# Modelling erosion of pre-embankment breaches in coversand ridges in the IJssel floodplain due to major flood events in medieval times

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**ABSTRACT**

Coversand ridges are natural elevated areas that formed in the last part of the glacial period due to wind transport. Some coversand ridges created a watershed between the Rhine and IJssel floodplain. Erosion of these coversand ridges was of major influence for the formation of the river IJssel as a Rhine delta distributary. A coupled hydrodynamic-erosion model is set up to simulate potential coversand ridge breach scenarios at different locations along the coversand ridges during flood events. Computed flow velocities and water depths from the hydrodynamic model were exported to an erosion model. This coupled modelling approach gives insight in the hydrodynamic conditions of different breaches during various floods. The first results imply that breaches in the coversand ridges located at the current location of the river IJssel are the most favourable for a breach to expand. This result gives insight in the landscape development of the Netherlands.

**Keywords:** Coversand ridge, Erosion model, Flood events, River formation, River IJssel.

## 1 INTRODUCTION

Rivers flow through their floodplains (river basins) like they have been there all the time, but rivers form, change and can run dry over time. A trigger for a change in the course of a river is often an extreme flood wave. A successful river change requires both reach-scale cross-channel flow potential energy exceeding a threshold, and the availability of a more favorable path at landscape-scale on its floodplain (Hajek et Wolinsky, 2012).

This case study focuses on the formation of the river IJssel, a distributary of the river Rhine in the Netherlands. Research showed that the river IJssel came into existence between 300 and 750 AD (Cohen et Stouthamer, 2012). Before that time, the IJssel floodplain was not part of the Rhine floodplain and had a separate drainage. A local higher elevated area created a watershed that splitted both floodplains. This higher elevated area consisted of coversand and is called a coversand ridge. The formation of the river IJssel is related to some flood waves, that had the potential to overtop these coversand ridges, initiated the erosion on the crests of the coversand ridges and eventually resulted in two breaches that can be found today (Cohen *et al.*, 2009). The first breach is located at the current river IJssel (referred to as the easterly breach) and the second breach is located approximately one kilometer West of the current river (referred to as the westerly breach). Where the easterly breach expanded and became part of the river IJssel; the westerly breach eventually silted. Understanding the annexation process of the IJssel floodplain by the river Rhine by the formation of the river IJssel is of archeological-historical interest and can offer an opportunity to quantify major historical floods of the river Rhine. The objective of this research is to find the hydrodynamic differences between both breaches during flood waves.

## 2 MODEL SET-UP

A Digital Elevation Model (DEM) of the Rhine and IJssel floodplain for the situation before the existence of the river IJssel is set up by Van der Meulen *et al.* (2020) and is used as a starting point in the static hydrodynamic modelling set-up in this research. In this approach several static moments in time during a developing breach in a coversand ridge are constructed and implemented in the DEM. A hydrodynamic model is set up with these pre-defined breaches, analogous to Bomers *et al.* (2019). The output of the hydrodynamic model, consisting of the flow velocity and water depth, is exported to an erosion model. These two models together form the coupled hydrodynamic-erosion model. The erosion model computes the erosion velocity ($v_e$) in m s$^{-1}$ and erosion rate ($E$) in kg m$^{-2}$ s$^{-1}$ in the pre-defined breaches with the following equation (van Rhee, 2010):

$$v_e = \frac{E}{\rho_s(1-n_0)}, \text{ where } \quad E = 0.00033\rho_s[(s-1)gd_{50}]^{0.5}(D_*)^{0.3} f_D \left(\frac{\theta-\theta_{cr}}{\theta_{cr}}\right)^{1.5} \quad (1)$$

In these equations $\rho_s$ is the sediment density in kg m$^{-3}$, $s$ is the relative density between sediment and water, $g$ is the gravitational acceleration in m s$^{-2}$, $D_{50}$ is the median grain size in m, $D_*$ is the dimensionless grain size parameter, $f_D$ is a damping factor for super critical flow, $\theta$ is the grain-related Shields parameter, $\theta_{cr}$ the critical Shields parameter and $n_0$ the in-situ porosity.

## 3 FIRST RESULTS

Two flood waves are used for the hydrodynamic simulations: (1) A flood wave with a peak discharge of 14,000 m$^3$ s$^{-1}$ in Andernach, Germany, which is the most probable trigger to overtop and erode the coversand ridges (first hypothesized in Cohen et Lodder (2007) based on geological grounds; supported by hydrodynamic modelling by van der Meulen *et al.* (In Prep)). (2) And a flood wave of 10,000 m$^3$ s$^{-1}$ to simulate subsequent floods of a more moderate magnitude.

Table 1: Erosion velocity in the pre-defined breaches [m s$^{-1}$] for various breach widths, depths and flood waves

| **Width** [m] | **Depth** [m] | **Discharge** [m$^3$ s$^{-1}$] | **Max. erosion velocity westerly breach** ( $*10^{-3}$) [m s$^{-1}$] | **Max. erosion velocity easterly breach (IJssel location)** ( $10^{-3}$) [m s$^{-1}$] |
|---|---|---|---|---|
| **50** | **2** | **10000** | 12.3 | 16.6 |
| **50** | **2** | **14000** | 13.8 | 17.6 |
| **50** | **4** | **10000** | 11.7 | 14.1 |
| **50** | **4** | **14000** | 13.3 | 15.3 |
| **100** | **4** | **10000** | 7.8 | 11.9 |
| **100** | **4** | **14000** | 9.3 | 12.9 |

Next to the higher erosion velocities in the easterly breach (Table 1), the flood wave reaches the easterly breach approximately twelve hours earlier. During this time period the erosion velocity that occurs in the easterly breach already reaches approximately 2 to 3 $*10^{-3}$ m s$^{-1}$, triggering this breach to expand in depth and in width.

## 4 CONCLUSIONS

From the results it can be concluded that in the easterly breach larger erosion velocities occur during a flood wave (Table 1) and that these flow velocities occur earlier during the flood wave. The hydrodynamic conditions at that location are more favourable for a breach to expand. The results from this study substantiate why the river IJssel formed at the location where it still flows today. The results are of archeological-historical interest.


## 5 ACKNOWLEDGEMENTS

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