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Domino Effect of River Training in Large Sand-Bed Braiding Rivers

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Abstract: Large sand-bed braiding rivers such as the Brahmaputra River form an enormous challenge to understand and to control. For efficient and sustainable management of these rivers, it is vital that we can predict the effects of river training works on the channel pattern and dynamics. In this study we used a computer model to simulate the dynamics of bars, islands and channel branches in a large sand-bed braiding river. We applied river training works in it to evaluate the nearby effects and the far-away effects. The results showed that a single river training work like bank protection or a groin can significantly affect the locations of bars, islands and channel branches far downstream. The downstream propagation of the effect of a river training work is a domino effect by means of bifurcation instability and bar shape adjustment. It means that a training work can adjust navigation channels, bank erosion and flooding over many kilometres downstream of the training work. Thus, a training work in a large sand-bed braiding river not only has local effects on the flow and river bed, but can also have major economic and social impacts. This is both a sign to be very careful with river training in these rivers, and a great opportunity to change a long river reach by a single, relatively cheap river training work.

Keywords: Discharge, Modelling, Rivers, River pattern, Sand transport

1. Introduction

The Ganges and the Brahmaputra are two of the largest rivers on Earth located in one of the most densely populated areas in the world. The rivers are monsoon driven and every year major flooding occurs, causing thousands of death and loss of residences and property. River banks are eroded with rates of hundreds m/year, taking away valuable and scarce land (Sarker et al. [1]). This is just one example and many other inhabited river plains and deltas worldwide face similar problems. Moreover, expected climate change and sea level rise will increase these problems. Yet the populations also depend on the rivers for drinking water, irrigation and transportation. In fact, maintaining fairways to guaranty navigability of rivers is a major challenge in view of the desired economic growth.

Multiple attempts to curb the rivers by training works only had limited and temporary effects (Mosselman [2]). Or, they solved local problems, but introduced new problems at other locations in the river.

In large sand-bed braiding rivers, the interaction between bars, islands and channel branches plays a major role in the dynamics of the river, with bifurcations being an important link between them (Schuurman et al. [3]).

In this study, we evaluate the effects of river training works on the channel morphology and morpho dynamics of large braided sand-bed rivers. We used numerical modelling in which we applied different kinds of river training works.

2. Methods

We used the well-established physics-based numerical model Delft3D to construct a ‘data set’ of large braiding sand-bed rivers an example of river training works.

Delft3D computes the hydrodynamics by solving the depth-averaged flow equations for momentum and mass balance. More detail about the Delft3D model can be found in Schuurman et al. [4]. The hydrodynamics are used to compute sediment transport and bed level change. In addition, the model accounts for bank erosion, spiral flow and bed slope effect.

We applied uniform sediment, constant discharge and a straight initial channel with flat bed. The model settings are given in Table 1. The channel dimensions, channel slope and discharge were inspired by the Brahmaputra River, but we had no intention to reproduce the Brahmaputra River. In one model run without river training works, the main channel of 3200 m wide had

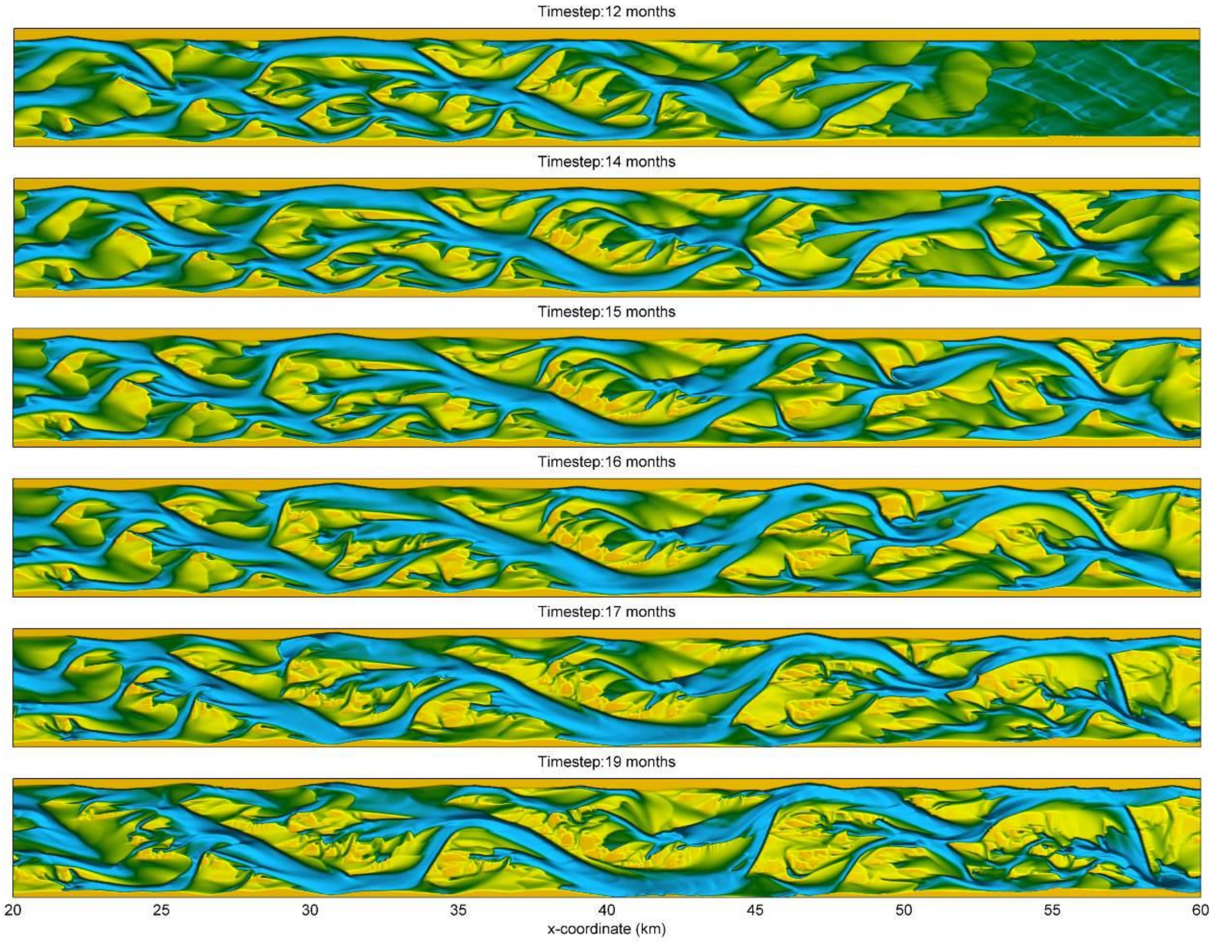

Figure 1: Bed level evolution in a model run with erodible floodplains. Flow is from left to right.

erodible floodplains along both sides that remained dry during the discharge of 40,000 m³/s. In the other model runs, we applied fixed banks without floodplains

Table 1: Model settings

Parameter	Value
Discharge	40,000 m³/s
Channel length	80,000 m
Channel width	3200 m
Channel slope	3,2 E^{-5}
Initial water depth	8.6 m
D_{50}	0.2 mm
Bed roughness	k_s = 0.15 m
Grid cell size	50 x 20 m

3. Results

3.1 Braiding channel pattern construction

Figure 1 shows the initiation and evolution of a braiding channel pattern in a straight channel, including the initiation of bars and channel branches. The bars were initiated at the upstream boundary and formed a downstream expanding front of bars. Thus, each bar triggered the initiation of a new bar further downstream.

Furthermore, the locations of the bars were linked to the locations of bank erosion. This is attributed to redirection of the flow towards the outer banks by the bars. This was a self-reinforcing process, as the bank erosion provides space for sedimentation and thus expanding of the bar. The bed evolution in the modelled channel also showed another interaction between bars and channel branches through bifurcations. New branches were formed when bars were dissected by cross-bar channels (e.g. at x = 52 km), and other branches where closed by expansion and migration of bars (e.g. at x = 28 km).

The channel reached a stable Braiding Index of about 3, which means the channel had on average about three parallel channel branches. Although this shows that the channel was braiding, some

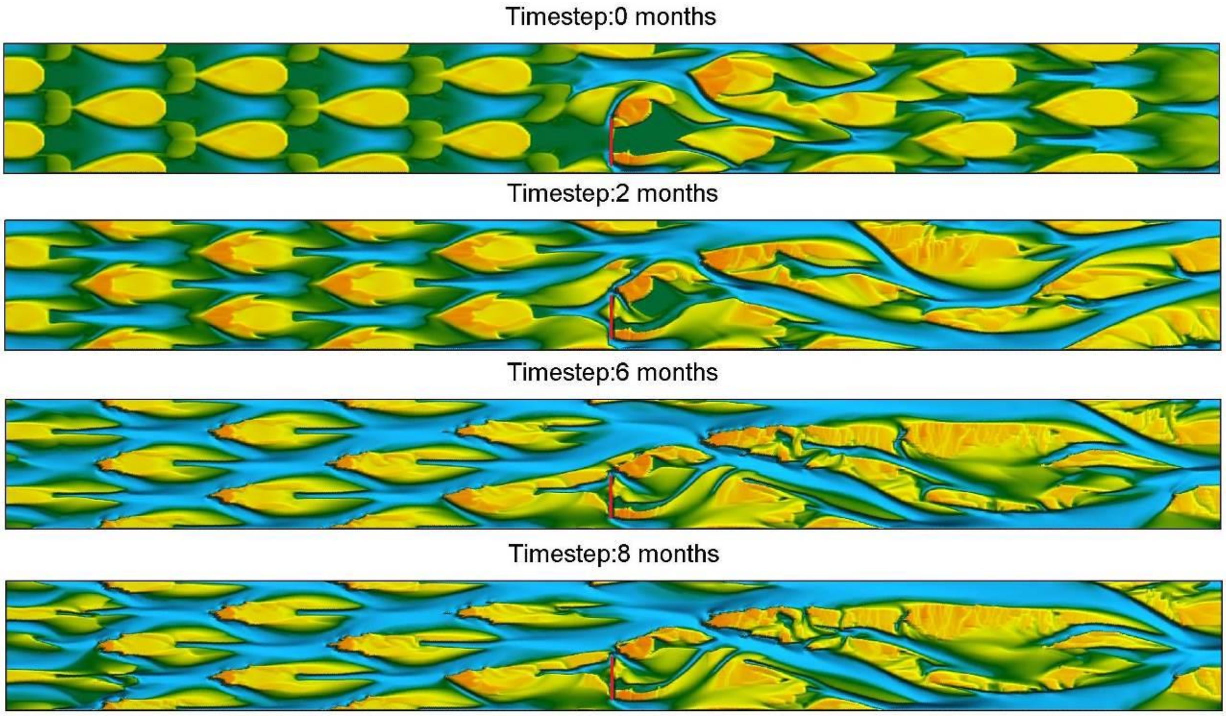

Figure 2: Bed evolution in case of a training work in an initially symmetric bar setting. The red line denotes the training work dam. Flow is from left to right. Adopted from Schuurman et al. [5].

channel branches had a meandering behaviour, with bank erosion in the outer bend and bar expansion in the inner bend (e.g. at x = 43 km in Figure 1).

3.2 Effect of river training works in initially symmetric bar settings

Now, we added a river training work in a channel with initially a symmetric pattern of mid-channel bars. In this case, the river training work was a dam to close one of the channel branches. The bed evolution as a response to this training work is shown in Figure 2.

The symmetrical bars upstream of the training were symmetrical at the start of the simulation and remained nearly symmetrical after 8 months. In contrast, shape of the bars near and downstream of the training work completely changed. This started near the dam, where the flow was steered around dam and incised the bed due to local flow acceleration. The eroded sediment was deposited further downstream, resulting in the formation of an enormous bar by merging of the initial bars.

Thus, here we could identify three zones of influence: the area in the vicinity of the training work that was directly affected by the training work; an area of adaptation to the directly affected area; and a long zone in which the bars and channel branches were indirectly affected by downstream propagation of the influence.

3.3 Effect of river training works in a complicated bar settings

Next, a training work was introduced in a complicated, more realistic setting of mid-channel bars and channel branches. Here we used a self-formed bar pattern and closed again one of the channel branches.

The result is given in Figure 3, with a closure dam built at the northern branch along bar D. Similar to the symmetrical bar setting, the dam redirected the flow, causing flow acceleration and local bed incision. In this case, the bed incision dissected bar D, forming two smaller bars D1 and D2. The training work in km 32 had enormous impact on the locations of bars and channel branches further downstream. For example, a 5 km long bartail-limb formed downstream of bar D2, connecting bar D2 with bar F. Along bar F, no clear main branch existed anymore in months 13 and 14, which would have serious economic consequences if navigation was important. It also had implications for the shape of bars G and H further downstream.

The downstream propagation of the effect of the training work in km 32 is shown in Figure 3B. Two months after construction of the dam, the influence zone expanded to near km 70. This implies a

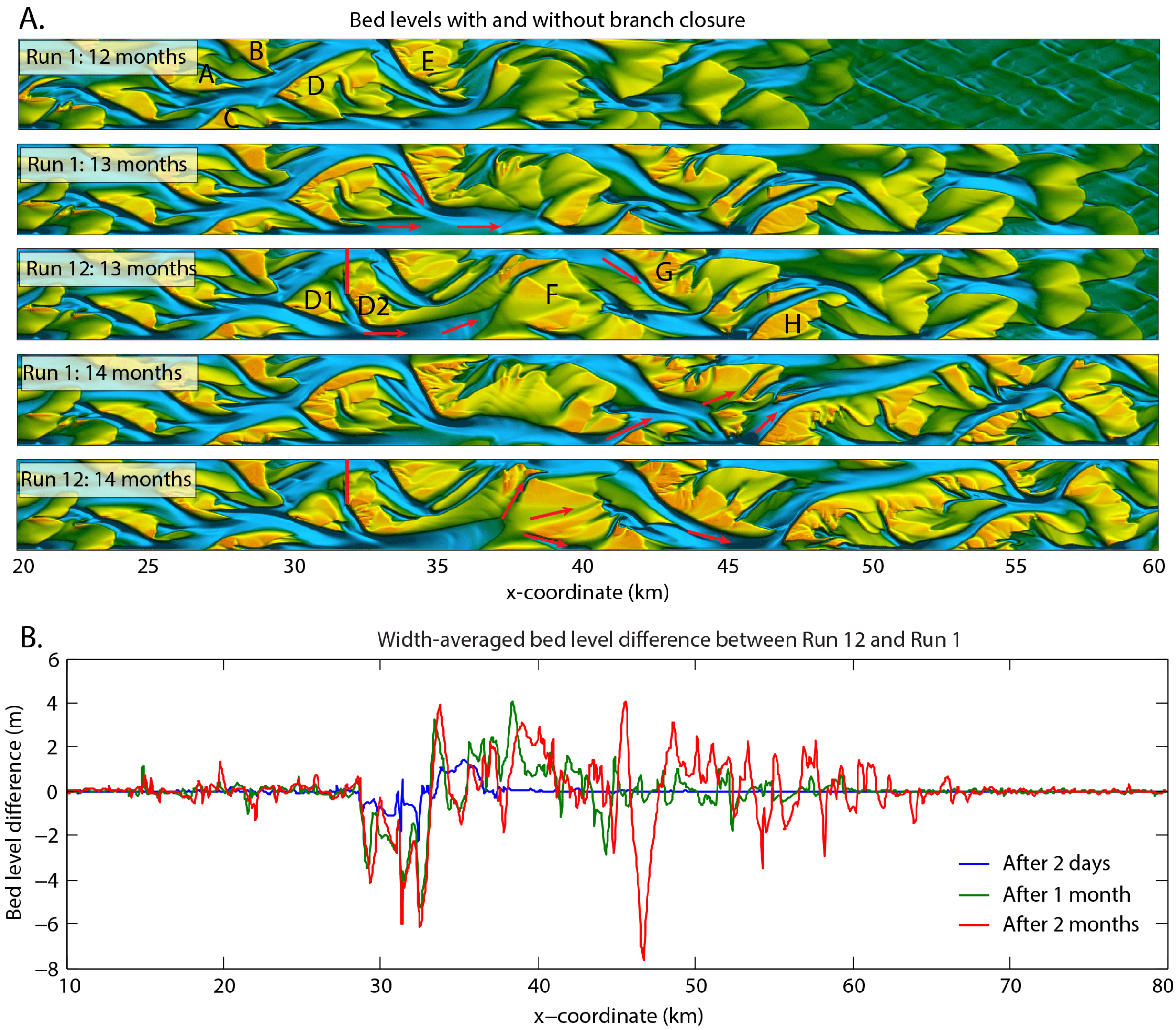

Figure 3: A) Bed evolution in a complicated bar setting with training work (Run 12) and without training work (Run 1). The red line at x = 32 km in Run 12 denotes the training work dam. Flow is from left to right. B) width-averaged bed level difference between the model run with and without training works, showing the downstream propagation of the influence of the training work. Adopted from Schuurman et al. [5].

propagation celerity of nearly 20 km/month. At the same time, the upstream effects of the training work was relatively small (Figure 3B).

4. Discussion

This study showed the effects of a training work in a large sand-bed braiding river using a state-of-the-art computer model.

The computer simulations showed different influence zones (Figure 4): a local, direct effect of the training work, which was channel incision in our case; an indirect effect by adaptation to the direct effects, which was deposition in our case; and an indirect effect due to adjusted locations of channel branches and bars.

Based on the interaction between bars, branches and bifurcations, plus the identified influence zones, we propose a conceptual model of the downstream propagation of the effect of a training work in a sand-bed braiding river. This conceptual model is illustrated in Figure 5 and further explained in Schuurman et al. [5]. The conceptual model comprises of the following steps, with numbering according to the numbering in Figure 5:

1. The training work adjusts the nearby flow and discharge division over the channel branches.
2. This both adjusts the shape of the bar by either erosion or bar expansion, and it

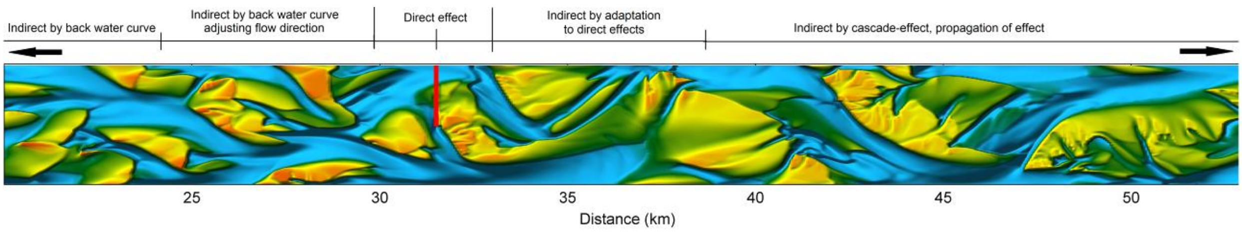

Figure 4: Zones of influence by a training work in a braiding channel

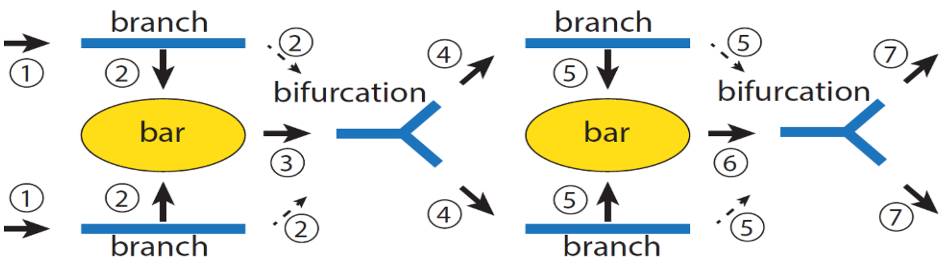

Figure 5: Conceptual model of downstream propagation of the effect of a river training work in a braiding channel, based on Schuurman et al. [4].

adjusts the flow approaching the downstream bifurcation.

3. The adjustment of the bar changes the approaching flow at the downstream bifurcation even more.
4. The discharge and sediment distribution at the bifurcation is changed.
5. The discharge and sediment in each branch is changed, which affects both the second bifurcation and the section bar.

These cyclic processes propagate in downstream direction like a domino game, and eventually affect the entire downstream river morphology.

The conceptual model is only valid for braiding rivers, as meandering rivers have no bifurcations. It was shown by, among others, Schuurman et al. [6] that a perturbation in a meandering river only propagates in downstream direction in case of meander bend, and the effects on alternate bars are limited to a few bar lengths. Also, narrow river sections might block the downstream propagation in a braiding river, for example in case of rock outcrops or engineering works. If these sections are too narrow for mid-channel bars, they may block the downstream propagation.

Nevertheless, it is important to understand that a relatively small adjustment to a braiding river, for example a training work, can have enormous effects further downstream. These effects include locations and amount of bank erosion, and the location and depth of navigation channels. Thus they may have social and economic impacts that are difficult to predict. However, it is also an opportunity to adjust a braiding river over large distance by a single, relatively cheap training work or other kind of perturbation. This requires more research to the natural response of the braiding river morphology to perturbations.

5. Conclusions

This study showed that a single river training work might have enormous consequences for the downstream morphology in large sand-bed braiding rivers. The hydrodynamic and morphological effects of a training work propagate in downstream direction by means of an interaction between mid-channel bars, channel branches and bifurcations.

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