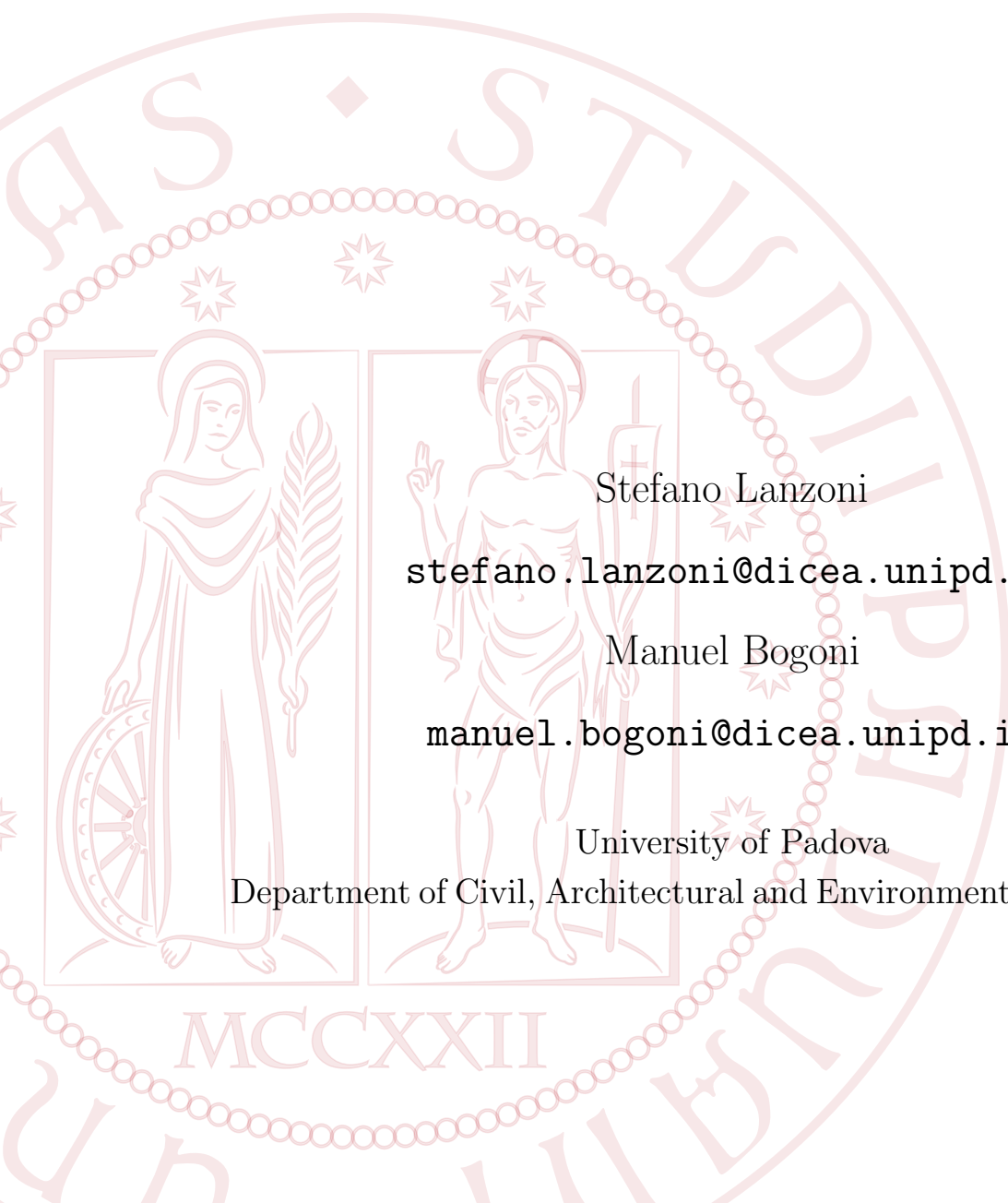


# MEANDER CENTERLINE MIGRATION MODEL (MCMM)

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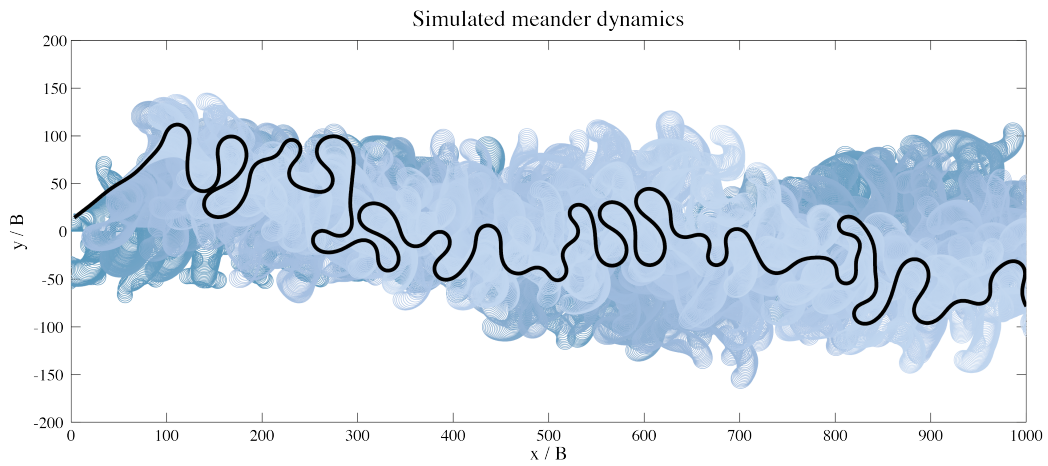
Department of Civil, Architectural and Environmental Engineering

## Contents

<b>1</b>	<b>Intro</b>	<b>3</b>
<b>2</b>	<b>Mathematical modelling of meander dynamics</b>	<b>4</b>
<b>I</b>	<b>Input files</b>	<b>17</b>
<b>3</b>	<b>File SIM</b>	<b>18</b>
<b>4</b>	<b>File XY</b>	<b>21</b>
<b>II</b>	<b>Output files</b>	<b>22</b>
<b>5</b>	<b>File SIMULATION</b>	<b>23</b>
<b>6</b>	<b>File PARAMETERS</b>	<b>24</b>
<b>7</b>	<b>File CUTOFFS</b>	<b>25</b>
<b>8</b>	<b>File CONFIGURATION</b>	<b>26</b>
<b>9</b>	<b>File OXBOW</b>	<b>27</b>
<b>10</b>	<b>File POINTBAR</b>	<b>27</b>
<b>11</b>	<b>File LAMBDA</b>	<b>28</b>
<b>III</b>	<b>Other files</b>	<b>30</b>
<b>12</b>	<b>File XY TEMP</b>	<b>31</b>
<b>13</b>	<b>Files FLOODPLAIN</b>	<b>32</b>
<b>14</b>	<b>File TIME</b>	<b>32</b>
	<b>References</b>	<b>33</b>

# 1 Intro

The MCMM, namely the Meander Centerline Migration Model, simulates the long-term evolution of a meandering river flowing above a heterogeneous self-formed floodplain. On one hand, the structure of the floodplain surface builds up and modifies because of the river migration leading to neck cutoff process and forming oxbow lakes and scroll bars. On the other hand, the river migration is affected by the heterogeneous distribution of the floodplain erodibility given by the presence of the above-mentioned environments on the floodplain surface.



## 2 Mathematical modelling of meander dynamics

This section is based on the work of Bogoni (2017) and outlines the mathematical and numerical tools required to build a model able to handle the long-term migration of meandering rivers flowing above heterogeneous floodplains. The main quantities and variables involved in the problem are outlined in Section 2. The frame of the numerical modelling builds upon other models available in literature, e.g. Camporeale et al. (2005); Lanzoni et al. (2006); Lanzoni and Seminara (2006); Frascati and Lanzoni (2009). It consists of a migration model for the river axis, a model for the floodplain structure, and a morphodynamic model for the curvature-driven flow field.

### References and notations

With reference to the sketch of Figure 1, let  $(x^*, y^*, z^*)$  be a Cartesian reference system where  $x^*$  is the longitudinal flow direction, and  $(s^*, n^*, z^*)$  be a orthogonal intrinsic reference system. Hereafter the superscript  $*$  will denote dimensional quantities. Moreover,  $R^*$  is the local curvature radius of the river axis, and  $\theta$  the local angle of the axis tangent with respect to the longitudinal direction. The curvature by definition is  $C^* = 1/R^*$ . As far as the channel cross section is concerned,  $2B_0^*$  and  $D_0^*$  are the width and the depth of a reference straight rectangular channel having the same flow discharge,  $2B_0^*D_0^*U_0^*$ , bed slope  $S$ , and characteristic grain size  $d_s^*$  of the considered meandering river (e.g.,  $d_{50}^*$ ), with  $U_0^*$  the cross-sectionally averaged velocity. In addition,  $\eta^*$  and  $H^*$  are the local bed elevation and the free surface elevation with respect to a given datum, while  $D^* = H^* - \eta^*$  is the local flow depth. The local velocity components along the longitudinal, transverse and vertical direction are  $u^*$ ,  $v^*$ , and  $w^*$ , respectively.

The next step is to scale the above relevant quantities through the uniform flow parameters. Hence:

$$(x^*, y^*, s^*, n^*, R^*) = B_0^*(x, y, s, n, R) \quad (1a)$$

$$(z^*, \eta^*, H^*, D^*) = D_0^*(z, \eta, H, D) \quad (1b)$$

$$(u^*, v^*, w^*) = U_0^*(u, v, w) \quad (1c)$$

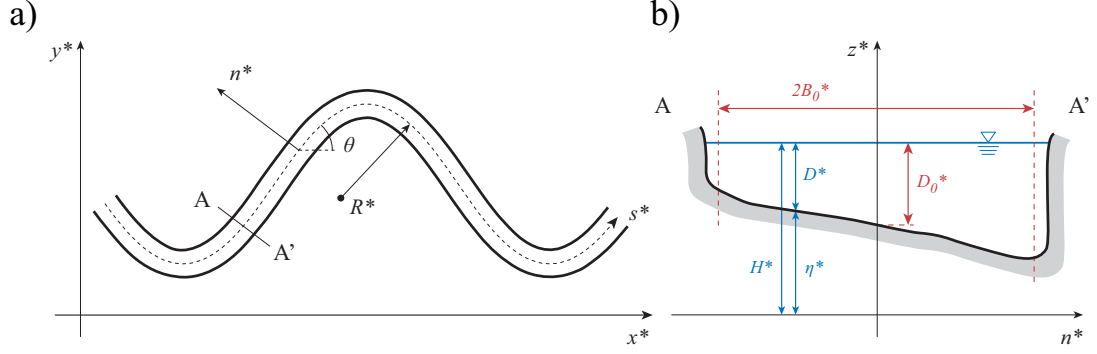


Figure 1: Reference systems and notation for a) the river planform and b) the cross-section.

A curvature parameter may be defined as follows:

$$\nu_0 = \frac{B_0^*}{R_0^*} \quad (2)$$

where  $R_0^*$  is a reference radius of channel axis curvature, e.g. the minimum value attained along the investigated reach. The fundamental hypothesis for deriving the mathematical model is that  $\nu_0$  is a small parameter, i.e. the river planforms are made by sufficiently gentle and wide bends such that the local curvature radius is much larger than the cross section width. The dimensionless local curvature  $\mathcal{C}$  turns out to be (Frascati and Lanzoni, 2013):

$$\mathcal{C} = -\frac{1}{\nu_0} \frac{\partial \theta}{\partial s} \quad (3)$$

The relevant morphological parameters are the half width to depth ratio  $\beta$ , the Shields number  $\tau_*$  and the dimensionless grain size  $d_s$ , defined as follows:

$$\beta = \frac{B_0^*}{D_0^*} \quad (4a)$$

$$\tau_* = \frac{C_f U_0^{*2}}{\Delta g d_s^*} \quad (4b)$$

$$d_s = \frac{d_s^*}{D_0^*} \quad (4c)$$

where  $g$  is the gravity acceleration,  $\Delta = (\rho_s - \rho)/\rho$  is the submerged specific gravity of the sediment ( $\rho_s \simeq 2650 \text{ kg / m}^3$ ,  $\rho = 1000 \text{ kg / m}^3$ ), and  $C_f$  is the friction coefficient.

Velocity and depth are related together through the Froude number:

$$F_0 = \frac{U_0^*}{\sqrt{gD_0^*}} \quad (5)$$

Finally, the sediment motion leads to a volumetric discharge per unit width denoted as  $q_s^*$ , which may be scaled as:

$$\Phi = \frac{q_s}{R_p \nu} \quad (6)$$

where  $\nu \simeq 10^{-6} \text{ m}^2/\text{s}$  is the kinematic viscosity of water, and  $R_p$  is the Reynolds particle number:

$$R_p = \frac{\sqrt{g\Delta} d_s^{*3/2}}{\nu} \quad (7)$$

Hereafter, under dominant bedload transport  $\Phi$  is computed through the formula of Parker (1990). The particle Reynolds number, which controls the intensity of suspended load transport (see, e.g., Frascati and Lanzoni, 2010) is also considered to evaluate the threshold above which suspended load takes place (Van Rijn, 1984a). In this case the total load predictor of Engelund and Hansen (1967) is used to compute  $\Phi$ . Moreover,  $R_p$  is used to establish whether the river bed is flat or dune-covered (Van Rijn, 1984b) when computing the friction coefficient  $C_f$  through the method of Engelund and Hansen (1967).

## The long-term migration of the river

The long-term migration of river planforms is driven by the complex interplay of the processes of erosion at the inner bank and deposition at the outer bank, possibly leading to spatial and temporal variation of the local channel width. Among others, the affecting factors may be the type of bank failure, the composition of the banks and of the slumped block material, and the vegetation properties. The erosion and deposition processes usually occur at different times and different time scales (Asahi et al., 2013). However, many meandering rivers tend to have a near constant width as channel sinuosity evolves (Parker et al., 2011), showing a normal distribution of channel widths when the fluvial system is subjected to a steady-forcing discharge (Wickert et al., 2013). Eventually, the typical ridge-and-swale bar topography develops (van De Lageweg et al., 2014). This scenario requires an active communication between bank

erosion at the outer bend, i.e. bank pull, and bank growth at the inner bend, i.e. bank push (Eke et al., 2014; van De Lageweg et al., 2014; Schuurman et al., 2016). As a consequence, a constant width of the river cross section may be assumed as a first approximation, and the river path may be described by its centerline.

Referring to the planimetric sketch of Figure 1, the configuration of the channel axis at a certain time  $t$  may be described by the current distribution of angles  $\theta(s^*, n^*)$  formed by the local tangent to the channel axis with the longitudinal direction. Indeed, Seminara et al. (2001) demonstrated that the planimetric evolution at the generic location  $s$  along the river axis is described by the following integro-differential equation:

$$\frac{\partial \zeta}{\partial s} = \frac{\partial \theta}{\partial t} - \frac{\partial \theta}{\partial s} \int_0^s \zeta \frac{\partial \theta}{\partial s} ds \quad (8)$$

where the lateral migration velocity  $\zeta$  and the time  $t$  are scaled as:

$$\zeta^* = U_0^* \zeta \quad (9a)$$

$$t^* = \frac{U_0^*}{B_0^*} t \quad (9b)$$

Equation (8) drives the lateral migration of the river path across the floodplain over the time, producing a local displacement  $\xi_n(s)$  normal to the channel axis:

$$\frac{d\xi_n(s)}{dt} = \zeta(s) \quad (10)$$

Because of the previous assumption of nearly constant cross section width, the relation proposed by Ikeda et al. (1981) to model the river migration across the valley surface may be assumed. In dimensionless form, the relation reads:

$$\zeta = E U_b \quad (11)$$

where  $E$  is a dimensionless long-term erosion coefficient, while  $U_b = U_b^*/U_0^*$  is the dimensionless excess near-bank velocity, i.e. the difference between the longitudinal velocity  $U|_{n=1}$  at the outer bank ( $n = n^*/B_0^* = 1$ ) and the longitudinal velocity  $U|_{n=-1}$  at the inner bank ( $n = n^*/B_0^* = -1$ ). All the involved terms are function of the coordinate  $s$  along the river centerline.

The problem outlined so far is solved numerically by discretizing the dimensionless river centerline  $s$  through a polyline made by  $N$  points  $P_i(x_i, y_i)$ , defined with respect

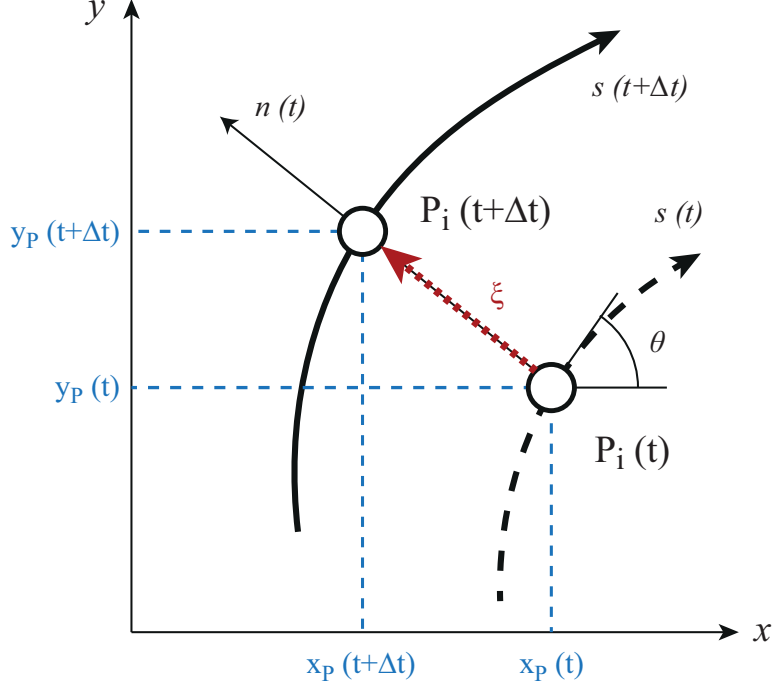


Figure 2: Sketch of the migration of a point  $P$  lying on the channel axis, due to the displacement from the configuration  $s(t)$  to the new configuration  $s(t + \Delta t)$ . Quantities may be either dimensional or dimensionless, the scaling factor being  $B_0^*$ .

to the Cartesian reference system of Figure 1. As described by the sketch in Figure 2, the differential equation (10) is solved numerically through finite differences. At each dimensionless time step  $t^{k+1} = t^k + \Delta t^k$ , the migration of the  $i$ th node in the direction  $n$  normal to  $s$  is computed through a time marching procedure of the form (Crosato, 1990):

$$x_i^{k+1} = x_i^k - \Delta t_i^k \frac{\zeta_i^k + \zeta_i^{k-1}}{2} \sin \theta_i^k, \quad (12)$$

$$y_i^{k+1} = y_i^k + \Delta t_i^k \frac{\zeta_i^k + \zeta_i^{k-1}}{2} \cos \theta_i^k, \quad (13)$$

where  $x_i^{k+1} = x_i(t^{k+1})$ ,  $y_i^{k+1} = y_i(t^{k+1})$ , and  $\zeta_i^k = E_i^k U_{bi}^k$ . The value  $\theta_i^k$  of the local tangent angle is computed by backward and forward averaging (Lanzoni and Seminara, 2006):

$$\theta_i^k = \frac{1}{2} \left( \arctan \frac{y_{i+1}^k - y_i^k}{x_{i+1}^k - x_i^k} + \arctan \frac{y_i^k - y_{i-1}^k}{x_i^k - x_{i-1}^k} \right) \quad (14)$$

This angle is also used to discretize the geometrical relationship (3) and to determine



the local value of the dimensionless curvature  $\mathcal{C}_i^k$ :

$$\mathcal{C}_i^k = -\frac{1}{\nu_0} \frac{\theta_{i+1}^k - \theta_{i-1}^k}{2\Delta s_i^k} \quad (15)$$

where  $\Delta s_i^k$  is the dimensionless distance between two consecutive points. The possible numerical anomalies arising from the curvature computation (Schwenk et al., 2015) are filtered out by using a Savitzky-Golay smoothing filter (Orfanidis, 1995; Motta et al., 2012a). The time step size  $\Delta t_i^k$  is controlled by requiring that:

$$\Delta t_i^k \leq \alpha \left( \frac{\Delta s_i^k}{E_i^k U_{bi}^k} \right)_{\max} \quad (16)$$

where  $\alpha$  is a parameter defining the threshold between stable and unstable computations, to be chosen empirically ( $\alpha \sim 10^{-2}$ ) on the basis of a balance between computational effort and accuracy of the numerical solution (Crosato, 1990; Lanzoni and Seminara, 2006).

Since the deformation experienced by the channel axis at each time step leads to continuous variations of  $\Delta s_i^k$ , the mesh is periodically re-built to maintain quasi-uniformity of the node spacings, adding or removing nodes to maintain the value of  $\Delta s_i^k$  into the range  $2/3$  and  $4/3$ .

The progressive elongation of the channel axis produces neck cutoffs, whereby the upstream and downstream portions of a bend loop approach each other and eventually intersect. The meander loop is then bypassed, and the older, more sinuous reach is abandoned by the active river, forming an oxbow lake when sedimentation closes its ends. These processes may last many years (Gagliano and Howard, 1984) but, because of the long time scales characterizing the evolution of the river planform, they can be assumed to occur instantaneously in the simulation model. Following Howard and Knutson (1984) and Sun et al. (1996), the presence of potential neck cutoffs is detected by controlling the dimensionless distance between a given point  $P_i$  and the nearby points  $P_{i+r}$  located sufficiently downstream (e.g.,  $r \geq 8$ ). This control is made through the algorithm developed by Camporeale et al. (2005) which improves the computational efficiency of the model. When the computed Cartesian distance between nodes  $P_i$  and  $P_{i+r}$  is lower than a threshold value, say  $\Delta s_r = 2.2$ , all the points  $P_{i+j}$ ,  $j = 1, r - 1$  are removed from the computational grid, defining a

new oxbow lake (Figure 3). A few nodes upstream of  $P_i$  and downstream of  $P_{i+r}$  (e.g.,  $P_{i-q}$ ,  $P_{i+r+q}$ ,  $q = 1, 2, 3$ ) are also removed to prevent the formation of a high-curvature river reach (Frascati and Lanzoni, 2009) that, in nature, is unlikely to persist owing to the rapid smoothing action of the current and the along river propagation of the geometric disturbances generated by the cutoff even (Hooke, 1995; Camporeale et al., 2008).

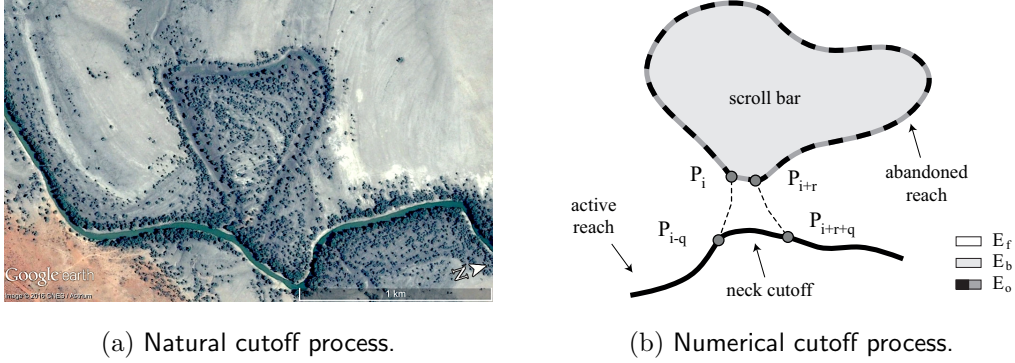


Figure 3: Example of (a) a natural neck cutoff process producing a different geomorphic environment inside the oxbow lake contour (Darling River, Australia,  $31^\circ 33' S$   $143^\circ 30' E$ , source: Google Earth Pro), and of (b) the numerical modelling of neck cutoff occurrence, with the formation of two new environments, namely the oxbow lake formed by the abandoned reach and the inner scroll bar bounded by the previous element. Symbols are as follows:  $r$  determines the points that are considered to check the occurrence of a incipient neck cutoff;  $q$  is the number of point removed to avoid the presence of a high-curvature river reach after a cutoff;  $E_f$ ,  $E_b$ , and  $E_o$  are the erodibility coefficients assigned to the pristine floodplain, the scroll bar environment and the oxbow lake environment, respectively.

The alternate form of cutoff, the chute cutoff, is not treated by this model.

As observed above, the total length of the channel and the bed slope change over time due to the elongation driven by migration and the shortening due to cutoff occurrences. As a consequence, suitable relations must be imposed in order to keep consistent steady flow and sediment transport conditions. Assuming a constant discharge and a temporally constant floodplain gradient, the relevant physical parameters between two

time steps  $k$  and  $k + 1$  are updated as follows:

$$\frac{\beta^{k+1}}{\beta^k} = \left( \frac{C_f^k}{C_f^{k+1}} \right)^{1/3} \left( \frac{\sigma_T^k}{\sigma_T^{k+1}} \right)^{1/3} \quad (17)$$

$$\frac{\tau_*^{k+1}}{\tau_*^k} = \left( \frac{C_f^k}{C_f^{k+1}} \right)^{-1/3} \left( \frac{\sigma_T^k}{\sigma_T^{k+1}} \right)^{2/3} \quad (18)$$

$$\frac{d_s^{k+1}}{d_s^k} = \left( \frac{C_f^k}{C_f^{k+1}} \right)^{1/3} \left( \frac{\sigma_T^k}{\sigma_T^{k+1}} \right)^{1/3} \quad (19)$$

where  $\sigma_T$  is the river sinuosity, defined as the ratio of the dimensionless intrinsic length  $L = L^*/B_0^*$  (computed along the channel centerline) to the dimensionless Cartesian length  $l_x = l_x^*/B_0^*$  (obtained projecting the river axis on the longitudinal axis  $x$  oriented in the direction of the floodplain gradient).

## Floodplain features

The model described so far has been found to effectively reproduce typical meander shapes observed in nature (simple bends, compound bends and multiple loops) for a constant (in time and space) floodplain erodibility (Frascati and Lanzoni, 2009). The bank erosion coefficient, however, generally depends on soil properties, deposition and consolidation processes, groundwater dynamics (Han and Endreny, 2014), and distribution of riparian vegetation (Perucca et al., 2007; Motta et al., 2012a,b; Wickert et al., 2013). To mimic these heterogeneities, the valley surface is, as a first approximation, schematized by three different geomorphic units with different local coefficients  $E$  (Figure 3), depending on the soil properties as well as on the vegetation cover.

The first geomorphic unit is the pristine floodplain, with coefficient  $E = E_f$ . It corresponds to the undisturbed floodplain consisting of sediment deposited by repeated flooding events, not yet impacted and consequently reworked by the river migration.

The second geomorphic unit corresponds to the oxbow lake environment, with coefficient  $E = E_o$ . It mimics the fine-filled abandoned channel reach which leads to the formation of plugs that may obstruct the lateral migration of the active channel (Toonen et al., 2012). Finally, the third geomorphic unit corresponds to the scroll bar environment, with coefficient  $E = E_b$ . It mimics the floodplain area bounded by an oxbow lake, characterized by the typical ridge-and-swale sequence. In particular,

coarse-grained sediments typically accumulates on the ridge, while finer sediment (silt and clay) deposit in the upper part (Nanson, 1980) because of the temporary flow expansions (van De Lageweg et al., 2014). The structure of vegetation reflects the local topography and hydrological conditions (Zen et al., 2016) contributing to the erosional complexity of the scroll bodies.

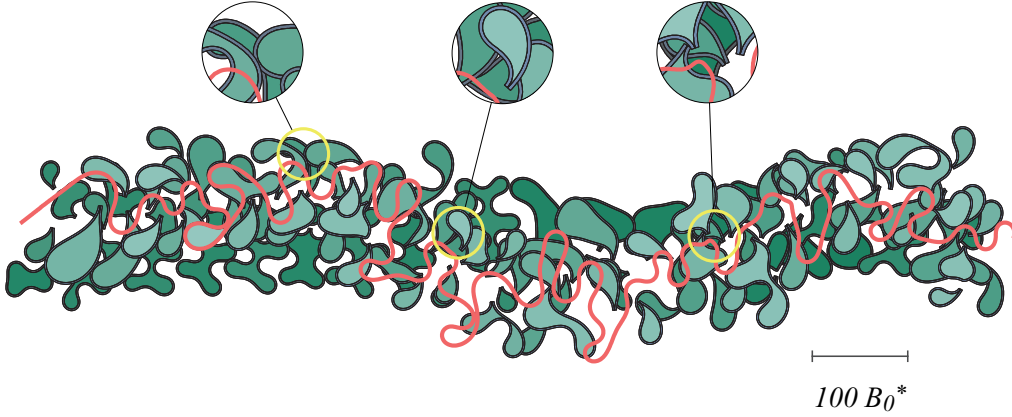


Figure 4: Example of a simulated planform dynamics, with the formation of scroll bars (older are dark green, younger are light green) and oxbow lakes (gray stripes bounding the previous elements, corresponding to the abandoned bends).

All the erosion coefficients are kept constant over time in order to maintain the modelling framework at the lowest possible level of complexity, thus temporal variations caused, e.g., by soil compaction and biological dynamics are not considered. Furthermore, incision, soil uplift, and subsidence are not accounted for, assuming that the floodplain surface is infinitely large and keeps its elevation constant over time. Possible changes in the hydrological regime and flow unsteadiness associated with flood waves are neglected as well.

Spatial variability ensuing from the meandering dynamics is accounted for as follows. All the progressively formed geomorphic environments (oxbow lakes and scroll bars) are saved as polygons given by the abandoned mesh nodes (Figure 4). As the generic node  $P_i$  of the active channel axis migrates laterally, the river may encounter three different environments during its lateral migration onto the valley. The winding number algorithm of Hormann and Agathos (2001) is used to identify whether the current

point lies within a pre-saved geomorphic unit and, hence, to choose the appropriate local erosion coefficient.

## The flow field

This section briefly summarizes the key points of two mathematical models of channel morphodynamics implemented in the model, namely the model developed by Ikeda et al. (1981), hereafter referred to as IPS model, and the model developed by Zolezzi and Seminara (2001), hereafter referred to as ZS, similarly to the approach of Frascati (2009). Both models are based on the assumption of a secondary bidimensional flow driven by the curvature distribution and superimposed to the primary uniform flow travelling the channel.

The use of two models entailing a different level of approximation is motivated by the importance that the coupling of the flow field and the sediment balance equations has on the quantitative reproduction of observed river planforms. The former model however, assumes empirically the form of the channel cross-section.

The IPS model has been widely used (see, among the others, Perucca et al., 2005; Güneralp and Rhoads, 2011; Schuurman et al., 2016). The decoupling of the equations governing the flow field and the sediment conservation does not allow to solve for the bed configuration, thus an empirical relation is required. The dimensionless excess near-bank velocity  $U_b$  takes the type:

$$U_b = U_0^* F \left[ \nu_0, \beta, C_f, \tau_*, \mathcal{C}, \int_0^s \mathcal{C}(\xi) e^{\lambda_0(s-\xi)} d\xi \right] \quad (20)$$

where the characteristic exponent  $\lambda_0 = -2\beta C_f$  drives the convolution integral which accounts for the effect of the upstream curvature distribution on the downstream reach (downstream influence).

The ZS morphodynamic model solves the steady flow field in a movable bed river with variable curvature of the channel axis. It was derived by integrating over the depth the continuity equation and the Reynolds-averaged Navier-Stokes equations (RANS), written in intrinsic coordinates, and by introducing a parametrization of the secondary flow driven by the channel axis curvature (Zolezzi and Seminara, 2001). The extension of the model to cases involving width variations was developed by Frascati and Lan-

zoni (2013). The resulting equations are fully coupled to the Exner sediment balance equation, also written in curvilinear coordinates, and closed by means of a suitable sediment transport law. All the relevant equations are then linearized, by expanding in terms of small parameters, taking advantage of the typically wide character of river bends (small curvature ratio  $\nu_0$ ). Eventually, the following functional relationship is found:

$$U_b = U_0^* F \left[ \nu_0, \beta, C_f, \tau_*, \mathcal{C}, \int_0^s \mathcal{C}(\xi) e^{\lambda_{mj}(s-\xi)} d\xi \right] \quad (21)$$

where  $\lambda_{mj}$  ( $m = 0, \infty; j = 1, 4$ ) are characteristic exponents for the  $m$ th lateral Fourier mode which are crucial to determine, through the related convolution integrals, whether flow and bed topography at a given position  $s$  are affected by the river reach located upstream (downstream influence) or downstream (upstream influence) (Zolezzi and Seminara, 2001; Lanzoni and Seminara, 2006). The four exponents are the solutions of the four-order ordinary differential equation that arises from the linearized continuity and momentum equations coupled with the sediment balance equation. Figure 5 shows three examples of the trends followed by the characteristic exponents  $\lambda_{mj}$  as functions of the values of the half width to depth ratio  $\beta$ , compared with the behaviour of the characteristic exponent  $\lambda_0$  resulting from the IPS approach. It is worthwhile to note that, generally,  $\lambda_{m1}$  is real positive,  $\lambda_{m4}$  is real negative. They describe non-oscillatory spatial perturbations which decay fairly fast either downstream or upstream. The other two exponents  $\lambda_{m2}$  and  $\lambda_{m3}$  are complex conjugate, having respectively equal real parts ( $\lambda_{m2r} = \lambda_{m3r}$ ) and opposite imaginary parts  $\lambda_{m2i} = -\lambda_{m3i}$ . They describe oscillatory spatial perturbations which decay fairly slowly, spreading their influence over a considerable channel length (Lanzoni et al., 2006). Moreover,  $\lambda_{m3r}$  can be negative or positive, depending whether the aspect ratio  $\beta$  is smaller or larger than a threshold value,  $\beta_r$ . Channels characterized by aspect ratios  $\beta < \beta_r$  are defined subresonant, leading to a downstream influence, as in the IPS model. On the contrary, channels characterized by aspect ratios  $\beta > \beta_r$  are defined superresonant, leading to an upstream influence. This latter condition can not emerge when using the IPS model, as the latter is driven by a first-order ordinary differential equation because of the uncoupling of the sediment balance equation and the flow field. Subresonant

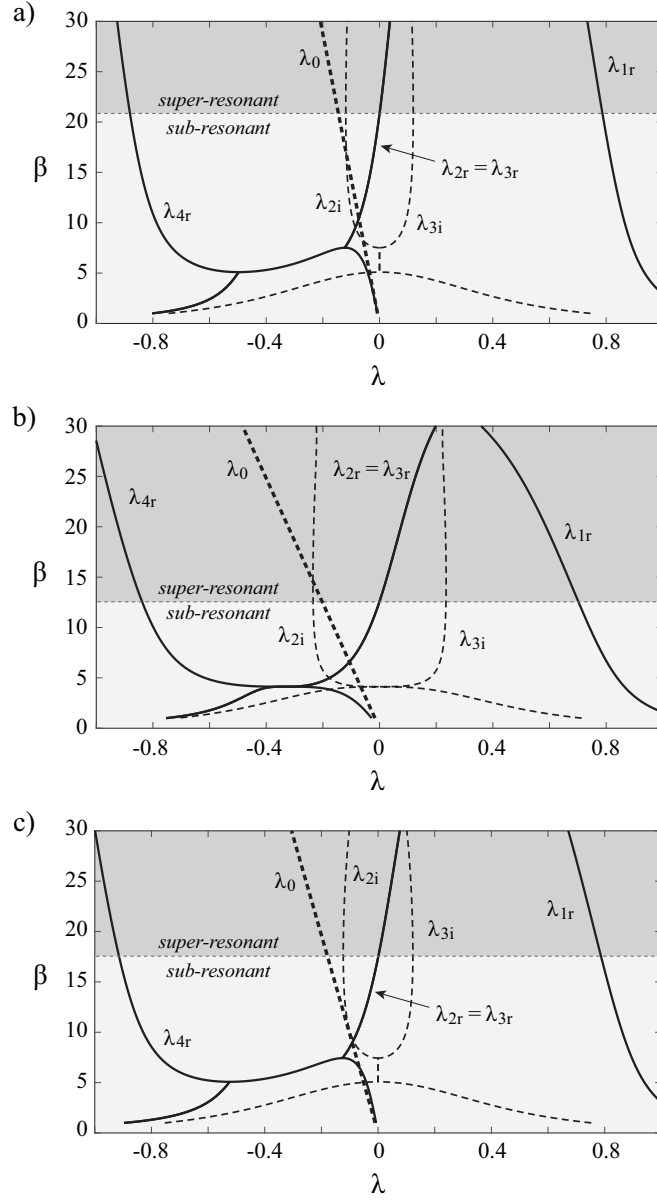


Figure 5: Typical behaviour of the four characteristic exponents  $\lambda_{mj}$  of the ZS approach as a function of the half width to depth ratio  $\beta$ , for three different scenarios. Continuous lines correspond to the real parts, dashed thin lines correspond to the imaginary parts, while the dashed thick line corresponds to the characteristic exponent  $\lambda_0$  of the IPS approach. The three scenarios are characterized by the following parameter sets: a)  $\tau_* = 0.1$ ,  $d_s = 0.005$ , flat bed; b)  $\tau_* = 0.3$ ,  $d_s = 0.001$ , dune-covered bed; c)  $\tau_* = 0.6$ ,  $d_s = 0.0001$ , dune-covered bed.

meanders are typically upstream skewed and migrate downstream, while superresonant meanders are typically downstream skewed and migrate upstream (Lanzoni et al., 2006; Lanzoni and Seminara, 2006).

Further details about the derivation, performances, and limitations inherent in linearization of the flow field model may be found in Zolezzi and Seminara (2001) and Frascati and Lanzoni (2013).

In order to increase the computational efficiency in the numerical implementation, the convolution integrals appearing in the expressions for the velocity perturbation (20) and (21) are evaluated using Simpson rule, truncating the integration when the function to be integrated, that decays exponentially, is smaller than a given tolerance, say  $10^{-4}$  (Lanzoni and Seminara, 2006).



**Part I**

**Input files**

### 3 File SIM

The SIM file is a formatted text file containing the leading parameters of the flow filed computation, the structure of the floodplain and the simulation parameters.

Variable types are as follows:

- I : integer variable,
- R : double precision variable (real\*8)
- S : integer switch
- T<sub>n</sub> : text with *n* maximum types.

Row	Variable	Type	Description
1	<i>Text row</i>		
2	<SIM name>	T <sub>20</sub>	simulation name (max 20 letters)
3	<i>Text row</i>		
4	$\beta$	R	half width to depth ratio
5	$\tau^*$	R	Shields number
6	$d_s$	R	dimensioless grain roughness
7	flagbed	S	source for bed configuration 1:from $R_p$ ; 2:from typebed
8	$R_p$	R	Reynolds particle number
9	typebed	S	fixed bed configuration 1:flat bed; 2:dune-covered
10	$r$	R	transverse transport parameter (Talmon 1995)
11	jmodel	S	flow field model 1: ZS approach; 2: IPS approach
12	$N_z$	I	number of points for the vertical flow integration in ZS model
13	$M_{dat}$	I	order of the Fourier expansion in ZS model

*File SIM continues on next page*

*File SIM continues from previous page*

Row	Variable	Type	Description
14	<i>Text row</i>		
15	$E_f$	R	erodibility coefficient of the floodplain
16	$E_b$	R	erodibility coefficient of the point bars
17	$E_o$	R	erodibility coefficient of the oxbow lakes
18	flag <sub>ox</sub>	S	flag for existing structure of the floodplain 0: no; 1: yes
19	<i>Text row</i>		
20	$N_0$	I	initial number of points
21	flag <sub>xy0</sub>	S	initial planform configuration 1: straight path randomly perturbed; 2: given configuration from filexy
22	filexy	T <sub>20</sub>	name of geometry file with dimensionless coordinates (maximum 20 letters)
23	$\Delta s$	R	resampling distance between axis points
24	$\Delta s_{\min}$	R	minimum allowed value of grid size (times $\Delta s$ )
25	$\Delta s_{\max}$	R	maximum allowed value of grid size (times $\Delta s$ )
26	$N_{\text{rand}}$	I	number of point interested by a slight perturbation if flag <sub>xy0</sub> = 1
27	$stdv$	R	standard deviation of initial perturbation if flag <sub>xy0</sub> = 1
28	toll <sub>c</sub>	R	minimum threshold before neck-cutoff
29	$j_{re}$	I	points removed upstream and downstream of a cutoff
30	$j_{nco}$	I	minimum threshold points for neck cutoff searching (> 2)
31	$k_{savgol}$	I	SavitzkyGolay flag

*File SIM continues on next page*

*File SIM continues from previous page*

Row	Variable	Type	Description
			$< 0$ : number of smoothing repetitions in each iteration (absolute value); $> 0$ : iteration wait between two smoothings; $0$ : no smoothing.
32	<i>Text row</i>		
33	$\text{flag}_{\text{time}}$	S	flag for defining the end of the simulation 1: time; 2: coefficient multiplying the time of first cutoff; 3: number of iterations; 4: number of cutoffs; 5: number of printed configurations.
34	$TT_s$	R	simulation time if $\text{flag}_{\text{time}} = 1$ (dimensionless years)
35	$k_{TT_{fco}}$	R	coefficient for first cutoff time if $\text{flag}_{\text{time}} = 2$
36	$n_{\text{end}}$	I	item number if $\text{flag}_{\text{time}} \geq 3$ (number of iterations / number of cutoffs / number of printed configurations)
37	$tt_0$	R	starting time (dimensionless years)
38	$\text{flag}_{dt}$	S	flag for time marching 1: fixed and equal to $dt_0$ ; 2: dynamic but always $< dt_0$ .
39	$dt_0$	R	fixed time step (dimensionless years)
40	$c_{\text{stab}}$	R	coefficient for time marching
41	$i_{\text{video}}$	I	iterations between two screen prints
42	$i_{\text{screen}}$	I	iterations between two file prints

*End of file SIM*

## 4 File XY

File **XY** contains the initial geometrical path of the computational domain, scaled with the half width  $B_0^*$ . This text file consists of a matrix with  $N_0$  rows, i.e. one row per node, and 2 columns which are the dimensionless longitudinal coordinate  $x = x^*/B_0^*$  and the transverse coordinate  $y = y^*/B_0^*$ , respectively.

$x_1$	$y_1$
$x_2$	$y_2$
$\dots$	$\dots$
$x_{N_0}$	$y_{N_0}$

## Part II

# Output files

## 5 File SIMULATION

File <SIM NAME> \_SIMULATION.DAT records the temporal trends of some geometrical parameters, i.e. number of points forming the river axis, number of floodplain features. This file consists of a matrix with  $nt$  rows, i.e. one row per printed time step, and 7 columns which are specified in the table below.

Column index	Variable	Description
1	$j_p$	index of the current printed step
2	$j_t$	iteration index
3	$t$	dimensionless time of the current step
4	$N$	number of points forming the channel axis
5	$N_{pb}$	current total number of axis points within the scroll bar environments
6	$N_{po}$	current total number of axis points within the oxbow lake environments
7	$N_{nco}$	cumulate number of neck cutoffs

## 6 File PARAMETERS

File <SIM NAME> \_PARAMETERS.DAT records the temporal trends of the leading morphodynamic parameters. This file consists of a matrix with  $nt$  rows, i.e. one row per printed time step, and 10 columns which are specified in the table below.

Column index	Variable	Description
1	$j_p$	index of the current printed step
2	$j_t$	iteration index
3	$t$	dimensionless time of the current step
4	$L = L^*/B_0^*$	dimensionless length of the current channel path, scaled by the half width
5	$\beta$	half width to depth ratio
6	$\tau^*$	Shields number
7	$d_s$	grain size to depth ratio
8	$C_f$	friction coefficient
9	typebed	bed configuration (1: flat bed, 2: dune-covered)
10	typeload	sediment flux type (1: bedload 2: total load)



## 7 File CUTOFFS

File <SIM NAME> \_CUTOFFS.DAT records the temporal trends of the cutoff occurrences. This file consists of a matrix with  $n_{nco}$  rows, i.e. one row per cutoff occurrence, and 10 columns which are specified in the table below.

Column index	Variable	Description
1	$j$	index of the current neck cutoff occurrence
2	$N_{rem}$	number of point forming the abandoned bend
3	$N$	former number of axis points
4	$j_{up}^{ch}$	last node of the channel axis upstream of the cutoff
5	$j_{up}^{co}$	upstream node of the cutoff
6	$j_{dw}^{co}$	downstream node of the cutoff
7	$j_{dw}^{ch}$	first node of the channel axis downstream of the cutoff
8	$N_{new}$	new number of axis points
9	$t$	dimensionless time of the current step
10	$j_t$	iteration index

## 8 File CONFIGURATION

File CONFIGURATION\_<jt>.OUT contains the geometrical features of the computational domain at the printing step  $jp$  which corresponds to the instant time  $t$ , basing on file SIMULATION. This file consists of a matrix with  $nn$  rows, i.e. one row per node, and 6 columns which are specified in the table below.

Column index	Variable	Description
1	$x = x^*/B_0^*$	dimensionless longitudinal coordinate
2	$y = y^*/B_0^*$	dimensionless transverse coordinate
3	$s = s^*/B_0^*$	dimensionless intrinsic coordinate
4	$-\theta$	negative local angle of the axis river with the longitudinal direction
5	$\nu_0\mathcal{C}$	dimensionless local curvature
6	$U_b = \frac{U^* _{n=1} - U^* _{n=-1}}{U_0^*}$	dimensionless excess near-bank velocity

## 9 File OXBOW

File OXBOW\_<j>.OUT contains the geometrical path of the current oxbow lake, scaled with the half width  $B_0^*$ . This text file consists of a matrix with  $N_{ox}$  rows, i.e. one row per node, and 2 columns which are the dimensionless longitudinal coordinate  $x = x^*/B_0^*$  and the transverse coordinate  $y = y^*/B_0^*$  forming the oxbow lake, respectively.

$x_1$	$y_1$
$x_2$	$y_2$
$\dots$	$\dots$
$x_{N_{ox}}$	$y_{N_{ox}}$

## 10 File POINTBAR

File POINTBAR\_<j>.OUT contains the geometrical path of the current point bar, scaled with the half width  $B_0^*$ . This text file consists of a matrix with  $N_{pb}$  rows, i.e. one row per node, and 2 columns which are the dimensionless longitudinal coordinate  $x = x^*/B_0^*$  and the transverse coordinate  $y = y^*/B_0^*$  forming the point bar, respectively.

$x_1$	$y_1$
$x_2$	$y_2$
$\dots$	$\dots$
$x_{N_{pb}}$	$y_{N_{pb}}$

## 11 File LAMBDA

File <SIM NAME> \_LAMBDA.DAT records the temporal trends of the characteristic eigenvalues of the mathematical model for the curvature-driven flow field.

When the flow field is computed by the IPS model, this file consists of a matrix with  $nt$  rows, i.e. one row per printed time step, and 4 columns which are specified in the table below.

Column index	Variable	Description
1	$j_p$	index of the current printed step
2	$j_t$	iteration index
3	$t$	dimensionless time of the current step
4	$\lambda_0$	characteristic exponent of the IPS model

When the flow field is computed by the ZS model, this file consists of a matrix with  $nt \times M_{dat}$  rows, i.e.  $M_{dat}$  rows per printed time step where  $M_{dat}$  is the order of the Fourier expansion in ZS model, and 12 columns which are specified in the table below.

Column index	Variable	Description
1	$j_p$	index of the current printed step
2	$j_t$	iteration index
3	$j_m$	current Fourier mode
4	$t$	dimensionless time of the current step
5	$Re(\lambda_{m1})$	real part of the first characteristic exponent of the ZS model
6	$Im(\lambda_{m1})$	imaginary part of the first characteristic exponent of the ZS model
7	$Re(\lambda_{m2})$	real part of the second characteristic exponent of the ZS model
8	$Im(\lambda_{m2})$	imaginary part of the second characteristic exponent of the ZS model
9	$Re(\lambda_{m3})$	real part of the third characteristic exponent of the ZS model
10	$Im(\lambda_{m3})$	imaginary part of the third characteristic exponent of the ZS model
11	$Re(\lambda_{m4})$	real part of the fourth characteristic exponent of the ZS model
12	$Im(\lambda_{m4})$	imaginary part of the fourth characteristic exponent of the ZS model

## Part III

# Other files

## 12 File XY TEMP

File XY.DAT is a text file containing the backup data of the last iteration. The header lines contain the last update of the leading parameters:

- $j_t$  : last iteration index;
- $t$  : dimensionless time of the current step;
- $\beta$  : half width to depth ratio;
- $\tau^*$  : Shields number;
- $d_s$  : grain size to depth ratio;
- $C_f$  : friction coefficient;
- $j_p$  : index of the current printed step;
- $N$  : number of points forming the channel axis;
- text line.

The file contains also a matrix with  $N$  rows, i.e. one row per node, and 2 columns which are the dimensionless longitudinal coordinate  $x = x^*/B_0^*$  and the transverse coordinate  $y = y^*/B_0^*$ , respectively.

$x_1$	$y_1$
$x_2$	$y_2$
$\dots$	$\dots$
$x_N$	$y_N$

## 13 Files FLOODPLAIN

The following files are generated and updated by the numerical code during the simulation runs, and they are required for a future new simulation which involves an existing floodplain structure.

- File <SIM NAME> \_NNCO.dat contains the number of cutoffs occurred so far.
- Files <SIM NAME> \_PB.dat contain the storage indices defining the point bar arrays.
- Files <SIM NAME> \_OX.dat contain the storage indices defining the oxbow lake arrays.

## 14 File TIME

File <SIM NAME> \_TIMESIM.DAT recors the date and time of beginning and end of the simulation, as well as the simulation duration.



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