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Effects of navigation on sediment distribution at river bifurcations

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Introduction

The Rhine is one of the busiest routes for navigation in the world. The main branch of its delta connects the sea port of Rotterdam with major urban and industrial areas in Germany. About every three minutes, a ship passes the border near Lobith, 24 hours a day and 7 days a week. It is plausible that the continuous passages of ships have effects on sediment transport, morphology and bed sediment composition. That is why differences in groyne field dynamics (Ten Brinke, 2005) and underwater dune growth (Cisneros et al, 2019) between the southern half and the northern half of the river have been ascribed to the different effects of eastbound loaded vessels sailing upstream and westbound empty vessels sailing downstream.

Kazi (1998) pioneered the two-dimensional depth-averaged modelling of the effects of a moving ship on the water motion around and below the ship. Usually, however, navigation effects are not represented explicitly in two-dimensional morphological models of the Rhine. Rather, they are lumped in the calibration of empirical predictors for hydraulic resistance and sediment transport processes. The river management authority, Rijkswaterstaat, traditionally found the resulting inaccuracies acceptable, because it uses models mainly for assessing the effects of interventions. Rijkswaterstaat assumed that most of the systematic errors due to poor representation of navigation effects would cancel out when comparing simulations with and without interventions. With increasing demands of accurate model results, however, we start questioning this assumption, especially at river bifurcations.

River bifurcations are key elements in morphological evolution and management of the Dutch Rhine branches. Their modelling has developed gradually in decades of research (Sloff & Mosselman, 2012). Meaningful morphological computations require two-dimensional or three-dimensional approaches, because one-dimensional models would depend on imposing a user-defined nodal point relation to describe the distribution of sediment transport over the branches downstream. It is not possible to derive a feasible nodal point relation from more detailed physics-based representations of the underlying mechanisms (Van der Mark & Mosselman, 2013). Moreover, nodal point relations change as the morphology evolves (Kleinhans et al, 2008). Navigation might affect the distribution of sediment transport too.

Our objective is therefore to assess the effects of navigation on the sediment transport distribution at bifurcations. We use the findings for recommending possible further steps to include these effects into the morphological models of the Rhine.

Method

We fielded a reconnaissance mission by boat to the Pannerdense Kop and IJsselkop bifurcations of the Rhine to qualitatively assess the effects of passing ships on the water motion at bifurcations (Fig. 1). We recorded our observations using photography and video. We inferred potential effects on sediment transport and morphology by interpreting the observed changes in the flow.

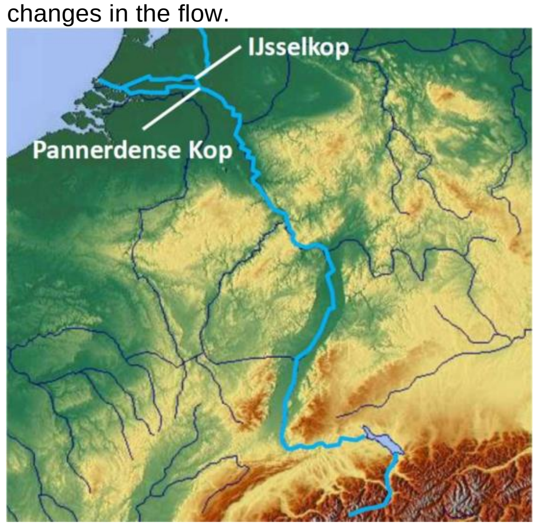

Figure 1. Location of Pannerdense Kop and IJsselkop bifurcations within the catchment of the river Rhine.

Results

The return currents around ships were so strong that they even drew water from the other branch, which means that water from a downstream branch flowed back to the bifurcation and then onward into the branch of the ship passage (Fig. 2). We inferred that this must also lead to a redistribution of the sediment transport at the bifurcation. The effect was stronger at the IJsselkop (Figs. 2-4) than at the Pannerdense Kop for two reasons. First, the rivers at the IJsselkop are about one third of the rivers at the Pannerdense Kop, so that ships occupy a larger part of the cross-section. Second, ship traffic was busy on both branches below the Pannerdense Kop but mainly limited to the IJssel branch below the IJsselkop. The latter asymmetry implies that the distribution of sediment transport at the IJsselkop is truly affected as sediment withdrawn from one branch is not compensated by sediment with-drawn in a similar way from the other branch.

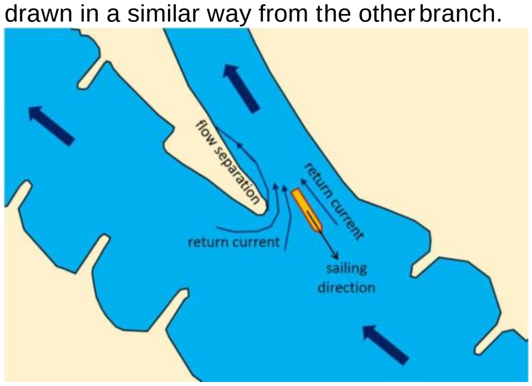

Figure 2. Sketch of ship-induced return currents drawing water and sediment from the left Nederrijn branch into the right IJssel branch.

Figure 3. Video still of flow caused by ship sailing from the IJssel downstream of the bifurcation into the Nederrijn upstream of the bifurcation. The IJsselkop is visible to the right. The flow towards the ship separates at the IJsselkop, leaving a trace of turbulent water at the mixing layer.

Another relevant observation was that ordinary discharge-induced flow separated at the bifurcation like in Bulle's (1926) experiments, despite the absence of pronounced bifurcation angles. This can be explained from the oblique approach flow that resulted from redistribution of flows over the cross-section to realize the discharge distribution that fits the downstream branches. Ship passages enhanced the associated phenomena of eddies and turbulence generation at the mixing layers.

Figure 4. Video still of flow caused by ship sailing from the IJssel downstream of the bifurcation into the Nederrijn upstream of the bifurcation.

Conclusion and recommendations

The observations suggest that navigation significantly affects the distribution of sediment transport at bifurcations. We recommend quantifying the potential effects by carrying out morphological computations using Delft3D with Kazi's (1998) representation of the hydrodynamic effects of moving ships. If this model study confirms that navigation effects are significant, we recommend developing physics-based parameterizations of navigation effects for inclusion in the routine morphological computations of Rijkswaterstaat.

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