# NATURE-BASED FLOOD RISK REDUCTION VIA MULTIPLE LINES OF DEFENSE

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## INTRODUCTION

Sea level rise, land subsidence and population growth lead to steadily increasing flood risks in low-lying coastal areas. Hard flood defense structures such as dikes and dams should be regularly heightened and strengthened to sustain their protective function. Further, such hard structures can induce negative effects on the surrounding ecosystem. Therefore, nature-based approaches to flood risk reduction are increasingly promoted.

## METHODS

In our study, we assess the failure probability of a configuration with double dikes and a salt marsh in between. The functioning and reliability of the system is described using fault and event trees (see Fig. 3). We compare this configuration with a traditional single dike in terms of effectiveness and life cycle costs, thereby taking into account sea level rise, marsh accretion and required maintenance of both dikes.

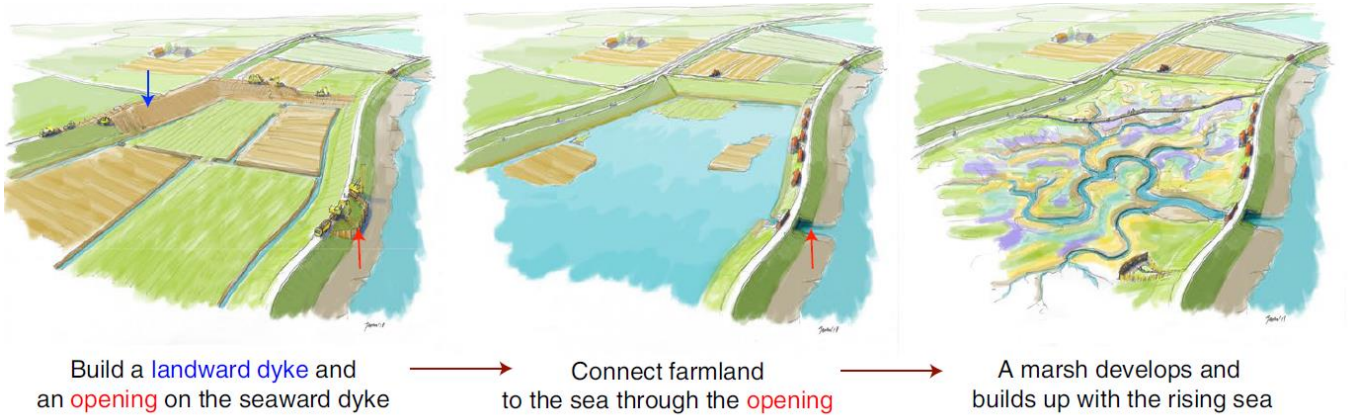


Figure 1 – Example of nature-based flood protection with marshes between multiple lines of defense (figure taken from Zhu et al. 2020, drawing made by Jeroen Helmer / ARK Nature)

Vegetated foreshores (such as salt marshes and mangrove forests) reduce wave loads on coastal dikes (Vuik et al., 2016). Furthermore, they are able to keep pace with sea level rise due to natural sediment accretion. However, foreshores cannot always exist in front of flood defenses, for example because of shipping lanes, protected habitats or harsh waves and currents. Even in such situations, coastal safety can be enhanced by creating salt marshes in between multiple lines of defense (double dikes).
In this study, we investigate the effectiveness, costs and coastal protection benefits of nature-based flood risk reduction via multiple lines of defense.

## MULTIPLE LINES OF DEFENSE

In a configuration with multiple lines of defense, the more seaward dike (the original flood defense) is opened to allow tidal flooding, sediment deposition and vertical marsh growth in between the primary and secondary dike (see Fig. 1).

Wave overtopping over the primary dike is allowable, as long as it provides sufficient shelter for the secondary dike. The secondary dike may be relatively low and cheap, because the primary dike and the salt marsh landscape lessen the wave loads. Further, a stable clayey salt marsh has a positive influence on dike failure mechanisms such as piping or macro-stability.

## RESULTS

In Zhu et al. (2020), we have shown that salt marshes mitigate flood risk in two ways:

1. Firstly, wave energy dissipation on salt marshes leads to lower failure probabilities due to wave breaking and wave attenuation by vegetation (Vuik et al., 2018).
2. Secondly, in case of a dike breach, salt marshes lower the flood magnitude by confining the breach size (see Fig. 2), which leads to less economic damage and loss-of-life (Jonkman, 2007).

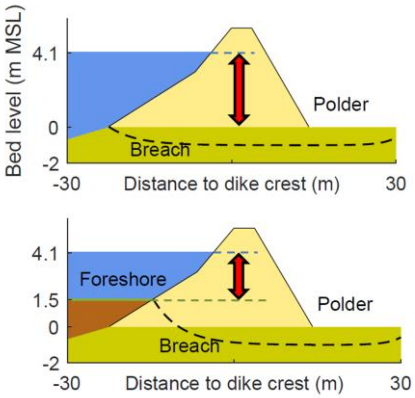


Figure 2 – The principle of the effect of a foreshore on breach depth (based on Zhu et al., 2020)

The latter effect implies that less stringent safety requirements can be applied to double-dike systems, while obtaining the same level of flood risk as for a single dike.

We compare the effectiveness, costs and benefits of nature-based coastal protection via multiple lines of defense with a more conventional strategy via regular heightening and strengthening of a (single) flood defense. We determine the conditions for which a double-dike system is a cost-effective alternative for a single dike, when achieving (a) the same failure probability or (b) the same level of flood risk.

The results will be presented in detail for several case studies in the southwestern delta of the Netherlands, after which we present general indicators to determine the conditions for which the nature-based strategy is to be preferred from the perspective of life-cycle costs.

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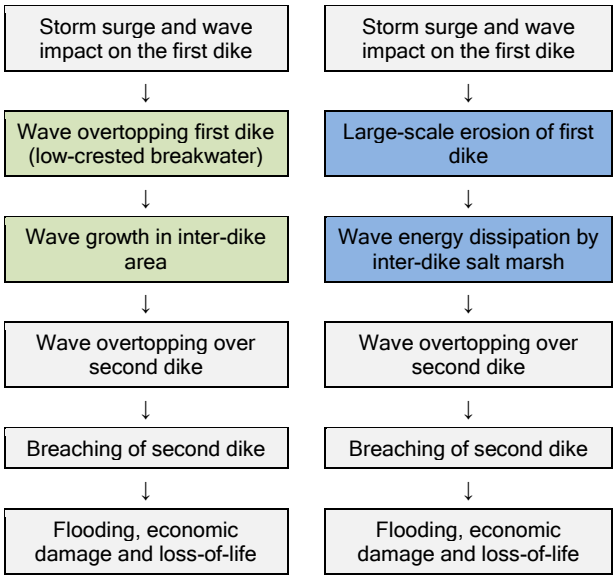


Figure 3 – Example of two event trees for a double dike system. The differences are shown in green and blue.