Aeolian transport of nourishment sand in beach-dune environments
van der Wal, D.

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CHAPTER 1
INTRODUCTION

SCOPE

Beach nourishment is used worldwide as a method for restoring and maintaining coastal areas threatened by structural marine erosion. Beaches are nourished either for recreational use or as a means of protecting the coastline by absorbing wave energy and so counteracting further erosion of the original beach and dune and preventing damage to coastal property. Beach nourishment implies a direct supply of sand to the beach. In recent years the primary source of sand for beach nourishment has been offshore deposits. These are dredged from the seabed, transported to the beach, and either dumped or pumped into the littoral zone (Komar, 1998). The fill is redistributed over the coastal profile during the lifetime of the nourishment by ambient marine and aeolian processes. Most sand will eventually be lost from the considered coastal stretch, as the basic cause of erosion and the negative sand budget often continue to exist after nourishment. Periodic replenishment is, therefore, often necessary. Yet, beach nourishment is often preferred to coastal protection schemes that use hard structures, because so many of these have resulted in subsequent loss of the beach by reflection scour (National Research Council, 1995; Bird, 1996).

In the Netherlands, nourishment appears to be an effective and economical measure, to be carried out flexibly at places with highest urgency (Rijkswaterstaat, 1988; Davison et al., 1992). More than 170 nourishment projects have been executed at about 50 coastal stretches (see Appendix). The coast has been nourished for various reasons, but the main reason was to safeguard the low-lying hinterland against flooding from the sea (Hillen & Roelse, 1995). A large part of the Dutch coastline consists of beaches bordered by shore-parallel foredunes of 10 to 20 m in height, which form the principal sea defence. More than half of this coastline is subject to erosion (De Ruig & Hillen, 1997).

Since the early fifties, weak dune areas were strengthened by artificial nourishment of type a, b and c in Fig. 1.1, to bring the dunes in line with the safety standard, as laid down under the Delta Act of 1953 (Deltacommissie, 1961). Since 1992, dunes along the Dutch coast all fulfil the safety
requirements (Technical Advisory Committee on Water Defences, 1984; 1995). In 1990, the Dutch government decided, after careful consideration of a number of alternatives, that coastal regression should be halted by means of the dynamic preservation of the coastline at its position in 1990, with nourishment being a recommended measure to counteract erosion (Rijkswaterstaat, 1990). Since that time, about $6 \times 10^6 \text{ m}^3$ of sand have been deposited along the Dutch coast every year (Hillen & Roelse, 1995). Currently, the fill is placed on the upper part of the beach (type d in Fig. 1.1). In some cases this type of nourishment is complemented by a so-called banquet (type e in Fig. 1.1), especially when the beach to be supplied is narrow. In other cases the fill material is spread over the foreshore (type f in Fig. 1.1), since this is often the place where the losses occur. However, nourishing the surf zone might be technically difficult (Van de Graaff et al., 1991). In 1993, an experiment was carried out with a nourishment in the nearshore zone, with fill placing in the trough between the middle and outer breaker bar (type g in Fig. 1.1) (Hockstra et al., 1994).

The planned life span of nourishments varies between three and ten years. Especially at locations where short-term morphological effects are unpredictable, frequent small-sized nourishments are preferred to nourishments with a long life span (Hillen & Roelse, 1995). In general, the nourishment sand is derived from the nearshore zone of the North Sea, as near as possible to the location to be nourished, but with the proviso that the source area is located seawards of the contour line of 20 m of depth, or more than 20 km offshore (Rijkswaterstaat, 1988).

![Figure 1.1](image)

**Figure 1.1.** Cross section with fill placing (a) at the landward side of the foredune, (b) on top of the foredune, (c) against the seaward front of the dunes, (d) on (the upper part of) the beach, often combined with (e) a high buffer ('banquet'), (f) on the foreshore, and (g) on the shore face.
Various methods are used to win, transport and emplace the fill material. Usually, the sand is extracted by a dredge and transported to a discharge location in the vicinity of the beach to be nourished. Then, the material is brought ashore by a dredge and spread out over the beach (Van Oorschot & Van Raalte, 1991). Bulldozers and cranes are used to remodel the fill.

An understanding of coastal geomorphology is an essential background for planning beach nourishment, and indeed for any modification of the coastline (Bird, 1996). The behaviour of the fill has to be studied to evaluate the effectiveness of beach nourishment and to justify additional inputs of sediment to the coastal system (Psuty & Moreira, 1992). One aspect that has to be studied is the response of aeolian activity to nourishment. Part of the nourishment sand will be subject to aeolian processes, and will be trapped in the (fore)dunes, where it is stored to be available during storm events. The aeolian sediment exchange rate between the beach and dunes may, however, change after nourishment. Changes in the rate of aeolian sand transport after nourishment are likely to depend on several factors, such as the techniques that are used for nourishment, properties of the nourishment sand and nourishment design (Fig. 1.2). For example, the fill may differ in grain-size distribution from the native beach sand, resulting in a different erodibility of the surface (Draga, 1983; Nordstrom et al., 1986; Olij, 1993; Van der Wal et al., 1995). Depending on nourishment design, the beach may be widened by nourishment, altering the availability (source) of sand for onshore transport.

Beach nourishment has become a condition for the dynamic preservation policy in the Netherlands; when the safety is guaranteed by means of beach nourishment, there are opportunities to allow for natural dynamics, such as sand drift (Arens & Van der Wal, 1998). Sand drift is a steering factor controlling development and dynamics of vegetated coastal foredunes (Sarre, 1989b; Arens, 1994). In the Dutch foredunes, the dominant plant species is marram grass (Ammophila arenaria). The plants stabilize trapped wind-blown sand with their root system, and promote dune building by upward growth. The plants are stimulated when they are regularly buried by beach sand; they can escape from their harmful soil organisms by upward growth, avoiding damage of the roots (Van der Putten, 1989).

However, anomalous wind-borne sand transport may have adverse impacts. Too much deposition of sand leads to suffocation of plants. The composition of sand (e.g., the mineral content) is also an important factor for vegetation; it largely explains the differences in plant species in the Dutch dunes (Rozema et al., 1985). Since offshore dredged material may differ in
composition from native beach sand, aeolian transport of this nourishment sand to the dunes can alter the characteristics of dune sand, and may subsequently affect vegetation. Apart from ecological impacts on vegetated foredunes, excessive sand-drift has other potentially adverse effects (Sherman & Nordstrom, 1994), e.g. on recreation, construction and drinking water abstraction, both on the beaches and dunes and on the (agricultural) hinterland. Anomalous wind-borne sand transport may also affect the efficiency of the nourishment.

**AIMS AND OBJECTIVES**

The aim of the study is to assess the impact of beach nourishment on aeolian sand transport and morphological development of the beach-dune system. The study focuses on the role of properties of the nourishment sand (e.g. grain-size distribution and shell content) and nourishment design parameters (e.g. beach width and shape of the nourishment) in:

1. the erodibility of the surface,
2. the availability of sand for aeolian sand transport, and
3. the erosivity of the wind,

as is schematized in Fig. 1.2.

**Figure 1.2.** Main impacts of artificial beach nourishment on aeolian sand transport to the foredunes.
APPREACH AND OUTLINE

The thesis has been compiled from a number of research papers dealing with wind-borne sand transport on beach nourishments along the Dutch North Sea coast. The text of some of the submitted and published papers has been slightly adapted to avoid overlap in this thesis.

In Chapter 2, the DONAR data base of Rijkswaterstaat, which comprises annual profile measurements of the coast, is used to assess the impact of beach nourishment on the development of the supratidal beach and dune. The study is conducted on several nourishment sites on a time scale of years.

In Chapter 3, wind tunnel experiments are presented. The study aims to assess the impact of the properties of the fill on aeolian sand transport. The grain-size distributions of samples collected at nourishment sites and nearby control sites are related to the erodibility of the surface, as determined in a wind tunnel.

Chapters 4 and 5 deal with field measurements. The measurements were carried out on two beaches, referred to as the Ameland site (located at 53°28'N, 5°43'E) and the Den Helder site (located at 52°55'N, 4°43'E). Aeolian sand transport, and factors that affect sand transport, such as wind conditions, beach width and sediment characteristics were measured in the field in the spring of 1996 for one month at each site. The two beaches were nourished in the summer of 1996. Then, in the autumn of 1996, the field measurements were repeated. The study focuses on the measurements on the nourished beaches, but data collected before and after nourishment are also compared. Deposition of nourishment sand was determined by mapping the colours of native and nourishment wind-blown sand (in the spring of 1998). In Chapter 4, the grain-size-selective processes of the fill material, and their effects on vegetated foredunes are elucidated for the Ameland site. Chapter 5 shows how the aeolian sand transport is affected by the fetch of wind over beach sand, a factor that is altered by nourishment due to enlargement of the beach.

Chapter 6 presents a model application. The development of the two sites was monitored by measuring topography and vegetation half-yearly between the spring of 1996 and the autumn of 1998. These data were the main input for the SAFE-HILL model system developed by Van Dijk et al. (1999) and Van Boxel et al. (1999). The models were applied to evaluate the impact of the properties of the fill and nourishment design.

Chapter 7 is a synthesis of the studied aspects of aeolian activity on beach nourishments and contains recommendations to optimize nourishment measures from a geomorphological and ecological point of view, and recommendations for further research. Finally, a summary of the thesis is presented.
composition from native beach sand, the movement and transport of this nourishment to the dunes can alter the characteristics of the sand of the dunes. Sand, and may reduce the height of the dunes and enhance the growth of grasses. The combination of these factors may result in the formation of a sand dune, which is a stable accumulation of sand. This process is often referred to as dune formation. The sand dunes may then serve as a barrier to the wind, reducing the amount of sand that is transported inland. This process can be further enhanced by the growth of vegetation, which provides additional stability to the sand dunes.

In Chapter 5, the role of dune formation is discussed in detail. The study aims to assess the impact of human activities on the dune systems and to determine the factors that influence dune formation. The study focuses on the processes of dune formation, including wind and water erosion, and the role of vegetation in stabilizing the dunes. The study also examines the impact of human activities, such as beach nourishment and coastal development, on the stability of the dunes.

Figure 1.1. A model of the process of dune formation, showing the movement of sand and the impact of vegetation on the stability of the dunes.