Comparative analysis of several sediment transport formulations applied to dam-break flows over erodible beds

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Introduction

We present a comparative analysis of different sediment transport formulations applied to dam-break flows over mobile beds. The formulations analyzed include the formulas of Meyer-Peter-Müller (1948), Wong-Parker (2003), Einstein-Brown (1950), van Rijn (1984), Engelund-Hansen (1967), Yalin (1973) and a general transport formula with ad-hoc coefficients.

Numerical results in two different test cases are presented. The first one consists in an instantaneous dam-break flow over a sand bed, presented in Soares-Frazao et al. (2012). The second one corresponds to the experimental studies performed at the Engineering Faculty of the UNAM (Fuentes-Mariles et al. (2010)) and consists in the erosion of a volcanic sand dike by an overtopping flow. In both cases experimental measurements are available.

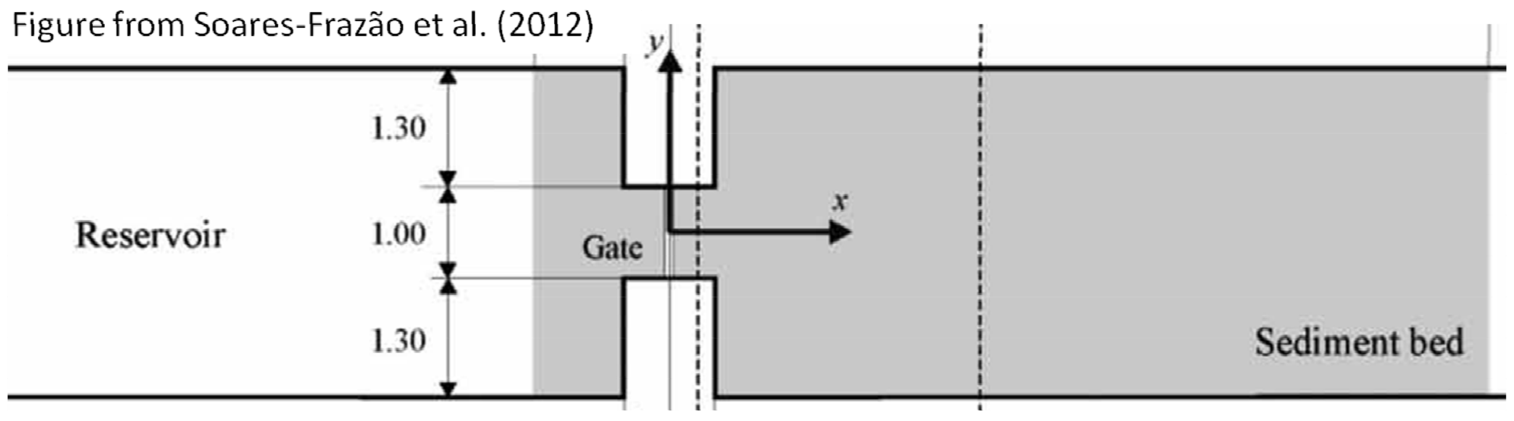
All the formulations have been implemented in the numerical model Iber (Bladé et al. (2014)), which solves the depth-averaged shallow water equations coupled to the Exner equation to evaluate the bed evolution.

First test case. Dam break over erodible bed

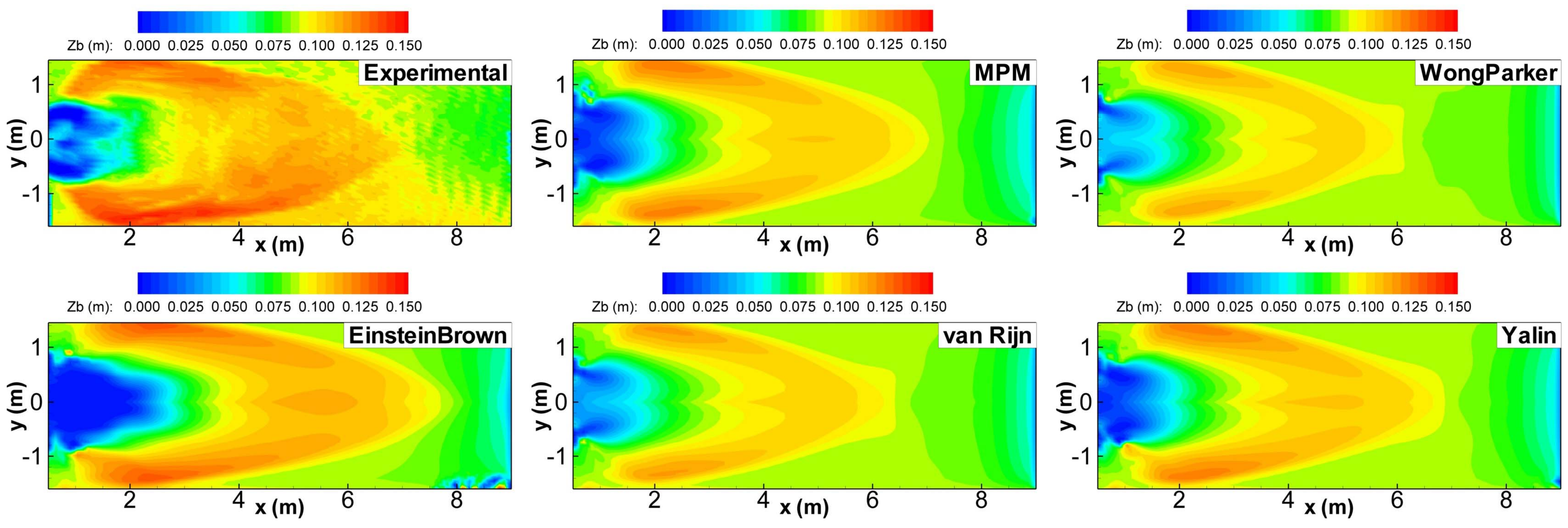
The first one consists in an instantaneous dam-break flow over a sand bed, presented in Soares-Frazao et al. (2012). The bed downstream the dam was made of a well-sorted sand with diameter of 1.61mm, porosity of 0.42 and density of 2.63 kg/m^3. The sand layer was completely saturated at the beginning of the experiment, and its thickness was 8.55 cm. Upstream water level was 47 cm, while downstream the water depth was zero.

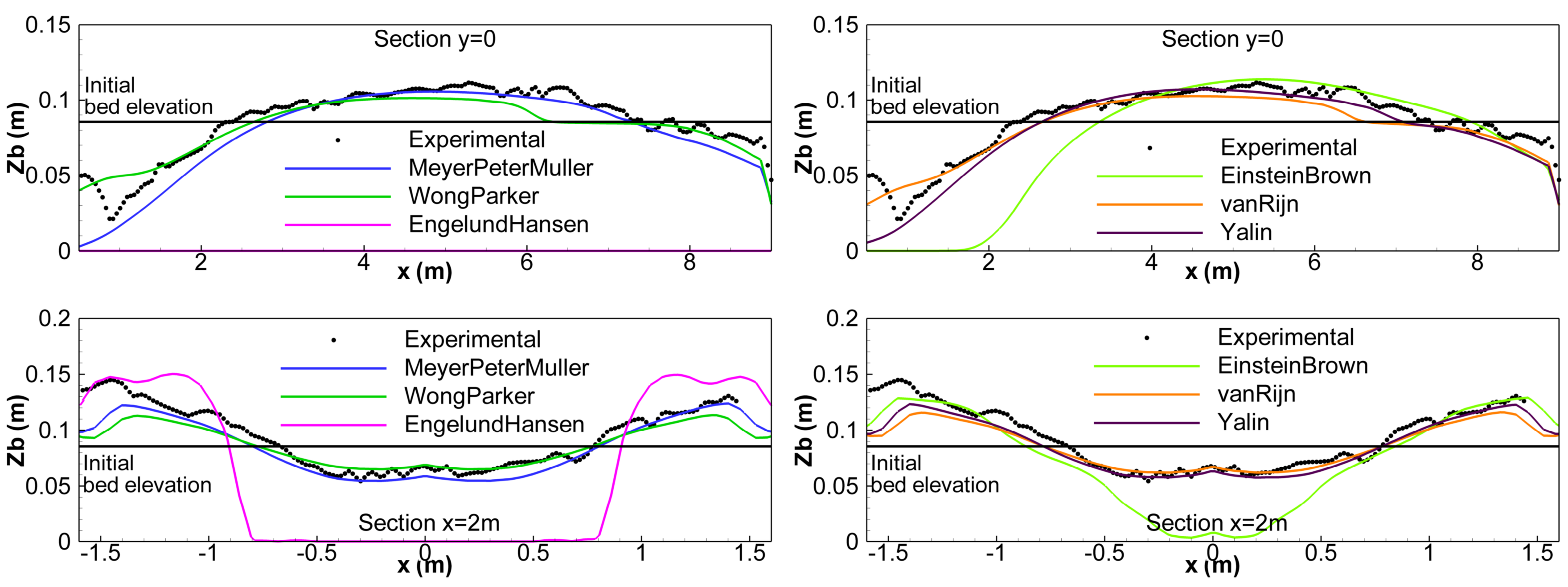
The finite volume mesh is built from 17970 quadrilateral elements of variable size. Average element size downstream the dam is 33.36 cm^2, and near the upstream contour 83.55 cm^2.

Figure from Soares-Frazão et al. (2012)



Model performance is analyzed in terms of the bed elevation at the end of the experiment. The best agreement between experimental and numerical data is obtained with Yalin and Meyer-Peter-Muller formulas, both of them give very similar results. The formulas of van Rijn and Wong-Parker underestimate slightly the sediment transport capacity and mobilize less sediment, although the comparison with the experimental results is still good. Einstein-Brown and specially Engelund-Hansen overestimate the sediment transport capacity and give much worse predictions of the bed erosion patterns.





Conclusions

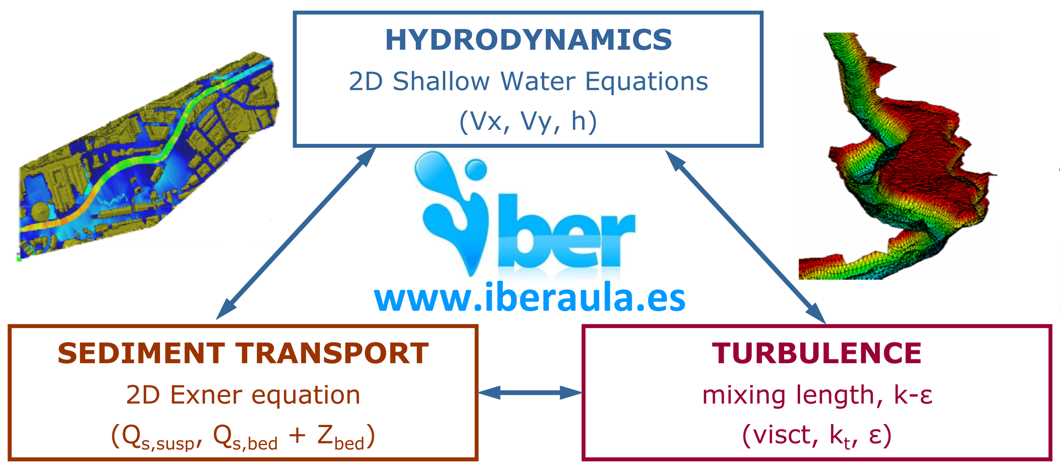
Experimental data from two different studies of dam break flow over erodible beds has been used to analyze the performance of six commonly used sediment transport formulations. None of these formulations were originally developed for modeling dam break flows, but they are nowadays implemented in many river modeling packages, and used beyond the uniform flow conditions for which they were calibrated.

The experimental cases were reproduced with the 2D shallow water model Iber. Despite the complexity of the hydrodynamic and sediment transport processes involved in dam break flows, the model gives stable results with all the sediment transport formulations which were tested. Yalin's formula is the only one which gives good numerical predictions in both test cases without any parameter calibration.

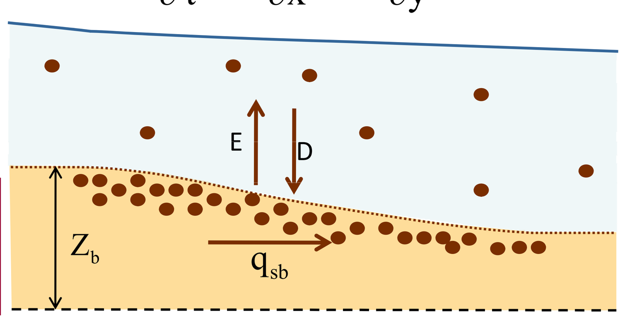
Model description

Iber is a free shallow water model which solves the 2D depth-averaged shallow water equations coupled to a turbulence module and a sediment transport module. The model is freely distributed via **www.iberaula.es**

The sediment transport module solves the 2D Exner equation considering both suspended and bed load transport. In the test cases analyzed in this work, only bed load transport was considered

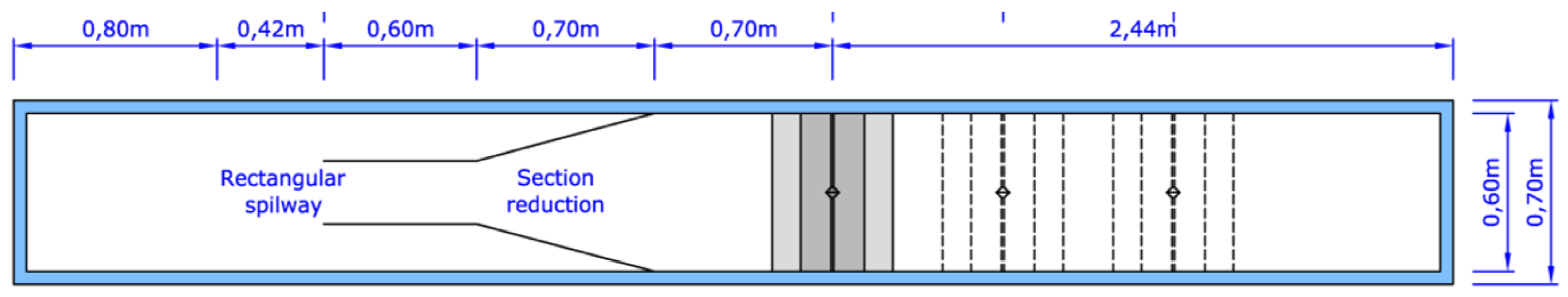


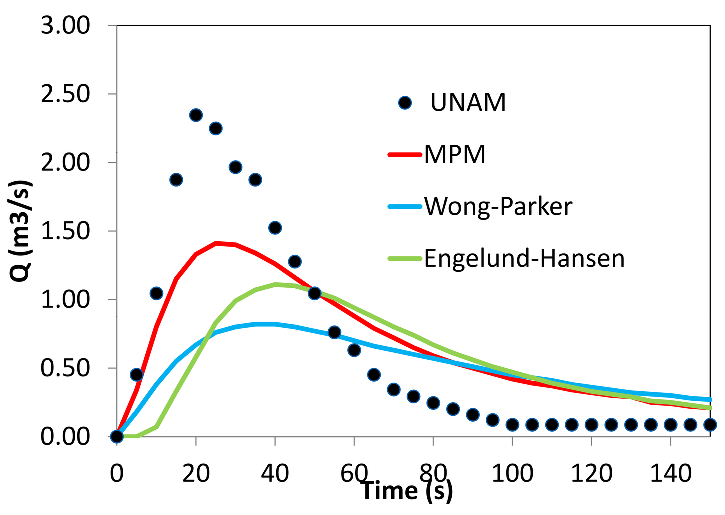
$$(1-p)\frac{\partial Z_b}{\partial t} + \frac{\partial q_{sb,x}}{\partial x} + \frac{\partial q_{sb,y}}{\partial y} = D - E$$

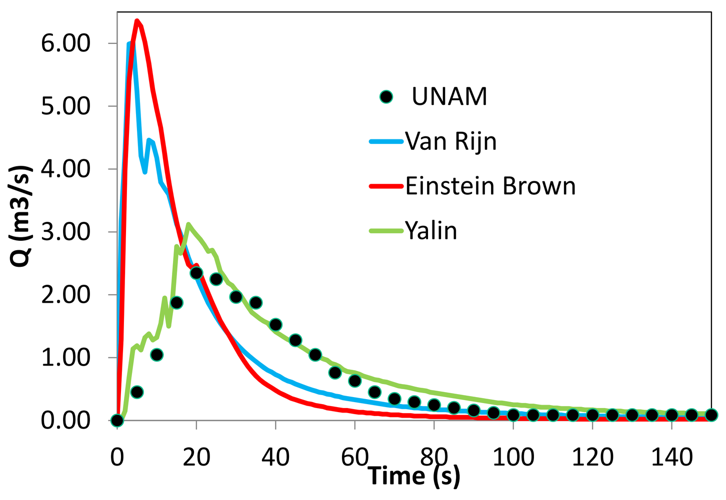


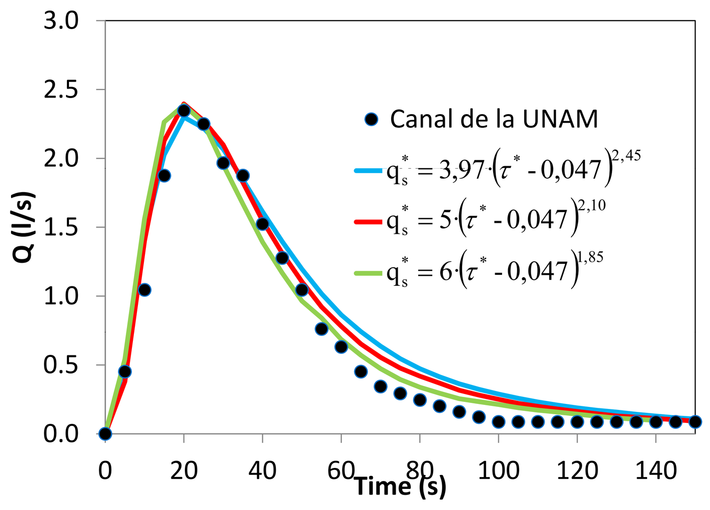
Second test case. Sand dyke failure by overtopping flow

Laboratory experiments on the failure of a small scale sand dyke were conducted at the UNAM Institute of Engineering (México). The laboratory model was built in a 5.66 x 0.60 m flume with no bed slope. The dam was made of a well-sorted sand with diameter of 0.25mm, porosity of 0.313 and density of 2.4 kg/m^3.



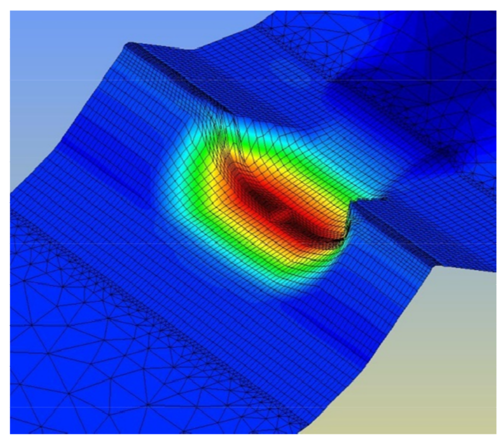






Yalin's formula is the only one with which the model gives a rather precise prediction of the outlet hydrograph, even though some instabilities appear at the beginning of the simulation, during the raising limb of the hydrograph. All the other standard formulas fail to predict the outlet hydrograph. Using the formulations of Meyer-Peter-Muller, Wong-Parker and Engelund-Hansen, the model under predicts the peak discharge, which means that the erosion rate given by those formulas is too low. On the other hand, van Rijn and Einstein-Brown formulas over predict the maximum discharge by a factor two, which implies that the erosion rates are too high.

A generic formula of the type $q_s^* = k\cdot(\tau^* - \tau_c^*)^\alpha$ was calibrated by comparing the numerical and experimental hydrographs, using for that purpose the parameters k and α, while keeping the non-dimensional critical shear stress equal to 0.047. Several combinations of parameters k and α were found which give a proper prediction of the outlet hydrograph.



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