

## NATURAL FORESHORES AS AN ALTERNATIVE TO TRADITIONAL DIKE RE-ENFORCEMENTS: A FIELD PILOT IN THE LARGE SHALLOW LAKE MARKERMEER, THE NETHERLANDS

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### ABSTRACT

Natural foreshores are shallow zones and beaches with a gradual slope and a (near-)natural vegetation that can be used as an additional protection against flooding by reducing the wave attack on existing dikes, or can even completely replace an existing dike system. In order to test the applicability of this concept a 500 m long pilot section of a sandy foreshore was constructed along an already existing dike in the large shallow lake Markermeer, the Netherlands. The pilot was equipped with permanent monitoring equipment for hydrodynamics and meteorological conditions and monthly surveys of the morphology of the pilot section. These measurements will be carried out for the coming four years. This paper presents the first results after the construction and the first winter season with the pilot in place.

**Keywords:** *Building with Nature, Natural Flood Defence, dike re-enforcement, coastal morpho-dynamics, vegetated foreshores*

### 1. INTRODUCTION

Increasingly, natural foreshores are seen as a valuable alternative for, or addition to conventional dikes. Natural foreshores consist of shallow zones and beaches with a gradual slope and a (near-) natural vegetation, e.g. freshwater reedbeds and wetlands, willow forests, salt marshes and mangroves. They create an additional protection against flooding by reducing wave attack on dikes or can even protect the dike completely from being attacked (Borsje *et al.*, 2011). Using wide beaches and dunes is common practice as a coastal flood defense solution in the Netherlands. However, so far, this approach is not applied inland at i.e. the larger delta lakes in the Netherlands. The shorelines of these lakes are at present protected by dikes, some several centuries old and important cultural historic monuments. Recently a discussion has started where the use of natural foreshores is considered as an alternative way to assure safety against flooding in the coming decennia (Van Slobbe *et al.*, 2013). This option is considered for various reasons. One is to spare the older dikes which otherwise would have to be completely rebuilt because of problems with macro-instability. But a soft defense may also offer a more cost-effective and also more flexible alternative. A soft defense along these larger lakes is a novelty and natural processes are expected to act differently from those at the coast. There are no tides, wave length is much shorter and vegetation will play a larger role in shore line development. The design of these defenses and also the expectations regarding the related maintenance can therefore not solely be based on experiences and insights gained over the past centuries on coastal dunes and beaches.

In order to better understand the crucial aspects of designing, constructing and maintaining a natural, vegetated foreshore, a pilot is being carried out along the 'Houtribdijk' between Lake Markermeer and Lake IJsselmeer (the Netherlands). This dike needs reinforcement since it no longer complies with Dutch safety standards. The pilot was constructed in summer 2014, and consists of a 500 m long stretch of sandy foreshore along the dike. Monitoring of hydrodynamic forcing and morphodynamics in relation to vegetation development takes place from 2014-2018 for aspects. This paper presents some initial results of the first year of monitoring after implementation.

### 2. METHODS

During the summer of 2014 a pilot section of a sandy foreshore (design slope 1:30 – 1:25) was constructed on the southwestern shore, halfway along the 'Houtribdijk', that separates the two lakes IJsselmeer and Markermeer since 1976. Lake Markermeer (700 km<sup>2</sup>) has a fetch of up to 40 km, and is on average 2-4 m deep, with sections up to 9 m deep in the south-eastern area of the lake. The natural foreshore was created by applying 85.000 m<sup>3</sup> of locally sourced sand using traditional sand nourishment techniques. At the northern end the foreshore is enclosed by pile planking. The pilot was divided into four test sections of each 100 m wide perpendicular to the dike and a fifth 'rest' section completely

below the water line that was not used in the further monitoring of the vegetation development. Two sections received an additional layer of clay carefully mixed through the top 50 cm sand layer to achieve a sand/clay mixture of 70:30 ratio to assess if this would stimulate vegetation development compared to applying sand only. Vegetation will be manually planted on half of each (100 m wide) section in the spring of 2015. On the shores of test section 3 and 4 a willow mat (100 m long, 16 m. wide) with young reed plants was constructed to see if this would allow reeds to establish themselves quicker than in the loose sand (figure 1). Six beacons were installed before construction to measure soil consolidation of the deeper sediment layers below the newly applied sand and grain size distribution was determined for all batches of sand brought to the pilot.

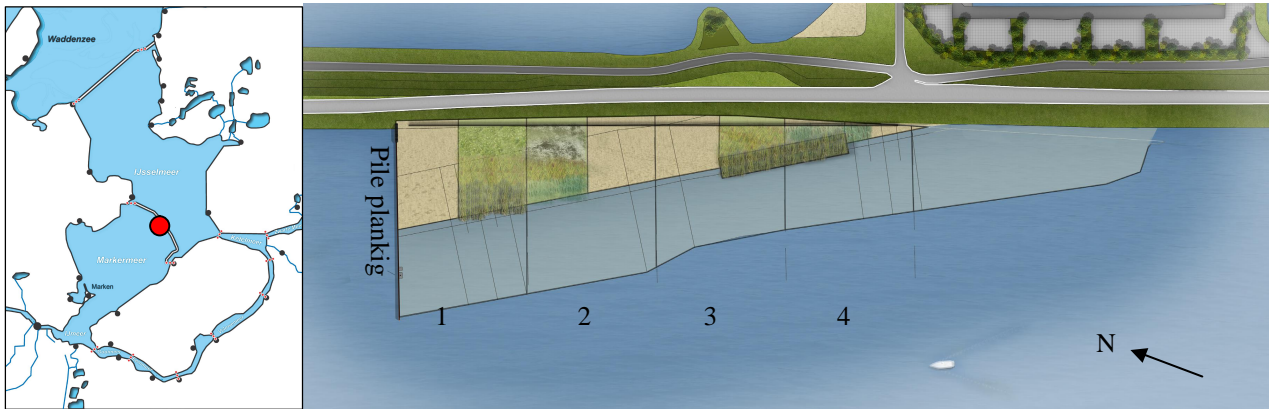


Figure 1 location (red dot) and lay-out of the pilot in Lake Markermeer with the four sections of each 100 m wide, and each section half planted manually, while the other half is left to develop on its own. The willow mats are located in the southern end of the pilot on the waterline.

## 2.1 Monitoring equipment and field measurements

A permanent monitoring station was installed on the pile planking consisting of a meteorological station (wind speed, wind direction, temperature, air pressure, precipitation), a water level meter and two photo camera's (one wide-angle and one tele-lens system). Also, a Nortek Vector was placed in an underwater frame 100 meters in front of the foreshore to measure the incoming wave climate. Data is recorded hourly on a data logger and sent via GPRS to an Open Earth Data Repository server, from where it is further processed for analyses.

Every month starting from three days after the formal delivery of the pilot (15th September 2014), the pilot is visited for detailed morphological monitoring using dGPS (Leica Viva GS14/GS10 GNSS system with base station). Transects of 15 m apart are surveyed. On land and in the very shallow zone (up to 1 m deep) the dGPS was placed on a roller construction, on the deeper water echosounding equipment was placed on a jetski (Hydrobox Single Beam Echo Sounder (SBES, measuring frequency of 10 Hz) ensuring overlap between the tracks of both instruments. Sediment samples were taken at three different depths to measure grain size distribution and evenly spaced over the dry section of the pilot.

## 2.2 Analyses

The dGPS data is merged with the data from the echosounder and transformed to xyz files, that were further interpolated to detailed digital elevation maps (DEMS). Ten transects were further analysed in depth for changes in the cross-sectional changes, while the full DEMS were compared to understand pilot-wide sand movement processes. Grain size analyses were carried out on a Coulter LS230 laser grain-sizer with a 5 mW 750 nm laser beam.

## 3. RESULTS

During the first winter season several storms occurred in the area of the field experiment. Nine storm events with wind speeds over  $15 \text{ m s}^{-1}$  were registered in the period from 15 September 2014 to 1<sup>st</sup> of February 2015. Morphological changes over the full width of the pilot are available for the four times the pilot was visited from September to December 2014 (figure 2a). A strong erosive pattern is seen in the most southern end of the pilot, and sedimentation has occurred in the more protected areas close to the pile planking (figure 2b). The dashed rectangle area delineates the area where the willow mats are placed. Along the pile planking the seemingly strong erosion is due to the interpolation techniques to acquire the full plot pictures. A small sediment bar has been elevated above the average waterline and a plateau shaped underwater profile is starting to develop.

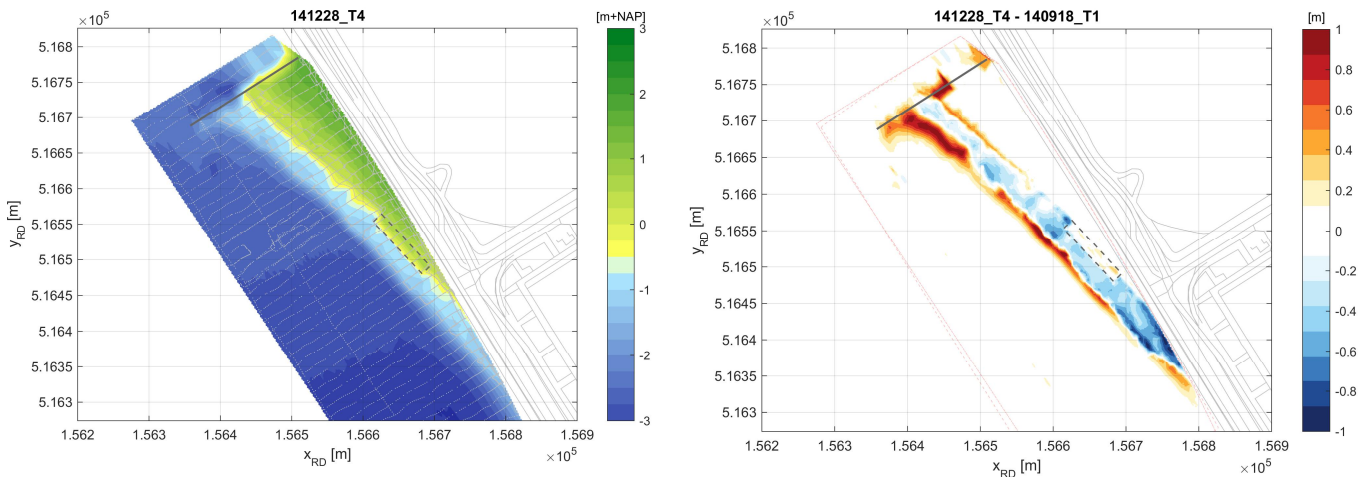


Figure 2a Elevation of the pilot (m +NAP – normalized Amsterdam water level). The average water level of the lake is -0.4 m NAP (light blue). Figure 2b Sedimentation and erosion expressed as changes in relative elevation (m) compared between 15<sup>th</sup> of September (T1) and 28<sup>th</sup> of December (T4).

Figure 3a-3c indicate the cross-sectional views of three transects at different locations on the pilot (figure 3d). The average water level is indicated with the light blue line, showing that above the waterline a small sand ridge has formed between T2 (26 October 2014) and T4 (28 of December 2014) in profile 2 and 4, while in profile 6 general erosion of the shallow areas is visible and an increase in the deeper areas. The pilot is designed with two different slopes: 1:30 for the area represented by profiles 2-5 and a slope of 1:25 for profile 6-10. This difference in design is also visible in the field measurements where profile 6 has a steeper slope than profile 2 and 4.

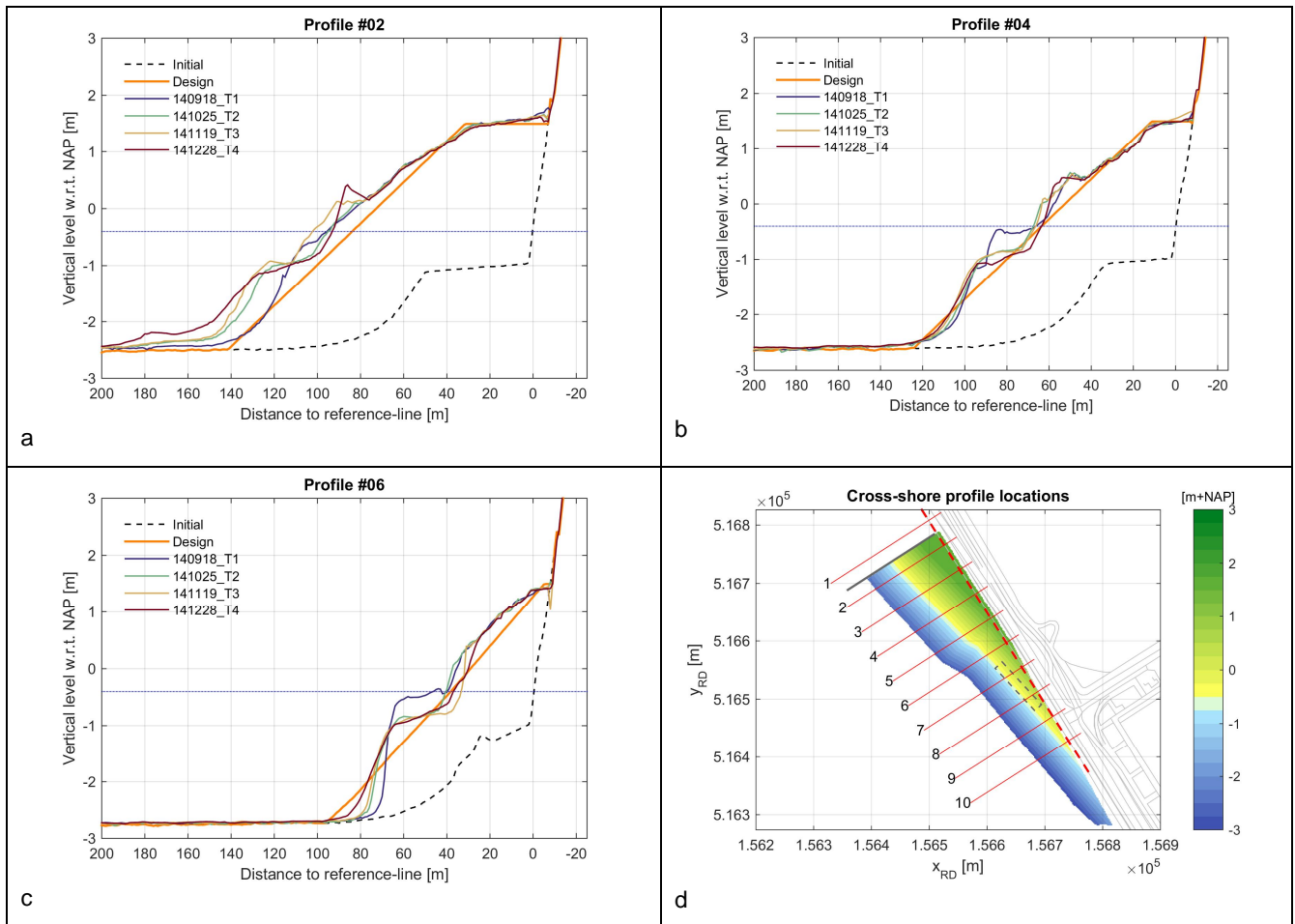


Figure 3a-3c Changes in cross sectional profile at location #2 (a), #4 (b) and #6 (c) over time compared to the original designed profile. The black dashed line represents the original lake bottom (before implementation of the pilot). Location of the different profiles is indicated in figure 3d.

The willow mats were not able to withstand the maximum forces of the incoming waves, and were damaged substantially after the seasonal storms. They did play an important role in reducing the erosion below the mats, but

increased erosion around the edges. As vegetation has not yet established, only results of the bare sand and sand/clay mixture are observed. The effects of the willow mats on shoreline vegetation establishment might be visible from the coming spring when common reeds (*Phragmites australis*) will be planted directly inside the mats.

#### **4. DISCUSSION**

The foreshore dynamics under extreme weather conditions, and the role of vegetation therein will be the focus of research in the coming three years. Currently the pilot is still without vegetation. In this stage the pilot is very exposed to waves and wind that create substantial changes during higher energy events. It is hypothesized that with time, when vegetation will develop changes due to these processes will be dampened. Insights from the pilot will be utilized to develop guidelines for natural foreshores based on a more generic understanding of the interaction of hydraulics, vegetation and morphology. By extension of this also a safety assessment methodology will be proposed. However a full safety assessment procedure requires response data for normative conditions, which are unlikely to occur in the study period. Additional tests in a large scale wave flume are required in this respect.

In the coming 4 years of monitoring on several occasions wave attenuation on the slope will be followed using pressure sensors at locations with differently developed vegetation and exclosures will be placed to understand the role of grazing (especially by geese) on the development of vegetation.

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