Channel dynamics and floodplain formation of a dynamic meandering river:

insights from flume experiments

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Research group
River and delta morphodynamics

1) Background

Rivers have distinctive patterns such as multi-channel braided and single-channel meandering. Why these different river patterns emerge is only qualitatively understood. Braided rivers emerge when banks are weak, whereas meandering rivers emerge for stronger banks (Kleinhans, 2010). Vegetated banks and cohesive floodplains provide bank strength, which reduces widening of the channel. The low channel width-depth ratio leads to formation of alternate bars instead of mid channel bars, which is seen as an indication for meander formation. Rivers self-organize their morphology through interactions between channels, floodplain and vegetation. In order to predict the migration and bank/floodplain development of rivers and their ultimate pattern, we unravelled these interactions in a series of flume experiments.

Objective

How does the interaction between channel dynamics and floodplain formation lead to the development of different river patterns?

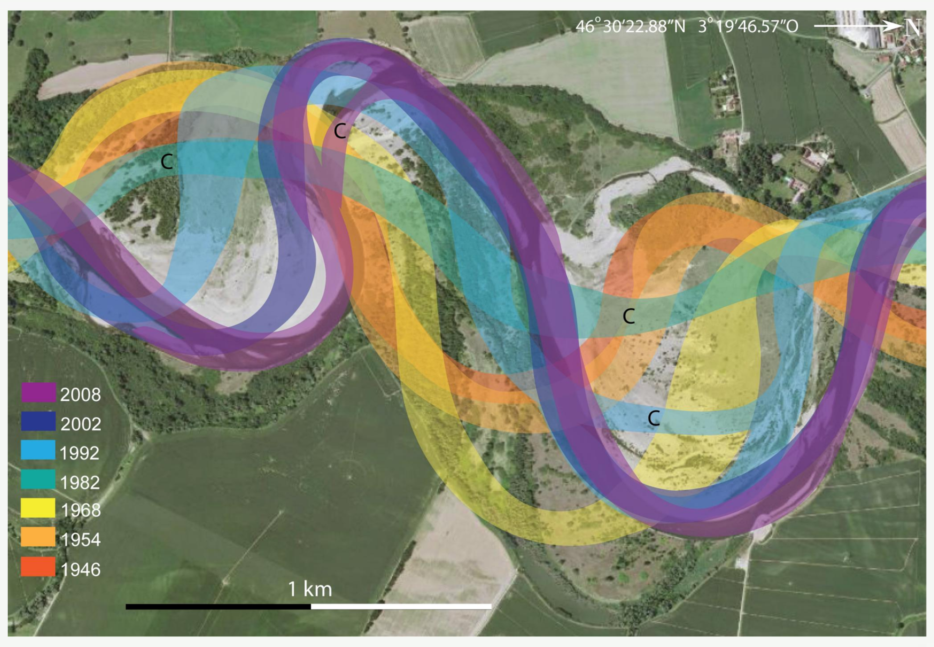


Fig. 1. The river Allier in France illustrates how the interaction between channel dynamics, floodplain and vegetation lead to a dynamic meandering river with bend growth and chute cutoffs.

2) Bar and bend theory vs. upstream perturbations

Meander formation theories:
Bar instability (*irregularities in channel bed*);
Low width-depth ratio → formation of alternate bars.
Bend instability (*irregularities in channel planform*);
Bar and bend growth → formation of meanders

Dynamic meandering as result from the nature of bend instabilities (Fig. 2):

- Absolute instability affects both direction and is forced by a single perturbation.
- Convective instability affects the channel in one direction and has to be sustained over time.

Lanzoni & Seminara (2006) found that for meandering rivers with low width-depth ratio bend instability is convective.

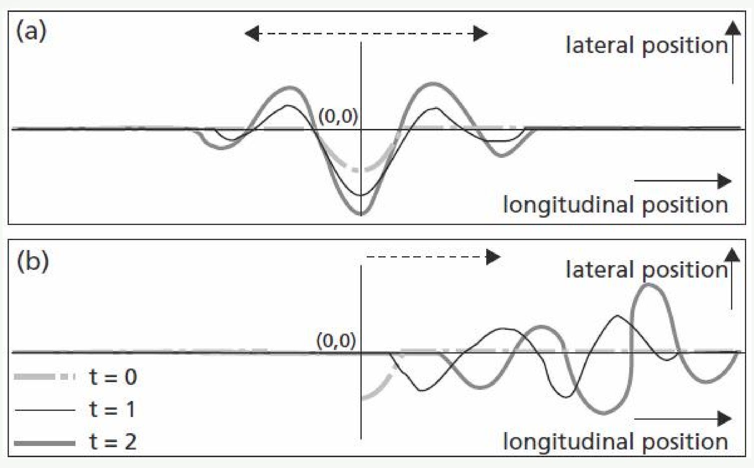


Fig. 2. Migration of a perturbation of the channel planform. (a) Absolute bend instability spreads in both direction. (b) Convective bend instability only migrates in downstream direction in the case of sub-resonant conditions and the dynamics decrease after the perturbation.

3) Alternate bar formation static perturbation

Alternate bars formed in a straight channel with a static perturbation upstream (Fig. 3). These bars and related bends grew to a maximum amplitude before chute cutoffs. Afterwards, the bends were fixed on one location, so that a low sinuous channel remained in the experiments.

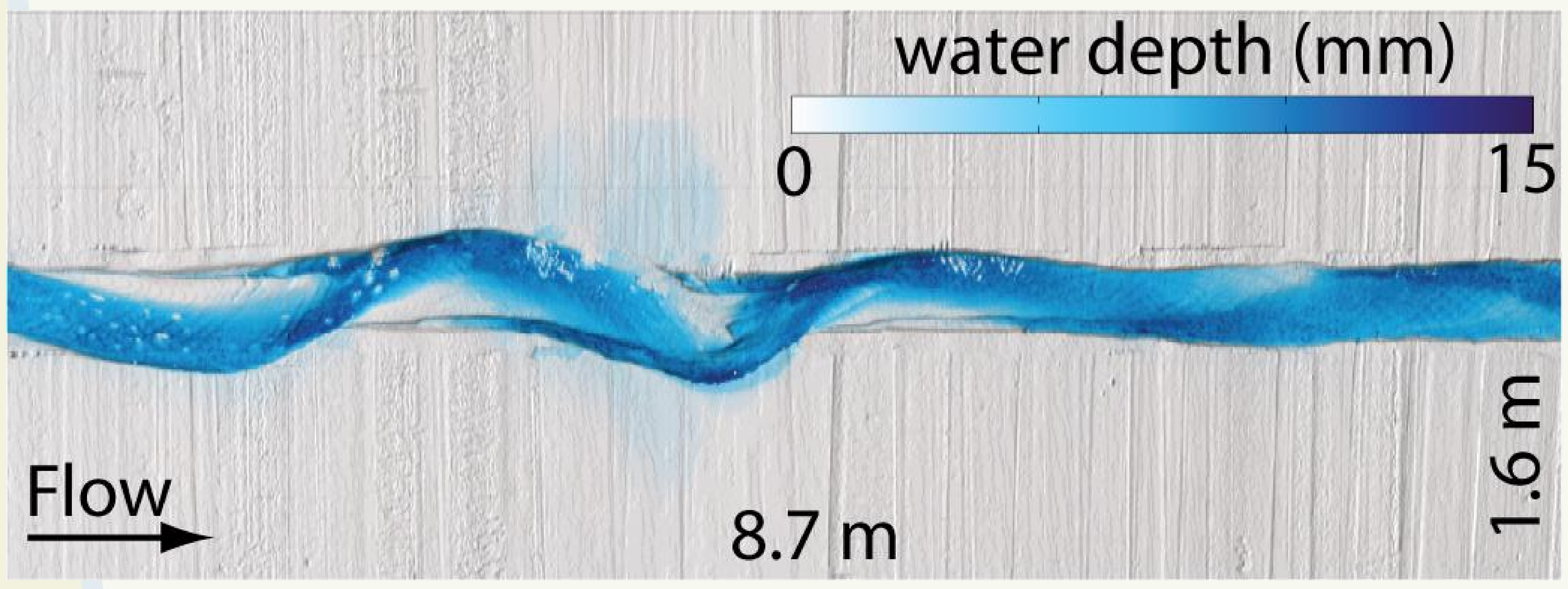


Fig. 3. Shaded Digital Elevation Model with blue colors to indicate the water depth. A series of alternate bars developed from an initial straight channel with a static perturbation, so that alternate bars are formed from upstream to downstream direction.

4) Dynamic lateral perturbation and meandering

Continuous erosion of the outer bank during bankfull conditions resulted in meander growth, while discharge exceeding bankfull discharge determined the development of chute cutoffs. With a continuous perturbation upstream, the channel developed to a dynamic meandering river with continuous bend growth and chute cutoffs (Fig. 4). Chute cutoffs limited the meander amplitude and channel sinuosity (Van Dijk et al., 2012).

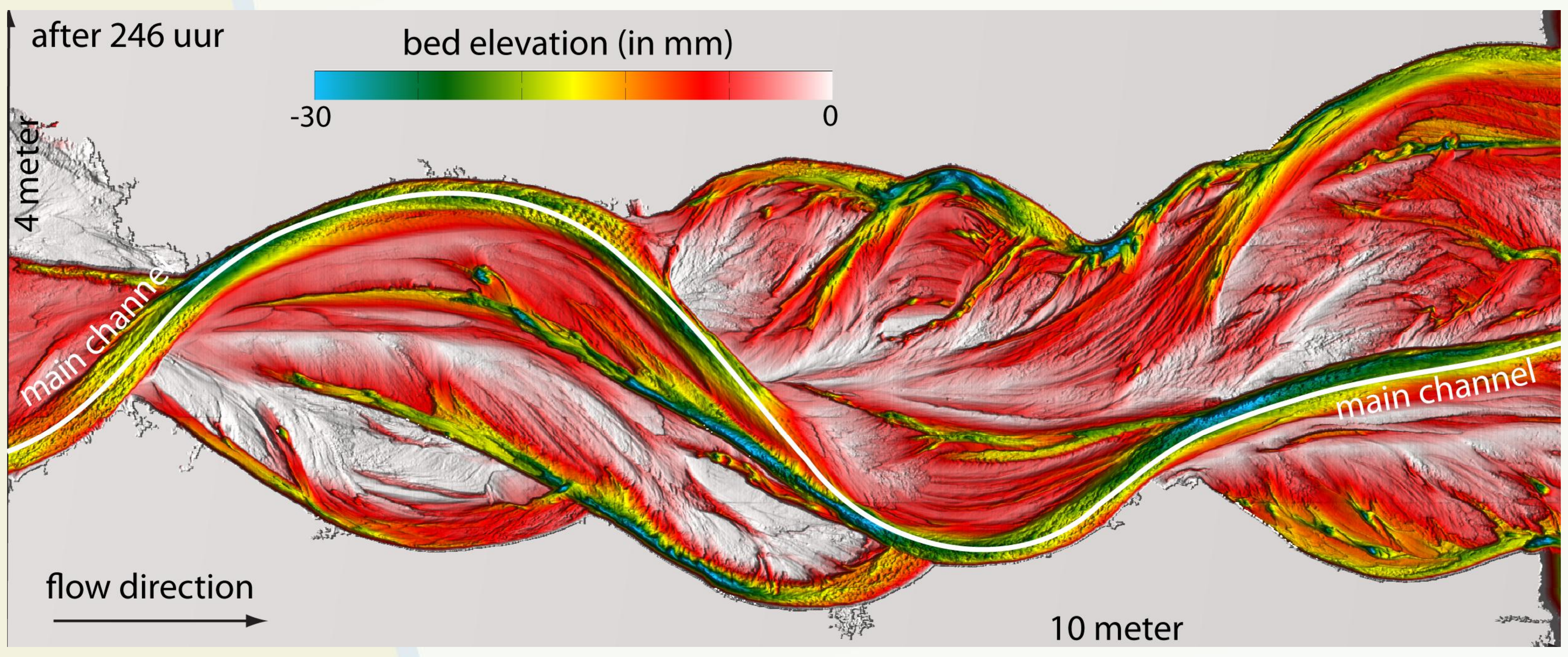


Fig. 4. The continuously transverse moving upstream boundary caused high-amplitude dynamic meandering river with scroll bars and infrequent chute cutoffs. After chute cutoffs, the former channel was closed by a plug bar and new meander bends were formed (Van Dijk et al., 2012).

5) Vegetated floodplain

We performed experiments in which vegetation was uniformly distributed on the floodplain of a meandering river. Vegetation increased flow resistance on the banks and decreased bank retreat. This led to tighter bends and a higher sinuosity compared to experiments without vegetation (Fig. 5).

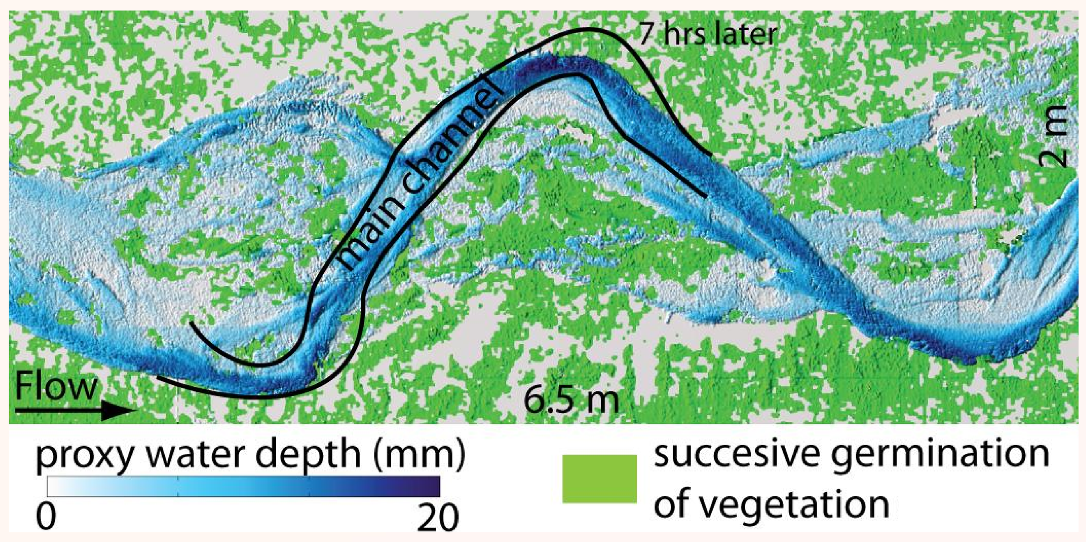


Fig. 5. Uniformly distributed vegetation on the floodplain stabilized the banks. Local differences in erosion rate developed tight bends after 7 hrs of flow. Bank erosion occurred irregular (photo, top) and by bank undercutting and bank collapsing (photo, bottom). Mortality of the vegetation resulted in a chute cutoff after 30 hrs of flow.

6) Floodplain construction and destruction

Bank erosion by bend migration and cutoff was balanced by deposition of sediment forming new floodplains. We conducted two experiments where the initial bed consisted of a poorly sorted sand. In one of the experiment we added a silt-size fraction in the sediment feed, which resulted in a meandering river instead of a braided river. The experiments had a simple hydrograph of bankfull discharge and discharge exceeding bankfull (Fig. 6, Van Dijk et al., 2013).

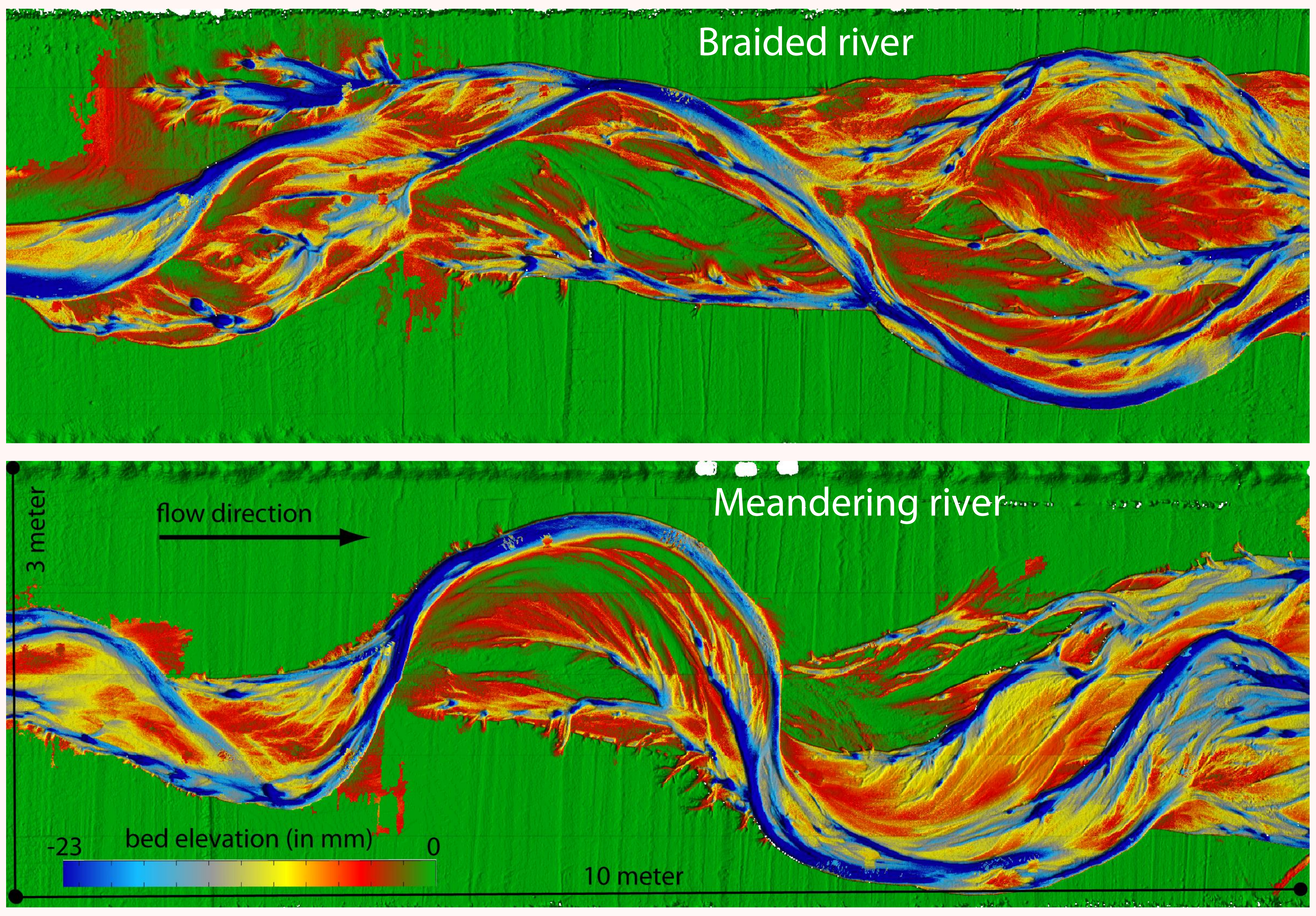
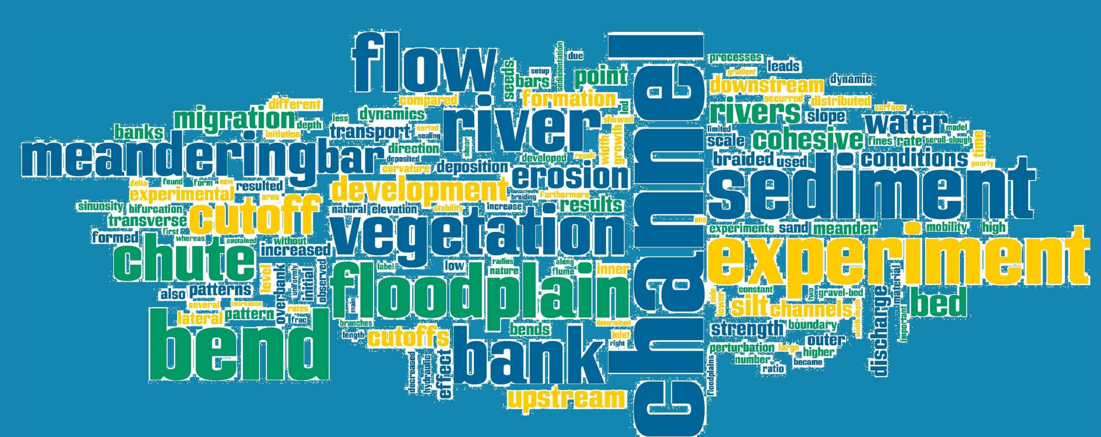
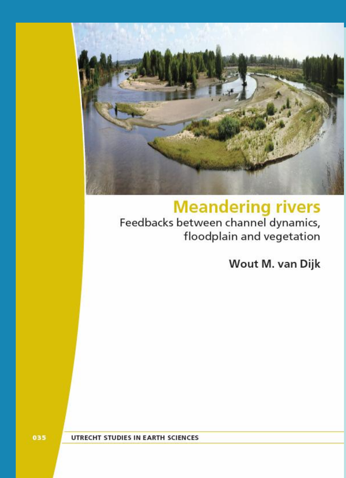


Fig. 6. Detrended Digital Elevation Maps of an experimental braided and meandering river after 120 hours of flow. Both rivers had lateral migration of the channel, but the deposition of silt led to sustaining of the meandering rvier due to less number of chute cutoffs (Van Dijk et al., 2013).

7) Conclusions

- In-channel morphology depends on the width-depth ratio, which determines the initiation of alternate bars.
- A static perturbation causes only low amplitude, static bends. A dynamic lateral upstream perturbation leads to dynamic and higher sinuosity meandering with a richer morphology than hitherto produced in experiments.
- Flow exceeding bankfull discharge determines the development of floodplain formation, which balances bank erosion. However, the discharge level and duration of the flow exceeding floodplain elevation may lead to chute cutoffs.
- Cohesive sediment results in distinctive floodplain that sustain dynamic meandering by limiting the number of chute cutoffs and parallel channels.
- Riparian vegetation induces concentration of flow in the main channel. Stabilization of banks by riparian vegetation results in sustained low channel width-depth ratios.





References & Acknowledgements

- Van Dijk, W.M. (2013). Meandering rivers – feedbacks between channel dynamics, floodplain and vegetation. PhD-thesis
- Van Dijk, W.M., Van de Lageweg, W.I. and Kleinhans, M.G. (2012). Experimental meandering with chute cutoffs - JGR-Earth Surface.
- Van Dijk, W.M., Van de Lageweg, W.I. and Kleinhans, M.G. (2013). Formation of a cohesive floodplain in a dynamic meandering river – ESPL.
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