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Approaches reproducing suspended sediment transport through vegetation

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Introduction

Working as natural filter, well-designed vegetation schemes have been widely applied to improve the quality of water (Aiona, 2013; Stefanakis, 2015). Proper design, however, requires appropriate physics-based modelling of their filtering capacity. Several theoretical models predicting sediment transport in vegetated flow have been proposed: Baptist (2005); Yang and Nepf (2018); Wu et. al. (2021); Tseng and Tinoco (2021); Yagci and Strom (2022); Wang et. al. (2023). Some of them have been implemented in numerical tools (e.g. Caponi et al., 2022; Li et al., 2022) and in particular in Delft 3D (Deltares, 2014). However, they have been mostly designed and verified based on bedload processes, and their performance for suspended load should be further investigated.

This work compares different approaches on their ability to reproduce the effects of vegetation on suspended solids concentration in two-dimensional models built in Delft3D. The work focuses on emerging vegetation, represented as rigid cylinders, and sediment deposition. Comparisons are based on the ability to reproduce flume experiments available in the literature by analysing both flow field and sediment deposition results.

Methodology

Sharpe's (2003) experiments, selected as test cases, were conducted in a straight 20 m long and 0.38 m wide laboratory flume. Woody rigid cylinders were used to represent reed stems with staggered patterns having three different densities. The flow discharge was kept constant during the tests and relatively-steady flow conditions were obtained by adjusting the downstream weir. Sediment with D_{50} = 0.17 mm was constantly fed as a line source at the middle of the flume. Selected tests were reproduced in 2DH models built in Delft3D. The flow was calculated as shallow water Navier-Stokes equations and suspended sediment transport by means of Advection-Diffusion equations with source and sink terms. Three approaches were applied to include the effects of vegetation: Baptist's (2005), representing vegetation as extra flow resistance; the Drag Force approach, which in 2D regards vegetation as an extra drag force in the momentum equations; and the Single Stem approach, distinguishing each stem in the numerical model.

Different experimental tests were considered for calibration and validation of the models. Comparisons between were based on the results of validation. The unvegetated models were calibrated based on bed roughness coefficient. Hydrodynamic calibration of vegetated flow was based on drag coefficient C_D for the Baptist and Drag Force approaches, and on horizontal eddy viscosity for the Single Stem approach. Morphodynamical calibration was based on longitudinal sediment deposition by tuning the settling velocity.

Results

The results of calibration for the flow field are shown in Tab.1.

Table 1 Calibrated parameters for vegetation modelling approaches

Calibrated parameter	Vegetated modelling approach		
	Baptist	Drag Force	Single Stem
Bottom Manning coefficient ($s/m^{1/3}$)	0.021	0.021	0.021
Drag coefficient	1.15	1.35	-
Horizontal viscosity (m^2/s)	1	1	0.00008

The results of validation are shown in Tab.2. All three approaches reproduce the flow field well with calibrated parameters. Differently from the other two, the Single Stem approach can reproduce the local flow field around the rigid stems, shown in Fig.1.

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Table 2 RRMSE for the flow field validation

Case	RRMSE		
	Baptist	**Single Stem**	**Drag Force**
1	5.6%	0.6%	0.8%
2	0.0031%	1.0%	0.2%
3	0.26%	0.1%	0.1%

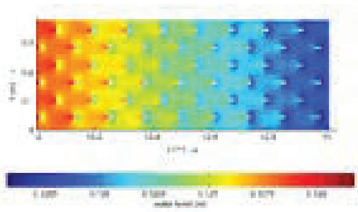


Figure 1 Water level distribution in the 12-13 m section. Results of the Single Stem approach.

For the sediment transport, the calibrated settling velocity is 10 mm/s. However, validation results show that all three approaches performed not so well in reproducing the longitudinal profile of sediment deposition (Fig. 2). The simulated deposition remains the same also with different vegetation density, which is different from experimental observations.

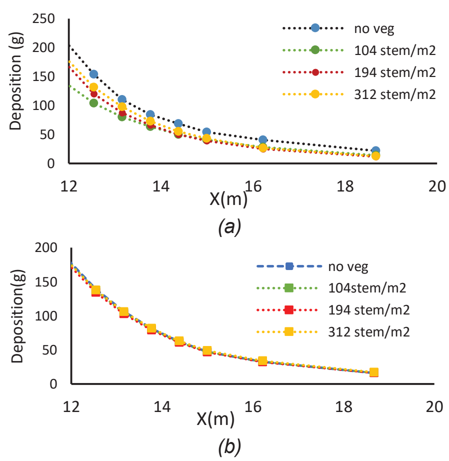
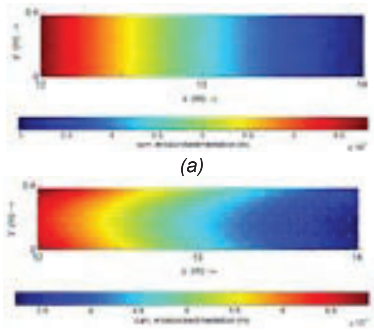


Figure 2 Longitudinal profile of sediment deposition (a) experimental results (b)computed with Drag Force approach

Baptist and Drag Force approaches result in uniform profiles of transverse sediment deposition. The Single Stem approach shows an asymmetry caused by the computational grid (Fig.3).

Conclusions

All three considered approaches perform well in reproducing the flow field inside the vegetated area. The Single Stem approach reproduce also the local flow field around rigid stems. All three approaches can't reproduce the observed changes of longitudinal sediment deposition with vegetation density. The reason may due to neglectying the effect of turbulence generated by the stems, which should be further studied in the future.



(a)

(b)

Figure 3 Sediment deposition distribution of the(a)Drag Force and Baptist approach (b) Single Stem approach

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