Efficient long-term one-dimensional morphodynamic modelling in alluvial rivers using simplified models – theory and validation

Barneveld, Hermjan; Hoitink, Ton; Mosselman, E.; Chavarrias, V.

Publication date
2021

Document Version
Final published version

Citation (APA)
Barneveld, H., Hoitink, T., Mosselman, E., & Chavarrias, V. (2021). *Efficient long-term one-dimensional morphodynamic modelling in alluvial rivers using simplified models – theory and validation*. 72-73. Abstract from NCR DAYS 2021. https://kbase.ncr-web.org/outputs/rivers-in-an-uncertain-future/

Book of abstracts

Rivers in an uncertain future

NCR days 2021| Enschede, February 11-12

Jord J. Warmink, Anouk Bomers, Vasileios Kitsikoudis, R. Pepijn van Denderen & Fredrik Huthoff (eds.)

NCR publication: 46-2021

Netherlands Centre for River studies NCR

NCR Days 2021

Rivers in an uncertain future

Jord J. Warmink, Anouk Bomers, Vasileios Kitsikoudis, R. Pepijn van Denderen & Fredrik Huthoff (eds.)

Organising partner:

UNIVERSITY OF TWENTE.

Co-sponsored by:

NWO Nederlandse Organisatie voor Wetenschappelijk Onderzoek

J.M. Burgerscentrum

Organising partner

University of Twente	telephone:	+31 53 489 35 46
P.O. 217	e-mail:	secretariat-mfs-et@utwente.nl
7500 AE Enschede	www:	https://www.utwente.nl
The Netherlands		

Contact NCR

dr. ir. K.D. Berends (programme Secretary)	telephone:	+31 6 21 28 74 61
Netherlands Centre for River Studies	e-mail:	secretary@ncr-web.org
c/o Deltares	www:	https://www.ncr-web.org
P.O. 177		
2600 MH Delft		
The Netherlands		

Cite as: Warmink, J.J., Bomers, A., Kitsikoudis, V., van Denderen, R.P., Huthoff, F. (2021), *Rivers in an uncertain future: NCR Days proceedings*. Netherlands Centre for River Studies, publication 46-2021

Photo credits cover: IJssel river from Bureau Beeldtaal Filmmakers (2018)

Efficient long-term one-dimensional morphodynamic modelling in alluvial rivers using simplified models – theory and validation

Hermjan Barneveld[a,b*], Ton Hoitink[a], Erik Mosselman[c,d], Victor Chavarrías[c]
[a] Wageningen University and Research, Hydrology and Quantitative Water Management Group, Department of Environmental Sciences, Droevendaalsesteeg 3, 6708 PB Wageningen, the Netherlands
[b] HKV lijn in water, Botter 11-29, 8232 JN Lelystad, the Netherlands
[c] Deltares, P.O. Box 177, 2600 MH Delft, the Netherlands
[d] Delft University of Technology, P.O. Box 5, 2600 AA Delft, the Netherlands

Keywords — river morphology, analytical approach, numerical modelling

Introduction

Morphodynamic numerical simulations can be time consuming, especially in a stochastic approach when multiple long-term simulations are required to address parameter uncertainty. To improved efficiency the flow and sediment dynamics can be decoupled when Froude numbers are below 0.8 (e.g. de Vries, 1965; Lyn, 1987; Lyn & Altinakar, 2002). A morphological acceleration factor can further speed up simulations. Another approach is to simplify models by neglecting terms in the governing equations. The quasi-steady approach may for example reduce simulation times to less than 25%.
The scope of this research is to assess how and when model simplifications are possible, without jeopardizing the predictive capacity in terms of sediment transport and riverbed development.

This work is part of a PhD research at Wageningen University & Research as part of the Rivers2Morrow programme (2018-2023). The PhD research is supported by the Dutch Ministry of Infrastructure and Water Management, HKV and Deltares.

Methododolgy

Theoretical analysis

Grijsen & Vreugdenhil (1976) performed a theoretical analysis, to assess the impact of simplification of 1-dimensional flow models on the propagation and damping of water waves. We extend their analysis to morphology. Basis are the St. Venant equations for water motion, the sediment mass balance equation and a closure relation for sediment transport.
The flag coefficients α_i (i = 1 … 4) can be 0 and 1 only. Values of 0 indicate model simplification.

$$\alpha_1 \frac{\partial u}{\partial t} + \alpha_2 u \frac{\partial u}{\partial x} + \alpha_3 g \frac{\partial h}{\partial x} + g \frac{\partial z}{\partial x} = -g \frac{u^2}{C^2 h}$$

$$\alpha_4 \frac{\partial h}{\partial t} + h \frac{\partial u}{\partial x} + u \frac{\partial h}{\partial x} = 0$$

$$\frac{\partial z}{\partial t} + \frac{\partial s}{\partial x} = 0$$

$$s = f(u, parameters)$$

with: t=time, x=longitudinal co-ordinate, u=flow velocity, h=water depth, z=bed level, C=Chézy coefficient, s=sediment transport per unit width, g=acceleration due to gravity.

We consider 2 simplified models:
1. Quasi-steady approach, neglecting time-derivatives: $\alpha_1 = \alpha_4 = 0$
2. Diffusive wave, neglecting inertia: $\alpha_1 = \alpha_2 = 0$

To assess the performance of these models, analytical solutions for the set of non-linear equations are derived through:
1. linearization
2. combination to one linear equation in the water depth h'
3. assuming a harmonic perturbation of flow and bed to get a solution for propagation and damping of water and sediment waves.

The ratio of solutions of the full dynamic model and simplified models determines how well simplified models perform. Three dimensionless parameters are important:

Froude number $Fr = \frac{u}{\sqrt{gh}}$

Water wave parameter $E = \sqrt{\frac{g^3 T^2}{C^4 h_o}}$

Transport parameter (uniform material) $\Psi = n \frac{s_o}{q_o}$

with: T = period of flood wave, n = power in sediment transport relation $s = mu^n$, q = discharge per unit width. Index $_o$ means undisturbed value.

* Corresponding author
Email address: hermjan.barneveld@wur.nl (Hermjan Barneveld)

Validation with numerical model

To check whether the results of the theoretical analysis are valid in practical, non-linear, cases, numerical simulations were performed. ELV is a one-dimensional numerical morphological modelling system (Chavarrías et al, 2019). ELV simulates the full set of equations, the quasi-steady model and the diffusive-wave model. Simulations were done with infinitesimal perturbations as well as with flood waves and larger bed disturbances in a quasi-equilibrium river reach. Flood wave characteristics, bed slope and grain sizes were varied within ranges realistic for lowland rivers. Figure 1 shows a sample result.

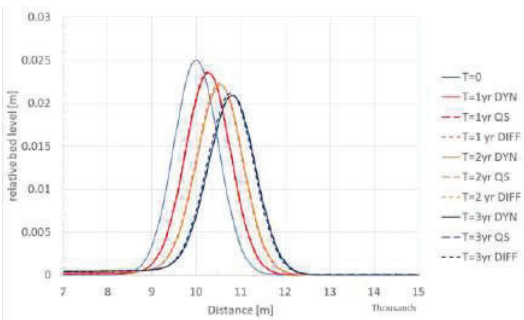

Figure 1. Propagation of small bed perturbation during 3 years with full dynamic (DYN), quasi-steady (QS) and diffusive-wave model (Diff). Vertical axis: bed level relative to mean bed slope. Fr=0.2, E=12,500 and Ψ=5.15e-5.

Results

Figure 2 shows the relative celerity of bed perturbations (*c/u*) according to theory (lines) and ELV (markers). The agreement is good for Froude numbers up to 0.3. For higher Froude numbers deviations occur.

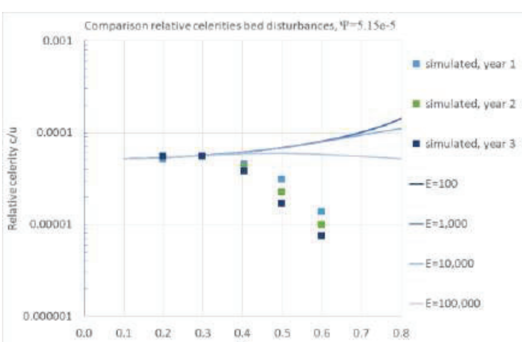

Figure 2. Relative celerity of full dynamic model: theory and simulated (ELV, average over three years).

In Figure 3 the full dynamic model (DYN) and simplified models are compared. The Figure shows the ratios of celerity of bed disturbances from theory (lines) and ELV (markers).

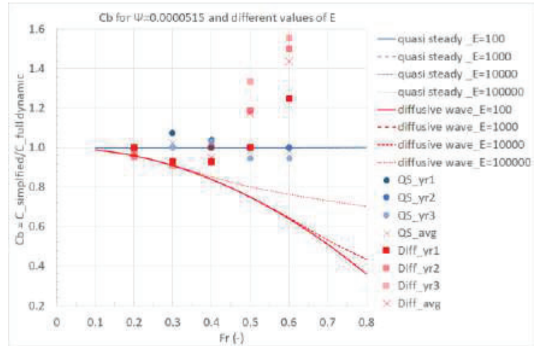

Figure 3. Ratio of celerities (c_b) from theory and ELV.

ELV results in Figure 3 are based on small perturbations for flow and bed. Simulations with large bed disturbances (aggradation 0.5 m over 1 km river length) and flood waves show similar trends.

Discussion

For Froude numbers up to 0.3, celerities of bed disturbances from theory and simulations agree. For larger Froude numbers the theoretical celerities are larger than according to numerical simulations. Nonetheless, for the quasi-steady model the theoretical error prediction for propagation (and damping) of bed disturbances is confirmed by numerical simulations. The quasi-steady model may be applied over a large range of hydrodynamic and morphological conditions. This model does not include flood wave damping. This aspect should be included alternatively.

The diffusive-wave model does describe flood wave damping, but the error prediction deviates from numerical results for *Fr*≥0.4. Up to *Fr*=0.3 the error in morphological changes with the diffusive-wave model is restricted to 10%.

Deviations between theory and numerical modelling require further research.

References

Chavarrías, V., Stecca, G., Siviglia, A., & Blom, A. (2019). A regularization strategy for modeling mixed-sediment river morphodynamics. Advances in Water Resources, 127, 291–309.

Grijsen J.G. and G.B. Vreugdenhil (1976). Numerical representation of flood waves in rivers; In: Proc. Int. Symp. Unsteady flow in open channels, Newcastle-upon-Tyne, BHRA Fluid Eng., Cranfield, paper K1, pp. K1.1-K1.16;

Lyn, D. A. (1987). Unsteady sediment transport modeling. Journal of Hydraulic Engineering, 113(1), 1–15.

Lyn, D. A., & Altinakar, M. (2002). St. Venant-Exner equations for near-critical and transcritical flows. Journal of Hydraulic Engineering, 128(6), 579–587.

Vries M. de (1965). Considerations about non-steady bedload transport in open channels. Proc. 11th IAHR-Congr., Leningrad.