Constructing water depth maps: comparison of bedform statistics and shoals

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Introduction

Rijkswaterstaat Oost-Nederland uses water depth maps to identify local shoals in the fairway and to assess the effects of river interventions on navigability of the Dutch Rhine branches. These maps are a key operational tool for fairway management and for the permitting of river interventions. In the maps, a theoretical maximum bed elevation is compared with the water level at the agreed low discharge (OLR, *overeengekomen lage rivierafvoer*). This results in a predicted water depth during low-flow conditions, which must exceed 2.8 m within the fairway to ensure safe navigation.

The water depth maps were recently due for an update, incorporating revised low-water reference conditions and the most recent multibeam bed elevation surveys. This update provided the opportunity to rebuild the methodology and integrate insights from recent research programmes, including Rivers2Morrow and related morphological studies of the Dutch Rhine branches.Compared to the previous edition, the main methodological differences are related to the incorporation of bedforms, as the quantification of dune heights is a critical aspect of shoal identification. How do dune amplitudes derived using the updated method compare with recent findings, particularly those reported by Lokin et al. (2021) and Zomer et al. (2023)? Methodological choices in trend estimation, spatial averaging, and the treatment of temporal variability directly influence the derived dynamic bedform amplitudes and, consequently, predicted fairway depth. The updated workflow therefore allows assessment of whether methodological improvements lead to systematic differences in estimated dune heights and associated shoal risk. In addition to evaluating bedform statistics, the updated maps were validated against reported shoals.

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Methods and data

The updated methodology builds on the approach of Sieben and Van Loo (2014), in which bed elevation time series are decomposed into a local morphological signal and superimposed spatially static and dynamic bedforms. The analysis was performed for all Rhine distributaries in the Netherlands, using multibeam bed elevation measurements collected between 2015 and 2024. In this abstract we focus on the Waal River branch.

First, the bed elevation rasters from repeated multibeam surveys were spatially aligned and analysed on a 1×1 m grid. For each location and each survey, the bed elevation was smoothed in the streamwise direction using a rectangular moving average window of 500 m length and 25 m width. The smoothed bed represents the underlying morphological signal. A linear temporal trend was derived from the smoothed bed elevations, representing bed level development.

Local deviations from the smoothed bed were subsequently analysed to characterise bedforms. The temporal mean of these deviations represents static bedforms (e.g. groyne-related features and other persistent structures), while the square root of the local temporal variance quantifies the amplitude of dynamic bedforms such as dunes. This decomposition enables separation of structural river training effects from migrating bedforms.

Shoals were identified by determining the probable highest bed elevation for each 1x1 m grid cell. This was done by superimposing: (1) the trend-based bed elevation for the reference year of the low-water reference, (2) the static bedforms, (3) the amplitude of the dynamic bedforms and (4) a correction representing the seasonal variance of the mean bed. Locations where the reconstructed highest bed elevation approaches or exceeds the fairway depth criterion (low-water reference minus the guaranteed depth) were classified as potential shoals. The spatial distribution of these predicted shoals will becompared with reported least measured depths to evaluate the performance of the method.

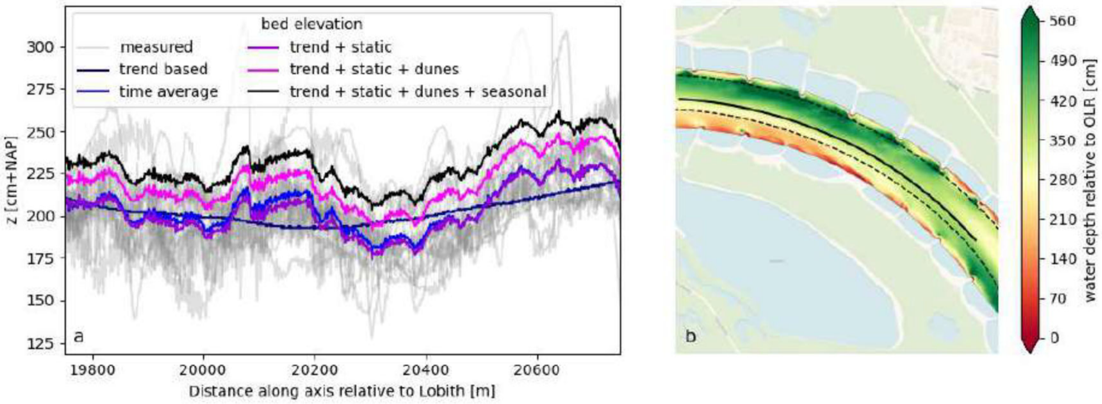

Figure 1: First results of the analysis in a snapshot of the Waal River bend between Ooij and Bemmel (river kilometre 877-879). A) the bed elevation results along the centre line transect. In grey all input measurements, in dark blue the bed elevation based for the reference year 2021 derived from the trend in the smoothed signal, in blue the local average, in black the bed elevation that will be used in the water depth maps, which is the bed elevation from the trendline, combined with the static bedforms, the standard deviation from the dunes and the seasonal variance. B) Reference bed elevation with respect to the OLR, water depth, for the reference year 2021. The dashed lines indicate the fairway and the black line indicates the location of the transect.

Results

Bed elevation and water depth

Figure 1a shows the bed elevation of a 1.5 km long stretch of the Waal River between Ooijen and Bemmel (rkm 877-879).

The grey lines represent the bed elevation measurements included in the analysis. Most of the measurement lie below the black line, which represents the reconstructed theoretical maximum bed level (trend + static bedforms + dunes + seasonal correction). The few exceedances correspond to large dunes measured during high-water conditions.

Figure 1b shows the water depths with respect to the reference water level, OLR. When this water depth exceeds 2.8 m in the fairway, the water depth is considered sufficient. Smaller depths can cause hinder for navigation.

Dunes

The spatial distribution and magnitude of derived dune heights were compared with results reported by Lokin et al. (2021) and Zomer et al. (2023). For the Middle Waal, between Nijmegen and St. Andries (rkm 890–924), previous studies reported dune heights between 0.5 m during low-flow conditions and 1.5 m during peak flows, defined as the vertical distance between dune crests and troughs.

Our preliminary results show standard deviations of the dune signal of approximately 0.3 m in this river reach. Because the standard deviation represents a statistical measure of amplitude rather than full crest-to-trough height, the results are consistent in order of magnitude but reflect a different definition of dune height.

For the Boven Rijn, the derived standard deviations are substantially smaller, between 0.05 to 0.1 m, reflecting the tendency of dunes in this reach to flatten during median to low-flow conditions.

Outlook

As a next step, the predicted water depths will be systematically compared with reported least measured depths (MGD, *minst gepeilde diepte*) to validate the water depth maps. This validation aims to confirm that shoals identified in the maps correspond to field observations, while ensuring that no significant shoals are missed. Additional validation steps include:

- Comparison of bed elevations, trends, and key bedform parameters with the current operational water depth maps.
- Comparison of derived erosion and sedimentation trends with reported results by Ylla Arbós et al. (2024) and Huthoff et al. (2021).

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