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Mid-Century Channel Response to Climate Change in the Lower Rhine River

Clàudia Ylla Arbós[a,*], Astrid Blom[a], Ralph M.J. Schielen[a,b]

[a] *Delft University of Technology, Department of Hydraulic Engineering, Faculty of Civil Engineering and Geosciences, PO Box 5048, 2600 GA Delft, the Netherlands*

[b] *Ministry of Infrastructure and Water Management - DG Rijkswaterstaat, Utrecht, the Netherlands*

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Introduction

Most of the world's large rivers are heavily engineered, and for centuries, human intervention has modified the channel characteristics of rivers worldwide (Best, 2019). Today climate change adds to these pressures, as it alters river controls through sea level rise and changing precipitation, thereby modifying the hydrograph and sediment supply (Verhaar et al., 2010). Both climate change and human intervention will be important drivers of future channel response.

Here we consider the Lower Rhine River, defined as the 300-kilometer reach of the Rhine River between Bonn (Germany) and Gorinchem (the Netherlands), including a bifurcation close to the German-Dutch border (Pannerdense Kop). The Lower Rhine River is a paradigmatic engineered river that has been impacted by interventions for centuries, both for flood safety and for navigation, and has also been intensively monitored. Decades of field data on water discharge, water and bed level, and bed surface grain size illustrate that human intervention has governed channel response over the past century (e.g., Ylla Arbós et al. (2021); Quick et al. (2019)). Our goal is to assess how channel response to climate-related changes in the river controls compares to channel response due to (future) human intervention, focusing on changes in channel bed elevation, bed slope, and bed surface grain size over the next century.

Method

Given the large spatio-temporal scale of our study, as well as the uncertainty associated to climate and intervention projections, we set up a highly schematized 1D numerical model of the Lower Rhine River based on available field data. We calibrate it against the temporal change of discharge partitioning at the Pannerdense Kop bifurcation, considering three ranges of water discharge ($<$1500, 1500-2500, and $>$2500 m^3/s), and against erosion rates over the period 1990-2020.

We perform 100-year model runs for different scenarios of climate change and human intervention, and compare the results to a do-nothing scenario (i.e., a reference case in which the river controls remain as they are, and no further human intervention is carried out). In this paper we consider the following controls and scenarios: (a) upstream water discharge, 5 scenarios (KNMI, 2015); and (b) upstream sediment flux, 3 scenarios based on Frings et al. (2014)'s measured sediment flux data and associated uncertainty. The translation of these climate scenarios into suitable boundary conditions for the numerical model is discussed in Ylla Arbós et al. (2021).

Preliminary results

Model runs up to 2050 provide insight on the mid-century channel response to climate change. We focus on bed elevation change.

Figure 1 shows the spatial difference in bed level over the period 2010-2050 for different water discharge and sediment flux scenarios, with the reference scenario (i.e., the base case) included for comparison. We observe generalized bed incision in all cases, except for the reach between river km 820-860, and the lowermost 15 km, where the river bed aggrades. The incision is more pronounced downstream of river km 860 (i.e., the Dutch Rhine). In this reach, incision decreases in the downstream direction, which implies that the main channel slope decreases. Upstream of river km 860 (i.e., the German Rhine), bed incision is milder. In the German Rhine, bed incision increases in the downstream direction between river km 640-750, and decreases in the downstream direction between river km 750-860, suggesting and increase in concavity. Overall, the behavior is in line with historical observations of bed level change in the Lower Rhine River and relates to an ongoing slope adjustment in response to channel narrowing (Ylla Arbós et al., 2021).

For all water discharge scenarios, the predicted incision is enhanced up to about 20%.

*Corresponding author

Email address: c.yllaarbos@tudelft.nl (Clàudia Ylla Arbós)

URL: www.tudelft.nl (Clàudia Ylla Arbós)

The scenarios consist of higher peak flows in the winter and lower base flows in the summer, which explains the increased incision rates, given that higher discharges (leading to river bed incision) are more relevant for morphodynamic change than lower discharges. Incision rates are relatively similar across water discharge scenarios in most of the domain, with slightly higher differences in the uppermost 60 km. Regarding sediment flux scenarios, higher sediment fluxes reduce the predicted incision up to 40%, while lower sediment fluxes increase it by a similar amount. The influence of changes in the sediment flux is limited to the uppermost 60 km during the considered period.

Some localized aggradational/degradational spikes are observed throughout the domain, for both the reference case and the climate scenarios. These spikes are related to the presence of fixed layers, and while in practice localized aggradation would likely be dredged, no intervention is considered in these runs.

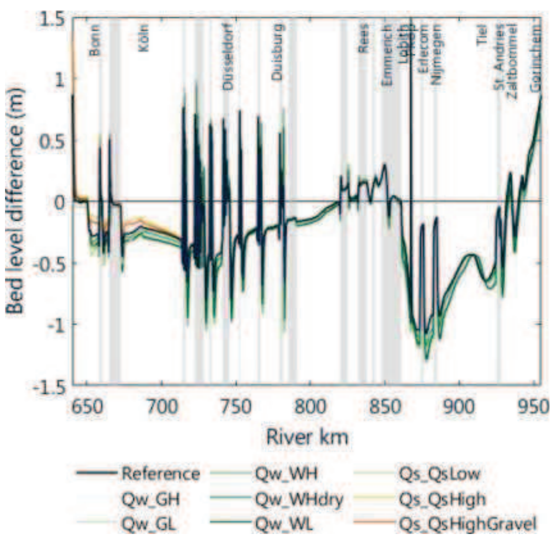

Figure 1: Bed level difference between over the period 2010-2050 for different scenarios of water discharge (Qw, following KNMI (2015) nomenclature) and sediment flux (Qs, following Frings et al. (2014) estimates). Gray areas indicate the presence of fixed layers.

Discussion and conclusions

Model runs of mid-century channel response show that the ongoing bed incision in the Lower Rhine River is enhanced up to 20% for all the water discharge scenarios. This is because these scenarios foresee increased peak flow rates, which are dominant in terms of channel response, and lead to river bed incision. Increased sediment fluxes reduce the predicted incision by up to 40%, though this effect is limited to the uppermost 60 km in the period of interest. For longer simulation times, the effect of a changing sediment flux will likely migrate further downstream.

Both historic data and the results of this study suggest that human intervention has played, and will keep playing a key role regarding channel response. In the past, this was mostly through channel narrowing (Ylla Arbós et al., 2021). In the present and future, this is more related to sediment management and river maintenance policies (e.g., fixed layers, Figure 1).

Future research will extend the period of analysis to 2100, and will consider scenarios for the remaining boundary conditions (downstream base level, sediment partitioning at the bifurcation), as well as for human intervention. This extension will include maintenance dredging, as very pronounced aggradation peaks are difficult to deal with numerically, but also not realistic.

References

Best, J. (2019). Anthropogenic stresses on the world's big rivers. *Nature Geoscience*, 12(1):7–21.

Frings, R. M., Döring, R., Beckhausen, C., Schüttrumpf, H., and Vollmer, S. (2014). Fluvial sediment budget of a modern, restrained river: The lower reach of the Rhine in Germany. *CATENA*, 122:91–102.

KNMI (2015). KNMI '14 Climate Scenarios for the Netherlands.

Quick, I., König, F., Baulig, Y., Schriever, S., and Vollmer, S. (2019). Evaluation of depth erosion as a major issue along regulated rivers using the classification tool Valmorph for the case study of the Lower Rhine. *International Journal of River Basin Management*, pages 1–16.

Verhaar, P. M., Biron, P. M., Ferguson, R. I., and Hoey, T. B. (2010). Numerical modelling of climate change impacts on Saint-Lawrence River tributaries. *Earth Surface Processes and Landforms*, 35(10):1184–1198.

Ylla Arbós, C., Blom, A., and Schielen, R. M. J. (2021). Scenarios for Controls of River Response to Climate Change in the Lower Rhine River. In *NCR Days 2021*, Enschede, The Netherlands.

Ylla Arbós, C., Blom, A., Viparelli, E., Reneerkens, M., Frings, R. M., and Schielen, R. M. J. (2021). River Response to Anthropogenic Modification: Channel Steepening and Gravel Front Fading in an Incising River. *Geophysical Research Letters*.