How sediment transport processes control the shape of simulated river dunes

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Highlights

- Simulating dune development with different sediment transport processes result in different dune shapes
- Only near incipient motion transport capacity is dune height limiting in the simulations
- Suspended transport limits dune growth and initiates the offset to upper stages plane bed

Overview

Understanding the processes in river dune dynamics is important for efficient and durable river management. These river dunes result from the constant interaction between the stream flow and the alluvial bed of a river, grow and decay with changing discharges. After flood waves have passed and during low flows, the dunes can limit the navigable depth. Therefore, the crests of these bed forms are dredged. This paper assesses the influence of different sediment transport processes on dune shape with a numerical dune development model. The knowledge of these processes is a key point in the understanding of river dune dynamics and prediction of problematic dune crest locations in the future.

The dune development model is based on a 2DV flow module, of which the calculated bed shear stresses are used in a sediment transport and bed update modules (Paarlberg et al., 2009). Within the transport module the Meyer-Peter & Muller transport formula is implemented. To keep the computation time of this model at a minimum, some assumptions are made. First, the model has periodic boundary conditions, which creates a virtually infinite row of identical dunes, Second, the model uses a constant eddy viscosity, limiting the ability of flow separation at the lee slope of the dunes.

Three sets of transport related conditions are simulated, for conditions varying from extreme low to median discharges in the Waal River (Figure 1~~Fig. 1~~.). The first set of simulations was done with the standard Meyer-Peter & Müller sediment transport formula including a correction for gravitational bed slope effects (Sekine & Parker, 1992). Secondly, a set of simulations similar to the first, but with an increased critical shear stress was done. This increased critical shear stress corrects for the higher flow velocity due to the absence of flow separation (Lokin et al., submitted). In the third set, parameterized suspension through linear relaxation, after Tsujimoto et al. (1990), is implemented.

Accounting for the different sediment transport processes in dune dynamics, realistic dune shapes can be simulated, while different dune behaviour is observed Limiting the total transport capacity, possibly due to lower flow velocities, can limit the dune height. When the transport capacity increases the domain length of the model is probably the limiting factor for the dune height. Suspended sediment smoothens the dunes and initiates the transition towards upper stage plane bed at low flow velocity where this process is not seen in data. Adding this in a parameterized, Meyer-Peter and Müller only assume bed load, enables this smoothing. The implemented gravitational bed slope effect limits the growth of the lee slope angle towards the angle of repose, which may explain the occurrence or low angle dunes in rivers.

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Transport effects on dune height

Dune heights generally increase with increasing water depth and therefore river discharge (Lokin et al., 2022). The dune height related to the flow conditions in the simulations differ from what is expected based on literature and data. In the “normal” shear stress case, the simulated dune height is relatively constant over the different discharge regimes, while the water depth increases as the discharge increases. A possible explanation for this might be that the dune length, which is determined by the domain length between the periodic boundary conditions, may be a limiting factor for dunes to grow further when the water depth increases. Only when the sediment transport capacity iis lowered, simulated by the increase of the critical shear stress, the dune height shows the expected behaviour.

The decrease in dune height at higher discharges in the simulations with the parameterized suspension is opposite to what is expected from data representative for the simulated discharge regimes. However, the link between suspended sediment and the flattening of dunes is an accepted theory for the transition towards upper stage plane bed. For extreme low flows flattening of dunes has been found for extreme low flows in the Waal River (Lokin et al., 2022).

Additionally, shipping on the Waal River is expected to increase the amount of sediment brought in suspension, especially during low flows when the thruster jets are closer to the river bed. Adding suspension trough a parameterized suspension that is inversely related to the bed shear stress may be able to simulate the effects of shipping on river dunes. This study has shown that increased suspension leads to flattening of river dunes. However, the effects of shipping on sediment transport still need to be quantified, which is an important issue for future research.

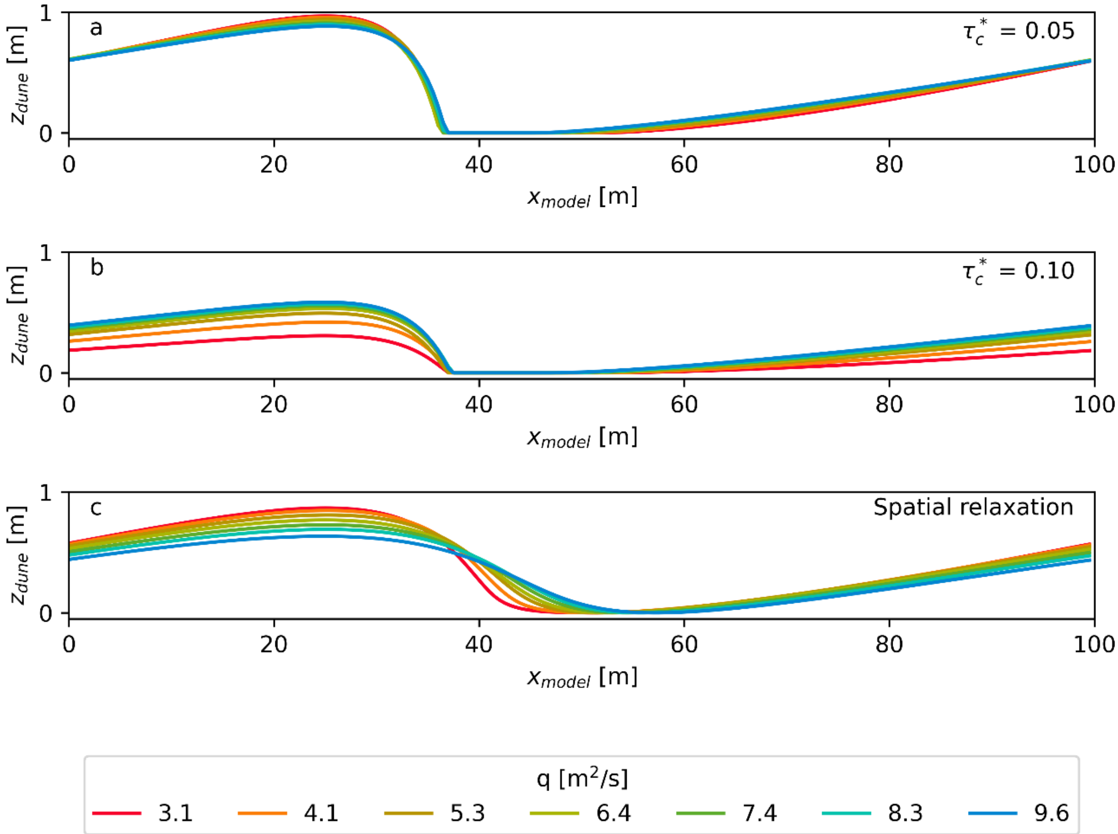

Figure 1. Equilibrium dune shapes resulting from the different sediment transport settings and increasing specific discharges representing discharges from extreme low up to mean discharges in the Waal River. a) Dune shapes resulting from the Meyer-Peter & Müller simulations with the critical shear stress according to the Shields diagram. b) Dune shapes resulting from the simulations with the increased critical shear stress. c) Dune shapes resulting from the simulations with parameterized suspension through linear relaxation.