Laying bare systemic river bed changes in the river Rhine

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Introduction

Sandy or gravel river beds are continuously evolving in response to flow conditions and to the sediment supply coming from upstream. These morphodynamic forcing mechanisms can be affected by river engineering measures such as channel widenings, placements or adjustments of navigation or flood-protection structures, dredging activities or rehabilitation measures such as re-meandering or side-channel connections. To be able to anticipate and appropriately act on morphological changes in rivers, it is important to link cause-and-effect relations between bed response and their dominating triggers. This is particularly important in highly-engineered navigable rivers, where multiple influences from close-by and further away can obscure the dominating causes of local bed level changes, and thereby possibly point in the wrong direction when it comes to sustainable river management practices.

In recent years, such aspects have become increasingly important for the river Rhine in the Netherlands, as it is now recognized that there may be severe implications for river navigation, ecology, drought risk and flood risk if existing large-scale morphological trends continue in the way as they are now. Specifically, an apparent systemic trend of bed incision within the Rhine branches may lead to bottlenecks for river navigation and flood plains may dry out under lowering of mean water levels (e.g. Hiemstra et al, 2020). Also, a possible shift in the discharge distribution at bifurcation points may create a new hydrodynamic equilibrium in the system, and distort various water management practices.

A key objective of the recent national Dutch Delta Programme on Integrated River Management is to get bed level incision under control while addressing river functions such as navigation, flood management and ecology. The challenge is to separate systemic large-scale morphodynamic trends in the river from more localized effects that are caused by specific river interventions and may only be of temporary nature (Paarlberg et al. 2020). Only if the rate and the spatial distribution of systemic river bed incision are known, appropriate countermeasures can be designed. For this purpose, we compare methodologies to study systemic bed level trends, and show that different methods can lead to different results. The different outcomes show that interpretation of morphodynamic trends should be done with great care, for the river Rhine, but also for other rivers around the world.

Large-scale bed changes according to different methods

The traditional approach to study large-scale bed level changes is to spatially-average river bed levels and to see how these progress over time. Fig. 1 gives an example of this approach for a location in the river Rhine near river-km 870. The blue points show how the bed locally moves up and down within a range of +/- 20 cm during a period of about 12 years. The orange points show the bed level changes if an average bed level of a reach of 5 km is considered (see also Ylla Arbos et al. 2019). A clear downward trend of about 1.4 cm/year then reveals itself. When applying the wavelet methodology as done in Van Denderen et al. (2020, 2021) for bed signals >30 km, the downward trend becomes only half as strong (green line).

This result from the wavelet-methodology suggests that the 5-km-average trendline is still affected by bed level changes that act on scales of 10-20 km. Changes that originate from such spatial scales can hardly be considered systemic for a river as the Rhine, and may be associated with time scales of “only” several years to one or two decades. Indeed, trends in spatially-averaged bed levels that change on such time scales can clearly be seen in Fig. 2 for the IJssel branch of the River Rhine (compare blue and yellow line).

Fig. 2 uses the same methods as in Fig. 1. Only now it is shown for a river reach of around 100 km in the IJssel branch of the river Rhine, depicting only the fitted bed-level trends. It can be seen that the trends of the 5-km-averaged bed level still vary significantly over the past 20 years: in the past 5 years the bed along the entire river IJssel mostly went up by 0.5 to 1 cm/year (blue line), while over the past 10 to 20

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years the bed was in some places stable and upstream of river-km 950 even went down by up to 1 cm/year (yellow and red line). The result from the wavelet analysis for signals >30 km (green line) shows a much smoother spatial distribution of bed level trends. The result is mostly consistent with the red and yellow lines in Fig. 2, but still some clear differences are found. For example, at river-km 960 a clear pronounced peak in bed level rise follows from the spatially-averaged methods, giving twice as large bed level change-rates compared to the wavelet result. Around river-km 900 the opposite is found: here, the wavelet method gives a downward trend of nearly 1 cm/year while the spatially-averaged methods produce a nearly stable to rising bed.

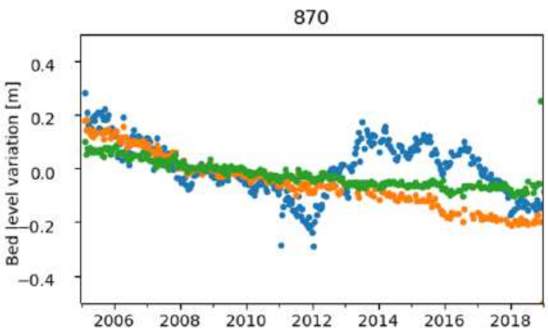

Figure 1. Bed level changes at location rkm870 in the river Waal just downstream of the Pannerdensche Kop when considering the raw local bed measurements (blue), when taking the raw data averaged over a reach of 5km (orange) and when using filtered wavelet analysis for signals >30km (green). Data as in Van Denderen et al. (2021).

Conclusions

The wavelet methodology allows to study morphological changes in a river associated with specific spatial scales. Here we filtered out smaller-scale effects to reveal systemic large scale trends. In a traditional spatially-averaged approach, smaller-scale processes remain present in the results. For the case of the river Rhine, where bed level incision has become a major concern in river management, it is important to identify exactly which trends are truly systemic, and how they will continue if no action is taken. It shows that traditional methods to estimate such trends can easily be off by a factor of two or more and can mistakenly interpret local temporary changes for longer-term systemic trends. It is recommended that the wavelet methodology as applied here becomes a standard tool for long-term river management, at the very least to provide complementary information to bed level trends derived from traditional spatially-averaged methods. Finally, also for rivers elsewhere around the world, the wavelet methodology is recommended to help identify systemic bed level trends.

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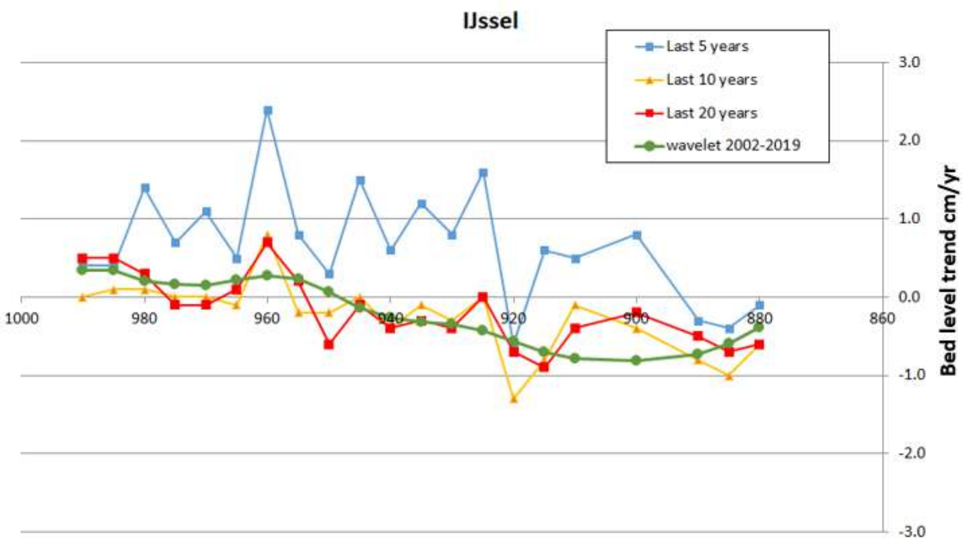

Figure 2. Yearly bed level changes in the river IJssel as derived from raw 5-km averaged data for the past 5, 10 and 20 years, together with results from the filtered wavelet analysis using 17 years of data for spatial scales >30 km.