21st Century Channel Response of the Lower Rhine River to Climate Change

Ylla Arbos, C.; Blom, A.; Sloff, C.J.; Schielen, R.M.J.

Publication date
2023

Document Version
Final published version

Citation (APA)
Ylla Arbos, C., Blom, A., Sloff, C. J., & Schielen, R. M. J. (2023). *21st Century Channel Response of the Lower Rhine River to Climate Change*. Abstract from 13th Symposium on River, Coastal and Estuarine Morphodynamics, Urbana-Champaign, Illinois, United States.

21st Century Channel Response of the Lower Rhine River to Climate Change

C. Ylla Arbós[1], A. Blom[1], C.J. Sloff[1,2] and R.M.J. Schielen[1,3]

[1] Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, The Netherlands, c.yllaarbos@tudelft.nl; astrid.blom@tudelft.nl

[2] Deltares, Delft, The Netherlands, kees.sloff@deltares.nl

[3] DG Rijkswaterstaat, Ministry of Infrastructure and Water Management, Utrecht, The Netherlands, ralph.schielen@rws.nl

1. Introduction

Climate change puts pressure on river systems, as it increasingly alters the river controls. Engineered rivers with a fixed planform respond to climate change and human intervention by adjusting the channel slope and bed surface grain size distribution. This response often consists of channel bed incision, over hundreds of kilometres, and during decades to centuries, resulting in serious disruptions of inland navigation, increased flood risk, and ecological degradation. Here we investigate how the lower Rhine River (Bonn, Germany – Vuren, the Netherlands, including the Pannerden bifurcation) continues to adjust to channelization measures of the 19th century (Ylla Arbós et al., 2021), and responds to different climate scenarios of control change over the 21st century, using a schematized one-dimensional numerical model for mixed size sediment.

2. Modelling the lower Rhine River

The initial state of our model is based on the current state of the system (1990-2020). Input variables are smoothened to filter out the small-scale variability of the system.

Water discharge is imposed by means of a 20-year cyclic hydrograph, chosen from the historical record such that its statistics best match those of the Sperna Weiland et al. (2015) reference period. The sediment load is set as a function of discharge, such that the mean annual sediment flux per grain size class is within the uncertainty range of the Frings et al. (2014) estimates. The downstream base level accounts for sea level rise at rates corresponding to the centreline of the KNMI (2015) projections.

We calibrate the model against field data on bed level change rates and temporal change of flow partitioning at the bifurcation over the period 2000-2010 and verify it for the period 2010-2020. Model accuracy is 0 to 0.6 cm/a for bed level change rates and 10% for discharge partitioning.

The reference case (i.e., no climate change scenarios) shows a continuation of the past domain-wide river bed incision (Ylla Arbós et al., 2021), especially downstream of the bifurcation, hinting at potential instability of the latter. Incision rates decrease over time (0 to 2.5 cm/a up to 2050 vs 0 to 1 cm/a between 2050 and 2100), indicating an approach to a new equilibrium state after channelization. The bed surface coarsens over the entire domain.

3. Channel response to climate change

Water discharge scenarios (Sperna Weiland et al., 2015, following IPCC, 2013 and KNMI, 2015) enhance the ongoing channel bed incision by up to 1 m in 2100, relative to the reference case. This is due to larger moderate-to-high discharges, which are most relevant to channel response and result in a smaller equilibrium channel slope.

Larger and smaller sediment fluxes (based on the upper and lower bounds of the Frings et al. (2014) estimates) respectively reduce or enhance the ongoing incision by up to 0.15 m in 2100. These changes originate at the upstream boundary and propagate downstream at about 2 km/a.

Higher or smaller rates of sea level rise (KNMI, 2015, IPCC, 2013) respectively reduce or enhance the ongoing incision by up to 0.3 m in 2100, through an upstream-migrating wave (~1 km/a).

In all cases, channel response to climate change accelerates with time, as the rates of control change accelerate. Climate scenarios do not significantly affect bed surface grain size.

4. Conclusions

Human intervention seems to dominate channel response in the lower Rhine River over the 21st century, through domain-wide river bed incision. Climate change enhances this incision, mainly due to increased moderate-to-high discharges. While channel response to human intervention slows down as the river reaches a new equilibrium state, channel response to climate change accelerates.

References

Frings, R. M., Döring, R., Beckhausen, C., Schüttrumpf, H., & 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*. http://www.climatescenarios.nl/

IPCC (2013). *Climate Change 2013: The Physical Science Basis.* (T. F. Stocker, D. Qin, G. K. Plattner, M. Tignor, S. K. Allen, A. Boschung, A. Nauels, Y. Xia, V. Bex, & P. M. Midgley (eds.)). Cambridge University Press.

Sperna Weiland, F., Hegnauer, M., Bouaziz, L., & Beersma, J. (2015). *Implications of the KNMI'14 climate scenarios for the discharge of the Rhine and Meuse*. Deltares, Delft, the Netherlands

Ylla Arbós, C., Blom, A., Viparelli, E., Reneerkens, M., Frings, R. M., & Schielen, R. M. J. (2021). River Response to Anthropogenic Modification: Channel Steepening and Gravel Front Fading in an Incising River. *Geophys. Res. Lett.*, *48*(4), e2020GL091338.