Modelling strategies for low flow dune behaviour

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Introduction

River dunes are dynamic bed forms which propagate in alluvial river beds, formed by the interaction between the flowing water and the erodible bed. Propagation speed and shape of these dunes depend on the sediment type in the bed and on the governing flow conditions. During low flow, dunes can decrease the navigable water depth while during high flow they increase the roughness and therefore result in increasing water levels. Understanding river and being able to predict dune behaviour, can therefore help to improve river bed management, especially in a changing climate where extreme river discharges, both high and low, are expected to occur even more (*Douville et al.*, 2021).

Initial dune growth, starting from a flat bed, shows linear behaviour. However, when a dune field is present on the bed, further development of the dunes is non-linear and also shows transitions linked to changes in sediment transport stage. For example the transition to upper stage plane bed is linked to the transition to suspended transport (*Naqshband et al.*, 2016). This transition to upper stage plane bed, occurring at extremely high discharges, has been studied extensively, while studies dune development during low flows in rivers are scarce.

A dune development model that may be used for predicting dunes must be able to simulate dune behaviour for both high and low flows well. We first give a short introduction into the dune behaviour during low flows in rivers, and then we introduce the dune model that will be used to simulate this behaviour and show how this model performs.

Low flow dune propagation

To better understand the behaviour of dunes during low flow situation, dunes were studied in a 16 km long stretch of the Waal River (river kilometres 894-910) over a period of 10 years by *Lokin et al.* (2022). This has shown that during low flow the relation between dune height and dune length is negative, e.g. the dunes become longer when the flow velocities drop towards low flow (Figure 1). This dune lengthening is related to diffusive behaviour; as the relative strength of gravition on sediment particles respective to the drag force by the current becomes more important for dune propagation towards low flows with mostly bed load transport. This causes the dunes to propagate in a diffusive manner (*Lokin et al.*, 2022).

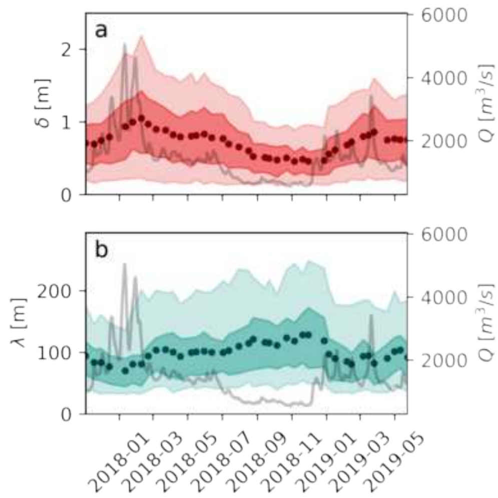

Figure 1: Dune height and length changes during a period between November 2017 and May 2019 in the Waal River, including a period with extreme low discharges. a) Dune height (δ, dots), with the 50% (dark band) and 90% (light band) confidence intervals, and the discharge at measuring station Tiel (grey line). b) Dune length (λ) with the 50% and 90% confidence intervals, and the discharge at measuring station Tiel.

The dune model

To simulate dune behaviour we use the dune development model initially developed by *Paarlberg et al.* (2009). This model simulates dune behaviour using separate flow and sediment transport modules. The flow is solved using the 2D vertical averaged shallow water equations assuming hydrostatic flow. For the sediment transport two transport formulations are currently available. The model has periodic boundary conditions such that the model

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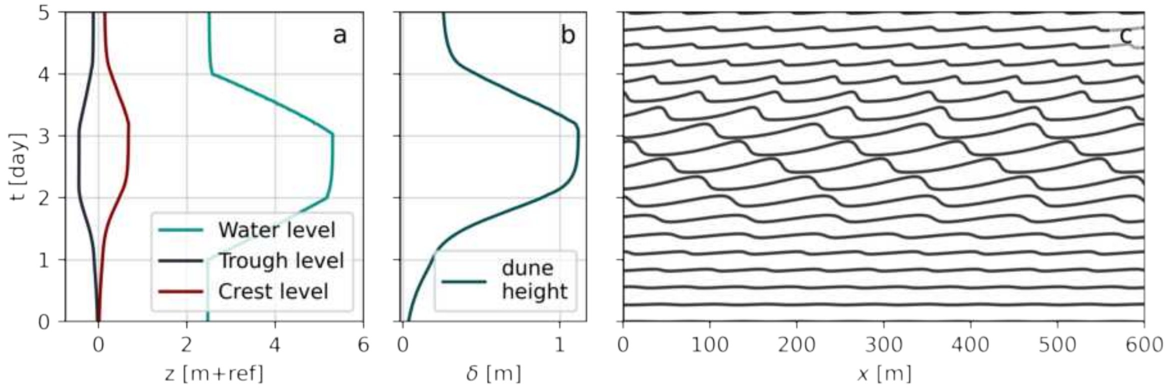

Figure 2: Dune development during a synthetic discharge wave with discharge varying between low and bank full in the Waal River. a) Development of the dune trough level, crest level and the water level. b) Dune height. c) Development of the dune shape.

domain covers one dune, which is actually an infinitely long train of identical dunes. The domain length is determined using a numerical linear stability analysis, in which the domain length is equal to the fastest growing mode.

This model is able to simulate dune height fairly well (Figure 2) and the general shape is representative for the dunes found in the Waal River: rounded off crests and a low angle lee. Dune height also lags the development of increasing and decreasing discharge, where dune height reaches its maximum half a day after the discharge is at its maximum.

Future model improvements

As the general dune shape and height are simulated fairly well, the simulated dune length does not yet follow the dune length found in the data. In the simulation the dune length is calculated with the linear stability analysis whenever the water level has changed by 5% with respect to the last timestep the lenght has been determined. The dune length, and consequently the model domain, is then instantaneously set to the newly determined length. This results in shorter dunes than found in the data and no effective lag in dune length adaptation, while this lag has been found in the data. Although dune height is well simulated, the model still need to be improved to simulate dune lengthening during low flows.

Conclusion

Dune lengths increase as discharges drop in the regime from median to low flows. This behaviour is likely related to the transition towards a mainly bed load dominated transport stage, where dunes propagate diffusively. Although the presented dune model is able to simulate the dune height fairly well, the simulated dune length development does not yet correspond to the data. The dune length is determined without accounting for the dune that is formed during previous higher discharges, this has to be implemented in the model to accurately simulate dunes during extreme low flow.

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References

Douville, H., Raghavan, K., Renwick, J., Allan, R.P., Arias, P.A., Barlow, M. et al. (2021). Water Cycle Changes. In *Climate Change 2021: The Physical Science Basis.* edited by V. Masson-Delmotte et al., Cambridge University Press. In Press.

Lokin, L.R., Warmink, J.J., Bomers, A., and Hulscher, S.J.M.H. (2022). River dune dynamics during low flows. *Submitted for publication.* University of Twente, Enschede

Naqshband, S., van Duin, O.J.M., Ribberink, J., and Hulscher, S.J.M.H. (2016). Modeling river dune development and dune transition to upper stage plane bed. *Earth Surface Processes and Landforms*, 41(3), 323–335. https://doi.org/10.1002/esp.3789

Paarlberg, A.J., Dohmen-Janssen, C.M., Hulscher, S.J.M.H., and Termes, P. (2009). Modeling river dune evolution using a parameterization of flow separation. *Journal of Geophysical Research: Earth Surface*, 114(1). https://doi.org/10.1029/2007JF000910