# The evolution of primary dunes during low flows on the Waal river

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**Keywords —** River dunes, Wavelet analysis, Low flows, Dune height

## Introduction

During low and extreme low flows in navigable rivers, dynamic bed forms such as river dunes influence the navigable depth. During extreme low flow, shippers depend on depth predictions to determine their maximum draft, and therefore the maximum load they can transport. Due to climate change extreme low flows are likely to occur more often in the future. Therefore, knowledge of dune evolution is key to model and predict water depths.

Most studies concerning river dunes focus on dune evolution during high flows for flood level predictions (eg. Wilbers and Ten Brinke, 2003), or dune shape statistics at specific moments in specific moments in time (eg. Cisneros et al., 2020). Also, most of the studies on river dunes are based on laboratory data. However, scaling of dunes from lab conditions to real rivers, gives inconsistencies in lee slope angles and the presence of higher order dunes. Therefore, knowledge of dune evolution in full scale rivers during low flows is lacking, while this is an important factor in determining minimum water depth.

## Method

In this study, we investigate the dune evolution in a stretch of 2 km Waal river, the Netherlands, between the cities of Tiel and St. Andries, focussing on the low water period of 2018. The bed elevation profiles are based on Multibeam Echo Sounding (MBES) measurements of the fairway, measured on average once per two weeks. As we are interested in the dynamic part of the bed, the mean bed over the period 2017-2020 was determined and subtracted from the bed profiles of the individual measurements. Fig 1. shows the mean bed for this period at the study location.

The resulting bed profiles only contain the dynamic part of the bed, which are the dunes, higher order dunes and ripples. From these profiles the dune evolution has been studied, first based on a qualitative approach, then on a quantitative approach using wavelet analysis (Torrence and Compo, 1998).

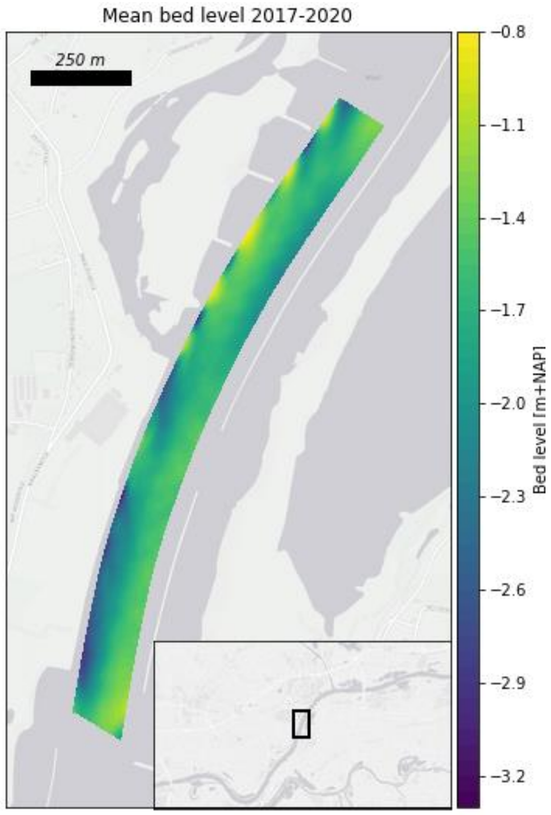


*Figure 1. Mean bed level between 2017 and 2020 at the study location.*

Based on the outcomes of the wavelet analysis, the signal of only the primary dunes was reconstructed. Next, the locations of the crests and troughs in the original signal were determined: these are needed to determine the dune heights. These, dune heights were then compared with the discharges, to derive a relation between these parameters.

## Results

Fig 2. shows the evolution of the dune profiles in time in the middle of the fairway, combined with the discharges at Lobith (Rhine river) and at Tiel (Waal river) from April until December 2018. Fig 3. shows the dune height related to this discharge. The showed period can be divided in two discharge regimes. First the discharge between April and June with a value varying between 2000 and 3000 m$^3$/s at Lobith,

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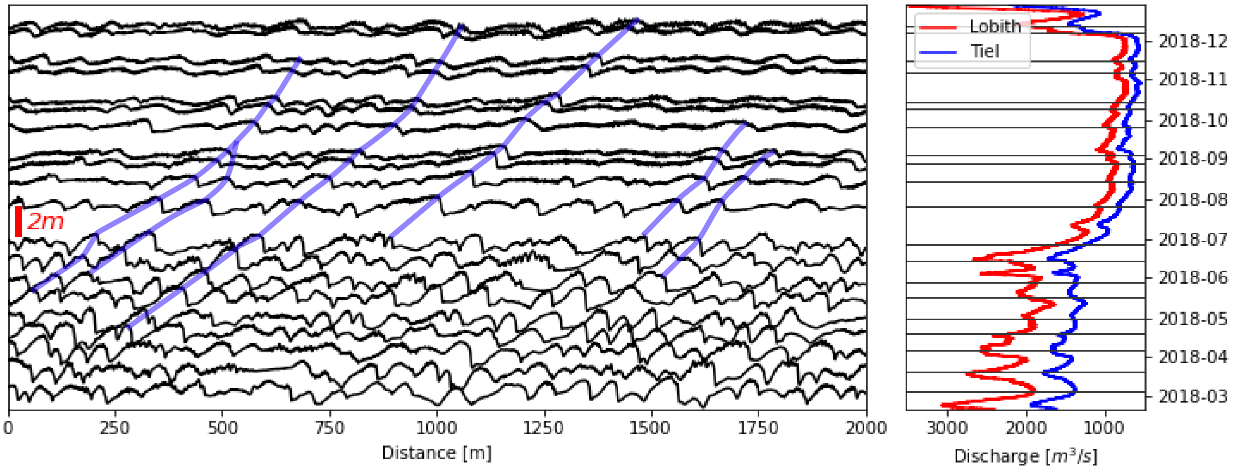


*Figure 2. Left) Dune evolution from April until December 2018 in the middle of the fairway, each line represents one measurement. The length of the red bar indicates 2 m in the dune profile heights, blue lines indicate the propagation of the crests. Right) Discharge in the Rhine at Lobith (red line) and in the Waal at Tiel (blue line), the horizontal lines indicate the dates of the measurements. Discharge data: ([www.waterinfo.nl](www.waterinfo.nl))*

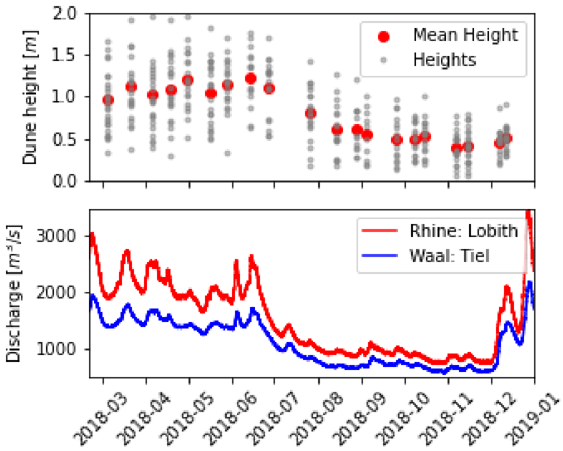


*Figure 3. Top) The mean dune heights (red dots) with all found dune heights for each measured profile in the middle of the fairway. For the same dune profiles as shown in Fig 2. Bottom) Discharges of the Rhine and Waal.*

which is around the median discharge for the Rhine river. Secondly, the discharge between July and December where the discharge varies between 800 and 1000 m$^3$/s at Lobith, which is extremely low. These two discharge regimes already show different dune evolution.

In the quantitative analysis, Fig 3., differences in dune height between the median and low discharge periods stand out. During the median flow, dune height varies around 1.1 m and the low flow results in dune heights around 0.6 m. In the transition from median flow towards low flow, the height adapts relatively fast to the new changed discharge.

These results can also be seen in the dune profiles in Fig 2: during the low discharges, the dunes are longer and slightly lower than during the period with the median discharge. During low flows dunes are still migrating, blue lines in Fig 2. These lines follow the dune crests during the low water period. While the dunes migrate, their shape is relatively constant compared to the median discharge period.

Here only the results for one line in the central part of the fairway are shown. However, this analysis can also be performed at any location in the cross-section of the river.

## Preliminary conclusions and lookout

From these first results we conclude that during a period of low flow in the Waal river, dunes are mobile. The dune height decreases and eventually becomes relatively stable during the period of low discharge.

In the next phase of this research the method to determine the location, height and length of the primary dunes will be further developed. Also, a quantitative analysis of the dune lee slope will be related to the discharge. Future work will also include the spatial variety in streamwise direction and over the cross-section, to develop a relation between dune shape and flow characteristics.

## 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. Our words of gratitude for collecting and sharing this data go out to technical staff of Rijkswaterstaat.

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