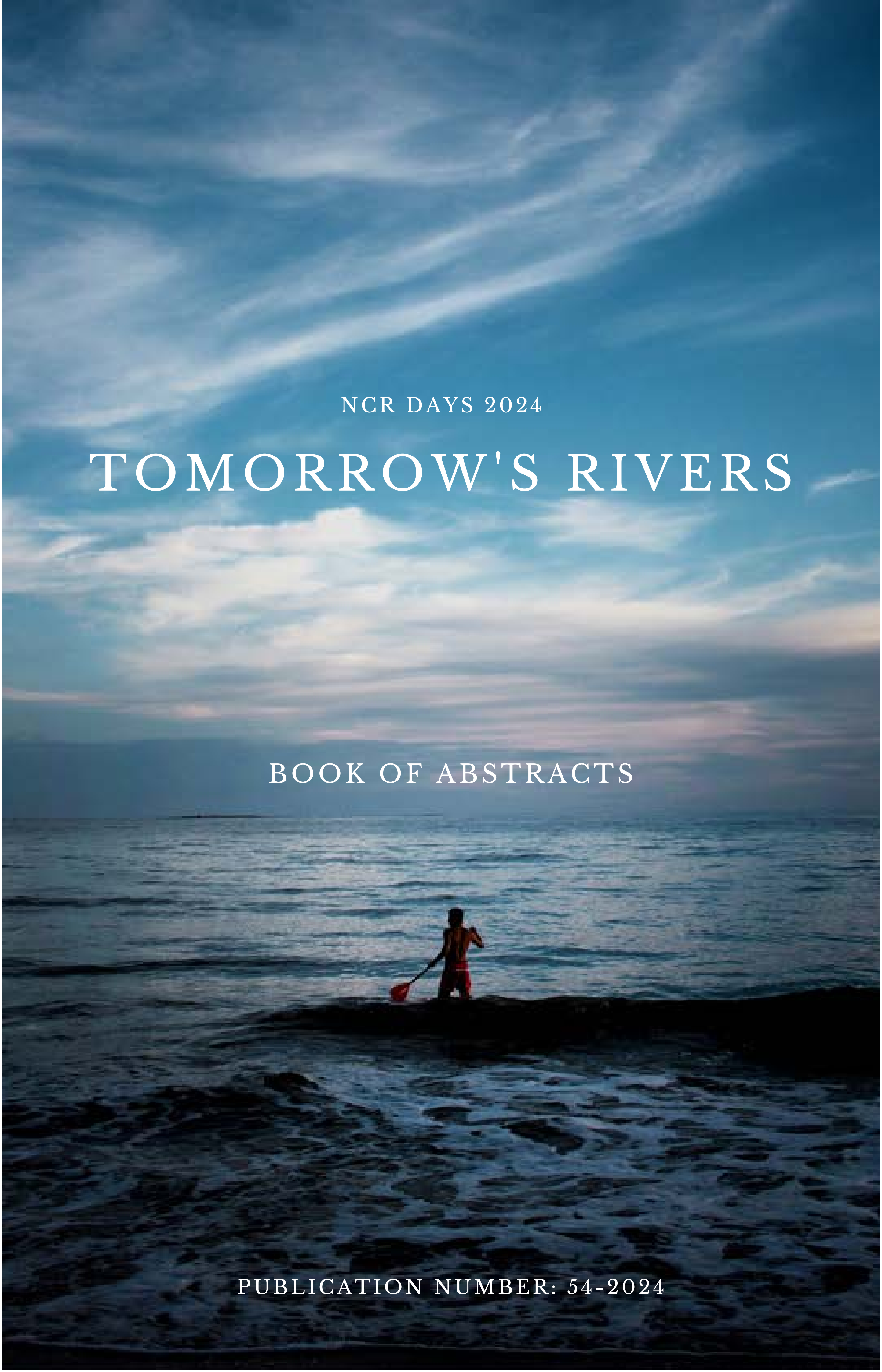

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Understanding the long-term dynamics of scour holes in lowland rivers

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Introduction

Scour holes are common features in lowland rivers. Scour holes are local depressions in the channel bed caused by erosion processes induced by hydrodynamic conditions (Ferrarin et al., 2018). The holes can have a depth of several meters and are generally no longer than 1 km in longitudinal direction. Deep scour holes are found all over the world, for example, in channel bends in the river Mahakam in Indonesia (Vermeulen et al., 2015), at channel confluences in the Venice lagoon in Italy (Ferrarin et al., 2018), and in the Grensmaas caused by the flood of 2021 in Limburg in the Netherlands (Barneveld et al., 2022). These deep scour holes may threaten the stability of infrastructure, like pipelines, embankments, and the foundation of bridges. Therefore, scour holes are generally filled up manually. Room for the river and nature-based solution projects aim to improve the river system's natural conditions, and therefore it might be desirable to leave these scour holes open after formation. A lot of research has been done on the formation of scour holes. However, by manually filling up the scour holes, less is known about the migration of the holes after formation and the possible threats of the scour holes in the long-term. For this reason, a better understanding of the long-term dynamics of scour holes in lowland rivers is required.

Formation of scour holes

The formation of scour holes is driven by hydrodynamic and geotechnical conditions (Wang et al., 2017; Knaake et al., 2023). The hydrodynamic conditions result from historical events (e.g., the flood in Limburg in 2021), channel geometry (bend, confluence, local narrowing), and constructions (bridge pillars, groynes, non-erodible fixed bed). Historical events result in peak discharges and high flow velocities. Changes in channel geometry and the presence of constructions cause local flow perturbations and additional turbulence to the flow. This local acceleration in flow velocity creates vortexes that remove the surrounding sediment if the river bed is susceptible to erosion, (Wang et al., 2017), resulting in deep scour holes. However, hydrodynamic conditions alone cannot account for all scour hole formations (Knaake et al., 2023). The geotechnical condition is also a key control for scour hole formation. The composition of the subsurface can explain the spatial variability in the occurrence and dimensions of scour holes. A heterogeneous subsurface consists of alternating easily erodible layers, like sand, and non-erodible layers, like clay or gravel. If the river bed consists of an erosion resistant top layer with an underlying layer with higher erodibility, deep scour holes can develop within a short amount of time, once the erosion resistant top layer breaks up (Huismans et al., 2021).

Migration of scour holes

After the formation of a scour hole, a hole can grow, decrease in size, or stabilize. The hydrodynamic and geotechnical conditions determine how a scour hole will evolve.

Van Denderen et al. (2022) analysed a scour hole downstream of the non-erodible fixed layer in the river Waal near Hurwenen in the Netherlands (see Figure 1). The scour hole deepens in the years with peak flow conditions and becomes shallow in the years with solely low to intermediate discharges.

Huismans et al. (2021) concluded that the growth of scour holes is bounded by the composition of the subsurface. Scour holes with edges composed of sand or a thin layer of clay are generally more elongated than scour holes in which both edges are composed of a thick layer of poorly erodible material.

Previous studies have related the migration of scour holes either to hydrodynamic or geotechnical conditions solely while we assume that in rivers with a heterogeneous subsoil, the migration of a scour hole is caused by a combination of hydrodynamic and geotechnical conditions. Little research has been done on how these combined conditions influence the evolution of a scour hole, for example how scour holes migrate during peak discharges. This

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knowledge is relevant to understand the long-term dynamics of scour holes and make a deliberate choice whether to fill a scour hole or remain the hole open after formation.

Method

In the river Waal, several scour holes with a depth of more than one meter are found. The scour hole downstream of the non-erodible layer at Hurwenen is one of them, see Figure 1. The navigation channel of the river Waal is measured bi-weekly using multi-beam measurements (Van Denderen et al., 2022) and is, therefore, a good dataset to analyse the effect of peak discharges on the migration of scour holes. In the present study, the dimensions of the scour holes (area, maximum depth, width) will be compared before and after the flood of 2021.

To get a better understanding of how the characteristics of the scour hole (e.g., upstream slope, depth, length) and the composition of the subsurface (thickness of the erosion resistant layer) contribute to the migration of the scour hole, an experimental study will be executed. With flume experiments with unsteady flow conditions, the dimensions, and the composition of the subsurface of the scour hole will be systematically varied to identify the key controls of scour hole migration.

The findings of the experiments will be used to set up an idealised (one-dimensional) numerical model for a first analysis of the processes in and around a scour hole.

Finally, a three-dimensional numerical model will be developed using an open source CFD (Computational Fluid Dynamics) model like OpenFOAM or a more applied model like Delft3D. The model will be validated with field data and experimental data. The scour model will be used to make estimations on the long-term evolution of scour holes and their effect on the stability of infrastructure.

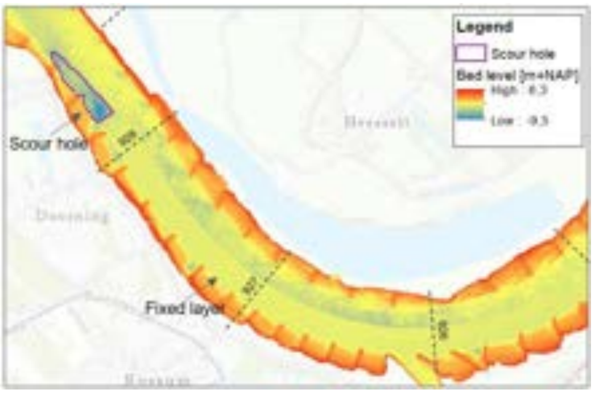

Figure 1. Bathymetry of the Waal near the side channel at Hurwenen (Source: RWS GeoWeb 12-06-2023).

Results

The analysis of the multi-beam measurements will show whether scour holes grow under peak discharges and eventually become stable over time. If possible, a relation between the initial dimensions and the migration rate will be found. The experiments and the numerical model are used to prove the relation by varying systematically the characteristics of the scour hole.

Based on model simulations a conclusion will be drawn whether a certain scour hole could be left open after formation. If the stability of infrastructure is at risk, a strategy will be developed on how to fill the scour hole manually, with the least negative effect on the long-term morphology of the river.

Conclusion

Analysing and identifying the key characteristics of scour holes and the processes in and around scour holes that cause the hole to migrate helps to understand the long-term evolution. Based on this knowledge a deliberate decision can be made to leave the scour holes open or to fill the scour holes manually after the formation. In this way, the stability of infrastructure is guaranteed, with the least possible disturbance of the natural conditions of the river system.

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