Aeolian transport of nourishment sand in beach-dune environments
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CHAPTER 7
SYNTHESIS AND RECOMMENDATIONS

DISCUSSION AND CONCLUSIONS

The present study aims to assess the impact of beach nourishment on aeolian sand transport and morphological development of the beach and adjacent foredunes. A number of methods have been used in this study, resulting in a contribution to the knowledge of aeolian transport of nourishment sand. In this section, the obtained results are discussed in relation to the general aim of the study.

In Chapter 2, aeolian transport of nourishment sand is studied on a time scale of years. Although a number of sediment budget studies have been made for the Dutch coast, these studies did not primarily focus on the aeolian component (e.g. Wijnberg & Terwindt, 1995), did not explicitly distinguish between aeolian and marine sediment transport (e.g. Van Vessem & Stolk, 1990; De Ruig & Louisse, 1991; Roelse, 1996), or did not quantify aeolian transport rates (e.g. Arens & Wiersma, 1994). In Chapter 2, aeolian input into the foredunes is quantified and compared to the magnitude of overall changes of the beach-dune environment. The study also provides insight into the impact of beach nourishment on aeolian sand transport. A significant increase in the rate of aeolian sand transport was found one year after beach nourishment. In addition, the buffer function of the nourishment against wave-energy and its role in foredune development is illustrated. However, the key parameter of the increase in aeolian sand transport after nourishment is not addressed in Chapter 2. This parameter may relate to, for instance, a change in the erodibility, availability of sand or beach topography, as has been studied in Chapters 3, 4, 5 and 6.

In Chapter 3, the impact of the characteristics of the fill material on the rate of aeolian sand transport has been studied. The properties of sand collected from nourishment sites and adjacent unnourished (control) sites are assessed. They are related to the susceptibility of sand to aeolian sand transport, as determined in a wind tunnel. In all cases, the nourishment sand corresponds to lower transport rates than the sand from nearby natural beaches, because of large amounts of shell fragments, poor sorting and suitability for compaction of the nourishment sand. These results confirm
observations of Draga (1983), who attributed poor aeolian activity of nourishment sand to compaction and poor sorting. They also correspond with aeolian studies on sand containing non-erodible elements (Logie, 1982; McKenna Neuman, 1998; Davidson-Arnott et al., 1997). However, the latter studies found an increase in aeolian sand transport at low densities of non-erodible particles, as these particles enhance turbulence. The present method does not allow for an assessment of such effects. The results of the wind tunnel study can also not directly be translated to the field situation, because conditions are confined to a dry and uniform surface and a uniform wind, whereas the field situation is more complex.

In Chapter 4, the behaviour of nourishment sand has been studied under field conditions, on a beach on Ameland. The study provides insight into the selective processes of the sea and the wind. Marine reworking results in a decrease of shell fragments and fines on the foreshore, providing a source for aeolian sand transport. Aeolian decoupling results in a backshore with surface lag deposits and superimposed wind-blown sand, and, on a time scale of years, foredunes with wind-blown nourishment sand that is more susceptible to wind erosion than the nourishment beach sand, but less than the native foredune sand. The study illustrates that selection processes can be more important on a nourished beach than on a native beach, as the latter often consists of well-sorted sand (cf. Pye, 1991), although sorting processes on native beaches can be significant (e.g. Shephard & Young, 1961; Bauer, 1991; Arens, 1994).

In Chapter 5, field measurements of aeolian sand transport are related to factors changed by beach nourishment, such as beach width and surface conditions. The rate of aeolian sand transport increases with increasing fetch of onshore winds over beach sand, as a saltation layer has to develop with distance downwind. Especially when there is no abundant sediment supply, fetch effects appear to be important (cf. Jackson & Cooper, 1999). The surface characteristics and conditions may control the availability of sediment sources for transport. However, the variability in surface characteristics and conditions inhibits a constant sediment flux. On a time scale of years, the wider beach is expected to result in larger transport rates (cf. Hesp, 1988; Davidson-Arnott & Law, 1990). The combined result of a wider beach and changed surface conditions on this time scale is unknown.

In Chapter 6, field measurements of the two sites are used to adapt, validate and apply the air flow (including its turbulent characteristics) model HILL (Van Boxel et al., 1999) and the aeolian sand transport model SAFE (Van Dijk et al., 1999). The model system explains cross-shore profile development due to aeolian processes on a time scale of months. The impact of several beach nourishment parameters is evaluated. Mean grain-size affects
the aeolian sand transport rate to the foredunes and therefore the morphology, by determining the threshold friction velocity. Adaptation length, which is a measure for the distance (fetch) over which sediment transport adapts to a new equilibrium condition, affects the topography of the beach in particular; the larger the adaptation length, the more the morphological development is suppressed. The topography of a beach nourishment has a limited impact on both aeolian sand transport and morphology. A number of factors that relate to beach nourishment are not yet well accounted for in the model system. Sorting and amount of shell fragments appear to be important in aeolian transport of nourishment sand (Chapters 3 and 4), but the model system assumes well sorted sand. In addition, adaptation length appears to relate to surface conditions, and, therefore, varies both in time and space (Chapter 5), but is incorporated as a constant in the model system. Marine processes, affecting beach width and topography, have to be incorporated in order to evaluate beach nourishment on a larger time scale (Chapter 2).

**IMPLICATIONS FOR COASTAL MANAGEMENT**

From a geomorphological and ecological point of view, beach nourishment is a sound method to counteract marine erosion, especially when compared to static protective measures, such as groynes (e.g., Nordstrom & Allen, 1980). Beach nourishment implies a direct supply of sediment to a beach. However, it also changes the sediment transfer rate in the beach-dune environment. Changes in the rate of aeolian sand transport have consequences for geomorphology, ecology, recreation, construction and coastal defence, and are therefore of significance to coastal management. In this section, considerations emerging from the present study are offered to optimize nourishment projects.

Performance of beach nourishment can benefit from environmental monitoring projects (Rijkswaterstaat, 1988; Roelse et al., 1991; National Research Council, 1995). Many projects, however, do not consider aeolian sand transport. The present study shows that aeolian sand transport can make a substantial contribution to the sediment budget of a coast, and it can be increased by nourishment. Therefore, it is recommended to include aeolian sand transport in sustained and accurate beach nourishment monitoring, where appropriate. The duration of a monitoring project with respect to aeolian sand transport will relate to the scale of nourishment. For nourishments with a planned lifetime of approximately five years, monitoring should start before nourishment and should continue preferably until the fourth year after
nourishment (Chapter 2). Annual height measurements in a fixed framework of cross-shore sections extending as far as the landward profile close-out, such as established for the DONAR (JARKUS) data base (De Ruig & Louisse, 1991), are sufficient for such a project. In addition to these yearly measurements, similar measurements of all sections within a nourishment area have to be performed directly after the fill has been placed.

When choosing compatible fill material, it is recommended not only to take into account the mean or median grain-size of the fill, but also the whole grain-size distribution and the spatial variability of sand properties in the source area (both horizontally and vertically), since different sources of well sorted sand may result in poor sorting of fill due to mixture (Chapter 3). For the Dutch situation, compatible fill consists of well sorted sand with a minimum amount of shell fragments, clay and silt.

The carbonate content of the sand largely determines the vegetation composition of the (fore)dunes (Rozema et al., 1985; Van der Wal et al., 1995). The present research shows that the carbonate content of the foredune sand is altered by nourishment, when using fill containing shell fragments. This suggests that vegetation effects can be expected. In some cases, such effects may be positive, for instance where carbonate influx can counteract soil acidification (Ketner-Oostra, 1998). Effects of carbonates and other constituents of nourishment sand on vegetation have to be anticipated when designing a beach nourishment (Chapter 4).

If the formation of shell pavements has to be avoided, nourishment sand containing large amounts of shells should be deposited mainly on the foreshore, rather than on the backshore. The shells are reworked by marine processes (Depuydt, 1972; Psuty & Namikas, 1991; Chapter 4), although armouring effects can also occur on the subaqueous beach (Swart, 1991; Tânczos, 1996). From a viewpoint of coastal protection, the shells in the nourishment sand offer a greater buffer against marine erosion than well sorted sand, since a part of the wave energy is used for the reworking of the shells. The reworked nourishment sand provides a source of well-sorted sediment for aeolian transport to the beach and dunes (Chapter 5).

The shape of a beach nourishment profile does not seem to have a pronounced effect on the erosivity of the wind and, therefore, on the pattern of erosion and deposition. However, the present study suggests that a banquet made out of well-sorted sand is reshaped due to wind speed-up at its stoss slope. The sand eroded at the slope is mainly deposited directly on top of the banquet (Chapter 6).
OUTLOOK

The understanding of aeolian transport of nourishment sand in beach-dune environments benefits from fundamental and applied studies of aeolian sand transport and coastal dunes. Although progress in understanding aeolian dynamics has been made in recent years, many opportunities and challenges for research still remain.

As suggested by Nickling and Davidson-Arnott (1990), aeolian research could consider more seriously the surficial and textural parameters that directly control the supply of sediment to the air stream and, ultimately, the sediment transport rate, rather than focus on loose, cohesionless sediments. The dynamic nature of surface conditions (coupled with the interaction between the wind, the surface and the developing saltation cloud) can also give rise to a fetch effect, i.e., the change in sediment flux with distance downwind (Gillette et al., 1996; McKenna Neuman & Maljaars, 1997; Chapter 5). In the present study, the role of sorting and shell lag development in aeolian sand transport is evaluated. Future research should aim to find a quantitative formulation of the complex (feedback) mechanisms of factors such as shells, silt, sorting, packing of the sand, and moisture and their impact on thresholds for wind velocity, sediment supply and the rate of aeolian sand transport. Ignoring the effects of these controlling factors on aeolian sand transport, and applying equations developed for an infinite, dry sand surface would, generally, result in an overestimation of the rate of aeolian sand transport. Efforts have to be made to incorporate these controlling factors, including their complex (feedback) mechanisms and their inherent spatial and temporal variability, in physical deterministic models such as the SAFE-HILL model system.

The present study suggests that the rate of aeolian sand transport is altered by nourishment on a time scale of years (Chapter 2). Aeolian dynamics on this time scale are not fully understood. There is a need for research that links the driving forces (meteorological and hydrodynamic conditions) and controlling factors (such as surface conditions and beach width) of aeolian sand transport to the sediment budget on a time scale of years. Process-response models of aeolian dynamics developed for this meso-scale could aid in evaluating the effects of beach nourishment on aeolian sand transport and foredune development.