Towards a model for river dune dynamics under high and low discharges

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Introduction
As result of climate change, the expected extreme river discharges become more frequent and extreme. High discharges will become higher. Extreme low discharges, such as occurred in the summer and autumn of 2018 in the Rhine River, will become more frequent and persistent (Klijn et al. 2015). The interplay of bedform dynamics, especially river dunes, and extreme flow conditions results in multiple challenges in river management. Uncertainty in flood water levels as result of bedform related roughness results in high safety factors for dike design. Decreasing this uncertainty results in more certain flood levels and therefore increases water safety. During low flow conditions vessels have to cut down on load, due to reduced fairway depth caused by persistent dunes. Preventive dredging may reduce this issue, however there is no model available to predict river dunes during low flow.

Existing dune development models
Paarlberg et al. (2009) presented a morphodynamic model which predicts dune parameters such as height, length, aspect ratio and propagation speed fairly well. This model has been improved by adding suspended sediment to model the transition to upper stage plane bed (Naqshband et al., 2016). It can be used to predict time and spatial variating dune parameters and related bed roughness relatively fast, as turbulence parameters are parameterized. Variability of individual dune parameters and processes as amalgamation and superimposition of bedforms show to be important in the adaptation of dune fields to varying flow (Reesink et al., 2018). Currently, no model is able to simulate, in a computationally efficient way, the processes of dune evolution and immobility in the transition to and during low flow.

Understanding dune evolution
Currently, the understanding of dune evolution towards low flow conditions and possible immobility are not well understood. Most research is done on high flow and flood waves as these conditions cause dunes to develop and increase in dimensions. Due to hysteresis between dune evolution and flow conditions under varying flow, dune dimensions have a temporal lag with respect to the steady state conditions. When extreme low flow follows shortly after a flood wave, river dunes will be too large with respect to the simultaneous flow conditions. What happens with dunes when the flow velocity is too small to transport sediment and the riverbed becomes (partly) immobile has not been studied yet. Understanding this process is key to develop an integral model for dune evolution which is able to simulate dune evolution under high, low and variable flow conditions.

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Objective
The final goal of this study is to develop a model describing the evolution of river dunes under high, low and varying flow conditions; the rising and falling stage of a flood wave and decreasing discharge towards extreme low flow conditions. The model will give a physics-based approach to better predict variable bed-form roughness. Under low flow conditions, especially following an extreme flood wave, the model is able to predict the development of the dunes and indicate locations where dunes become obstacles in the fairway. This enables the fairway manager to plan maintenance.
To reach this final goal, first a better understanding of the dune evolution is needed. This includes the situations of a (partly) immobile bed during low flow and the development of upper stage plane bed in high flow conditions.

Methodology
To describe dune growth and reduction during flood waves and periods of low flow, the understanding of the processes playing a role needs to be increased. Improving this understanding will be done by combining existing multibeam data and the COVADEM dataset. The COVADEM dataset has a high temporal resolution, while the multibeam

datasets have a large spatial resolution. First a routine has to be developed to derive bedform statistics and evolution from this dataset. Earlier research has proven that the COVADEM dataset is valuable for determining bed level elevations (van der Mark et al., 2015). Afterwards, analysis of the evolution of bedforms in time and space, combined with discharge, water depth and flow velocity information, will result in improved understanding of dune evolution theory. This analysis will focus on dune evolution under varying flow and during periods of extreme low flow. Data of the bed level development in 2018 might prove to be valuable, as this year has both a high flow as extreme low flow (Figure 1).

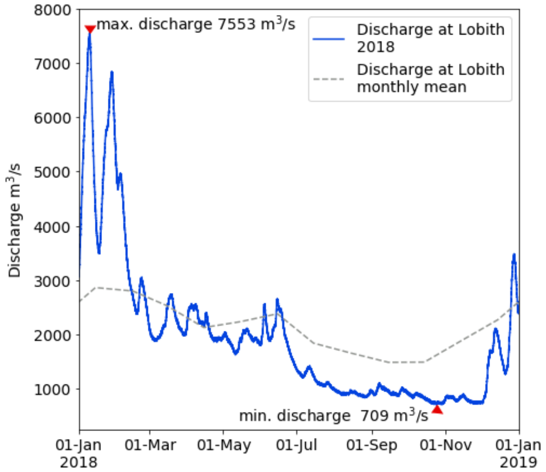

Figure 1. Discharge development over the year 2018 in the Rhine at Lobith. The blue line indicates the discharge in the Rhine at Lobith in 2018, the grey dashed line indicates the monthly mean discharge between 1901 and 2019. Data: Rijkswaterstaat (2020).

Improved dune evolution theory will be translated into a dune evolution model. Before this is done a suitable model will be chosen. Data from the COVADEM dataset, as well as data from other researches will be used to validate the model.

Expected results

This research strives to obtain a more complete understanding of river dune development and to implement this understanding in a dune evolution model. The model will be able to predict dune evolution for high flow up to upper stage plane bed conditions, low flow where the bed and bedforms become partly immobile and varying flow between these stages.

This model can be applied in operational water level predictions as well as in bed level predictions for navigational purposes.

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