DOI: 10.3990/2.180

Morphological developments after a beach and shoreface nourishment at Vlugtenburg beach

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ABSTRACT

Typically a beach is out of equilibrium after a nourishment is installed. To observe how a nourished beach behaves on the timescale of storms a monitoring campaign was set up at Vlugtenburg beach after a nourishment in the spring of 2009. Here we show a sediment budget analysis of the first 2.5 years for a coastal domain spanning 1750 m alongshore from -9 to +5 m NAP. To investigate the redistribution of nourished sand different sections of the profile are examined. Observations show that the initial response (first 6 to 12 months after construction) is large where the sediment eroded from the beach is transported offshore to form a subtidal bar. In the following period (until present) the losses in the domain are on the order of 40 m^3 per m alongshore per year. These losses are concentrated in the profile around the waterline.

INTRODUCTION

For the last decades Dutch coastal policy requires to maintain the coastline at its 1990 location. A large part of the Dutch coast suffers from structural erosion and to prevent coastal retreat these parts are nourished every few years. The total volume of these nourishments is 12-15 million m^3 per year and this large volume is likely to increase in the upcoming decades. Over time, the nourishment strategy has evolved from a direct protection approach to a feeder approach. Hence, instead of placing the sand on the beach or dune where it directly benefits safety, sand is rather placed on the shoreface or alongshore concentrated. The underlying hypothesis is that natural processes redistribute the sand over the profile and alongshore.

To make optimal use of natural forces it is essential to understand how (nourished) sand is redistributed over time. Within this context a coastal stretch is monitored from the completion of a large beach and foreshore nourishment onwards.

The objective of the current paper is to show the morphological response observed at the nourished Vlugtenburg beach. Special attention is given to the redistribution of sand along the profile, transforming the artificial man made profile to a more natural profile.

FIELD SITE AND NOURISHMENT

The nourishment under investigation is the '*Duincompensatie*' project at Vlugtenburg beach, close to the town of Hoek van Holland on the southwest part of the Dutch coast. This part of the Dutch coast, called Delfland, is a 17 km long open sandy coast long intersected by the harbourmoles of the port of Rotterdam and Scheveningen.

Notorious for its structural erosion, a large nourishment scheme was initiated in 2008, strengthening the Delfland coast with 12.5 million m^3 of sand on shoreface, beach and dune.

The largest coastline reinforcement on the Delfland coast has been executed in the spring of 2009 at Vlugtenburg beach, located approximately 3 km north of the harbourmoles of the port of Rotterdam. Prior to the construction, Vlugtenburg beach had a slightly concave coastline (Figure 1a). The coastline planform shape of the coastline was straightened by moving the shoreline up to 300 m. The nourished volume is about 2500 m^3 per m alongshore in the middle of the field site (Figure 1b).

The extensive beach and shore face nourishment created a new profile (Figure 1) consisting of an artificial dune 200 m from the old dune foot. The lens-shaped area in between the old and new dune row forms a new dune valley and is intended to become a nature reserve.

OBSERVATIONS

The newly constructed area is surveyed monthly since the completion of the construction in April 2009. The alongshore extent of the observed coastal cell is 1745 m centered around the beach entrance. The surveyed area is subdivided in 22 profiles roughly 80 m apart (Figure 1c). These profiles extend 900 m offshore to approximately -9 m NAP. Dutch datum level (NAP) used here is around mean sea level. On the landward side the profiles are bound either by the dune foot on the new dune (app. 5 m NAP) or the crest of the old dunes (app. +10 m NAP).

Approximately half of the profiles extend beyond the new dune row through the dunevalley into the old dunes. These profiles are used to evaluate the aeolian transport in the dune valley, which are not discussed here. Sea and landward limits of the profiles are selected rather far apart to obtain a closed sediment balance in cross-shore direction (at least on the timescales discussed here).

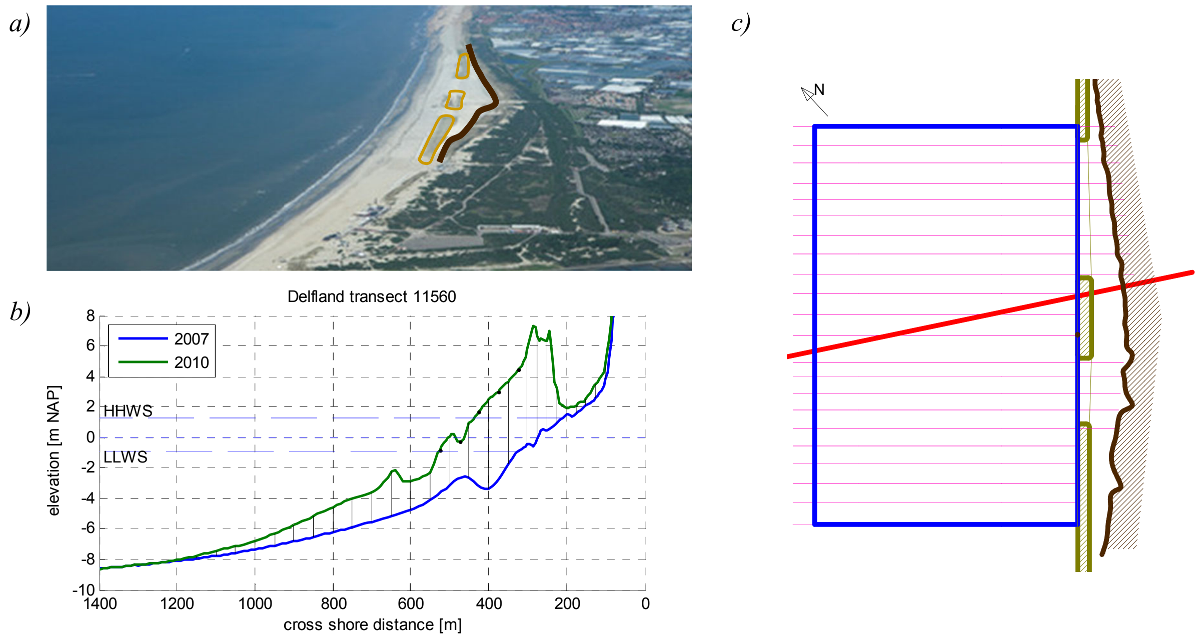

Figure 1. a) Overview of the Vlugtenburg field site. Old dune (app. +10 m NAP) shown as the dark brown line. New constructed foredune (app. +6 m NAP) given by the brown line. b) Jarkus profiles before and after construction of the nourishment. c) Overview of the survey area. 22 TUD profiles given by the magenta lines, Jarkus 115.60 profile in red. Sediment budgets are calculated within the blue rectangle.

Surveys are executed using two techniques, walking and jetski surveys. The sub aerial part of the profile is surveyed using RTK-GPS backpack surveys. These backpack surveys have accuracy in the order of 3 cm and extend to the low water line. The sub aqueous part of the profile is surveyed using the TUD survey jetski. The jetski is equipped with a single beam echosounder and Real Time Kinematic-GPS to acquire depth sounding with accuracy in the order of 5 cm (*van Son et al.* [2010]). Vertical displacements of the jetski due to tide and waves are compensated using the elevation of the jetski recorded by the GPS.

A substantial part of the error in the jetski surveys is the estimation of the speed of sound, used by the echo sounder. As the sound speed is dependent on the seawater temperature, it is calculated each survey with the Mackenzie formula (*MacKenzie* [1981]) using the daily averaged water temperature measured offshore at Europlatform. From March 2011 onwards, sound speed is measured during the survey on location using a sound velocity profiler, thereby also including salinity effects on the sound speed.

Surveys are typically executed during spring tide resulting in maximum overlap of both techniques. Jetski surveys are executed around high tide and backpack surveys around low tide. Transects of both jetski and backpack surveys are in line and the same profiles are surveyed since the beginning of the field campaign reducing the need of interpolation of the survey data over large distances between survey lines.

Both walking and jetski surveys result in *x,y,z* data points scattered around the predefined survey lines. The scattered data are interpolated to the shore-normal profiles with a cross-shore step size of 5 m.

RESULTS

Sediment budget

Sediment budget is calculated for the area seaward of the dunefoot of the new foredune (Figure 1c, blue box).

Topography maps are constructed out of the 22 shore normal profiles and integrated to obtain monthly sediment volumes in the area.

Annual Jarkus profiles every 250 m alongshore are interpolated calculated to the same grid. Jarkus profiles of 2007 and 2010 were used, to compute the nourished volume. Jarkus profiles of 2008 and 2009 were not used here as they extend only to -7m NAP (2008) or are measured during construction (2009).

The nourished volume with respect to the Jarkus 2007 elevation is presented in Figure 2 for all TUD surveys. As can be seen from the figure the total amount of nourished sediment in the control area was in the order of 2.7 million m^3.

The additional volume decreases with approximately 200.000 m^3 over the domain (i.e. 115 m^3 / m alongshore) within the two and a half years investigated here (Figure 2).

The first 6 to 12 months show a rapid decrease in sediment volume after which a more gradual loss of sediment can be observed. In the last 12 to 18 months the volume fluctuates, but a small downward trend of app. 70.000 m^3/yr (i.e. ~40 m^3 / m /yr) can be distinguished.

Timeseries of sediment volume in the area show slight variability on a monthly time scale. This variability originates partly from small inaccuracies *O* (0.5 %) in the sound speed which

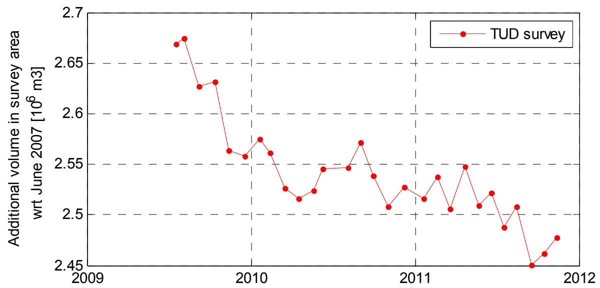

Figure 2. Sediment volume within the full alongshore stretch. Volume obtained from interpolation of Jarkus 2010 profiles given by the triangle.

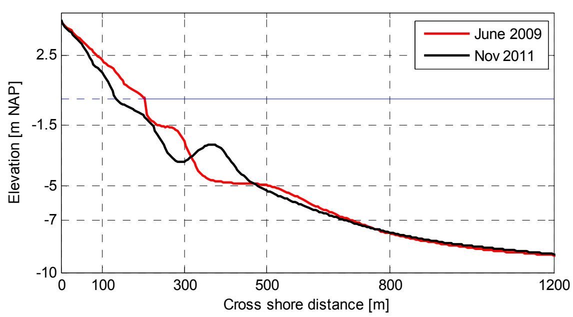

Figure 3. Alongshore averaged profile just after construction (in red) and in November 2011 (in black). Mean water level given by the solid blue line.

affects the depth measurement. Sound speed estimates/measurements in this area are prone to small errors, since the field site is close to the river mouth of the Rotterdam harbor. Sound speed profiles occasionally show strong temperature fluctuations as well as shear in salinity of 15 to 27 ppt over depth depending on the tidal phase. Consequently sound speed is varying over depth, spatially and temporally, even within a single survey. These variations yield to *O* (5 cm) over/underestimation at the deeper parts of the profile which influences sediment budget. This variability also partly be due to the (varying) sediment fluxes across the borders of the domain.

Redistribution of nourished sand over the profile

Profiles show that a large redistribution of sand occurs (Figure 3). Initially a steep sloping profile was created by the nourishment, especially below the low water line from -2 to -4 m NAP. Over time extensive erosion has taken place on the upper profile, and over a 2.5 year period the mean water level has shifted 75 m landward. The beach is consequently much smaller at present than in the first months after construction. Sediment from high up the profile has partly settled in the nearshore forming a large subtidal bar (Figure 3). This subtidal bar originated from the beach and migrated in the first 12 months towards 200 m from the low tide water line. Ever since the bar crest has moved back and forth but remains mostly stable.

The slope of the most active part of the profile (+1.5 to -4 m) is reduced as a result of these changes. To investigate the redistribution of sediment over the profile the domain is subdivided in various coastal sections, ranging from close to the dunes to far offshore. In addition, a division is also made based on elevation. The first approach indicates primarily if sand is moving landward or seaward, the latter shows if sand is moving up or down the profile.

Sediment balances for cross-shore boxes and elevations are shown in Figure 4a and 4b respectively. Cross-shore boxes are divided at cross-shore locations 100, 300, 500 and 800 m, elevation sections are divided by the +2.5, -1.5 ,-5 and -7 m NAP contour lines.

In the deep and offshore zones of the profiles a significant sedimentation of *O* (50 m^3/m alongshore) is observed. This is further confirmed by the profiles showing a bed level increase of about 10 cm at -9 m NAP. This is surprising as the seaward limit of the profiles was selected quite far offshore to obtain a closed sediment balance.

As discussed previously, a small scatter is found in the sediment volumes due to the sound speed. As the absolute error increases with depth, the largest scatter is found in the most seaward / deepest sections.

Subdivision in cross-shore boxes (Figure 4a), shows very clear the shift of sand offshore from the beachface (magenta line) to a subtidal bar (black line). The large losses observed near the waterline, are compensated by the formation of the bar. In the last year no clear migration of the bar was observed, and the volume changes in this section of the profile have become very small. The majority of the losses observed in profiles in this last year can be attributed to the zone around the water level (magenta line in both panels).

The observed changes are correlated with nearby wave data to investigate the impact of storm events. It is observed that in autumn when wave forcing is strong, the profile adaptation is accelerated, whereas in spring changes are less pronounced. Higher up the profile the volume changes are much more gradual, showing less seasonality.

DISCUSSION

Results falsify the initial hypothesis of a cross-shore closed sediment balance using an offshore limit of -9 m NAP. Considering the observed bed level changes at seaward side of the domain (over 1 km from the shoreline at a waterdepth of 9 m) it is likely that the closure depth is deeper and sediment is leaving the domain offshore. On the landward side of the profiles no significant bed level changes were observed. However, it is well possible that sand is transported by wind beyond the landward border of the domain towards the dune valley and the old dune row. First estimates of the volume transported towards the dunes is the dune growth in the area over the last decades of *O* (30 m^3 / m / yr) (*De Vries et al.* [2011] Figures 3,4). Visual observations of the area as well as the profile data that extend to the old dune confirm a deposition of windblown sand of this order of magnitude in front of the old dune row.

It is therefore open to discussion how much of the ~40 m^3 / m / yr losses as obtained from the sediment budget analysis for the last period can be contributed losses in either the alongshore or the

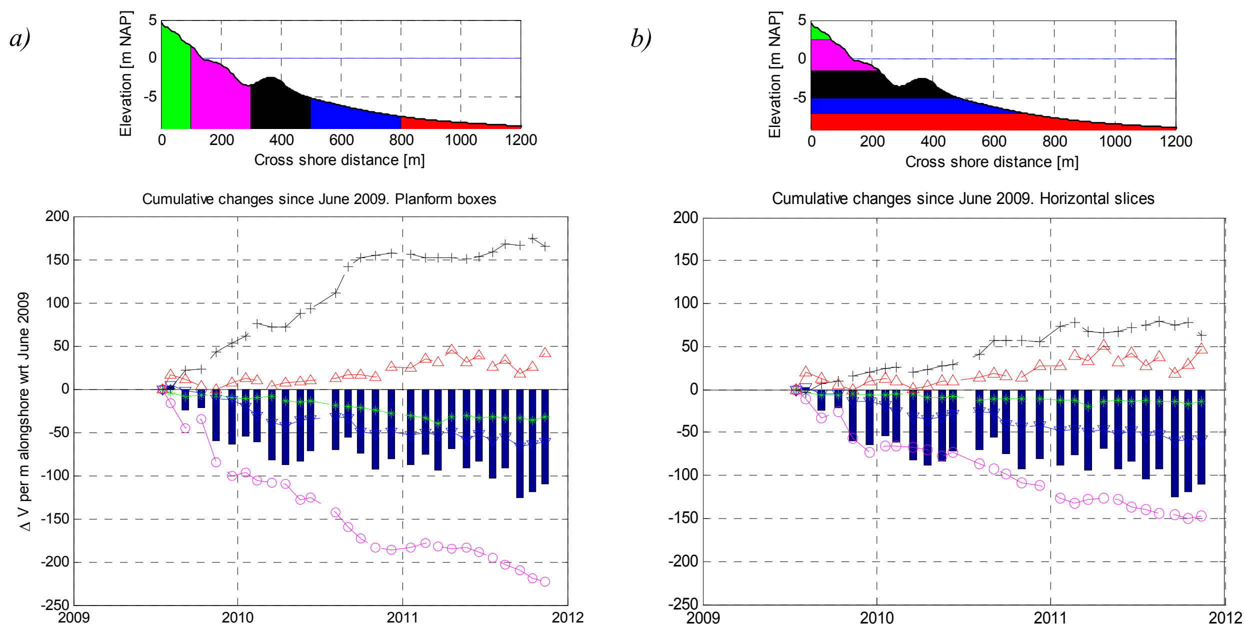

Figure 4. Alongshore averaged volume changes since the start of the monitoring in June 2009, subdividing in cross-shore boxes (left panel) and elevations (right panel). Different cross sectional areas are given in colors, clarified by the cross section above. Bar graphs show the profile averaged behavior (identical in both panels).

cross shore (seaward or landward). Ongoing investigation of the individual profiles and the dune area will provide more insight in this.

Surveys in deep water are found to be noisy at this field site due to the vicinity of a river mouth, hampering a conclusion on the morphological changes due to storms at the very deep parts of the profiles. In the shallow zone and/or with sufficient morphological variations these errors are insignificant. As a result deeper parts of the profiles however are less suited to investigate on a monthly scale.

CONCLUSIONS

Two and a half years of morphodynamic data were collected and analysed after a nourishment was installed at Vlugtenburg beach. Monthly surveys (28 in total) show in detail the transition from man-made profile shape towards a more natural profile.

Observations show that over the entire period about 200.000 m3 of sediment (115 m^3 per m alongshore) is lost from the survey area, which is less than 10 % of the nourished volume. The morphodynamic evolution can be characterized by two periods; first a period of 6 to 12 months of rapid changes followed by a second period of more stable topography. Sand is redistributed quickly within the profile. In the first period of very rapid response sand high up the profile is displaced to from a subtidal bar, thus reducing the steep construction profile slope to a more milder slope. In the following 14 to 22 months (until present) morphological changes are milder, showing a gradual loss of about 30-40 m^3 per m alongshore per yr.

ACKNOWLEDGEMENTS

M. de Schipper and S. de Vries were funded by the innovation program Building with Nature under project code NTW 3.2 and 2.1 respectively. R. Ranasinghe and M. Stive are supported by the ERC-Advanced Grant 291206 – NEMO. The ‘Kustlijnzorg’ program is greatly acknowledged for their support in the development of the TUD survey jetski. The Ministry of Transport and Infrastructure and Open Earth Tools are acknowledged for the use and distribution of the Jarkus data.

The Building with Nature program is funded from several sources, including the Subsidieregeling Innovatieketen Water (SIW, Staatscourant nrs 953 and 17009) sponsored by the Dutch Ministry of Transport, Public Works and Water Management and partner contributions of the participants to the Foundation EcoShape. The program receives co-funding from the European Fund for Regional Development EFRO and the Municipality of Dordrecht.

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