Levee morphology and evolution in the fluvial-tidal realm

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Introduction

Natural levees are sloping deposits of sand, silt and/or mud that are build up along the sides of a channel. They are common and pronounced geomorphological features in river and delta landscapes in which they form elevated areas in further low-relief floodplains (Adams et al., 2004). The along channel position of levees and their morphology influences hydraulics and the distribution of water and sediment within river and delta systems (Brierly et al., 1997). Despite its relevance on delta evolution, research on levees is sparse and commonly limited to case-studies (e.g. Cazanacli and Smith, 1998; Adams et al., 2004; Filgueira-River et al., 2007) losing the general understanding and implications of levee development on a larger scale. The need for a comprehensive understanding was underlined by Pierik et al. (2007) who found that levee dimensions vary throughout the delta over space and time, driven by changes in hydraulic and sedimentary processes. Their field based method focussed on the comparison of purely fluvial levees in the Rhine/Meuse delta, excluding the lower tidal rivers and estuaries as well as different boundary conditions that occur in other deltas and river systems. Therefore, the objective of this study is to assess the influence of boundary conditions on levee morphology and evolution.

Methods

To assess the influence of boundary conditions a systematic study was conducted with morphodynamic numerical modelling in Delft3D. The model enclosed 4 sand sediment fractions (300/250/125/75µm) as well as silt and clay while the initial bathymetry resembled the lower Old Rhine system during the early-mid Holocene. In addition, field data from this system was collected for comparison. The influence of three different boundary conditions was tested, aiming to cover distinct hydraulic regimes where levees can be formed: 1. Constant fluvial discharge without tides (Q=700 m^3/s), 2. Varying fluvial discharge without tides (Q=690-1000 m^3/s), 3. Constant fluvial discharge with tides (Q=700 m^3/s, M2=0.50 m).

Results

Levee development is simulated in all three contrasting models, see morphologic results in Figure 1. In general, higher discharge magnitudes and larger tidal amplitudes cause the maximum levee height to increase (not visualised). Yet, an increase in tidal amplitude has a larger influence on maximum levee height than an increase in fluvial discharge.

In all model runs levee evolution can be divided into several phases. These phases are caused by the morphologic evolution of the levee itself and by the development of crevasses in the levees. In general, three phases of levee evolution can be distinguished (Figure 2): 1. A heightening phase, in which the levee grows in height; resulting in a triangle shape cross-section. 2. A widening phase, in which the levee starts to widen significantly while continuing to grow in height. 3. A phase linked to the crevasse channels, in which the crevasse channels evolve more and create their own levees in the larger complex. In the lithological cross-sections of the Old Rhine river system multiple phases of levee formation can be found as well (Figure 3).

The overall morphology of the levee-complexes becomes more complex when water fluctuations are induced. In the model without water level fluctuations (Figure 1a), smooth levees form. When water fluctuations are introduced (Figure 1b,c) crevasses form that breach the levees. In the case of the tidal water level fluctuations the crevasses form simultaneously with the origination of the levee complex. With variable discharge crevasses seem to originate when the levee complex is already established.

Conclusions

Levees form as the result of differential sedimentation of fine sand, silt and clay as water and sediment flow over the edges of a channel. The maximum height of levees is controlled by the maximum water level, determined by discharge magnitude and tidal amplitude.

Undisturbed levees form when fluctuating water levels are absent during formation (Figure 1a). When water fluctuations are relatively small and occur on a yearly basis, relatively smooth levees are still able to form. These levees are only breached by a small amount of crevasses after a significant amount of time (Figure 1b). However, when larger water level fluctuations occur on a daily basis (e.g. by tides) intricate levee-crevasse complexes evolve where levees and crevasses develop simultaneously (Figure 1c). In general, the evolution of levees consists of multiple phases that are induced by feedbacks between accommodation space (max. water level), evolving morphology (heightening, widening and crevasse formation) and hydrodynamics. This demonstrates that multi-phase levee deposits do not have to be initiated by extreme up- or downstream events but can simply form due to the evolution of the levee itself. Aforementioned findings will help in unravelling the causes of levee phases in natural systems.

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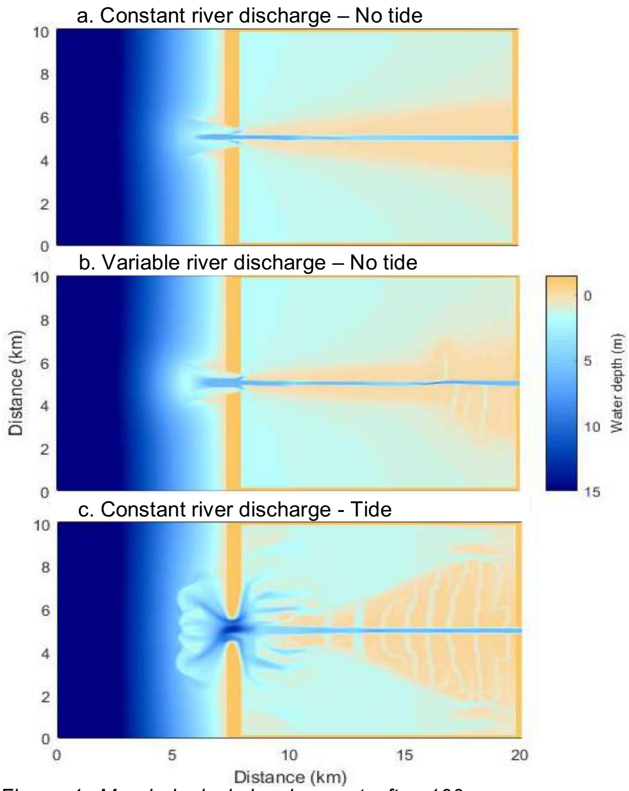

Figure 1. Morphological development after 100 years. a. Constant river discharge (700 m^3/s) without tides. b. Variable discharge (691-1000 m^3/s) without tides c. Constant river discharge (700 m^3/s) and tide (M2=0.50 m).

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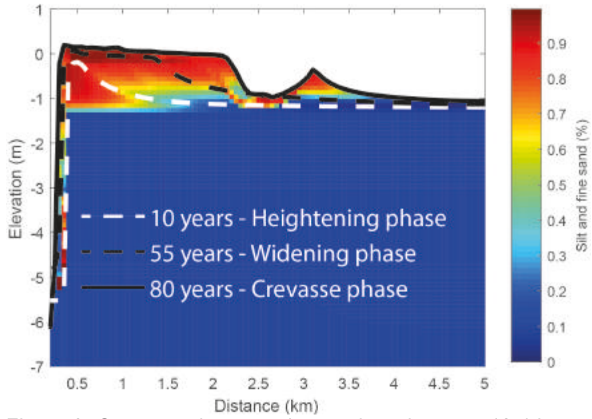

Figure 2. Cross-section over the southern levee at 18.4 km displaying the combined percentage of silt and fine sand from the model with fluctuating discharge without tides (b. in Figure 1). Lines represent bathymetry at three moments in time representing the three key phases in levee development: heightening (dashed white), widening (dashed black) and crevasse evolution (black).

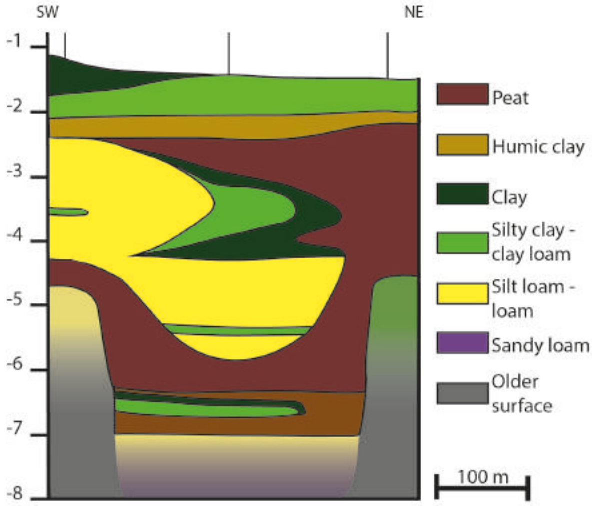

Figure 3. Lithological cross-section of overbank deposits of the Old Rhine river system east of Alphen aan den Rijn. The cross-section shows two levee phases. The oldest levee phase is preceded by a crevasse system. Depth is below NAP. Vertical lines indicate location of boreholes.

References
Adams, P.N., Slingerland, R.L., Smith, N.D. (2004). Variations in natural levee morphology in anastomosed channel flood plain complexes. Geomorphology, 61(1-2): 127-142.

Brierly, G.J., Ferguson, R.J., Woolfe, K.J. (1997). What is a fluvial levee? Sedimentary Geology, 114(1-4): 1-9.

Cazanacli, D., Smith, N.D. (1998). A study of morphology and texture of natural levees – Cumberland marshes, Saskatchawan, Canada. Geomoprhology, 25(1-2): 43-55.

Fielgueira-Rivera, M., Smith, N.D., Slinterland, R.L. (2007) Controls on natural levee development in the Columbia river, British Columbia, Canada. Sedimentology, 54(4): 905-919.

Pierik, H., Stouthamer, E., Cohen, K. (2017). Natural levee evolution in the Rhine-Meuse delta, the Netherlands, during the first millennium ce. Geomorphology, 295: 215-2