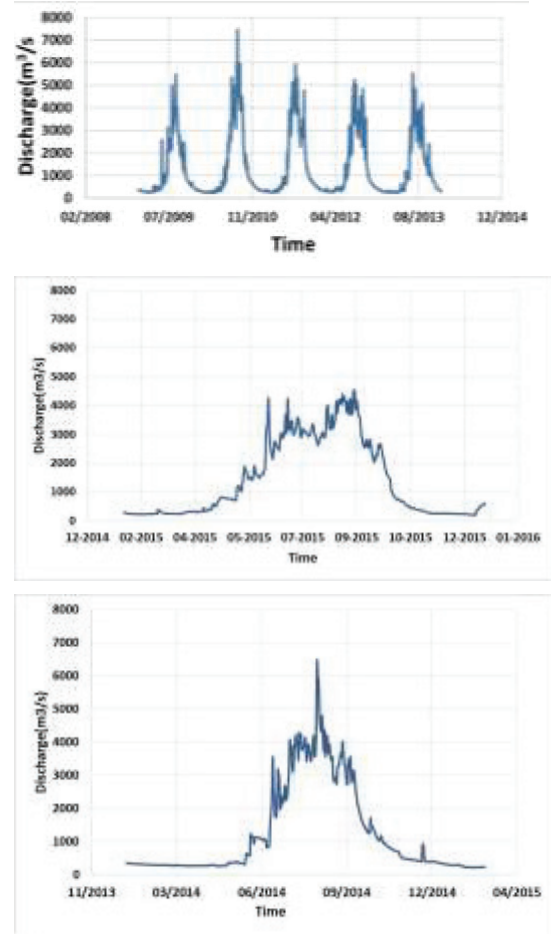


Figure 2: Upstream discharge boundary condition for reference case (top), the periods of presence of right cofferdam (middle) and left cofferdam (bottom)

River channel consists of sediments of varying sizes and properties. Gradation of the sediment particles have significant influence on sediment transport and finally to the topography of the river bed. The selected gradation of the reach for the model is based on field data. The grain size varies from 0.075 mm to 80 mm. This sample data was taken at a distance of 42 km upstream of the existing Koshi barrage. The range between 64 - 128 mm, 32-64 mm, 8-16 mm, 4-8 mm and 2-4 mm are designated as small cobbles, very coarse gravel, coarse gravel medium gravel and very fine gravel respectively. About 95 % of the sediment of the sample in the river is above 4 mm size, therefore the river reach can be considered to be a gravel bed river. Different percentiles values calculated for the grain size has been tabulated as follows:

Table 1: Grain size distribution

D ₁₆	8.79 mm
D ₅₀	36.67 mm
D ₈₄	72.63 mm
D ₉₀	75.39 mm

In Delft3D, it is possible to model different class of sediment as graded sediment input. We have

divided the above sediment size in 3 different class ranges to give as an input to the model. The class range is as follows:

Table 2: Sediment fraction and relative thickness of river bed active layer

Class range	Percentage	Thickness (m)
40-80mm	49	$0.49 \times 5 = 2.45$
12.5-40mm	35	$0.35 \times 5 = 1.75$
1.18-12.5mm	16	$0.16 \times 5 = 0.8$
Total	100	5

The sediment fraction to be included in the model should be chosen such that it would not increase the simulation time and also represent the real field conditions. The use of sediment class in the model also gives the idea about how well different sediment sizes participates in the morphological changes (van der Wegen et al. 2011). Generally, it is difficult to judge how much would be the thickness of the subsurface sediment to be considered in the model, since such data is difficult to find. For our study, 5 m thickness of the active layer has been assigned with different percentages of sediment sizes which have been described as shown above in Table 2. In the mode, total thickness of 5 m is divided in to 3 parts based on the percentage of each sediment class. The sediment thickness file can be created in Delft3D using QUICKIN.

The model uses some parameters to replicate the effect of transverse slope and spiral flow on morphology, particularly at river bends. Some sensitivity tests have been carried out until current morphological pattern of the river has been replicated. Bedload sediment transport is calculated using Mayer-Peter-Muller formula given its suitability for such a river reach with graded sediment. The boundary condition for the sediment inflow at the upstream boundary has been considered to be equilibrium sediment inflow given that there is no data available.

C. Simulation of Reference Case

Since there is no bathymetry data available for the mode reach, the morphological simulation with a flatbed topography (based on available data of the river slope) under the pre-construction hydraulic condition has been carried out for about five year. The model has replicated the bathymetry which resembles the riverbed feature of pre-construction period as shown in Figure 3. This also demonstrates that the morphological model is useful when there is no data. This model is used as a reference model for simulation of other scenarios.

D. Reproducing morphological effect of cofferdams

The reference model, created above, has been used to simulate the morphological effect of the cofferdams. Cofferdam at right bank was constructed on April 2014. This cofferdam was present in the field for about 11 months during the period of April 2014 to February 2015. In the second phase, cofferdam was

constructed at left bank of the river. At first, morphological simulation with right cofferdam has been carried out. Subsequently, the simulated bed has been used as an initial condition for the next simulation with left cofferdam to replicate its morphological effect. The sequence of simulation result is presented in Figure 4, which shows eventual formation of a mid-channel bar.

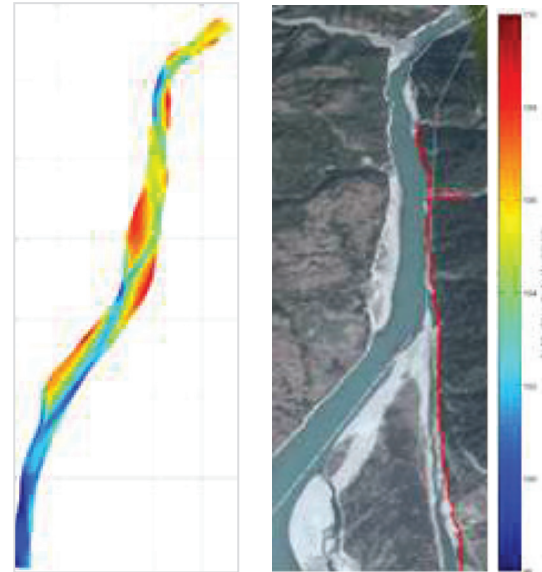


Figure 3: Comparison between spin up model and google earth image

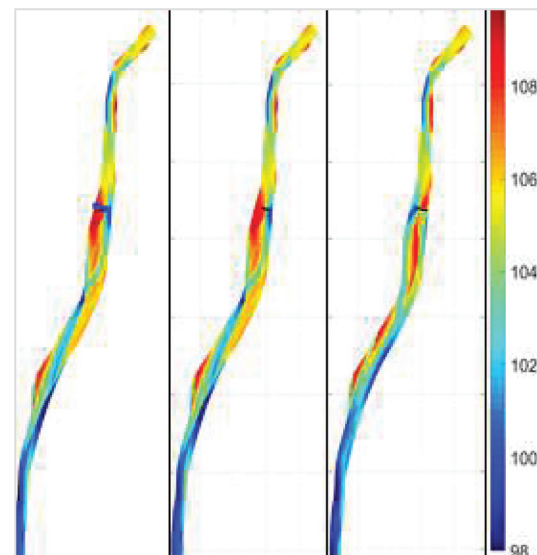


Figure 4: simulation result showing impact of construction of right cofferdams and eventually formation of a mid-channel bar (right) as presented in Figure 1.

We have simulated a scenario, in which the left cofferdam was not removed. The result is depicted in Figure 5. The result shows a distinct morphological change (sedimentation along the left bank) around the intake area after the left bank cofferdam was constructed and not removed.

E. Simulating scenarios after formation of the mid-channel bar including effect of the intervention

We have attempted to simulate a couple of scenarios after the formation of mid-channel bar to assess the possible changes including the effect of the groyne that has been constructed at the right back.

The simulation result, depicted in Figure 6, shows erosion of upper part of the mid-channel bar. This can also be seen from a recent image. Besides, a groyne has been constructed along the right bank, which seems to have effect of erosion of the bar and diversion of the channel (and the flow) towards the intake. We have attempted to simulate this scenario, the result of which is depicted in Figure 7. The result shows the channel along the left bank and shift of sandbar along the right bank as it was in pre-construction period.

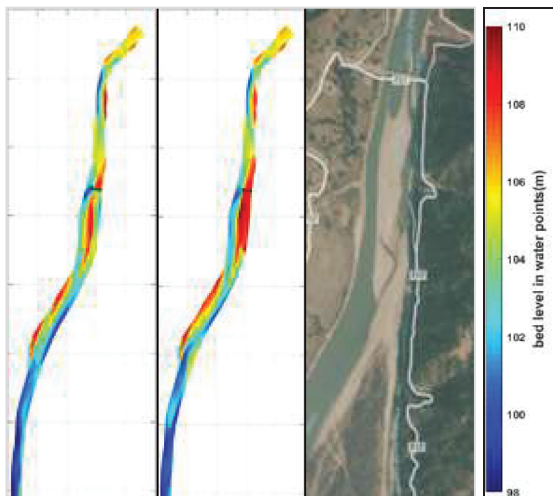


Figure 5: Simulation result for the scenario when left cofferdam was not removed

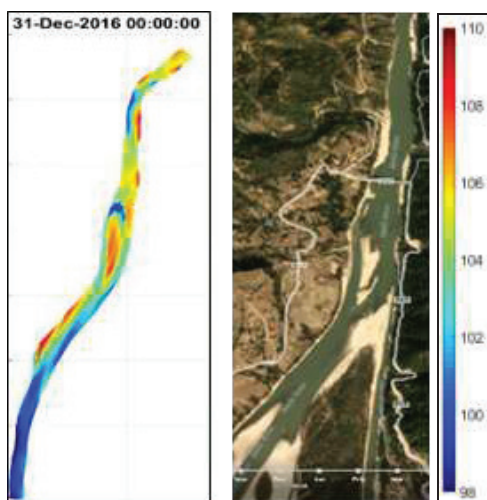


Figure 6: Simulation scenario showing erosion of mid-channel bar

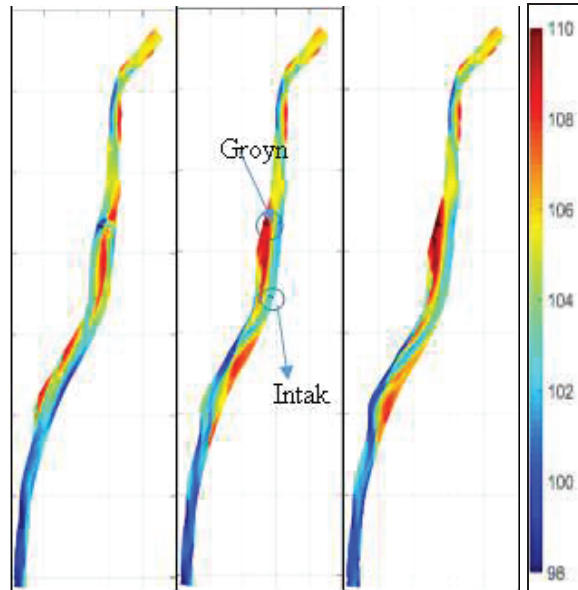


Figure 7: Simulation scenario with the groyne at right bank showing erosion of mid-channel bar and shift of sandbar towards the right bank and the deeper channel along the left bank

F. Simulating hydraulic effects of morphological changes

We present here hydraulic effect of morphological changes, presented above, particularly how the discharge towards the intake decreases after the formation of mid-channel bar. This is depicted in Figure 8, which shows much lower discharge along the left branch (towards the intake) up to zero during low flows. On the other hand, the result for the scenario that shows the erosion of the mid-channel bar (see Figure 6 above) reveals the increase of flow towards the left channel showing almost similar discharge distribution as depicted in Figure 9.

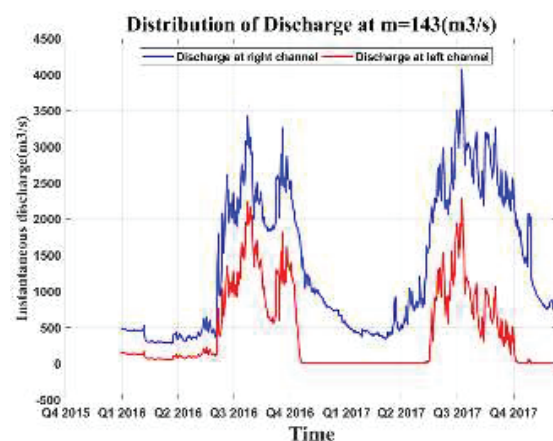


Figure 8: Distribution of discharge at the bifurcation showing less discharge towards the intake (red line)

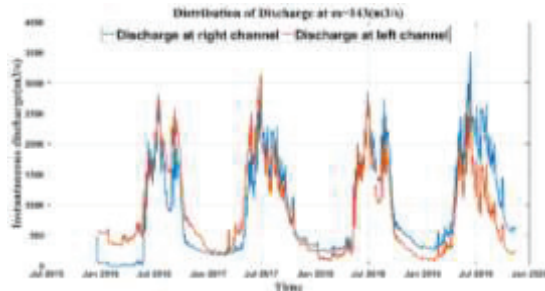


Figure 9: Discharge distribution at the bifurcation after the erosion of mid-channel bar showing almost same amount of discharge flowing through the both channels

G. Simulating hydraulic and morphological changes at the intake

We have attempted to present the simulation result on hydraulic and morphological changes near the intake for one of the scenarios. Figure 10 shows that the bed level of the river near the intake is 104 m, which stayed below the sill level for two years up to pre monsoon of 2017 with sufficient water level at the intake. Therefore, dredging is not essential during this period. The bed level rises during the flood period which is due to high sedimentation at this area. The worst scenario is when the bed level at the intake increases every year after the monsoon of 2018. The bed level at intake reaches 106 m after the monsoon of 2018 and increases even further.

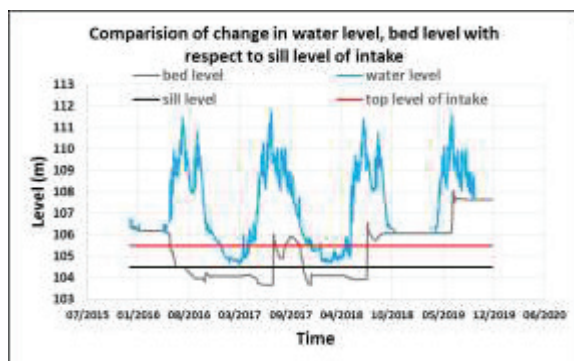


Figure 10: Simulated changes of bed level, water level and sill level at the intake

IV. CONCLUSION AND RECOMMENDATION

The study shows how a morphological model can be useful to simulate hydraulic and morphological impacts of the intervention in a river reach (in this case, the effect of cofferdams during a bridge construction). It is very important to assess such impact before constructing any kind of infrastructures on a river.

A. On formation of the mid-channel bar

It can be concluded that the formation of the mid-channel bar downstream of the Chatara- bridge is

triggered by the construction of the lateral cofferdams. In particular, left bank cofferdam was responsible for the formation of the mid-channel bar. Our simulation shows that if left cofferdam was completely removed, the mid-channel bar again moved to its original position at right bank. Thus, the formation of the mid-channel bar seems to be a temporary phenomenon.

B. On the impact of morphological changes on the performance of the SMIP intake

Formation of the mid-channel bar has led to creation of bifurcation near the intake. This bifurcation divided the flow into two channels resulting in less discharge, flowing towards the left channel where the intake is located. The bed level in the left channel increased as well due to sedimentation. This increase in the bed level near the intake area above the top level of intake has obstructed the flow from entering into the intake.

C. On effect of the measures, taken after the formation of mid-channel bar

As a solution to divert more flow towards the left channel for easy extraction of water into the intake, a groyne was constructed upstream of the Chatara bridge at right bank. It is not clear whether the erosion of the upper part of the bar occurred due to this measure or it was a natural phenomenon. We do not have proper information about this, thus this has to be explored in future. In our simulation, the erosion of mid-channel bar is evident with and without groyne (the channel along the intake flows better in case of groyne). Simulation shows increase in discharge towards the intake after the erosion of mid-channel bar and shift towards the right bank.

D. Recommendation

The study can be elaborated and improved when additional information and data are available. Also, a study by incorporating the SMIP canal networks in this model to assess the effect on the canal can be carried out.

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