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Five common mistakes in fluvial morphodynamic modeling

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ABSTRACT

Recent years have seen a marked increase in the availability of morphodynamic models and a proliferation of new morphodynamic codes. As a consequence, morphodynamic models are increasingly developed, used and evaluated by non-experts, possibly leading to mistakes. This paper draws attention to five types of common mistakes. First, new morphodynamic codes are developed as extensions of existing hydrodynamic codes without including all essential physical processes. Second, model inputs are specified in a way that imposes morphodynamic patterns beforehand rather than letting them evolve freely. Third, detailed processes are parameterized inadequately for application to larger spatial and temporal scales. Fourth, physical and numerical phenomena are confused when interpreting model results. Fifth, the selection of modeling approaches is driven by the belief that complete data are a prerequisite for modeling and that the application of 2D and 3D models requires more data than the application of 1D models. Examples from fluvial morphodynamics are presented to illustrate these mistakes.

1. Introduction

Fast technological developments have fuelled impressive advances in two-dimensional depth-averaged (2DH) numerical models of river morphodynamics over the past eighty years. Van Bendegom's [17] numerical code was solved by hand in the 1930s, when a calculator was still a profession instead of a machine. Today, river engineers visit a river in a far-away country, collect elementary data on the spot, set up a computational grid based on Google Earth in their Wi-Fi-equipped hotel room in the evening, run a morphodynamic simulation, and present plots and animations of the morphodynamic evolution to the client or stakeholders the next morning.

The technological developments have also increased the number, the availability and the user-friendliness of morphodynamic codes. As a consequence, morphodynamic models are increasingly developed, used and evaluated by non-experts. Mosselman [10] and Sloff and Mosselman [13] argue, after Van Zuylen et al. [18], that modeling of river morphodynamics requires teams or communities with specialists in (i) domain knowledge based on experience with real rivers; (ii) knowledge about model concepts such as the underlying mathematical equations; (iii) knowledge about model constructs such as grids, time steps, morphological acceleration factors and spin-up times; and (iv) knowledge about model artefacts such as user interfaces and file formats. Mistakes are possible if the modeling team does not cover this full range of expertise. Our objective is to share our experiences on five common mistakes from over 25 years of involvement in executing, supervising and reviewing modeling of river morphodynamics. This has been inspired by Salt's [12] similar but broader paper on mistakes in simulation modeling that bears relevance for river morphodynamic modeling too.

Our approach in this paper is as follows. We set up a simple numerical model for water flow in a straight channel with a mobile bed. We run simulations with this model to illustrate two of the five mistakes. The other three mistakes are explained without model simulations. We discuss a few considerations behind the list of common mistakes, the use of a morphological acceleration factor, and the implications for model validation. Finally, we provide recommendations for modelers as well as supervisors and reviewers of numerical computations in fluvial morphodynamics.

2. Set-up of numerical computations

We set up a Delft3D model, based loosely on the numerical model of Crosato et al. [4], for a 10 km long and 90 m wide straight channel (Fig. 1). The gradient, i, was equal to 0.1 m/km, the discharge, Q, was 180 m^3/s and the Chézy coefficient for hydraulic roughness, C, was 42.84 $m^{1/2}/s$. These values produced a reach-averaged flow depth, h_0, of 2.793 m and a reach-averaged flow velocity, u_0, of 0.716 m/s. The median sediment grain size, D_{50}, was equal to 0.2 mm. At the entrance of the channel, a 30 m long cross-dam protruded perpendicularly from the left bank into the channel in order to

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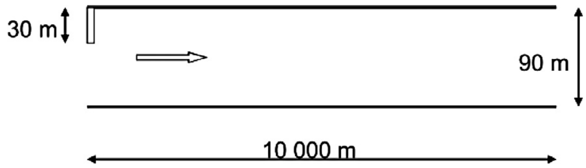

Fig. 1. Basic set-up of numerical model for water flow in a straight-channel with a mobile bed.

generate the development of a pattern of steady alternate bars downstream [15]. We used the Engelund and Hansen [7] formula to calculate sediment transport, and the following formula to calculate the influence of transverse bed slopes on the direction of sediment transport:

$$f(\theta) = 0.5\theta^{0.5} \tag{1}$$

where θ denotes the Shields parameter and $f(\theta)$ is a function weighing the influence of transverse bed slopes, following the notation of Struiksma et al. [15] and Talmon et al. [16]. We did not attempt to calibrate the model on any particular channel in reality, because the purpose of the computations was simply to demonstrate the effect of certain settings, representing mistakes, on model results.

The computations were carried out with a morphological acceleration factor of 10. The computations were terminated after simulation of 500 days. We computed a reference case, leading to a longitudinal bed level profile along the right bank presented in Fig. 2, and two cases illustrating common mistakes. The first illustration regards the effect of omitting the dependence of sediment transport direction on gravity pull along transverse bed slopes. The second effect regards the effect of non-homogeneous distributions of hydraulic roughness.

3. The five common mistakes

3.1. Codes with inadequate representation of physical processes

An important feature of sediment transport in rivers is that its direction can deviate from the depth-average flow direction by two mechanisms. First, the interplay of centrifugal forces and pressure gradients in curved flows gives rise to a helical motion by which flow velocity vectors exhibit an inward deviation near the bed and an outward deviation near the water surface. Accordingly, the direction of bedload differs from the depth-average flow direction. The same holds for the depth-average vector of suspended sediment transport as long as the corresponding concentrations are not distributed homogeneously over the vertical. The second mechanism for deviations

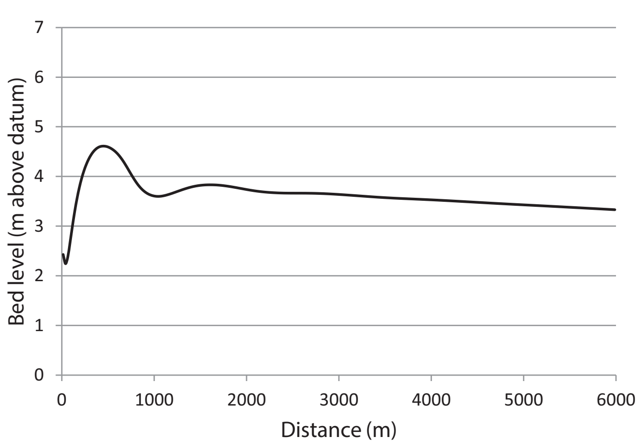

Fig. 2. Reference bed level profile along the right bank, associated with a pattern of steady alternate bars attenuating in downstream direction.

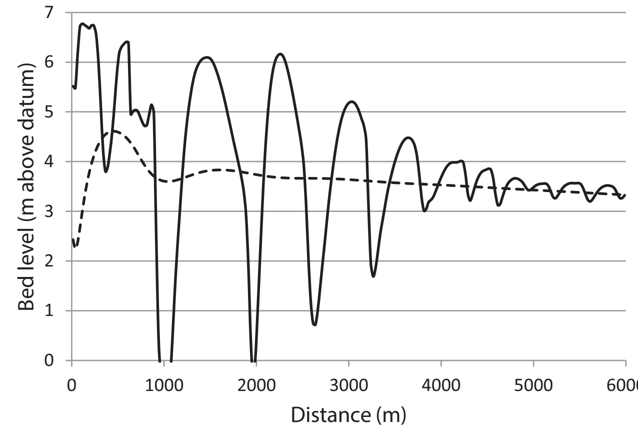

Fig. 3. Bed level profile along the right bank as a result of omitting the effect of transverse bed slopes on sediment transport direction (solid line), compared to the reference profile of Fig. 2 (dashed line).

between the direction of sediment transport and depth-average flow is that sediment particles move by a combination of flow forces and gravity. Particles moving over a transversely sloping bed thus experience gravity pull in a direction perpendicular to the direction of the flow shear stresses, producing a difference between the directions of flow and sediment transport.

Results of morphodynamic computations appear to depend sensitively on these differences in direction. Well-established morphodynamic codes account for these differences through parameterized representations of these mechanisms. In new codes, however, these effects are not always accounted for, often because they are developed as simple extensions of 2D or 3D hydrodynamic codes with sediment transport formulas and a sediment mass balance. Fig. 3 shows the effect of omitting the effect of transverse bed slopes on sediment transport direction from our model. The resulting bed morphology is completely different, with a shorter wave length and less downstream attenuation.

Apparently the bed slope effect has a damping or stabilizing influence on morphodynamic evolution of the river bed. This can be understood by considering the 2D depth-averaged sediment balance for flow in x direction (cf. [8]):

$$\frac{\partial z_b}{\partial t} + \frac{\partial q_{sx}}{\partial x} + \frac{\partial q_{sx} \tan\alpha}{\partial y} = 0 \tag{2}$$

with

$$\tan\alpha = -\frac{1}{f(\theta)}\frac{\partial z_b}{\partial y} \tag{3}$$

in which z_b denotes bed level, q_{sx} is the sediment transport rate per unit width in flow direction, α is the angle between the directions of flow and sediment transport, t is time, and x and y are co-ordinates in flow direction and transverse direction, respectively. Substitution of the latter equation into the sediment balance yields

$$\frac{\partial z_b}{\partial t} - \frac{q_{sx}}{f(\theta)}\frac{\partial^2 z_b}{\partial y^2} = \frac{\partial z_b}{\partial y}\frac{\partial}{\partial y}\left(\frac{q_{sx}}{f(\theta)}\right) - \frac{\partial q_{sx}}{\partial x} \tag{4}$$

This is a diffusion equation for bed level, forced by gradients in sediment transport. The diffusive second term is responsible for the damping or stabilization. This explains the reduced attenuation of alternate bars when omitting the effect of transverse bed slopes.

Similar diffusion terms, however, arise from truncation errors in the numerical discretization. For instance, a simple upwind discretization of the transverse bed gradient could be

$$\frac{\partial z_b}{\partial y} = \frac{z_b^n - z_b^{n-1}}{\Delta y} \tag{5}$$