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Projected climate-change impacts on the flow partitioning in the bifurcation region in the upper Rhine delta

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Introduction

In engineered river systems such as the Dutch Rhine, bifurcation dynamics play a crucial role in providing flood safety, freshwater supply, and inland navigation. While regulation measures in the past caused bed erosion (Ylla Arbós et al., 2021) and peak discharges may have caused changes in flow partitioning (Chowdhury et al., 2023) at the bifurcation points, climate change is expected to further alter hydrological patterns, impacting sediment transport and increasing bed erosion (Ylla Arbós et al., 2023) as well as affecting flow partitioning again.

The objective of this study is to investigate the effects of climate change on the Dutch Rhine bifurcation system over the next 150 years, focusing on hydrograph variations, sea level rise, and the influence of past engineering interventions. Understanding these dynamics is critical for future river management and adaptation strategies.

Methods

We have developed a one-dimensional numerical model to simulate flow partitioning and bed level change over a 540 km domain of the Rhine River. The domain of interest extends from Bonn (Germany, river km 640) to its downstream boundaries in the Waal (at Vuren, Netherlands), the Nederrijn-Lek (at Schoonhoven, Netherlands), and the IJssel (Keteldiep, Netherlands). As such, the model includes the Pannerdense Kop and IJsselkop bifurcations.

The model is informed by a two-dimensional model to account for sediment partitioning at the bifurcations and has been calibrated against measured data on flow partitioning and order of magnitude and sign of channel bed erosion rates. It is verified against water levels at four stations in the different branches. Climate change scenarios, including different hydrograph change projections (Buitink et al.,

2023; Van Verseveld et al., 2024) and sea level rise projections (Van Dorland et al., 2023), were incorporated based on the KNMI'23 climate scenarios. The model simulates the bifurcation response in these scenarios, providing information on trends in discharge redistribution at the bifurcations, sediment flux, and channel bed erosion and deposition.

Results

Our projections indicate that while past human interventions continue to influence flow partitioning in the near term, climate change effects will become increasingly significant from 2060 onward.

In the reference scenario, the Waal-to-Lobith discharge ratio increases gradually, while the IJssel-to-Lobith discharge ratio declines, reflecting ongoing channel adjustments. Under climate change scenarios, hydrograph alterations lead to a further increase of the Waal-to-Lobith discharge ratio (Figure 1) and a coarsening of sediment flux arriving at the bifurcations.

By 2150, the dominant Waal branch is projected to experience a 5–8% increase in discharge, while the IJssel branch may see reductions of up to 30% during low-flow conditions. These trends result from intensified erosion in the bifurcation region due to sediment flux coarsening, which yields an increased mismatch between sediment supply and sediment transport capacities immediately downstream of the bifurcations.

Sea level rise has a counteracting effect on these hydrograph-induced changes, slightly increasing IJssel discharge by allowing backwater effects to propagate upstream. However, the impact of hydrograph modifications outweighs that of sea level rise in most scenarios. The bifurcation system response is largely driven by shifts in medium water discharges rather than extreme peak flows, indicating a gradual but persistent transformation of flow partitioning.

Conclusions

This study highlights the evolving role of climate change in shaping the Dutch Rhine bi-

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furcation system. While past engineering interventions have dictated historical and current flow patterns, their influence will decrease as climate-driven changes accelerate.

Climate-related hydrograph changes, rather than sea level rise, emerge as the dominant factor affecting the flow distribution at Pannerdense Kop and IJsselkop.

Our findings underscore the necessity of water management strategies to address changing hydrological conditions. Future policies must explicitly consider sediment flux coarsening and erosion dynamics to mitigate the long-term impact of climate change on the river bifurcations in the upper Rhine delta. By integrating these insights into planning efforts, policymakers and engineers can ensure the resilience of the Dutch Rhine delta against future climate-related hydrograph changes.

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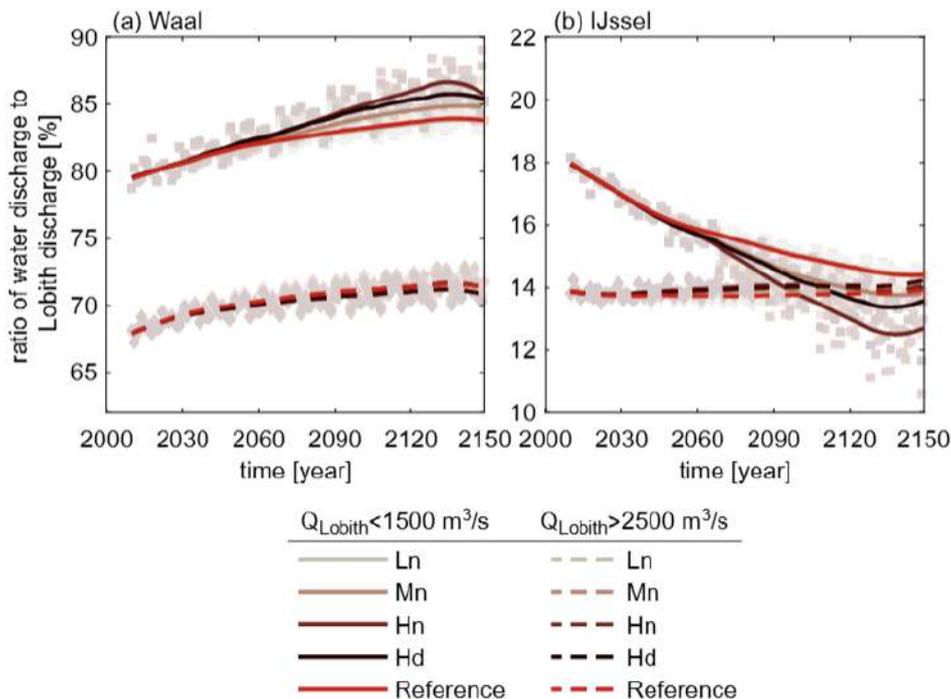


Figure 1: Waal-to-Lobith (left column) and IJssel-to-Lobith (right column) discharge ratios as a function of time, for low, middle and high (L,M,H) and dry and wet (d and n) hydrograph scenarios (Buitink et al., 2023) for high (i.e., open Driel-weir) and low (i.e., closed Driel-weir) Lobith discharges.