

Analysing the spatio-temporal variability of river dune induced bed roughness for the Midden-Waal

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Highlights

- We analyse the spatio-temporal variability in dune induced bedform roughness
- The spatio-temporal variability in dune induced bedform roughness is high
- Roughness sections in hydrodynamic river models should be as small as possible

Overview

Rivers are an important part of the Dutch landscape. Proper management protects us from floods and mitigates the effects of low flows. In order to adequately deal with the effects of climate change on the discharge regime, accurate predictions of future water levels are needed to avoid over- or undersized interventions with their financial and societal consequences. Hydrodynamic river models, commonly used for water level prediction, are calibrated using a main channel bed roughness parameter. Once calibrated, no distinction can be made between the contributions of sources such as groins, bed forms, grain sizes and other unidentified sources into this calibration. The roughness caused by these sources changes with discharge and varies along the rivers, introducing model errors.

Spatio-temporal variation of river dune induced roughness is analysed in order to reduce the uncertainty in the main channel roughness parameter in hydrodynamic river models. By decomposing the contribution of dune-induced roughness to this parameter, a first step is made towards reducing the uncertainty in the prediction of extreme reach water levels. This will be part of further research.

River dunes are subject to changes in flow and associated sediment transport and their geometry depends on the flow conditions. Warmink (2014) observed hysteresis in dune height and length and dependence on flood wave characteristics. Lefebvre & Winter (2016) showed that the lee side angle determines the magnitude of flow separation and Lokin et al. (2022) concluded that dunes become longer during low flow, contrary to the common assumption at the time that the aspect ratio between dune height and length is constant.

We re-analysed the response of dune height and length to changing discharge and mapped the spatio-temporal variability of river dune induced roughness by averaging the dune field over sections of different size.

In line with existing literature, we showed that dune height is positively correlated with discharge while dune length increases with decreasing discharge. The spatio-temporal variability in river dune induced roughness increases with increasing discharge and decreases when the dune field is averaged over larger river sections. River dune induced roughness is strongly location dependent.

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Acknowledgements

This research is a part of the research program *Rivers2Morrow* (2018-2023). *Rivers2Morrow* is financed by the Dutch Ministry of Infrastructure and Water Management. All measurement data was made available by Rijkswaterstaat and HKV Consultants.

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Response of dune dimensions to discharge

Dune dimensions respond to changes in discharge. Figure 1 shows the response of dune height to discharge. Dune height is positively correlated with discharge, but does not follow the small deviations from the overall trend. The confidence interval in dune height is larger during periods of approximately constant discharge compared to the transition periods between low and high discharge. The response of dune length (figure not shown here) is somewhat different. Dunes become longer as discharge decreases. Compared to dune height, dune length is more sensitive to small variations in discharge. In contrast to dune height, the confidence interval of dune length increases during the low discharge. Translating these results using the formula of van Rijn (1984), $k_s = 1.1H \left(1 - e^{-\frac{25H}{L}}\right)$, shows that river dunes cause higher roughness heights during higher discharges. At low flow rates, the roughness height decreases with increasing dune length.

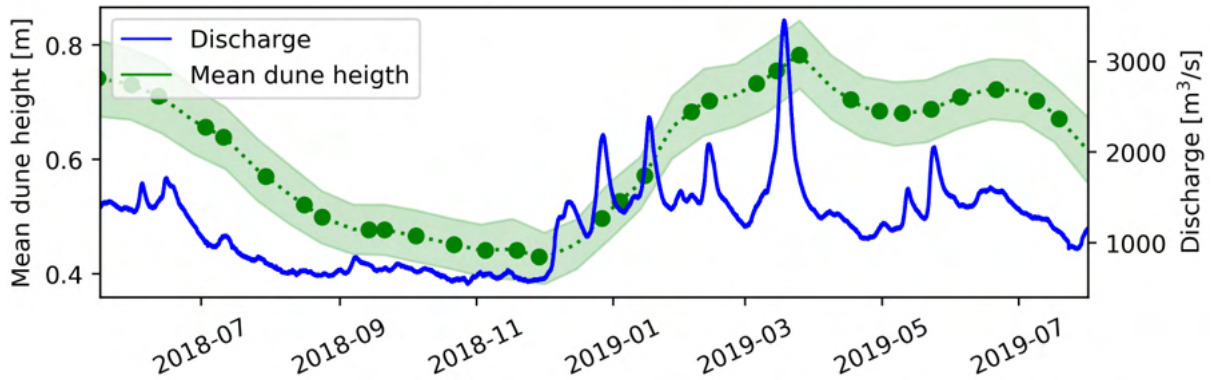


Figure 1 Mean and 95% confidence interval of dune height calculated over the whole Midden-Waal. The green dots show the dates on which the bed measurements are done. The blue line corresponds to the discharge

Spatio-temporal variation in roughness height

Figure 2 shows the spatio-temporal variation in river dune induced roughness in the Midden-Waal. The spatio-temporal variation is relatively small during low discharge periods. When the river is divided into more sections, over which the roughness height is calculated using averaged dune field statistics, more spatial variation appears. At the end of the low flow period, the roughness height has decreased compared to the beginning of the low flow period. After the discharge has increased, the spatial variation has become much larger compared to the period of the low flow. Apparently, dunes become much higher and/or shorter at some locations along the river. It can be concluded that the river dune induced roughness height is location dependent, both in length and width direction.

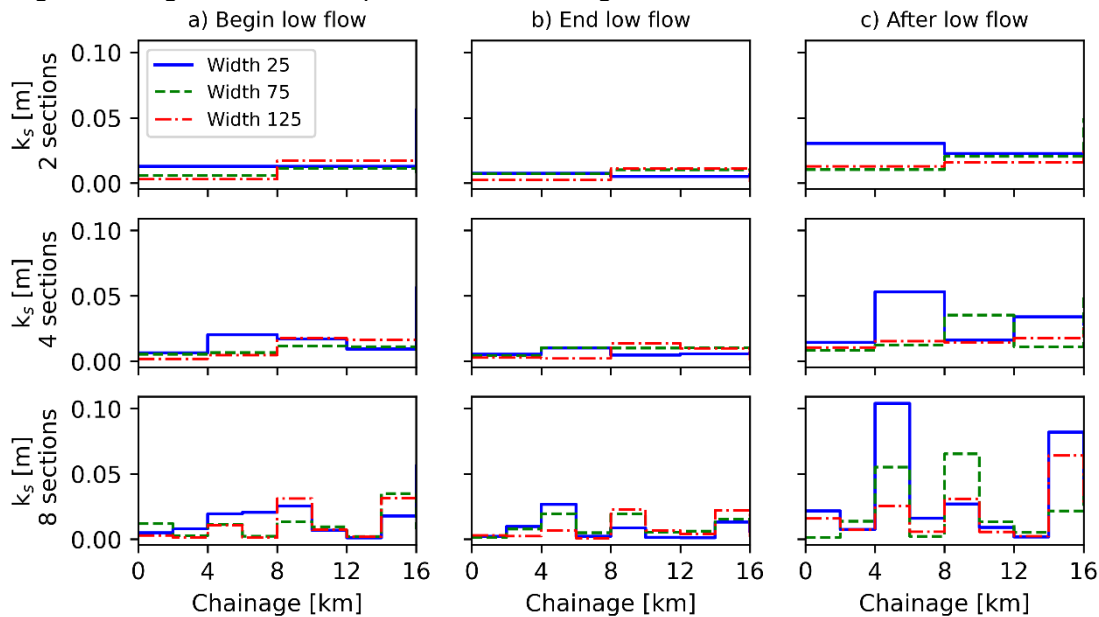


Figure 2 Spatio-temporal variability in river dune induced roughness in the Midden-Waal. Calculated at three locations [25, 75, 125] meter in the fairway of approximately 150 meters wide. Columns a) and b) show the spatial variation at the start and end of the low flow ($Q = \sim 800 \text{ m}^3/\text{s}$): 2018-08 – 2018-11. Column c) shows the spatial variation two months after the low flow ($Q = \sim 2000 \text{ m}^3/\text{s}$): 2019-01. The Midden-Waal is approximately 16 km long. The three rows show the spatial variability in river dune induced roughness when using dune dimensions averaged over 2, 4 and 8 sections of equal length.