Response of the upper Rhine-Meuse delta to climate change and sea level rise

NKWK RIVERS2MORROW @ DELFT UNIVERSITY OF TECHNOLOGY

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Introduction and objective

Recent publications in Nature and Natural Hazards and Earth Systems Sciences have indicated that the melting of the ice cap on Antarctica proceeds much faster than previously thought (DeConto and Pollard, 2016, Tollefson, 2016, De Winter et al., 2017). This has major consequences for the expected sea level rise in the next century and beyond. The KNMI indicates that this faster melting of the ice cap may lead to an additional increase of 70 cm in 2100, 2.5 m in 2200, and 7 m in 2500. Sea level rise results in enhanced aggradation in the Rhine-Meuse estuary, and this aggradational wave slowly migrates upstream in the Rhine-Meuse catchment, up to the most downstream dam. In the current project we will analyze the consequences of the accelerated sea level rise regarding bed level, channel slope, and the partitioning of the water and sediment discharge over the branches of the Rhine-Meuse delta (i.e., the Bovenrijn, the Midden-Waal, the Pannerdensch Kanaal, the Lek, the Grensmaas, and the Zandmaas).

A problem that to date has not received sufficient attention yet acting on the same time scale as sea level rise is the ongoing bed degradation in the upper Rhine-Meuse delta (Blom, 2016). The rate of bed degradation is an order of magnitude larger (2 cm per year) than the current rate of sea level rise (2 to 3 mm per year). This bed degradation is the slow response to the river normalization works conducted in the 19th and 20th centuries. The main channel was significantly narrowed through the construction of groynes and a few bends were cut off. The aim was to increase the flow depth (to facilitate navigation) and to prevent the formation of ice dams (to reduce flooding). The bed degradation has continued to date, which increasingly hinders navigation. More specifically, these navigational problems arise from the spatial variation of the bed degradation rate due to natural and manmade non-erodible river reaches. These shallow reaches result in local bottlenecks that reduce the maximum vessel draught. Nowadays it is the non-erodible layer near Nijmegen that, under base flow conditions, determines the maximum draught of vessels sailing to the Ruhr area. Such a reduction of the draught has economic consequences, given the annual cargo volume transported over the Rhine River (200 million tons on the German Dutch border and 310 million tons on the Dutch Rhine). In addition, the degrading bed threatens the stability of structures such as locks, fixed layers, bank protection, and groynes, and increases the risk associated with exposure of cables and pipelines that cross the river.

The bed degradation may also negatively impact flood risk. The difference in the degradation rate between the Waal branch and the Pannerdensch Kanaal affects the partitioning of the water discharge at the bifurcation point Pannerden. The currently more rapidly degrading Bovenwaal can slowly start to attract more discharge at the expense of the Pannerdensch Kanaal. This would have consequences to flood risk, as the level of levees in the downstream branches is designed based on a given partitioning of the water discharge over the bifurcates. The question here is whether we are dealing with an unstable system and how the partitioning of the flow over the branches develops in the long term.

In addition, there are clear indications that the gravel share (i.e., fraction content of gravel) in the sediment supply to the Rhine-Meuse delta is increasing: the Bovenrijn has transformed from a sand-bed river into a gravel-bed river within a period of only 20 years. This coarsening of the sediment supply from the German Rhine influences the bed elevation and surface texture in the area of the bifurcation point Pannerden, as well as the partitioning of the sediment load (gravel, sand, silt, and clay) over the downstream branches (Frings et al., 2015, Ten Brinke et al., 2001). What does the increased dominance of gravel in the (upper) Rhine-Meuse delta affect navigability, flood safety, and the ecosystem? And how fast does this coarsening process proceed and how quickly does the coarsening effect migrate to the downstream part of the delta? And from when will we experience a decrease of the sediment supply due to dams in the German Rhine at Iffezheim and upstream?

This coarsening of the sediment supply and the resulting bed surface coarsening may already play a role in the current bed degradation. This is because a coarsening wave is often accompanied by a preceding degradational wave: local coarsening reduces the local sediment transport capacity and so the sediment supply to the downstream part of the river.

And how does climate change change the probability distribution of the water discharge? If it affects only (the probability of) the extreme values (minima and maxima) of the water discharge (Sperna Weiland et al., 2015), the effects on channel slope and bed surface texture are limited but logically the effect on flood risk may be significant. If the probability distribution of the flow rate is affected more strongly than just its extremes, we can also expect an effect on the channel slope and the bed surface texture (Blom et al., 2017).

The aim of this research project is to gain insight on the response of the branches in the upper Rhine-Meuse delta to (a) the accelerating sea level rise, (b) a changing probability distribution of the flow rate as a result of climate change, (c) the coarsening of the sediment supply, and (d) foreseen measures. Insight on such long-term river response is important from a fundamental point of view but also in anticipating future change of the Rhine-Meuse delta and in the design of measures such that their negative effects remain limited.

Rivers respond slowly to changes in the boundary conditions: the current adaptation of the channel slope and surface texture takes place on a time scale of the order of tens to hundreds of years. An example is the river adjustment to measures of the Room for the River program in the coming decades. The time scale considered in the proposed project is longer than the one typically considered in engineering (i.e., the time scale that is of interest to river managers). Where the latter time scale is typically in the order of 5-50 years (for instance, WFD or Room for the River programs), in the current project we are looking at time scales of the order of 50-250 years. In addition, the spatial scale is large, with a large part of the catchment area being considered, including the German Rhine and Belgian Meuse.

In the proposed NKWK Rivers2Morrow subproject we will closely collaborate with two other subprojects of the NKWK Rivers2Morrow program: the subproject ‘Effects of climate change on the lower Rhine-Meuse delta’ (PI Kleinhans, starting in 2018) and the subproject on ‘Bifurcation points in the Rhine-Meuse delta’ (PI Schielen, starting in 2019). It will be important to exchange information regarding the current project’s 'downstream boundary' with the subproject of PI Kleinhans, as this downstream boundary at the same time is one of the upstream boundaries in the modeling of the future adjustment of the Rhine-Meuse estuary. Close collaboration with the Numerical RiverLab (Deltares, HKV Consultants, RHDHV, zie https://www.riverlab.deltares.nl/) will enable an efficient start of the project, as well as the communication of insights and model adjustments to the community.

Research activities

Below we briefly outline the different steps in the research project.

1. The trends

Here we investigate past and modern trends in the temporal change of the upstream branches of the Rhine-Meuse delta, and more specifically those of the bed elevation (channel slope), the bed surface texture, statistics of the flow rate, sediment supply from the catchment area, and the partitioning of sediment over the river branches.

2. Scenarios for the boundary conditions

Here we analyze the expected temporal change of factors that determine the long-term development of the upper Rhine-Meuse delta. We set up scenarios for the boundary conditions for the next 50-250 years, as well as for the floodplain morphology and nature restoration in the floodplains.

We also expect to set up scenarios for the partitioning of the sediment load (for gravel, sand, silt, and clay separately) over the bifurcates at the bifurcation points. We will do this in consultation with the sub-project on river bifurcations (PI Schielen). We focus on scenarios because of (a) the limited amount of field data (Frings et al., 2015), (b) the high level of uncertainty of nodal point relations that describe the partitioning of gravel, sand, silt, and clay over the bifurcates, and (c) the still limited reliability of 2D model outcomes in this area. In principle a 2D model could be used to predict the partitioning of gravel, sand, silt, and clay over the downstream branches of a bifurcation point (and possibly to validate nodal point relations), but such model outcomes are still uncertain due to the sum of uncertain submodels (for mass conservation, sediment transport, hiding effects, lateral transport, interaction with the substrate, and friction) and are even unreliable under conditions where the model is ill-posed (Ribberink, 1987, Chavarrías et al. 2018).

3. Expected measures

Future measures and the associated timeline are inherently uncertain. We develop a method of how to deal with future interventions, such as additional river widening or structural sediment nourishment measures, in long-term morphodynamic predictions.

4. River response to scenarios and interventions

Here we determine the river response to scenarios and interventions. We address the following questions:

- how do we set up a morphodynamic model when it comes to long-term (50-250 years) calculations;
- how do we calibrate and validate such a model;
- how do we distinguish the various sources of uncertainty in the model outcomes (i.e., uncertainties in (a) the model equations, (b) the closure relations, (c) the initial conditions, (d) the boundary conditions, and (e) the model calibration)?
- how does the river response to sea level rise and other changing boundary conditions interact with the current bed degradation;

- what is, in this interaction, the role of the uncertain sediment supply from the upstream part of the catchment area and the uncertain partitioning of water and sediment over the river bifurcates?

5. Anticipating expected change

How does the expected river response affect the river functions (flood safety, navigability, maintenance, the discharge of ice, ecology, freshwater availability) over time? Here we anticipate expected change and we advise, if possible, on smart (sediment) management in the upper Rhine-Meuse delta.

Added value for Rijkswaterstaat and DGWB

We expect that this research project provides us with insight on the system behavior of lowland rivers, and how the upper Rhine-Meuse delta will change over the next 50-250 years. This enables the design of measures that 'work with' the river system rather than measures that 'frustrate' the system or the associated river functions. It is important to understand how the river system responds to implemented and foreseen measures, as a large number of measures have been implemented (Room for the River, WFD) and new large-scale measures are under preparation (sediment nourishment, new measures within the framework of the Delta Program). This research provides essential knowledge and input for this. The research also fits well with initiatives in the framework of Living Rivers, (Beekers et al., 2017, https://www.levenderivieren.nl/).

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