

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 (Nepal). 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 highly dynamic and sediment-laden river like Koshi.

Keywords: Koshi River, morphology, Sunsari-Morang Irrigation Project (SMIP), Delft3D

1. 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 with a confluence near Tribeni. The river then flows through a gorge into a plain lowland area becoming a braided river. The intake of the Sunsari Morang Irrigation Project (SMIP) is about 10 km downstream of the confluence (just upstream of the braided reach). 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 irrigation system. The intake is located about 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 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. 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 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 (it was not visible). While the second cofferdam built on the left bank has affected the morphology of the river resulting in the formation of a mid-channel bar just downstream of the bridge. It is to be noted that the cofferdam in the left bank was not removed completely after the construction, which made the situation worse. The replication of formation of the mid-channel bar and its effect on the SMIP intake by using a morphological model (Delft 3D) is the subject of this study.

2. SATELLITE IMAGE ANALYSIS

The river morphology can be studied analytically, using satellite images, ground data analysis as well as building a physical model and/or using numerical model. We attempted to detect the problem using satellite images. Morphological development before and after the construction of cofferdams in both side of the river reach can be seen from some instantaneous Google earth images as depicted in Figure 1, which clearly shows the formation of mid-channel bar after the construction of the cofferdams. It can also be seen that the bank and sandbar at the right side was eroded, apparently as an impact of the left cofferdam. In fact, this was a major reason for the formation of the mid-channel bar. It is to be noted that the left cofferdam was not removed properly after the construction. The reach was rather stable before this intervention.



Figure 1. Google earth images showing the evolution of mid-channel bar as an effect of cofferdam

3. NUMERICAL MODELLING

In this study, we have used a two-dimensional morphological model, namely Delft 3D to replicate the problem of formation of mid-channel bar that we detected as mentioned above. The numerical model was used to confirm our observation (and hypothesis) about 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.

3.1 Model set-up

This part consists of building a hydrodynamic/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. The model domain with computational grid and initial bathymetry is depicted in Figure 2. It should be noted that due to absence of bathymetry data before the construction of the bridge, we used a flatbed initial bathymetry and carried out spin-up computation to generate a bathymetry that somewhat resembles the morphological feature before the bridge construction.

Different processing tools of Delft3D such as RFGRID, QUICKIN and GUI were 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 is used to assign input parameters to complete the model. In GUI, values for the flow discharge time series, boundary conditions in the model domain, sediment transport formula etc. are assigned as inputs.

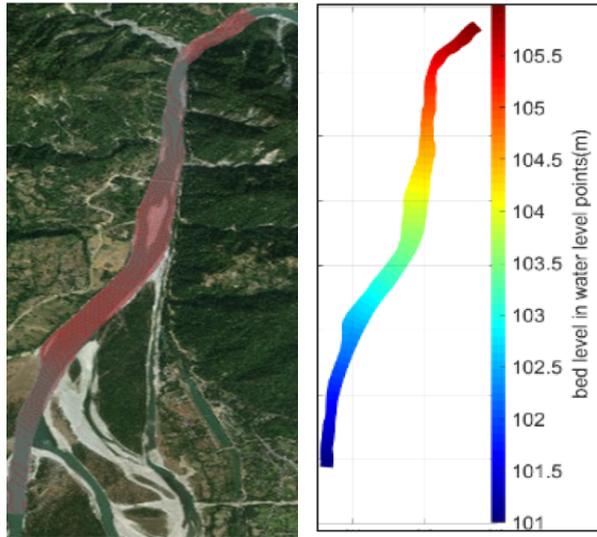


Figure 2. Model domain with computational grid (left) and a flatbed initial bathymetry (right)

3.2 Flow and sediment conditions

At upstream boundary, we assigned the time series of flow discharge values, 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 are no gauge station in the area where we defined the downstream boundary in the model, a rating curve is derived with the information on the width, roughness of the river (i.e. uniform depths for the selected discharges). In this study, we simulated the hydraulic and morphological conditions before, after and during the construction of cofferdams. Therefore, daily inflow hydrograph of respective period was used as upstream boundary conditions based on observed data as shown in Figure 3.

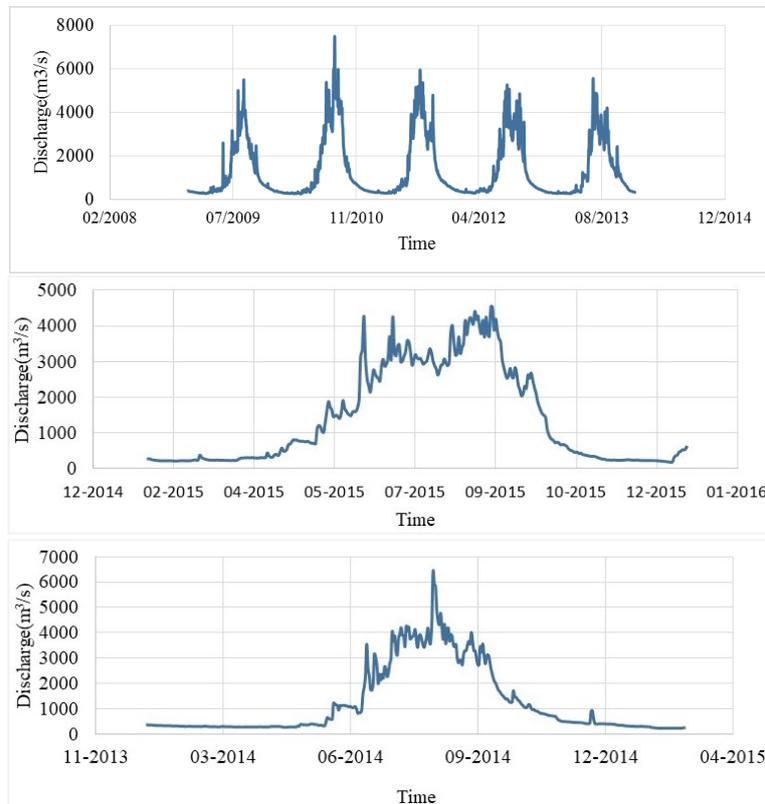


Figure 3. Upstream boundary condition of the reference case (top), the period of presence of right cofferdam (middle) and left cofferdam (bottom)

River channel consists of sediments of varying sizes and properties. Gradation of the sediment particles has significant influence on sediment transport and eventually on the riverbed topography. 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. 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 is 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 presented in Table 2. The sediment fraction to be included in the model should be chosen such that it would not increase the simulation time and at the same time represent the real-field conditions reasonably. The use of sediment class in the model also gives an idea about how well different sediment sizes contributes to the morphological changes. 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 are difficult to find. For our study, 5 m thickness of the transport layer was assigned with different percentages of sediment sizes as described in Table 2. The distribution of the sediment fractions in 5m thick bed is proportional to their content. There are options in Delft3D to provide thickness or volume of sediment fractions, and in case of assigning thickness, the model eventually computes the volume.

Table 2: Sediment fraction of riverbed transport layer

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

The model uses some parameters to replicate the effect of transverse slope and spiral flow on the morphology, particularly at river bends. Some sensitivity tests were carried out until current morphological pattern of the river was replicated. Bedload sediment transport was 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 was considered to be equilibrium sediment inflow given that there is no data available.

3.3 Simulation of Reference Case

Since there is no bathymetry data available for the model reach, the morphological simulation with a flatbed topography (based on available data of the river slope) under the pre-construction hydraulic condition was carried out for about five years. The model replicated the bathymetry which resembles the riverbed feature of pre-construction period as shown in Figure 4 (left plot). This also demonstrates that the morphological model is useful for such studies when there is no data. This model is used as a reference model for the simulation of other scenarios. Different scenarios that are simulated are briefly described in table below.

Table 3: Brief description of different scenarios

S.no.	Scenarios	Conditions	Remarks
1	Simulation of reference case		Figure 4 (left side)
2	Reproducing morphological effect of cofferdams	a) Right bank cofferdam was placed initially. b) Then, left bank cofferdam was placed.	Figure 4 (right side)
3	Scenario after formation of mid channel bar	a) Left bank cofferdam not removed b) Groyne at u/s and d/s of Chatara bridge at right bank and left bank cofferdam not removed. c) Groyne at u/s of Chatara bridge at right bank and left bank cofferdam removed d) Groyne d/s of Chatara bridge at right bank and left bank cofferdam removed	Figure 5 (left side) Figure 5 (right side) Figure 6 Figure 7

3.4 Reproducing morphological effect of cofferdams

The reference model created above was used to simulate the morphological effects of the cofferdams. A cofferdam at the 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 the left bank of the river. At first, morphological simulation with right cofferdam was carried out. Subsequently, the simulated bed was 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 (right plot), which shows eventual formation of a mid-channel bar.

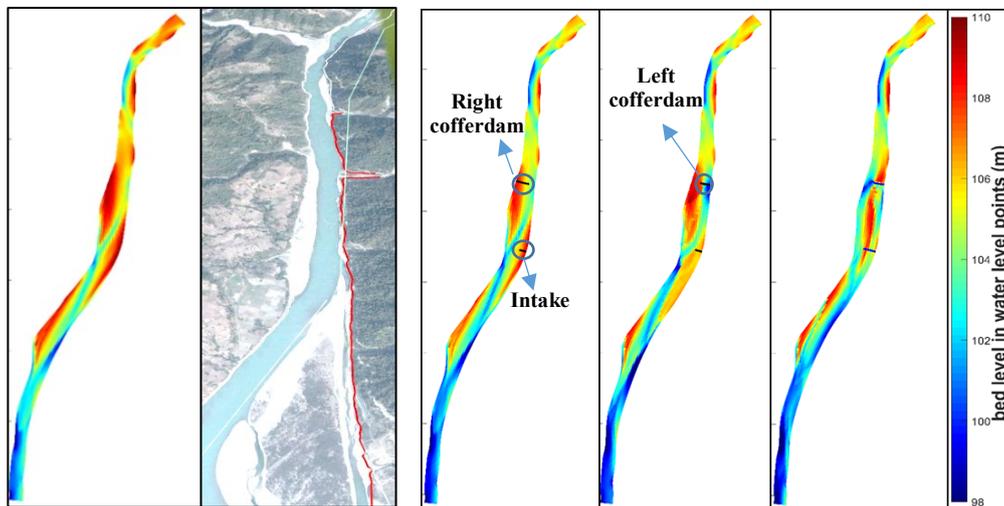


Figure 4. Comparison between the river bed after spin-up simulation (from initial flatbed condition) and Google earth image before the construction of the bridge (left), and simulation result showing impact of construction of right and left cofferdams and eventually formation of a mid-channel bar (right) as shown in Figure 1

3.5 Simulating scenarios after formation of the mid-channel bar

We simulated a scenario, in which the left cofferdam was not removed. The result is depicted in Figure 5 (left plot). 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. Furthermore, we 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 bank. The simulation result, depicted in Figure 5 (right plot), shows erosion of upper part of the mid-channel bar. This can also be seen from a recent image. A simulation was carried out with a groyne upstream of the bridge (the left bank cofferdam removed) which shows that the mid-channel shows a tendency to move back to its original position as shown in Figure 6. Besides, a groyne was constructed along the right bank below the bridge (and the left bank cofferdam removed in this case), which seems to have effect on erosion of the bar and diversion of the channel (and the flow) towards the intake. We attempted to simulate this scenario also, 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.

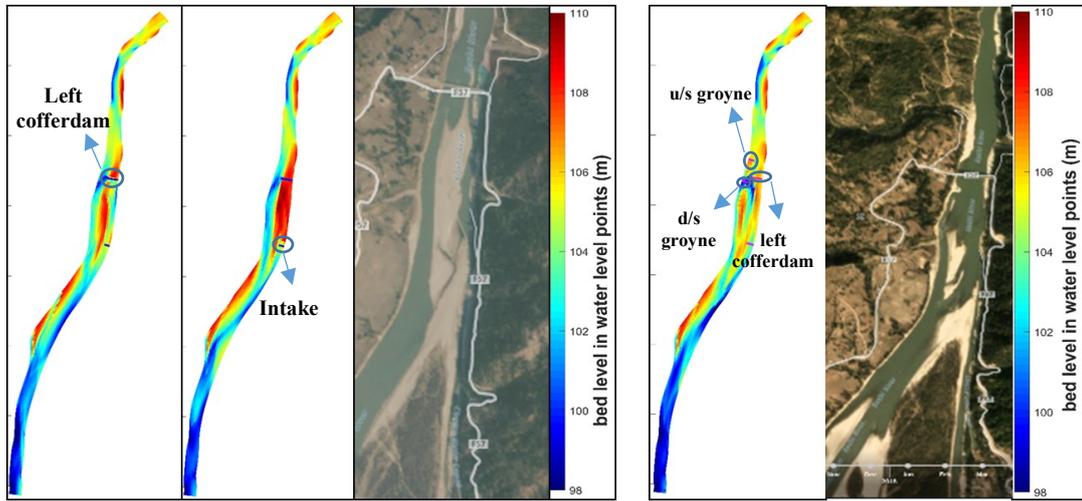


Figure 5. Simulation result for the scenario when left cofferdam was not removed (left) and the scenario showing erosion of mid-channel bar and comparing to Google Earth image (right) {Google earth images; left: Feb 2016 and right Dec 2018}

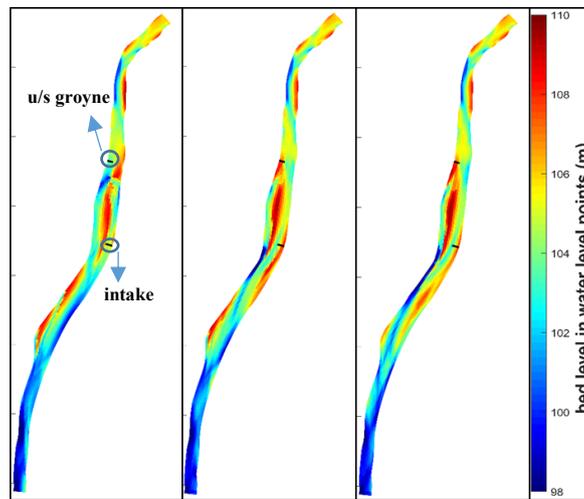


Figure 6. Simulation scenario with the groyne at right bank showing erosion of mid-channel bar and shift of sandbar towards the right bank and the deeper channel along the left bank

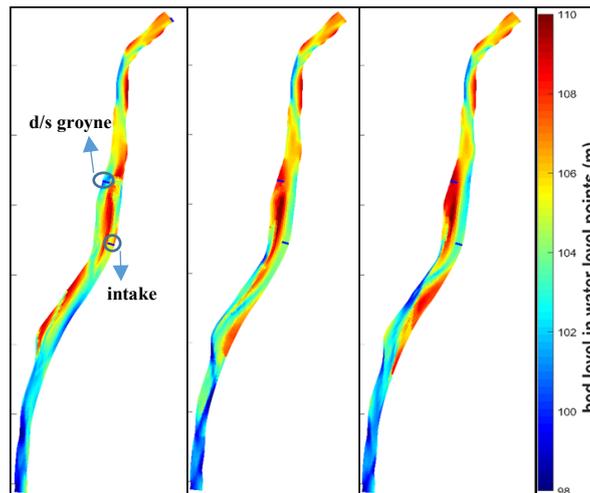


Figure 7. Simulation scenario with the groyne at the right bank d/s of the bridge (cofferdam at the left bank removed) showing erosion of the mid-channel bar and shift of sandbar towards the right bank and deeper channel along the left bank

3.6 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 (left plot), 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 above in Figure 5) reveals the increase of flow towards the left channel showing almost similar discharge distribution in both branches as shown in Figure 8 (right plot).

3.7 Simulating hydraulic and morphological changes at the intake

We attempted to present the simulation result near the intake for two scenarios as shown in Figure 6 and Figure 7. Figure 9 shows that 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 case 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. While Figure 10 (for the scenario as shown in Figure 7, when the groyne was constructed at the left bank below the bridge) shows that the bed level has stayed below the sill level for number of consecutive years with sufficient water level at the intake. The bed level rises during the flood period above the sill level of the intake and goes down below the sill level after the flood, thus facilitating the flow of water into the intake.

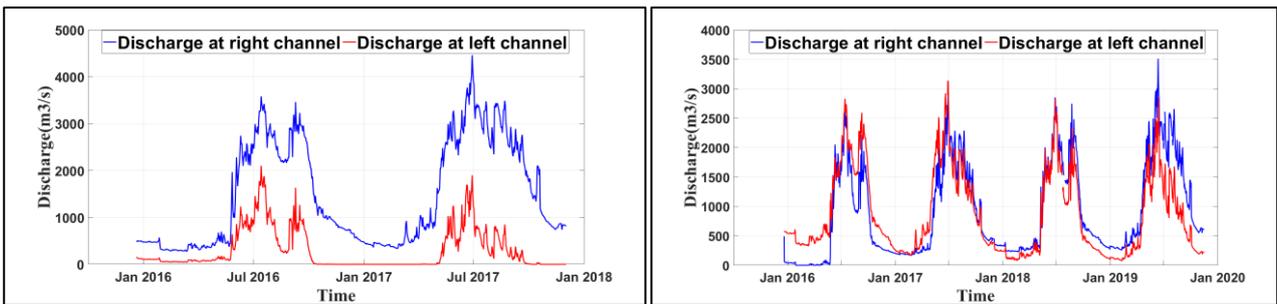


Figure 8. Discharge distribution at the bifurcation after formation of the mid-channel bar showing less discharge towards the left branch where intake is located (indicated by red color line in left plot), and after the erosion of the mid-channel bar showing almost similar amount of discharge flowing through both the branches (right)

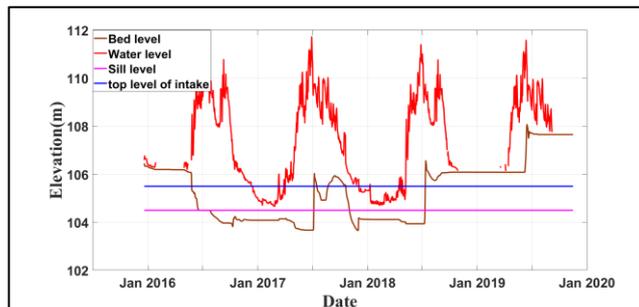


Figure 9. Simulated changes of bed level, water level and sill level at the intake for the scenario shown in Figure 6

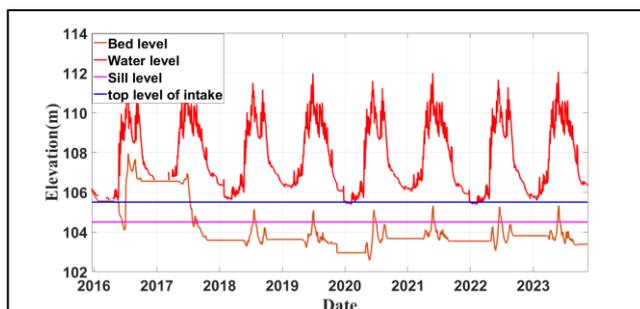


Figure 10. Simulated changes of bed level, water level and sill level at the intake for the scenario shown in Figure 7

4. 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 interventions on a river.

4.1 On formation of the mid-channel bar

It can be concluded that the formation of mid-channel bar downstream of the Chatara bridge was 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 bank cofferdam was completely removed, the mid-channel bar again could move to its original position at the right bank. The simulation also shows that the formation of the mid-channel bar appears to be a temporary phenomenon.

4.2 On the impact of morphological changes on the performance of the SMIP intake

Formation of mid-channel bar led to formation of a 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. This was simulated well by the model as well. 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 appeared to obstruct the flow from entering into the intake (however, this may not be related to the formation of mid-channel bar only).

4.3 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 which was not successful in doing so as shown in Figure 9. While a groyne at the left bank below the bridge appeared to be effective to divert flow towards the SMIP intake (Figure 10). 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 was evident with and without groyne (the channel along the intake flows better in case of groyne). Simulation shows that the erosion of the mid-channel bar and shift towards the right bank. Thus, this helps in locating a proper position of the mitigation measures in the field to escape the unnecessary structures as was done in SMIP projects where a series of groynes was constructed upstream of the bridge.

4.4 Recommendation

The study can be elaborated and improved when additional information and data are available. Also, more precise modelling study by incorporating other downstream anabranches including the SMIP intake in the model can be carried out. The model will be useful to apply to assess the effects of other proposed measures (e.g. dredging, construction of new barrage etc.).

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