

**Delft University of Technology** 

# Approaches reproducing suspended sediment transport through vegetation

Liu, Jiaqi; Bregoli, Francesco; Crosato, Alessandra; Calvani, Giulio

**Publication date** 2024 **Document Version** Final published version

Citation (APA) Liu, J., Bregoli, F., Crosato, A., & Calvani, G. (2024). *Approaches reproducing suspended sediment transport through vegetation*. Abstract from NCR DAYS 2024, Wageningen, Netherlands.

Important note To cite this publication, please use the final published version (if applicable). Please check the document version above.

**Copyright** Other than for strictly personal use, it is not permitted to download, forward or distribute the text or part of it, without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license such as Creative Commons.

Takedown policy

Please contact us and provide details if you believe this document breaches copyrights. We will remove access to the work immediately and investigate your claim.

This work is downloaded from Delft University of Technology For technical reasons the number of authors shown on this cover page is limited to a maximum of 10.

# Approaches reproducing suspended sediment transport through vegetation

Jiaqi Liu<sup>a,b\*</sup>, Francesco Bregoli<sup>b,</sup>, Alessandra Crosato<sup>a,b</sup>, Giulio Calvani<sup>c</sup> <sup>a</sup>Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, the Netherlands; <sup>b</sup>Department of Water Resources and Ecosystems, IHE Delft Institute for Water Education, Delft, the Netherlands

<sup>c</sup>Platform of Hydraulic Constructions (PL-LCH), IIC, School of Architecture, Civil and Environmental Engineering, EPFL, Lausanne, Switzerland

Keywords - suspended sediment transport, vegetated flow, Delft 3D

#### 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 twodimensional 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

Email address: j.liu@un-ihe.org (Jiaqi Liu)

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  | Vegetated modelling approach |       |                |  |
|---|------------------------------|-------|----------------|--|
| parameter   | Baptist Drag Force           |       | Single<br>Stem |  |
| Bottom<br>Manning<br>coefficient<br>(s/m <sup>1/3</sup> ) | 0.021                        | 0.021 | 0.021          |  |
| Drag<br>coefficient                                       | 1.15                         | 1.35  | -              |  |
| Horizontal<br>viscosity<br>(m²/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.

<sup>\*</sup> Corresponding author

Table 2 RRMSE for the flow field validation

| 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% | Cara    | RRMSE   |             |            |  |
|---|---------|---------|-------------|------------|--|
| 1 5.6% 0.6% 0.8%   2 0.0031% 1.0% 0.2%   3 0.26% 0.1% 0.1%  | Case    | Baptist | Single Stem | Drag Force |  |
| 2 0.0031% 1.0% 0.2%<br>3 0.26% 0.1% 0.1%  | 1       | 5.6%    | 0.6%        | 0.8%       |  |
| 3 0.26% 0.1% 0.1%   | 2       | 0.0031% | 1.0%        | 0.2%       |  |
| a da  | 3       | 0.26%   | 0.1%        | 0.1%       |  |
| 1 10 10 10 10 10 10<br>101 a  | ал<br>Э |         |             |            |  |
|   | _       |         | and a       |            |  |

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.



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

#### References

- Baptist, M. J. (2005) Modelling Floodplain Biogeomorphology. PhD thesis, Delft University of Technology.
- Caponi, F., Vetsch, D.F, Vanzo, D.(2023) Baseveg: A Python Package to Model Riparian Vegetation Dynamics Coupled with River Morphodynamics. SSRN Electronic Journal 22(101361):2352-7110.
- Deletic, A. (2005) Sediment Transport in Urban Runoff over Grassed Areas. J. of Hydr. 301(1-4):108-22.
- Deltares. 2014. 3D/2D Modelling Suite for Integral Water Solutions: Hydro-Morphodynamics. Delft.
- Li, J., Claude, N., Tassi, P., Cordier, F., Vargas-Luna, A., Crosato, A., and Rodrigues S.(2022) Effects of Vegetation Patch Patterns on Channel Morphology: A Numerical Study. *Journal of Geophysical Research: Earth Surface* 127(5):1– 20.
- Sharpe, R. (2003) Suspended Sediment Transport through Non-Submerged Reeds. University of the Witwatersrand.
- Alexandros, S. (2015) Constructed Wetlands: Description and Benefits of an Eco-Tech Water Treatment System. 281–303p
- Tseng, C. Y., Tinoco, O.R. (2021) A Two-Layer Turbulence-Based Model to Predict Suspended Sediment Concentration in Flows With Aquatic Vegetation. *Geophysical Research Letters* 48(3):1–14.
- Wang, X., Gualtieri, C., Huai, W. (2023) Grain Shear Stress and Bed-Load Transport in Open Channel Flow with Emergent Vegetation. *Journal of Hydrology* 618:129204.
- Wu, Haoliang, Nian Sheng Cheng, and Yee Meng Chiew. 2021. "Bed-Load Transport in Vegetated Flows: Phenomena, Parametrization, and Prediction." Water Resources Research 57(4):1– 25.
- Oral, Y., Strom, K. (2022) Reach-Scale Experiments on Deposition Process in Vegetated Channel: Suspended Sediment Capturing Ability and Backwater Effect of Instream Plants. *Journal of Hydrology* 608(11):127612.
- Yang, J. Q., Nepf H. M. (2018) A Turbulence-Based Bed-Load Transport Model for Bare and Vegetated Channels. *Geophysical Res. Letters* 45(19):10,428-10,436.