Erosion processes and retreat prediction of re-naturalized banks in regulated navigable rivers

Duro, Gonzalo; Crosato, Alessandra; Kleinhans, Maarten G.; Uijttewaal, Wim S.J.

Publication date
2020

Document Version
Final published version

Citation (APA)
Duro, G., Crosato, A., Kleinhans, M. G., & Uijttewaal, W. S. J. (2020). *Erosion processes and retreat prediction of re-naturalized banks in regulated navigable rivers*. 122-123. Abstract from NCR Days 2020, Nijmegen, Netherlands.

Erosion processes and retreat prediction of re-naturalized banks in regulated navigable rivers

Gonzalo Duró[a,b*], Alessandra Crosato[a,c], Maarten G. Kleinhans[d], Wim S. J. Uijttewaal[a]
[a]*Delft University of Technology, Dep. of Hydraulic Engineering, PO Box 5048, 2600GA Delft, the Netherlands*
[b]*Witteveen+Bos, Leeuwenbrug 8, 7400AE Deventer, the Netherlands*
[c]*IHE-Delft, Department of Water Engineering, PO Box 3015, 2601 DA Delft, the Netherlands*
[d]*Utrecht University, Department of Physical Geography, PO Box 80115, 3508 TC Utrecht, the Netherlands.*

Keywords — Bank erosion, navigation, restoration, modelling

Introduction

A balanced combination of economic and ecological functions of a river system is a challenge due to requirements that are often conflicting (e.g., Boeters et al, 1997). Current legislation promotes restoration of trained banks to improve the habitats of plants and animals, and the water quality (WFD, 2000). The result is that bank protection works are removed in an increasing number of channelized river reaches which now experience bank erosion and channel widening. This research aims to characterize the processes and drivers of bank erosion in regulated navigable rivers, and based on the insights gained propose a model to predict the final bank retreat. The ultimate goal is to allow for optimized approaches that combine multiple functions through a better understanding of the system.

Methods

The methodology is based on systematic field measurements and observations of a case study that presents a broad range of bank erosion rates after the removal of protections in 2010 (Duró et al., 2019). The study site is located in the Meuse River near the cities of Gennep and Boxmeer in the Netherlands. We measured ship waves, bank material properties, flow velocitites and the bank topography every 2 months for two years with UAV-SfM (Duró et al., 2018). Vegetation growth was also observed and recorded with photographs during the same period.

Field observations and interpretation

Ship waves frequently act on the banks at the minimum regulated water level of the river, which created a shallow area (terrace) over the last 9 years. The terrace, dividing the profile in upper- and lower-bank areas, is where waves currently break and dissipate. Deep primary waves shear the terrace during drawdown through transverse currents and as bores during upsurge. These also attack the upper-bank toe, together with secondary waves. Erosion progression shows that both ship waves and floods contribute to erosion (Figure 1), which is possible to distinguish due to their different timing over the year. At banks with long terraces, floods only produced mass failures without net material loss.

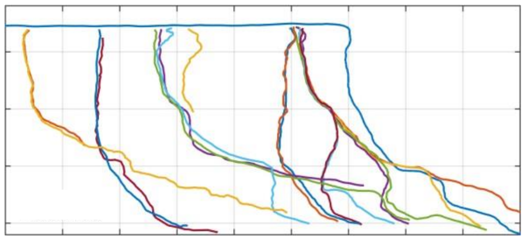

Figure 1. Upper-bank erosion at km 153.963. Note zero net erosion between yellow and blue profiles on the left, after mass failure during a flood event. Gridline spacing = 1 m.

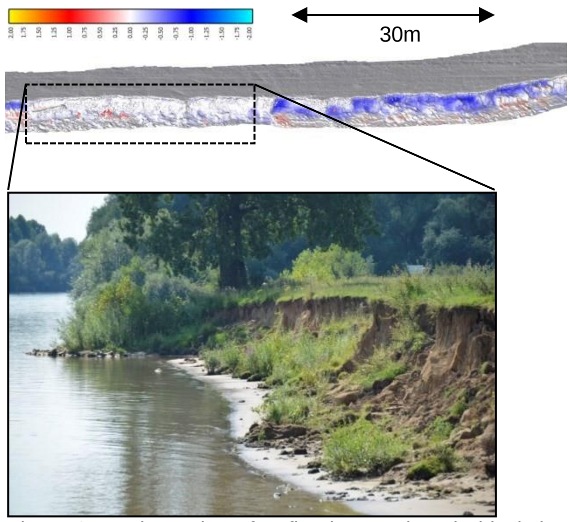

Figure 2. Bank erosion after flood event (top, in blue), km 153.490-153.630. Stretch with vegetation at upper-bank toe (bottom) does not present erosion or failure events.

Grown vegetation at the bank toe was observed to prevent mass failures during floods (Figure 2). Nevertheless, the continuous erosion of the terrace that lowers its elevation, led to increasing wave penetration and higher wave impacts on the upper bank. As a result, vegetation patches progressively lost their

* Corresponding author
Email address: gonzalo.duro@witteveenbos.com (G. Duró)
URL: //kbase.ncr-web.org/rivercare/projects/project-b2

substrate and were dislodged, especially during low-flow conditions.

Flow currents during floods were significant at banks with short terraces and salients, contributing to bank erosion at all phases of the cycle, i.e., also entraining bank material and transporting slump-blocks.

Bank erosion model

Bank retreat is mainly dependent on bank material properties for given loads at the study site (Duró et al., 2019). The terrace geometry and morphological development was found to correlate well with soil cohesion, and three type of bank profiles have been characterized. After these findings, a model to compute the final extension of bank retreat for homogeneous banks is proposed, based on a Patheniades type of formulation (Equation 1).

$$\frac{dZ_b}{dt} = \varepsilon(\tau_b - \tau_c) \qquad (1)$$

Where Z_b is the bed elevation, ε is an erodibility coefficient, τ_b is the bed shear stress induced by ship waves, and τ_c is the critical shear stress for entrainment of cohesive soils.

τ_b are computed considering primary wave drawdown and the shoaling, refraction and dissipation of primary and secondary waves based on energy balance (Battjes and Jansen, 1978). The model also considers run-up by combining Bergsma et al. (2019) and Pujara et al. (2015) formulae. For the study site, the model is calibrated through ε against measured profiles.

The results indicate that primary wave bores exert the highest loads on banks and ultimately shape the final terrace configuration. Figure 3 shows three types of banks after 7 years of development and at the final predicted configuration. Less resistant banks evolve faster and still 50% of further bank retreat is expected after 7 years (Fig. 3a), whereas more resistant banks (Fig. 3c) evolve slower and final retreat is estimated almost 3 times larger than after 7 years of evolution.

Future work will focus on expanding the model for unregulated rivers and improve accuracy of predicted erosion rates by including more factors and processes.

Acknowledgments

This study is part of the RiverCare programme, funded by NWO (project no. 13516), with partners Rijkswaterstaat, LievenseCSO, HKV Consultants, and Royal HaskoningDHV. The research benefitted from cooperation within the network of the Netherlands Centre for River Studies (NCR).

References

Battjes, J. A., & Janssen, J. P. F. M. (1978) Energy loss and set-up due to breaking of random waves. In Coastal Engineering 1978 (pp. 569-587).

Bergsma, E. W., Blenkinsopp, C. E., Martins, K., Almar, R., & de Almeida, L. P. M. (2019) Bore collapse and wave run-up on a sandy beach. Continental Shelf Research, 174, 132-139.

Boeters, R. E. A. M., Havinga, H., Litjens, G., Verheij, H. J. (1997) Ten years of experience in combining ecology and navigation on Dutch waterways. 29th PIANC Congress.

Duró, G, Crosato, A, Kleinhans, M.G., Uijttewaal, W.S.J. (2018) Bank erosion processes measured with UAV-SfM along complex banklines of a straight mid-sized river reach. Earth Surface Dynamics 6: 933-953.

Duró, G., Crosato, A., Kleinhans, M.G., Winkels, T.G., Woolderink, H.A.G., & Uijttewaal, W.S.J. (2019) Distinct patterns of bank erosion in a navigable regulated river. Earth Surface Processes and Landforms.

Pujara, N., Liu, P. L. F., & Yeh, H. (2015) The swash of solitary waves on a plane beach: flow evolution, bed shear stress and run-up. Journal of Fluid Mechanics, 779, 556-597.

WFD (2000) EU Water Framework Directive 2000/60/EC (http://data.europa.eu/eli/dir/2000/60/oj, last access Dec. 2018).

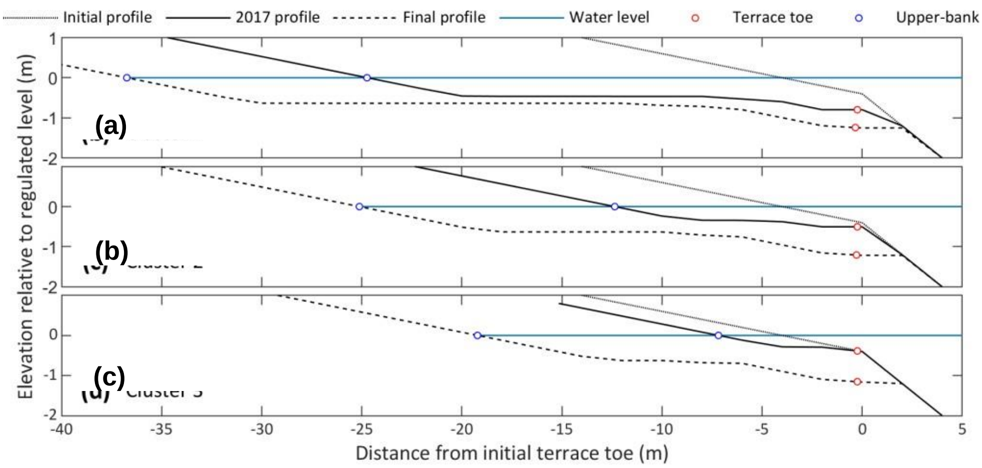

Figure 3. Predicted final upper-bank retreat for three bank types located in Oeffelt, the Meuse River. The soil critical shear stress for bank types 1 (a), 2 (b) and (c) 3, are τ_c = 8,12 and 18 Pa, respectively. The profiles measured in 2017 correspond to km 153.975, 153.100, and 154.025.