CHUTE CUTOFFS INITIATION AND THE FLOW FIELD INSIDE THE MAIN CHANNEL BED

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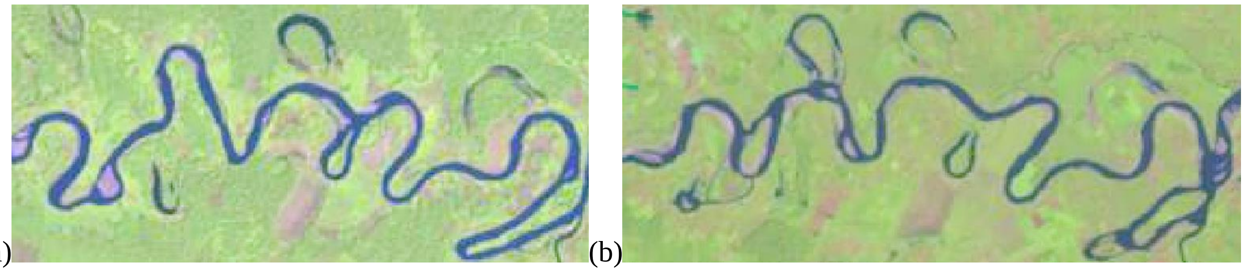
KEY POINTS:

- *Analysis of chute cutoff formation in meandering rivers, focusing in the hydraulic patterns inside the main channel for detection possible triggers.*
- *Use of a linear mathematical model for meandering rivers accounting for the effects of both curvature and width variation.*
- *Application to a chute cutoff occurred in the Chixoy River, Guatemala.*

1 CHUTE CUTOFF

A meander consist of a series of turns with alternate curvatures connected at the points of inflection or by short straight crossings. Meandering rivers are the result of streambed instability, in particular when instability affects the river banks (*Dey*, 2014). Meandering rivers are dynamic systems that migrates and evolve along flood plains as a consequence of complex interactions involving the channel forms, flow and sediment transport (*Seminara*. 2006).

Cutoffs strongly affect the dynamic of the meandering rivers, since they produce dramatic changes in the river morphology and morphodynamics (*Zinger et al*., 2011). Mainly, two different kind of cutoffs can be identified: neck cutoff, in which the migrating bend connects to the subsequent bend thus closing the loop and creating an oxbow lake (*Camporeale et al*., 2008), and chute cutoff, in which the bend is bypassed because of a new straight channel that cuts the bend (see Figure 1).



(a) (b)

Figure 1. Examples of different cutoffs occurred in the Chixoy River, Guatemala: (a) neck cut off in 1988 (b) chute cutoff in 2011.

Chute cutoffs are one of the most fascinating and less predictable mechanisms that affect the dynamics of alluvial rivers. Different efforts have been made to understand the mechanisms leading to chute cutoffs. *Grenfell et al*. (2011) proposed a probabilistic approach. Analyzing chute cutoffs occurred along the Sacramento River, *Constantine et al*. (2010) proposed a physics-based model, while *Micheli & Larsen* (2011) identified significant ranges for different morphometric indicators related to chute formation. *Van Dijket et al*. (2011) carried out a stability analysis concerning the bifurcation process that leads to chutes, *Harrison et al*. (2015) analyzed hydraulic proprieties related to chute formation based on a case study.

At least three different mechanisms have been supposed to lead to chute cutoffs, all of them involving floods whereby the water flows from the riverbed through the floodplain. In large meandering rivers with uniform floodplain topography, chute cutoffs can occur by downstream extension of an embayment, located along the outer meander bank, which progressively elongates into a channel. These embayments are typically the result of localized bank erosion processes and, hence, the initiation of this type of chute cutoffs likely depends on the erosive power of the stream inside the main channel (*Constantine et al*, 2010). Nerveless, the existence of particular conditions within the main riverbed that lead to chute cutoff initiation is still to be explored.

2 HYDRAULIC APPROACH

In this contribution, we focus on bankfull flow field inside the main channel to investigate the incipient formation of the class of chute cutoffs described above. The hydraulic behavior of a meandering river is a complex process that entails three-dimensional helicoidal flow structures. The problem is commonly analyzed with different approaches, from 1D and 2D simplified models to 3D models using computational fluid dynamics (*Hooke,* 2013).

Most of the simplified models used in the analysis of meandering rivers were derived through linearization and dimensional analysis. These models are used, mainly, to analyze the long-term meander evolution because of their low computational cost (*Ikeda et al*., 1981). Here we use the mathematical model developed by *Frascati & Lanzoni* (2013), which accounts for both width and curvature variations along the river.

The width variations could be one of the mechanism to consider for the chute cutoff formation (*Constantine et al*., 2010; *Parker et al*., 2011). In addition, the formation of bars that regards to the width variation could be one of the process that affects the chute cutoff formation (*Seminara*. 2006; *Camporeale et al*., 2008; *Church*, 2014; *Dey*, 2014).

The model considers four main equations: the momentum equation in x, y axes, the continuity equation, and the Exner equation (eq. 1-4, respectively):

$$\mathrm{N}u\mathcal{L}_b u + B^{-1} v u_{,n} + w u_{,z} + N\nu C u v = -N\left(\mathcal{L}_b h - \beta C_{fu}\right) + B_u \sqrt{C_{fu}} (\nu_{T,} u_{,z})_{,z} \quad (1)$$

$$\mathrm{N}u\mathcal{L}_b v + B^{-1} v v_{,n} + w v_{,z} + N\nu C u^2 = B^{-1} h_n + B_u \sqrt{C_{fu}} (\nu_{T,} v_{,z})_{,z} \quad (2)$$

$$\mathrm{N}\mathcal{L}_b u + \left(N\nu C + B^{-1}\frac{\partial}{\partial n}\right) v + w_{,z} = 0 \quad (3)$$

$$\mathrm{N}\mathcal{L}_b q_s + \left(N\nu C + B^{-1}\frac{\partial}{\partial n}\right) q_n = 0 \quad (4)$$

where B is the local half channel width, C is the curvature of the channel axis, C_{fu} is the uniform flow friction coefficient, h is the local water surface elevation with respect to the horizontal plane containing n, $\mathcal{L}_b$ is a differential operator, N is vertical distribution of the eddy viscosity, (q_s, q_n) are the longitudinal and lateral components of the unit width sediment flux, (n, z) are the intrinsic lateral and vertical coordinates, (u, v, w) are the longitudinal, lateral and vertical local velocity, respectively, ν is the curvature ratio, and ν_T is the turbulent eddy viscosity. Those equations are solved in non-dimensional form by a perturbation method (for further details, we refer the reader to *Frascati & Lanzoni*, 2013).

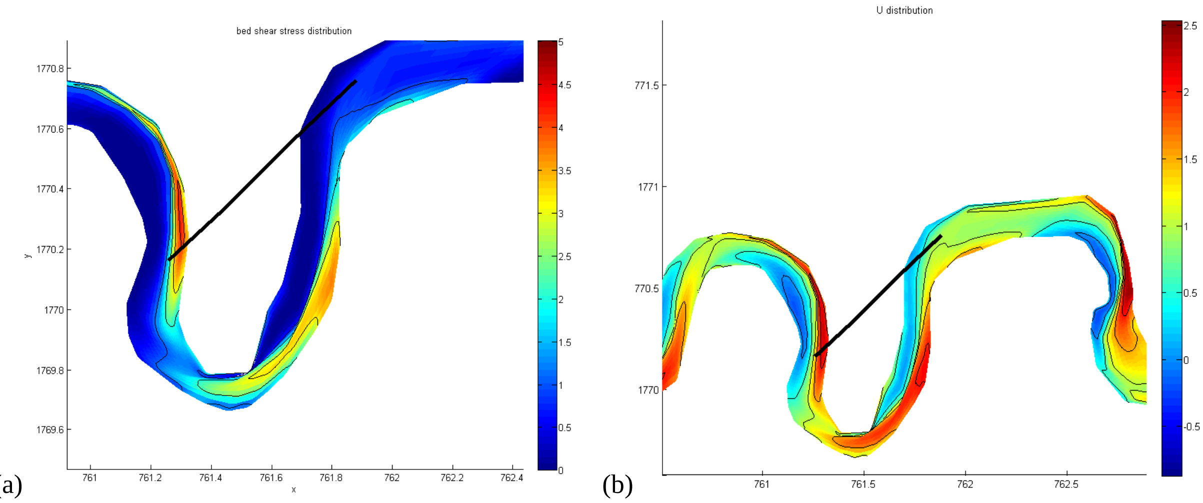
This set of equations, which includes local width and curvature, describes both the laterally antisymmetric flow field due to the channel curvature and the laterally symmetrical pattern due to width variations.

3 APPLICATION

We applied the model to study a chute cutoff occurred in the Chixoy River (Guatemala) in 2011. We extracted model input data from available maps and remote sensing data, including Digital Elevation Maps (DEM) and NASA-USGS Landsat images in which the cloudiness was low enough to make the main channel clearly visible. Denoting by IAC the first image in which the chute cutoff is visible, and by IBC an image just before its occurrence, we digitized the rivers banks and the main channel from the IBC, and noted down the chute location from the IAC. We then analyzed the available discharge time series, in the period between images IAC and IBC were taken, to estimate the potential discharge that could lead to chute formation. The sediment size was assumed based on qualitative granulometric information.

The geometric input data is pre-processed and cast in dimensionless form to apply the mathematical model. Then, in a post-processing step, we recast the variables to their dimensional form and analyzed the modelled flow field close to the location where the chute was then formed.

Figure 2 clearly shows that local maxima of both flow shear stress (panel a) and velocity (panel b) are found close to the upstream section of the chute cutoff. The model results suggest that the flow field inside the main channel could play a key role in leading to the chute formation.



(a) (b)

Figure 2. Model application to the Chixoy River in 2011: (a) shear stress distribution, and (b) velocity distribution. The black line detonates the chute cutoff channel.

Nevertheless, these preliminary results are obviously not sufficient to infer quantitative relations on chute cutoff formation. It is necessary to analyze more rivers in order to draw a significant relation between the hydraulic flow field within the main channel and the chute cutoff initiation.

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