Massive morphological changes during the 2021 summer flood in the River Meuse

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Introduction

In July 2021, an exceptional flood developed in the River Meuse and its tributaries. High rainfall intensity lasted for several days in a number of sub-catchments in Belgium, Germany and the Netherlands, causing devastating floods. In the River Meuse, the peak discharge was highest since measurements started in 1911. At St. Pieter the maximum discharge was 3260 m^3/s with a return period of about 120 year. The flood event was particularly exceptional because floods normally occur in winter. During the flood, which lasted for 5 days only, flow velocities probably exceeded 5 m/s (based on numerical simulations) and unprecedented morphological changes occurred, especially in the permanently free flowing river section, referred to as the Common Meuse. Scour of the riverbed and river banks caused damage to infrastructure like ferry landings and pipe lines crossing the river. Morphological changes of this intensity and magnitude during extreme events are only sparsely reported in literature.

Objective

The objective of the study was to improve understanding of the morphological processes during extreme floods, by focusing on the Common Meuse. Here, the riverbed surface is composed of gravel and the longitudinal bed slope is five times steeper than the downstream canalized river.

Methodology

Post-event, multibeam echosoundings were done to reveal the morphological changes in the riverbed. Field measurements were carried out to assess the sand deposits on the floodplains (Fig. 1). Airborne lidar measurements after the flood were applied to validate and enrich these data.

We analysed the volumes and composition of the floodplain deposits in relation to the riverbed material, morphological changes in the main riverbed, sinuosity of the river and the flooding intensity of the floodplains.

Figure 1 Field work by Wageningen University and Research on sediment deposits, location Bosscherveld, August 2021.

Results

The echosoundings showed that in a section of 15 km long, more than 20 deep scour holes developed in the riverbed, with depths sometimes exceeding 15 m (Fig. 2).

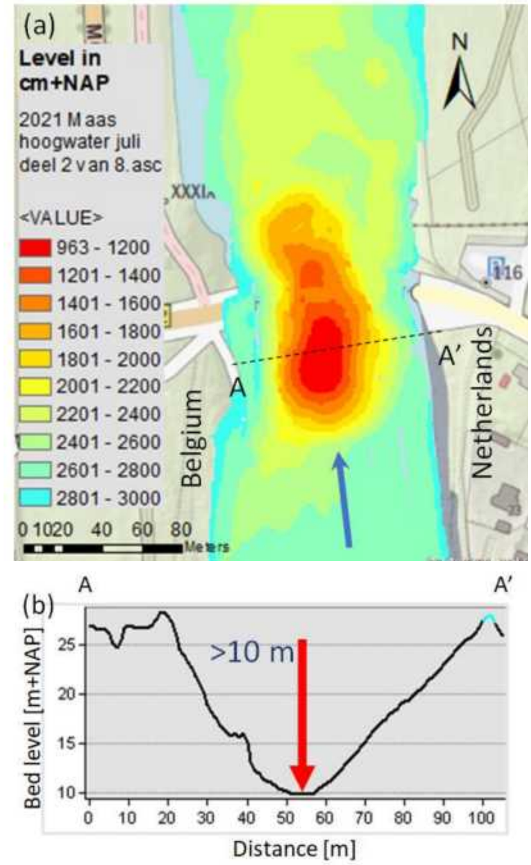

Figure 2 (a) Erosion on the Common Meuse at the location Berg. (b) cross-section A-A'. Source: multibeam measurements RWS-CIV, July 2021.

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Over 400,000 m^3 of sediment eroded from the scour holes. On the floodplains at least 170,000 m^3 of sand was deposited. The composition of these deposits in the reach directly downstream of the erosion holes, was identical to the fine sand found in the erosion holes after the flood.

Discussion

We expect that the massive morphological changes were caused by rapid erosion of fine sand layers underneath a thin layer of gravel on the riverbed (Meijer et al, 2011). We believe that the high flow velocities during the event caused the breaking up of the coarse armour layer on top of the riverbed and the consequential mobilization of the thin gravel layer. The fine sands underneath the gravel were quickly eroded when that happened, creating the deep scour holes.
Our analysis suggest that the main ingredients for thinning of the gravel layer on the riverbed are ongoing gradual channel incision up to 2 cm/yr, the vertical composition of the riverbed and altered flow conditions.

- Previous river training works, weirs and sediment mining created a supply-limited river system and an eroding trend.
- In the Meuse valley, several tectonic faults are found. In uplifting areas, known as horsts, the gravel layer on the riverbed is relatively thin (Meijer et al, 2011), as the river continuously erodes the rising riverbed.
- Room for the River measures carried out since the 1995 flood event, lowered flood levels, but also increased flow velocities in river reaches that were not or only marginally widened (see Figure 3).

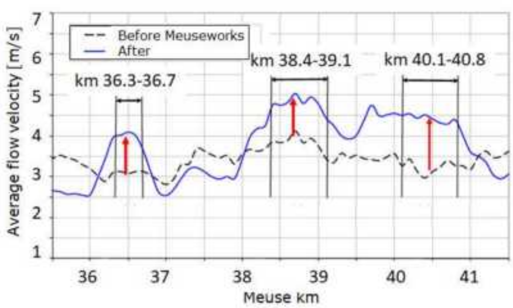

Figure 3 Change in maximum average flow velocities due to MeuseWorks (Room for the River programme for the Meuse River) under flood conditions. Source: Meijer & Vieira da Silva (2007).

A large portion of fine sediments released from the riverbed underneath the gravel layer was deposited in comparatively wide floodplains located further downstream. Compared to the floods of 1993 and 1995, the volumes of sand deposited on the floodplains of the more downstream reaches appeared to be relatively small. This can be explained by the short duration of the flood wave in 2022, the large wave damping and thus shorter duration of flooding of the floodplains. The curvature of the river, height of the banks and concentrated flow directed towards the floodplains appear to determine locations of the main sand deposits and their composition. At locations with lower floodplains and large secondary flood channels (Ooijen-Wanssum) coarser sand deposits were found (Fig. 4).

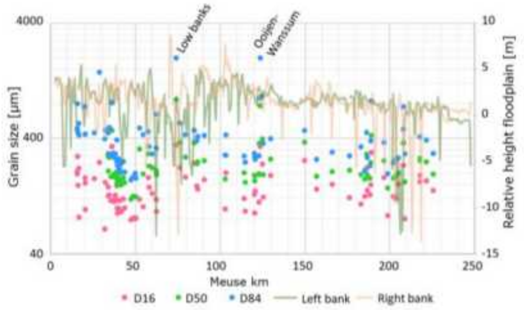

Figure 4 Characteristic grain diameters (D16, D50 and D84) sand deposits and relation to elevation of floodplains (bank) and secondary channels. Source: Beijer et al, 2021.

The unprecedented morphological changes may have a decisive impact on the morphological trends as well as on stability of infrastructure and flood safety. Climate change and ongoing river bed erosion may cause that these morphological processes occur more frequently in the future, also in other river sections, requiring new river management strategies to avoid catastrophes.

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