Response of the Upper Dutch Rhine Bifurcation Region to Peak flows

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Publication date
2023

Document Version
Final published version

Citation (APA)
Chowdhury, M. K., Blom, A., Ylla Arbós, C., Verbeek, M. C., Schropp, M. H. I., & Schielen, R. M. J. (2023). *Response of the Upper Dutch Rhine Bifurcation Region to Peak flows*. 82-83. Abstract from NCR Days 2023, Nijmegen, Netherlands.

Towards 2048: the next 25 years of river studies

Book of Abstracts
NCR DAYS 2023
12-13 April | Radboud University

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Marie-Charlott Petersdorf (eds.)

NCR Publication: 51-2023

NCR DAYS 2023

Towards 2048: The next 25 years of river studies

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Organising partner:

Radboud University

Conference venue

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Cite as: Wilco Verberk, Frank Collas, Gertjan Geerling, & Marie-Charlott Petersdorf (eds.) (2023), *Towards 2048: The next 25 years of river studies: NCR DAYS 2023 Proceedings*. Netherlands Centre for River Studies publication 51-2023

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Response of the Upper Dutch Rhine Bifurcation Region to Peak flows

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Highlights

- We analyze historical hydraulic, bed level, and bed texture data from the Pannerdense Kop bifurcation region
- Discharge fraction into the Waal branch has slowly increased over the last three decades at the expense of the Pannerden Canal.
- In-channel sediment deposition due to a rapid succession of peak flows likely triggered this change in flow partitioning.

Overview

Flow partitioning at a river bifurcation influences navigation, freshwater supply, and flood risk. Such flow partitioning is strongly related to the bed level development within the bifurcation region. Here we analyze the response of a bifurcation region in a river system with a fixed planform to engineering measures over the last century.

We address this by assessing measured data on water level, bed level, and bed surface grain size within the Pannerdense Kop bifurcation region (Fig. 1a) over the last century. We use data on water discharge both upstream (4 km) and downstream (1 km) of the bifurcation. Data on water discharge, water level, bed surface texture, and bed level for the Dutch Rhine originate from Rijkwaterstaat.

We show that the Waal branch has gradually received an increasing discharge fraction relative to the Bovenrijn over the last 30 years. This slow change in flow partitioning is associated with the Waal branch eroding faster than the Pannerden Canal branch.

Aggradation in the upstream part of the Pannerden Canal due to the rapid sequence of peak flows in 1993 and 1995 (and possibly 1998) seems to have triggered this gradual change in flow partitioning and erosion rate difference.

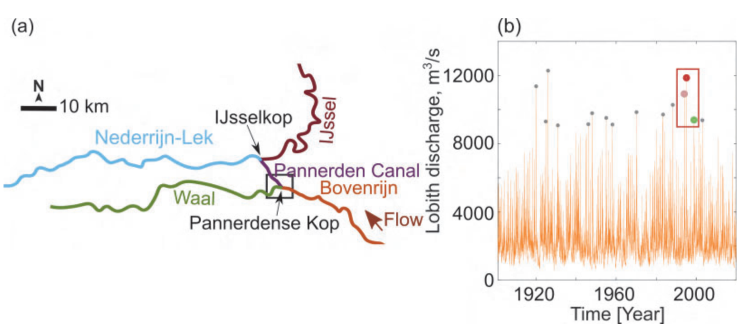

Figure 1. (a) Field site, Pannerdense Kop bifurcation in the upper Dutch Rhine and (b) measured water discharge at Lobith since 1901. The dots indicate peak flows with magnitude larger than 9000 m^3/s.

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Kleinhans, M. G., A. W. E. Wilbers, W. B. M. ten Brinke, 2007. Opposite hysteresis of sand and gravel transport upstream and downstream of a bifurcation during a flood in the River Rhine, the Netherlands. Netherlands Journal of Geo-sciences 86(3), 273–285

Flow Partitioning at the Pannerdense Kop Bifurcation

Figure 2a shows that, despite a relatively large scatter, the Waal fraction of the Lobith water discharge follows a relatively constant trend between 1970-1990. The Waal fraction of the Lobith water discharge appears to start to change following two (or three) consecutive peak flows in 1993 and 1995 (and 1998). Subsequently, the annual mean Waal fraction of the Lobith discharge has gradually increased (by 0.2-0.4% per year) since the mid-late 1990s for two discharge regimes (low, $Q_{Lobith} < 1500$ m^3/s and high, $Q_{Lobith} > 2500$ m^3/s). The operation of the Driel weir influences flow partitioning in the medium flow regime $1500 < Q_{Lobith} < 2500$ m^3/s and is not discussed here.

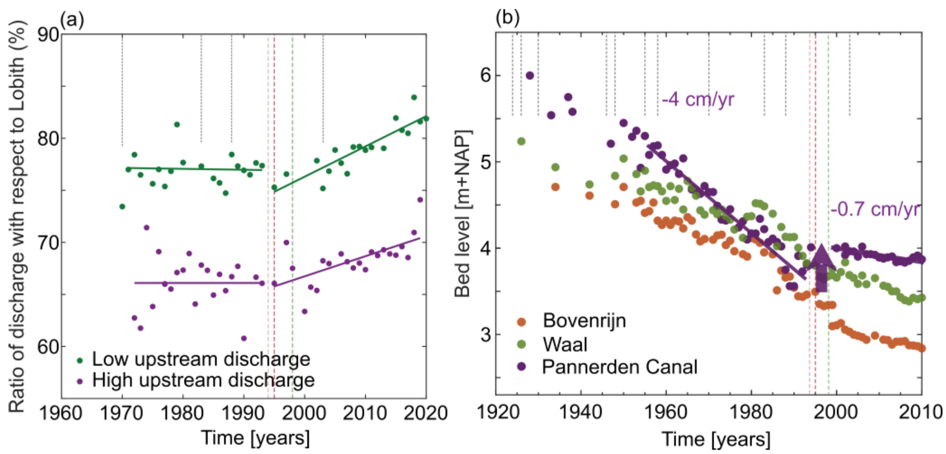

Figure 2. (a) Waal fraction of the Lobith water discharge and (b) bed level at a position 0.5 km upstream and downstream of the bifurcation as a function of time. Vertical lines indicate peak flows shown in Fig. 1b.

Change in Bed Level at the Bifurcates

The channel bed of the Waal and the Pannerden Canal branches has eroded over the last century primarily due to channelization measures (e.g., Havinga, 2020). Before the mid-1990s, the channel bed at the upstream end of the Pannerden Canal had eroded faster than the Waal. After the peak flows, we see rapid aggradation at the upstream end of the Pannerden Canal (Fig. 2b). Furthermore, right upstream of the bifurcation, the channel bed in the Bovenrijn rapidly eroded following the peak flows.
This rapid deposition at the upstream end of the Pannerden Canal seems to have triggered the slow change in flow partitioning in favour of the Waal branch. And it seems that the larger the Waal share of the Lobith water discharge, the more the upstream part of the Waal branch erodes.
Since the consecutive peak flows, the upstream end of the Waal branch has eroded faster than the Pannerden Canal. As a result, the Waal depth gradually increases with time relative to the Pannerden Canal. The consequence is a gradual increase in the Waal discharge fraction. These changes have also resulted in a reduction of the erosion rate at the upstream end of the Pannerden Canal compared to the situation before the peak flows (Fig. 2b).

Discussion

The Waal discharge fraction increasing with time suggests that the Pannerdense Kop bifurcation is currently unstable. An unstable bifurcation is defined as one where the water discharge in one branch increases at the expense of the other branch. The rapid deposition at Pannerden Canal following the peak flows likely triggered the instability. Previous research also suggested that large peak flows could unbalance a bifurcation and cause a change in flow partitioning (Kleinhans et al., 2007). We want to understand why the 1993-1995(-1998) peak flows have resulted in a different bifurcation response than other peak flows (Fig. 1b). We hypothesize that the response is likely associated with the following: 1) the duration, magnitude, and sequence of the peak flows and 2) the temporal coarsening of the bed surface sediment and sediment flux in the bifurcation region.
The observed bifurcation response may influence river functions in the future. Future research will investigate the bifurcation response to climate change.

Acknowledgement

This study is part of the research program Rivers2Morrow, financed by the Dutch Ministry of Infrastructure and Water Management. We thank the technical staff of Rijkswaterstaat for sharing the data used in this study.