Paper 146 - Quantifying Effects of Policy Changes on Navigability in the Dutch Rhine Delta

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ABSTRACT: In the Bovenrijn (where the Rhine enters the Netherlands), bed level degradation is ongoing at a rate of approximately 2 centimeters per year as the river is still adapting to the river training, which has taken place over the last centuries. To counteract this, two sediment nourishments are foreseen in 2016 and 2019, and possibly more will be performed in the future. The effect of such nourishments on navigability is investigated within the scope of this paper.

1 INTRODUCTION

In the Bovenrijn (where the Rhine enters the Netherlands, see Figure 1), bed level degradation is ongoing at a rate of approximately 2 centimeters per year as the river is still adapting to the river training which has taken place over the last centuries. To counteract this, two sediment nourishments are foreseen in 2016 and 2019, and possibly more will be performed in the future.

The Dutch Rhine is a busy navigation route for transport from the port of Rotterdam to the German Hinterland. The above mentioned measures to counteract the effects of the bed level degradation influence the morphology of the river bed, and thus affect navigability. To maintain navigability the navigation channel is regularly dredged, and in the Netherlands the regulation is that the sediment should also be dumped back into the river except for locations which are governed by sedimentation or for maintenance of the summer bed lowering, where sand mining is allowed.

In order to quantify the cumulative effects of the combined measures, a case study of the Dutch Rhine (Bovenrijn, Waal, Nederrijn and IJssel) was setup and computed using the hydrodynamic and morphologic modeling system Delft3D (e.g. Lesser et al. 2004).

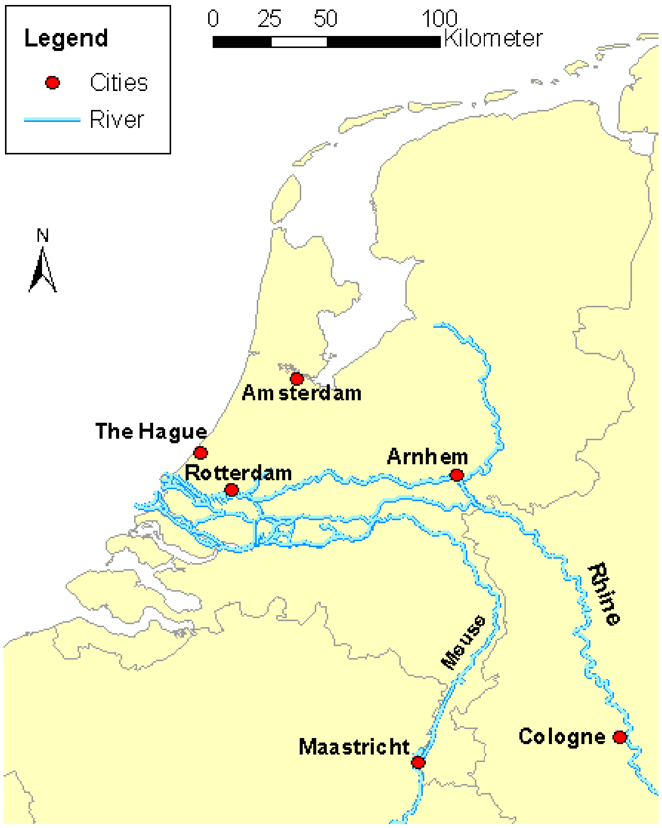

Figure 1: Overview of the Rhine-Meuse estuary (courtesy Anke Becker).

2 MODEL SETUP

2.1 Introduction

In this chapter a short introduction to the model history, the reference model setup (including implementation of the current sediment management policy), and two scenarios with adapted sediment management policies are presented.

2.2 History

The initial development of a model for aiding in sustainable navigation depth in the Rhine started in 2005 (see e.g. Mosselman et al. (2005), Van Vuren et al. (2006)). Over the last decade, the model has been further refined including many innovative aspects for process description (e.g. module for sand mining, dredging and dumping, dune height prediction, graded sediment) and model acceleration (e.g. piecewise constant hydrograph, domain decomposition, cf. Figure 2). Recently, the model was used to evaluate the morphological implications of Room-for-the-River measures (Sloff et al., 2014), and more recently it was used to evaluate bed stabilizing nourishments (Ottevanger et al., 2015).

2.3 Reference model

A quasi-3D model (2D Saint-Venant including helical flow) for the hydro-morphodynamic model is set up using a stepwise (quasi-steady) hydrograph approach including different hydrographs which follow the trend of the last 40 years. The morphological model includes 13 different horizontally and vertically varying sediment fractions ranging from coarse gravel to fine sand, three of which are tracers, such that the path of the nourished material can be tracked.

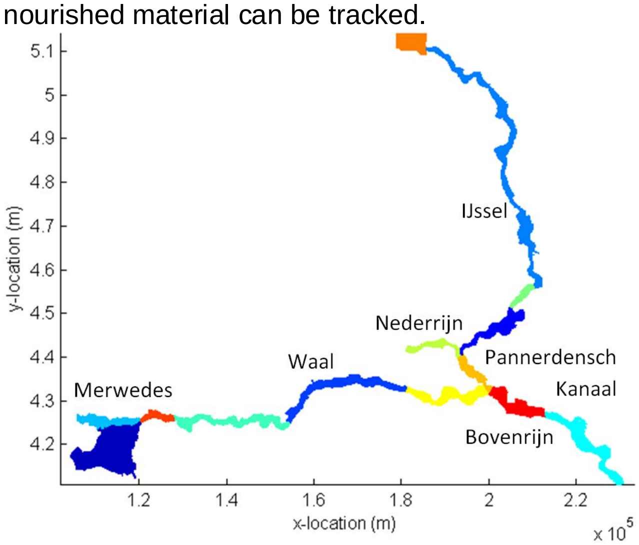

Figure 2: Overview of the 12 computation domains used in the hydro-morphodynamic computations.

Table 1: Dredging and dumping settings for maintenance depth and minimal depth for dumping.

River Reach	Maintenance depth [m]	Minimum depth for dumping [m]
Bovenrijn	2.80 + 0.50 clearance	4.00
Waal	2.80 + 0.50 clearance	4.00
Boven Merwede	4.50 + 0.45 clearance	5.40
Beneden Merwede	4.50 + 0.45 clearance	5.40
Nieuwe Merwede	4.50 + 0.45 clearance	5.40
Pannerden sch Kanaal	2.80 + 0.50 clearance	4.00
Nederrijn (until Driel)	2.80 + 0.50 clearance	4.00
IJssel	2.50 + 0.50 clearance	3.50

Table 2: Overview of sand mining settings

River Reach	River kilometres	Sand mining volumes [m^3/year]
Waal	925–953	90000
IJssel	975–1002	up to 10000
Boven Merwede	953–861	125000

2.4 Scenario 1

In addition to the simulation of hydrodynamics and morphodynamics, sediment management (i.e. dredging and dumping, sand mining) according to the current policy is also included in the model. To maintain navigability in the Dutch Rhine, dredging maintenance is required. Contracts with dredging companies are defined in which a minimum garanteed depth w.r.t to ALW (Agreed Low Water Level, cf. Van der Mark et al., 2014) is specified (see Table 1). According to policy, the dredged sediment may not be removed from the river, and is subsequently dumped back into deeper parts of the river. In certain locations, where permanent sedimentation takes place, dredging without dumping is permitted (see Table 2). In the present scenario the settings are chosen as defined in Kroekenstoel (2014).

Besides the inclusion of sediment management policy, the foreseen nourishments at Millingen aan de Rijn (Bovenrijn) in 2016 and 2019 are included in the model as well. A layer with a thickness of 30 cm will be nourished at all locations which have a bed elevation less than ALW – 4.0 m between river kilometers 862 and 864.5. In 2019 similar nourishment is performed.

2.5 Scenario 2

Scenario 2 is the same as Scenario 1, but from 2020 onwards bed stabilization nourishments are performed every year over a greater reach. Similar to Scenario 1, nourishment of 30 cm are performed at all locations in the fairway which satisfy shipping requirements (see Figure 3).

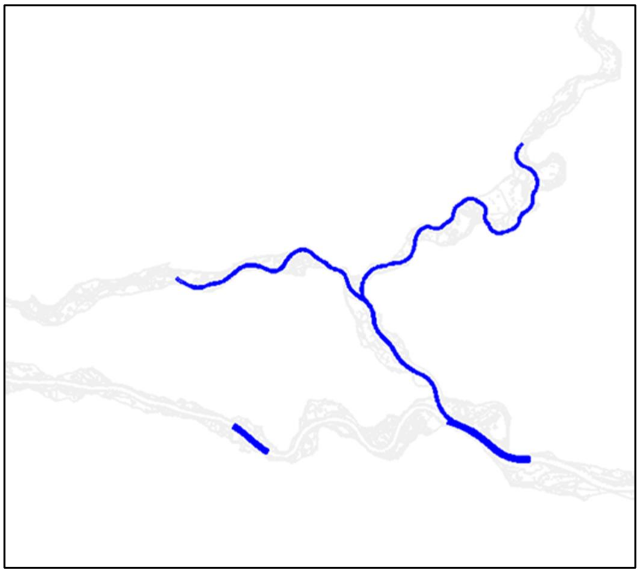

Figure 3: Areas considered for yearly bed stabilisation from 2020 onwards in the Bovenrijn, Pannerdensch Kanaal, IJssel (first 40 rkm), Nederrijn and behind the fixed layer at Nijmegen.

3 RESULTS

3.1 Propagation of bed stabilization

The evolution of the nourished material at Millingen aan de Rijn is shown in Figure 4. A tracer, which consists of the median diameter of the nourished material, is slowly transported in downstream direction. In 2019, second nourishment is performed. This material is again nourished approximately at the same location, which also reveals the propagation in downstream direction.

3.2 Effect on average bed level

The effect of the nourishments on the average bed level in the Bovenrijn, Waal and Pannerdensch Kanaal is shown in Figure 5.

Figure 5a shows that the average bed level in the Bovenrijn is clearly influenced by the nourishments at Millingen aan de Rijn in 2016 and 2019. The yearly nourishments, performed in Scenario 2, lead to an almost constant average bed level over time.

The average bed level in the Waal (cf. Figure 5b) for the cases with nourishment is lower than the bed level in the reference case. Scenario 2 shows a slower decrease than Scenario 1.

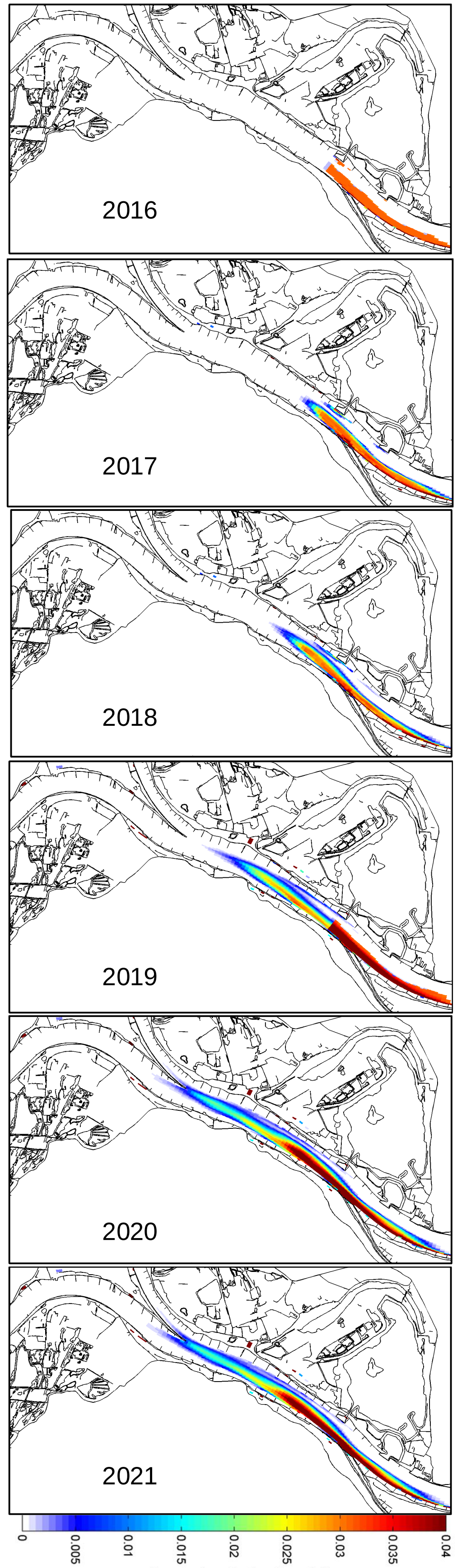

Figure 4: Evolution of the nourished sediment at Millingen aan de Rijn in 2016 and 2019.

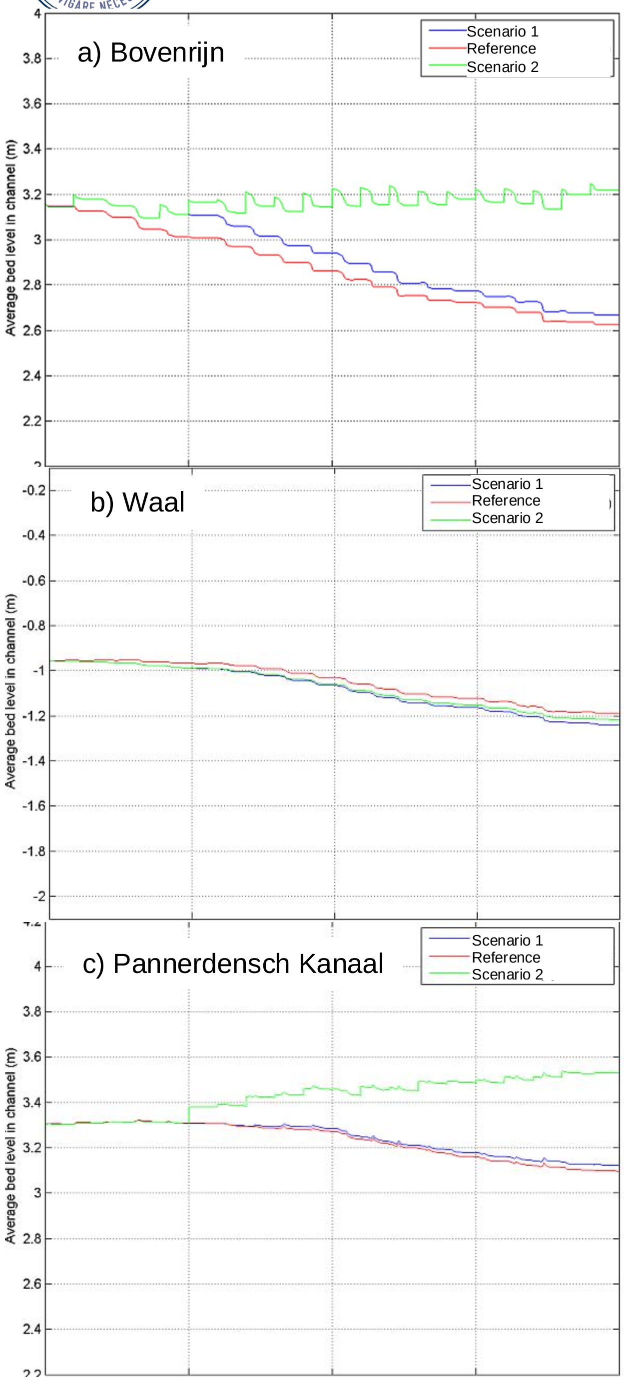

Figure 5: Average bed level for different river reaches for the different cases.

In the Pannerdensch Kanaal (cf. Figure 5c) the behavior in the reference and Scenario 1 is quite similar, although in Scenario 1 the bed level drops slower. The bed level in Scenario 2 increases slightly over time.

3.3 Effect on discharge distribution

The nourishment also affects the discharge distribution as can be seen for the two discharges in Figure 6. From 2020 onwards, a clear acceleration in the trend of the discharge distribution can be observed comparing Scenario 2 with Scenario 1.

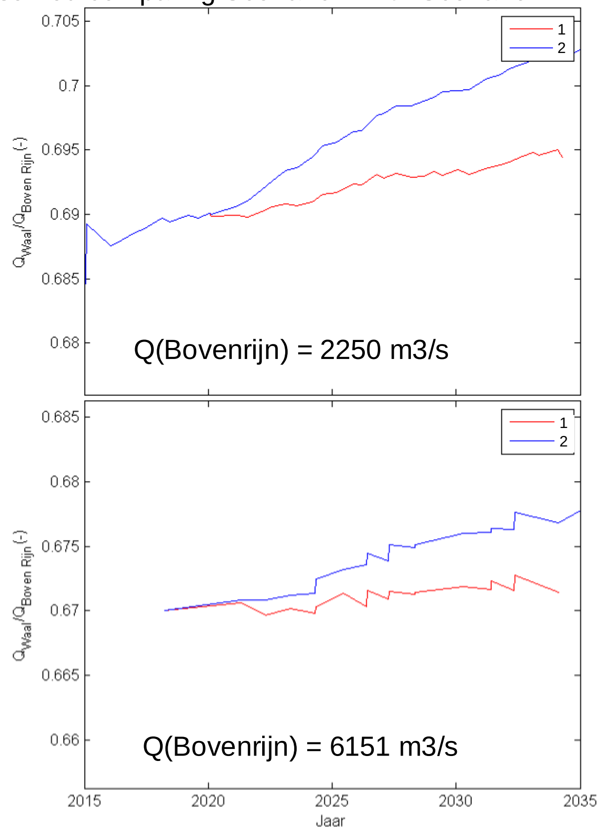

Figure 6: Ratio of the discharge flowing the Waal at the Pannerdensche Kop at low and high discharge levels.

3.4 Effect on navigability

To assess the how the nourishment affects the navigation depth, the 10th percentile of the depth is considered per river kilometer block is considered. Figure 7 shows the distribution of the depth with respect to to ALW as well as the 10th, median and 90th percentile depths (red circles).

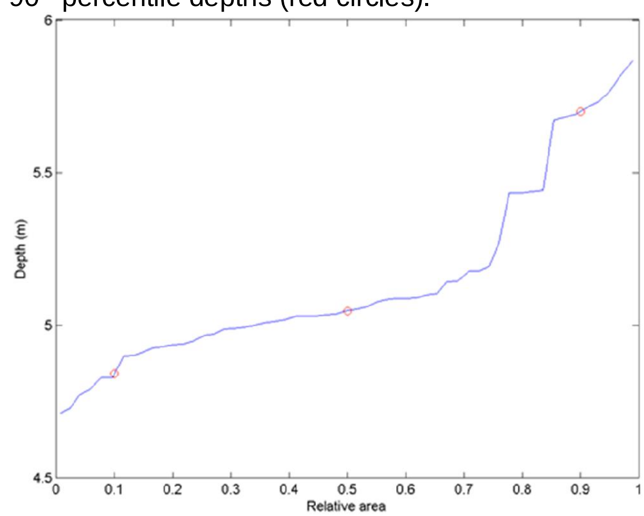

Figure 7: Depth distribution as function of the relative area in the navigation channel.

Figure 8 shows the effect of nourishment on the 10th percentile of the depth with repect to ALW along the Bovenrijn, Waal and Nieuwe Merwede (solid lines). The dashed lines indicate the variability of the 10th percentile of the depth with repect to ALW during the year. From this plot, it can be seen that the navigation depth is not significantly affected by the yearly nourishments from 2020 onwards. In the Bovenrijn, a reduction of the navigation depth is visible (rkm 860-875). In the region of the nourishments the navigation depth remains larger than the maintenance depth. The fixed layer at Nijmegen does however show up as a possible bottleneck for navigation. This is however not related to the nourishments.

Figure 9 shows the effect of nourishment on the 10th percentile of the depth with respect to ALW along the Pannerdensch Kanaal and IJssel. In the Pannerdensch Kanaal, a decrease in the navigation depth is visible along rkm 868-880.

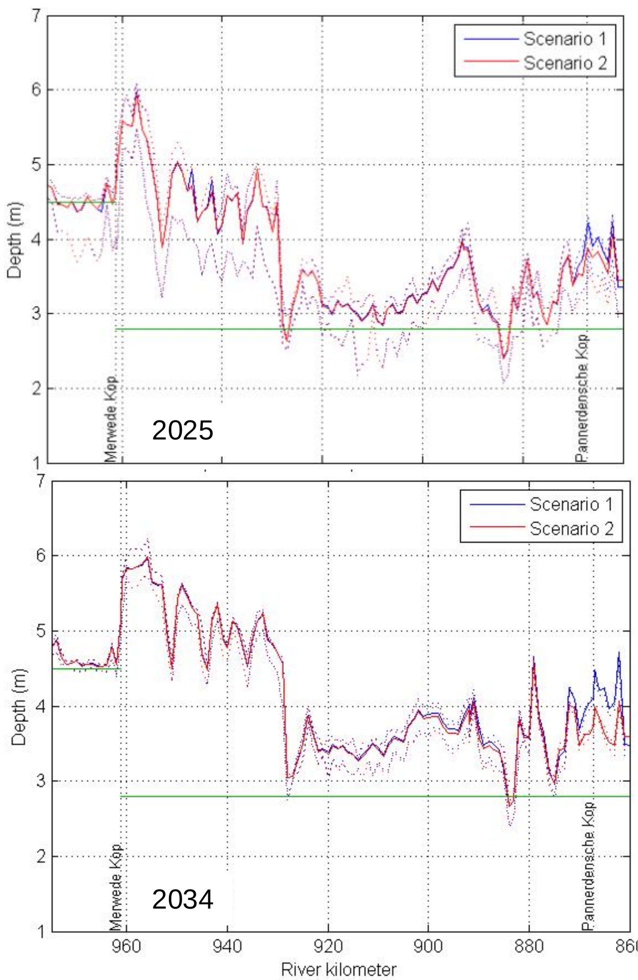

Figure 8: 10th percentile of the depth with respect to ALW per kilometre block in the Bovenrijn, Waal, and Nieuwe Merwede. The green line denotes the maintenance depth.

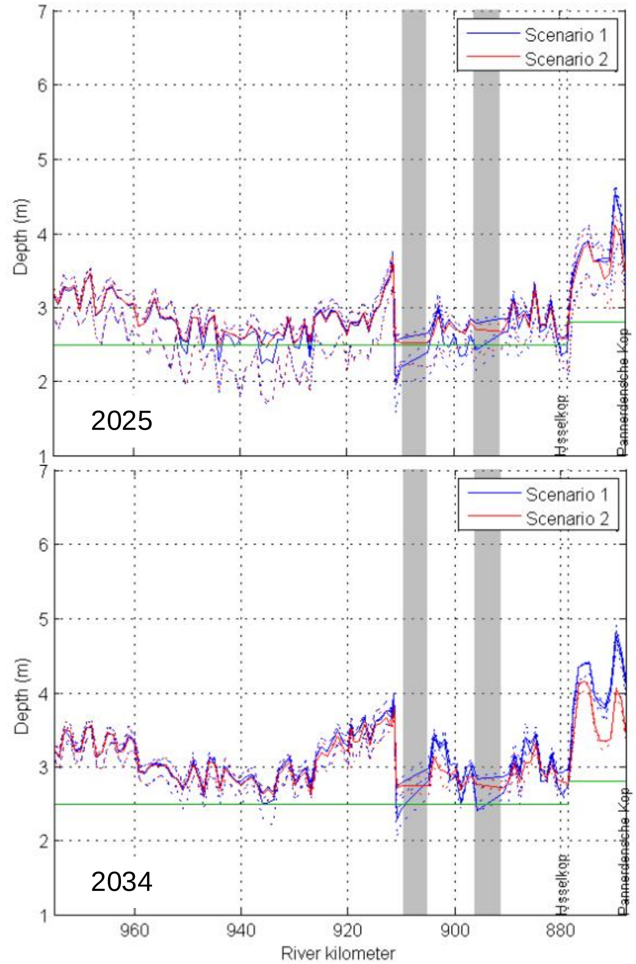

Figure 9: 10th percentile of the depth with respect to ALW per kilometre block in the Pannerdensch Kanaal and IJssel, the shaded areas denote jumps in the river kilometres, caused by former bend cut-offs. The green line denotes the maintenance depth.

4 DISCUSSION

The present research shows two scenarios in which nourishments are performed. The nourishment at Millingen aan de Rijn shows propagation of approximately 1 kilometre per year in downstream direction (cf. Figure 4). The nourishments are shown to positively affect the average bed level in the Boverijn and the Waal. In the Pannerdensch Kanaal, however, an increase in the average bed level is observed (cf. Figure 5). The reason for this is twofold: firstly the criteria for nourishment, and secondly the discharge distribution on the Pannerdensche Kop bifurcation (cf. Figure 6). The criteria for nourishment are checked per river kilometer and not per river reach, so this can lead to an increase in the average bed level along a river reach. The change in bed level also leads to an increase in the discharge, which is transported to the Waal in Scenario 2. This shows that it is important to impose similar measures on both downstream branches to avoid large changes in the discharge distribution. Figure 8 and Figure 9 show the navigation depth is lowered in the upstream areas due to the nourishments, but these areas still satisfy shipping requirements.

5 CONCLUSION

The results indicate that bed stabilization nourishments help to stabilize the bed. The computations show that the navigation depth is reduced at the location of the nourishments. However other locations, not yet affected by the nourishments, have the least navigation depth.

The outcomes of the simulations show that further optimization of the bed stabilization, both in nourishment criteria as well as balancing the nourishments in both downstream branches, is recommended.

The model is also shown to be a valuable tool to assess the effects for navigation based on the combined influence of multiple river engineering measures, and changes in the sediment management policy for the decades to come.

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