Partitioning of water and sediment over bifurcation points under the influence of climate change: consequences and mitigation

NKWK RIVERS2MORROW @Twente University

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Introduction

When lowland rivers approach the sea, they form deltas that are characterized by the presence of bifurcation points. In pristine circumstances, a delta is dynamic and changes constantly due to avulsions. As a result, a delta is characterized by (many) bifurcation points where the river splits into two (or more) branches which eventually builds the characteristic form of a delta. It is a dynamic pattern of branches. In engineered rivers, bifurcation points exist within confined geometry. The confinement comes from the presence of levees, groynes and revetments. It depends on the location of the bifurcation point (upper delta, lower delta) whether gravel, sand, silt or a gravel-sand or sand-silt mixture is distributed over the branches.

Examples of bifurcation points in engineered rivers can be found in, among others, the Netherlands (the Rhine river), in Romania (the Lower Danube), in the USA (Mississippi) and in Myanmar (the Ayeyarwady river) (see figure 1).

Stability of river bifurcations is important for safety reasons and for navigation. Stability in this context means, that the bifurcating branch stays open (does not silt up) and hence, that the distribution of water and sediment remains between reasonable bounds. In the Netherlands for instance, the safety downstream of the bifurcation points in the Rhine River is determined under the condition of a fixed partition of the discharge over the bifurcation points (Schielen et al. 2007), Schielen et al. 2018). If this partition is not in accordance with the assumptions, one of the branches gets too much discharge (with respect to the agreed standards) and as a result, the water levels in that branch become higher. Especially at extreme discharges, this may then cause a severe safety problem for those branches.

Insight in the stability properties of bifurcation points (i.e. whether both branches stay open or not) , and in measures that are able to steer water and sediment to restore or maintain the stability is therefore vital knowledge for water authorities that have bifurcation points in there maintenance-area.

Aim of the research

The aim of this research is (1) to study the partitioning of water and sediment at bifurcation points in lowland rivers, (2) analyze the long-term behavior and stability properties with respect to discharge of water and sediment of these bifurcation points and (3) study measures that are able to control the morphology of the bifurcation points. The project is limited to lowland rivers, including bifurcation points in the downstream part of the delta, i.e. under tidal influence.

Method

The method that may be used to study the bifurcations varies from using simple, conceptual 1D models with uniform sediment to gain insight in the basic mechanisms and principles, to more complex 2D/3D-morphological models with mixed sediment. It will be necessary to perform a thorough analysis of available morphological data of existing bifurcation points, and (if not available or scarce) collect data in the field or perform experiments in the laboratory. The theoretical approach may lead to new model concepts that can be calibrated and validated with existing and new data.

We propose the following steps

WP1: As a start, we study the temporal evolution of bifurcation points and the trends that follow from that. This gives insight in the state that the bifurcation points are: stable, unstable or transient. Parameters are (among others) the changing conditions over time of the sediment composition of the bed, (large and intermediate scale) bedforms, the state of the floodplain and the partitioning of the water discharge. Different river systems are compared to eachother with respect to these parameters.

WP2: Based on the insights of WP1, we analyse the essential mechanisms and processes that play a role in the evolution of bifurcation points and in the partitioning of water and sediment. In particular, we study the influence of mixed size sediments, of changing geometry of the floodplains and of changing boundary conditions as result of climate change.

WP3: This workpackage is on the advances in numerical modelling of bifurcation points in lowland rivers. The insights of WP2 are used to model the bifurcation points. We start by reduced complexity models (1D) but also use more advanced 2D and 3D models.

WP4: Once we sufficiently understand the dynamics of bifurcation points, we can think of measures that influence the partitioning of water and sediment in such a way that the stability of bifurcation points is guaranteed for the long term.

More on river bifurcations and some cases

The stability of bifurcations in rivers in general is an open question. Analyses with (idealized) models indicate that there are multiple stable configurations possible in which both branches remain open, or in which one of the branches silts up. Wang et al. (1995)) use a stability analysis for this problem with a very simple 1D-approach under the assumption of uniform sediment and show that there are stable configurations with both branches open, as well as stable situations with one branch closed. Since then, many authors have made extensions to that pioneering work, often with the assumption of a constant discharge. A number of studies address the stability of bifurcations with less idealized models, focusing on a particular situation (presence of bars (Bertoldi et al. 2009), bends (Kleinhans et al. 2008), Kleinhans et al. 2011) or secondary flow (Dutta et al. 2017). Results show that there are multiple stable situations possible with both branches open, depending on model parameters like the Shields parameter. Schielen and Blom (2018) analyzed the stability of bifurcating points with a reduced complexity model including mixed sediments. They also find the there are multiple stable states with both branches open, and they show that the equilibrium state which is reached (both branches open, or one branch closed) is dependent on initial conditions with respect to depth of the branches and composition of the bed.

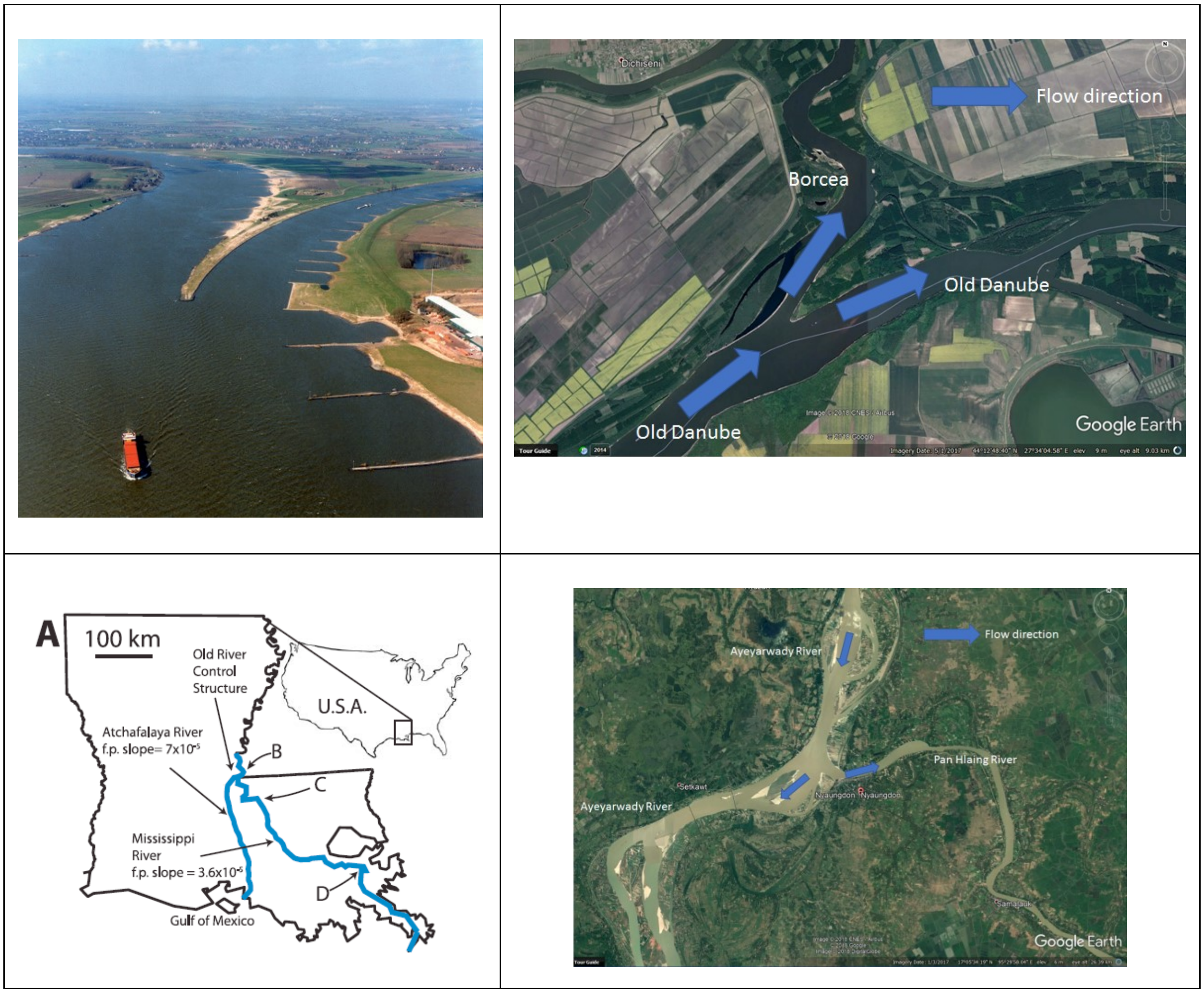

Figure 1: Top left: Bifurcation of the Upper Rhine into the Waal River (left) and Pannerdens Canal (right). Courtesy B. Broekhoven. Top right: Google Earth image showing the Old Danube – Borcea bifurcation. Bottom left: Schematic representation of the Misissippi-Atchafalaya bifurcation. From Edmonds (2012). Bottom right: Google Earth image of the bifurcation of the Ayeyarwady river near Nyaung Don, Myanmar.

The fact that river bifurcations might be unstable over a long temporal scale may lead to a situation where one of the branches silts up and closes (tipping point). As a result, the discharge partitioning changes (i.e. with the same upstream discharge, the partitioning over the branches changes over time, eventually leading to a situation where one of the branches doesn't get any discharge at all). Thus, what we now consider as a basic state in the field (e.g., the configuration of the bifurcation point at the Rhine river), might actually be a transient situation towards a state with only one open branch. Insights with respect to stability-properties may provide valuable input for river managers. They can use that information to consider their maintenance and management decisions. Another reason for instability is that bed degradation (which is the combined response of river normalization of decades to centuries ago, and probably also the response to dam construction which withholds sediment), acts differently on the bifurcating branches. Hence, one branch might erode more than the other one, and the discharge partitioning changes. This can already be observed in the Dutch Rhine branches (see Blom 2016) where measurements show that the bed degradation at the Pannerdens Canal is higher than the bed degradation of the Waal River (and hence the Pannerdens Canal attracts more discharge). The two Rhine bifurcation points therefore have control structures which regulate the discharge and hence, mitigate possible morphological developments. The third reason why a discharge partitioning might change is the consequence of climate change (i.e. changing discharge regimes, changing sediment composition and sediment supply and changing flood plains, which (all or part) may affect the slope of the river).

Possible solutions are sediment augmentation, measures in the river bed that actively direct discharge (sediment and/or water) to one of the branches or high-tech and large impact regulation works.

Possible case-studies

Mississippi

Edmonds (2012) observes similar behavior as mentioned above with respect to long term changes in discharge partitioning for the Mississippi-Atchafalaya system. As a result of slope differences between the Mississippi and the Atchafalaya it was shown that at very high upstream discharges (higher than 12.600 m^3/s), the discharge of the Atchafalaya increases at the expense of the Mississippi. At lower discharges, it is the other way around. It was also shown that if the bifurcation is not controlled by a structure (as it is to date), the Atchafalaya would become the dominant river over a timespan of approx. 300 years.

Upper and Lower Rhine-Meuse delta

The most obvious appearance of bifurcation points in the Netherlands can be found in the most upstream part of the Rhine. As a result of two subsequent bifurcations, the upper Rhine bifurcates in three different branches. The partitioning of discharge at extreme conditions determines the downstream safety and risks, which is the reason that this discharge is ‘fixed as is explained in the Introduction. In the downstream part of the Rhine-delta, in the south-western part of the Netherlands, there are still the remains of the once dynamic delta, revealing a number of bifurcation points. The dynamics of these bifurcations is somewhat different than the upstream ones, which is due to (1) the nature of the sediment, (2) the presence of tidal effects and (3) density stratification effects due to salt water intrusion. Here the bed sediment consists of silt and clay rather than gravel and sand and hence the partitioning over the branches is different than the case where the bed consists of gravel and sand.

Lower Danube

Yossef et al. (2016) describe the dynamics of a bifurcation in the lower Danube delta, the Bala-Lower Old Danube bifurcation. Historical discharge measurements show that the Lower Old Danube has received significantly less discharge over the last 45 years. Simulations with a 2D-morphological model indicate that over the next 50 years, the discharge towards the Lower Old Danube decreases with another 25%. This is the result of the morphological changes. The bed level in the Lower Old Danube aggrades with approx. 1 cm/a while the degradation rate in the other branch is approx. 0.6 cm/a. Yossef et al. (2016) showed that taking measures in the Bala-branch (constructing a sill and a guidance wall) would reduce the discharge in the Lower Old Danube considerably to only 5% of the discharge instead of 25%. This would enhance the stability of the bifurcation point.

Ayeyarwady River

A final example that can be mentioned is the bifurcation of the Ayeyarwaddy river near the city of Nyaung Don, Myanmar. The city is located right downstream of an almost T-shaped river bifurcation of the river. During high discharges, the large morphological activity influences the flood water levels and hence the flood safety of the city. At this moment, there is hardly any data available to set up a proper model to make predictions about the long-term evolution of this bifurcation point. This evolution, however, is extremely important for the city, as well as for the downstream delta where many other bifurcation points are present. The upstream geometry, and the grain size distribution of the bed sediment over a reach of 20-25 kilometers upstream most likely also plays a role in analyzing this problem.

These examples show that the dynamics of bifurcation points in (highly or moderate) engineered rivers is uncertain. In general, it is difficult to predict the time-evolution of the discharge of water and sediment over the bifurcation points. For the (spatial and urban) development of the area around the bifurcation point, and for the planning of measures to reduce flood risk, it is important to know the long-term trends in the discharge of water and sediment, as well as the consequences of measures. In particular, in most cases one wants to maintain a more or less stable situation in which both bifurcating branches remain open. For this, it is important to have insight in the possibilities of engineering or natural measures to regulate the partitioning of both water and sediment. Examples of such measures are sills, regulation works, and possibly underwater vanes and guidance walls.

Connection to other Rivers2Morrow projects

This project is closely connected to *Response of the Rhine-Meuse upper delta to climate change and sea level rise* (lead by TU Delft), *Response of the Rhine-Meuse lower delta to climate change and sea level rise (*lead by Utrecht University*)* and *Improved quantification of lowland sediment transport* (lead by Wageningen University and Research). These 4 projects will have regularly meetings to exchange knowledge and ideas and implement the feedback from RWS and DGWB.

Added value for RWS (executive department) and DGWB (policy department)

Especially the discharge partitioning at the two upstream bifurcation points of the Rhine River is important for maintenance and policy. In the Deltaprogram (a vision on how to organize the Netherlands such that the country remains safe from floods and has enough fresh water, up to 2100 and beyond, and under a changing climate), one of the knowledge gaps that were addressed is about the bifurcation points. The question was raised whether it is necessary to adapt the current discharge partitioning of the bifurcation points. And if the discharge is to be adapted, in what way and how to achieve this. Preliminary studies have been carried out indicating that most probably, up to 2050 no additional action is needed. For the time between 2050 and 2100 however, there is no conclusive answer yet. This PhD-project adds to the knowledge that is needed to reach consensus about that.
The PhD-project also provides insight in the stability of bifurcation points in the lower delta and the measures needed to maintain that stability, and the relation between safety and fresh water supply. As a result of sea level rise, the tidal influence will be noticeable further landward, salt intrusion increases, and the partitioning of sediment over the bifurcation points might chance. The consequences of this

behavior are not yet known but have a potentially large effect on the stability of the bifurcation points and hence on the water policy.

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