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Effects of 20 years of nourishments: Quantitative description of the North Holland coast through a coastal indicator approach

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ABSTRACT

The Dutch coast has been eroding over more than a thousand years. Coastal retreat puts coastal functions (e.g. safety against flooding) under pressure. Since 1990, the Dutch policy aims at preventing further retreat of the coastline, but in the meantime taking the valuable dynamical behaviour of the coast into account. Therefore, sand nourishments have been preferred over hard structures to counteract the systematic erosion. In this study, the morphological development of the North-Holland coast since 1965 has been analyzed by looking at a number of indicators. These indicators are 1) representative of the morphological development of the Dutch coast at different temporal and spatial scale and 2) related to policy objectives. The indicators cover the entire coastal profile from dunes to deeper water. The analysis showed how the trends of the different indicators have been affected by the nourishment schemes applied over the last 20 years, by the natural forcings (i.e. yearly storminess), and by the construction of hard structures. From this data-analysis, lessons can be learned regarding future nourishment strategies.

INTRODUCTION

The Netherlands is a low-lying country, where approximately 27 percent of the territory is located below mean sea level and 55 percent is prone to flooding. Protection against flooding is traditionally the primary objective of coastal policy in the Netherlands. However, since 1990 coastal policy has been subject to a number of modifications, and new objectives have been added to cope with the structural erosion problems of the Dutch coast. To fulfill these new objectives, the yearly volume of sand for nourishments was first increased to 6 millions m^3 sand per year in 1990 and then to 12 millions m^3 per year in 2001. Even higher volumes might be necessary in the future to cope with the more severe sea level rise scenarios predicted.

Deltares has been commissioned by Rijkswaterstaat Waterdienst to develop the knowledge needed to carry out an effective nourishment strategy. *Toestand van de Kust* (State of the Coast) is one of the sub-projects of a multi-year program, with the aim of identifying the impact of nourishments for a number of indicators along the Dutch coast. Learned lessons from the past are further used to improve future nourishment strategies. During this first year, the analysis has focused on the North Holland coast. The objective of the present study is twofold. The first objective is to support the Waterdienst in determining where to nourish, by indicating on which spots along the North Holland coast the sediment buffer is limited. This buffer does not only concerns sediment volumes, but also a wider range of coastal indicators. The second objective is to derive the effect of the nourishment strategy in the past to improve the future nourishment schemes.

METHODOLOGY

A number of indicators have been defined that are 1) representative of the morphological development of the Dutch coast at different temporal and spatial scale and 2) related to policy objectives and system function (safety, nature and recreation). An overview of the indicators is given in Table I. The

Table 1: Indicators chosen for describing the morphological development of the coast. Indicators are derived by Rijkswaterstaat (Kustlijnkaartenboeken), Deltares [Giardino et al., 2012], HKV [Van Balen et al., 2011] and Arcadis [Van Santen and Steetzel, 2011].

System function	Policy objective	Indicator
Short term safety	Maintenance of safety	Erosion length Probability of breaching
Medium term safety	Suistainable maintenance of safety	TKL (Toetsen KustLijn) MKL (Momentane KustLijn) BKL (Basis KustLijn) MDL (Momentane DuneLijn)
Long term safety	Suistainable maintenance of safety	Sand volumes at different water depths
Nature and recreation	Suistainable maintenance of dunes	Dune foot position Beach width

Table II: Division of North Holland coast in sub-areas with homogeneous nourishment strategy and autonomous trend.

Area code	Limit sub-region	Length [m]	Nourishment strategy / coastal type	Autonomous trend before 1990	*Wijnberg* [2002] (km from Den Helder)
1	90 – 588	4 980	Mainly beach nourishment	Eroding	~ 3-8 Eroding, profile steepening
2	608 - 1808	12 000	Mainly shoreface nourishment	Eroding	
3	1827 - 2023	1 960	Mainly beach nourishment	Eroding	~ 8-23 Eroding, profile flattening
4	2041 - 2606	5 650	Hondsbossche Zeewering	-	
5	2629 - 3200	5 710	Mainly shoreface nourishment	Eroding	
6	3225 - 3925	7 000	Mainly beach nourishment	Eroding	~ 23-55 Fluctuating
7	3950 - 4975	10 250	Nearly no nourishments	Alternating (erosive-accretive)	
8	5000 - 5500	5 000	Nearly no nourishments – under the effect of IJmuiden jetties	Accretive	

indicators were computed for the entire Dutch coast, for the years between 1965 and 2010. The analysis was subdivided in three periods of time (1965-1990, 1991-2000, 2001-2011), corresponding to radical changes in the nourishment policy. Within these predefined time windows, the study investigated changes in linear trends. The analyses were carried out both, at Jarkus transect level and at larger scale throughout the use of sub-areas, characterized by a homogeneous nourishment policy (e.g. beach nourishments, shoreface nourishments, no nourishment), and a similar autonomous trend erosive or accretive).

STUDY AREA

The North Holland coast is a sandy, microtidal, wave-dominated coast. This stretch of coast has a length of 55 km, and it is bounded in the North by a tidal inlet (the Marsdiep) and in the South by the 2.5 km long jetties of IJmuiden. The plan shape of the coast is slightly concave, with some disturbance near the Petten seawall which protrudes into the sea, giving to the shoreline a local convex curvature.

The alongshore sediment transport along the Holland coast has been derived by several authors using different models, verified by few field measurements [*Kleinhans and Grasmeijer*, 2005].

Studies of *Van Rijn* [1995, 1997] compared these results: despite the wide spreading, the general trend is southward-directed transport between the IJmuiden jetties and approximately km 30, and northward directed transport for the Northern stretch of coast. The magnitude ranges between -200.000 m^3/m/year in the south up to +500.000 m^3/m/ year in the north.

Time variations in sediment volumes at different water depths were computed by several authors [*Van Rijn,* 2010], [*Vermaas* 2010], based on field measurements. A general trend from erosive to accretive can be noticed along the all Holland coast, when comparing periods before and after 1990.

The nourishment policy in the Netherlands has been undergoing several modifications in the last 20 years. Along the North Holland coast, besides the increase in time of total nourishment volumes added, the tendency is towards an increase of shoreface nourishments with respect to beach nourishments. In addition, dune management over the years and man-made constructions (*e.g.* Petten seawall) along the North Holland coast represent the effort made on supporting important coastal functions.

Besides the anthropogenic intervention (nourishments, dune managements, man-made structures), nature plays a main role into the coastline morphological development. Given the complexity of the natural processes in the nearshore area, a unique relation between natural forcing and the different indicators does not exist. Moreover, the interference of the anthropogenic action and especially the huge nourishment volumes deposited on the beach, dune and breaker bars in the last years make even more difficult to distinguish between natural and anthropogenic processes.

The division in sub-areas that is applied in this study is presented in Table II. Sub-areas are characterized by a homogeneous nourishment policy and a similar autonomous trend. The main findings from *Wijnberg* [2002] on morphological trends are included in the last column of the table.

RESULTS

In this paper the results are presented for a number of indicators: the probability of breaching of the first dune row (P), the momentary coastline position (MKL) and the dune foot position (DF). More information concerning the analysis and the results for the complete set of indicators can be found in *Giardino et al.* [2012].

The time variation of the indicators was at first analyzed at Jarkus transect level, in relation with the amount of sand

Table III: Averaged nourishment volumes per sub-area (m^3 per m per year).

Area code	1965-1990	1990-2000	2001-2010
1	0	26	149
2	14	17	88
3	0	47	79
4	0	1	47
5	0	26	81
6	2	80	50
7	0	1	9
8	0	8	0

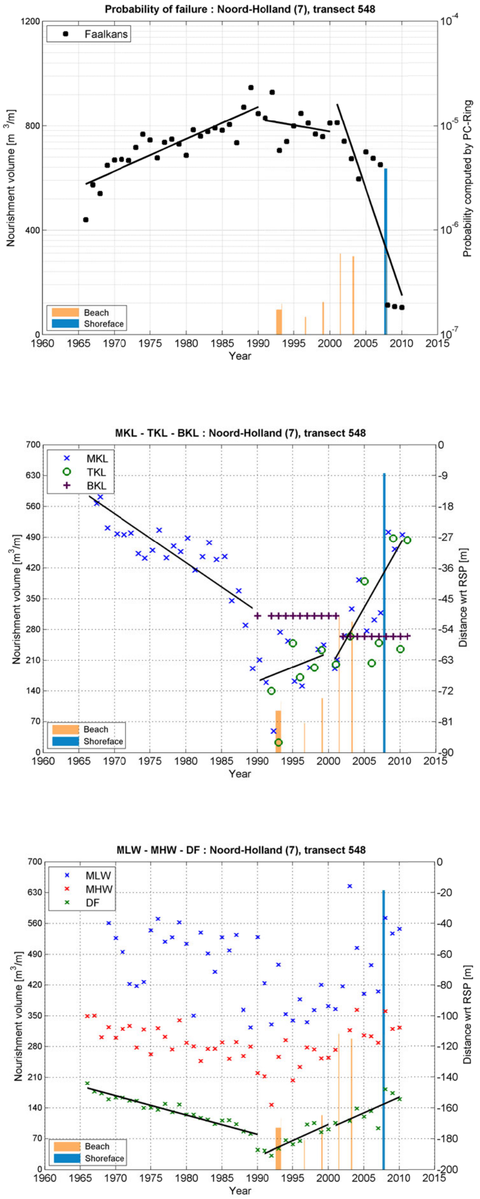

Figure 1. *Change in indicators and nourishment volumes (orange and blue bars) in time at Jarkus transect 548. Upper panel: probability of breaching (black dots). Middle panel: Momentary Coastline (MKL, blue crosses), Testing Coastline (TKL, green circles) and Basic Coastline (purple crosses). Lower panel: Dune foot (DF green crosses), mean low water (MLW, blue crosses), mean high water (MHW, red crosses).*

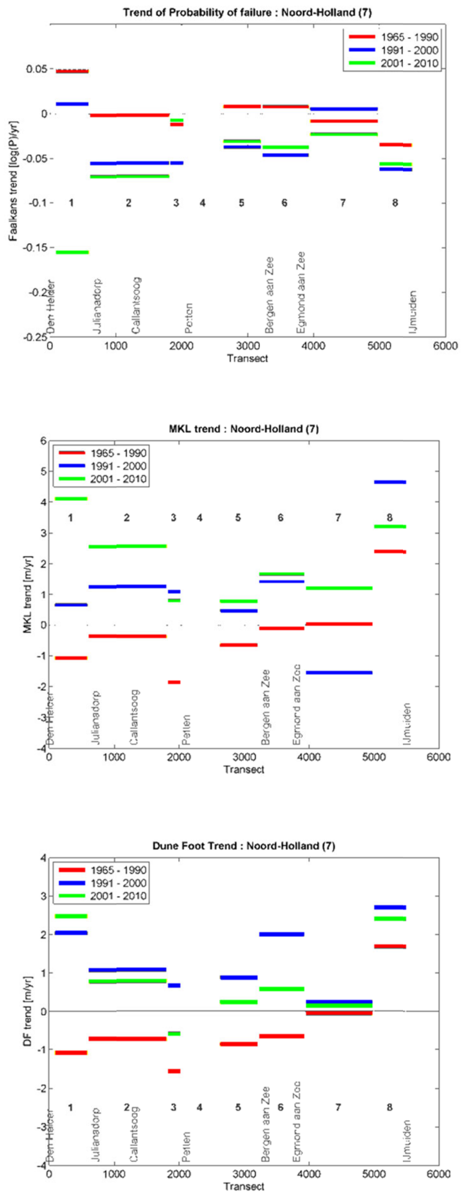

Figure 2. Averaged trend in probability of breaching (upper panel), MKL position (middle panel) and dune foot position (lower panel) within each of the eight areas with homogeneous autonomous trend and nourishment strategy. A relative change in trend of 0.1 year^{-1} on the upper plot, corresponds to a change of one order of magnitude in safety, for a time window of 10 years.

nourished. Figure 1 gives an example, clearly showing that nourishments led to a 'positive' effect in this stretch of coast (decrease in probability of breaching, seaward shift of both MKL and dune foot position). The relation between short term and medium term safety indicators for the all Holland coast, at Jarkus transect level per year, was investigated by *Van Santen* [2011].

The average trends in indicators (a linear trend for the three time windows, averaged over the sub-areas) also show a substantial change towards an average decrease in probability of failure and seaward shift of MKL and dune foot (Figure 2). The change in trend is especially evident for area 1, where mostly beach nourishments were applied. This would suggest that beach nourishments, on this time-scale, have a larger effect than shoreface nourishments. However, shoreface nourishments are built considering a long term prospective (5-10 years), rather then short term effects. On the same line are the modeling results presented in *Giardino* [2010], which showed that a beach or banquette nourishment of 200 m^3/m would lead to an instant decrease of 35-47 % in dune erosion for a 10 year return period storm, while a 400 m^3/m shoreface nourishment has the potential of reducing it only of 2-5 %. However, the effect of shoreface nourishments may show up later in time. Nourishment volumes for each sub-area and time window are given in Table III.

Also hard structures such as the IJmuiden jetties appear to have an effect on increasing safety levels. Area 7 and 8 are characterized by a decrease in the probability of breaching whereas no nourishment were applied. The trend analysis confirms the previous observation that in general nourishments have led to an improvement of safety (change in trend from positive to negative values) and a seaward shift of MKL and dune foot.

It is important to point out that the probability of breaching only refers to the first dune row, while between transects 2606 and 5200 a multiple dune row system exists. This implies that a decrease in probability of breaching in the more northern transects (*i.e.* between transects 90 and 2041) has a more significant impact on safety against flooding than in the southern transects (*i.e.* between transects 2606 and 5200).

The relations between trends in different indicators and between nourishment volume and indicators have also been derived at the scale of sub-areas (see Figure 3 [*Stronkhorst and Bruens*, 2012]).

CONCLUSIONS

The main objective of the study was to derive the effect of the nourishment strategy in the past. Has the nourishment policy applied since 1990 in The Netherlands led to a ‘positive’ (seaward) development of the indicators?

The analysis has shown that the nourishment strategy has in general led to positive effects. Short term safety, described by the probability of breaching of the first dune row, has in general increased overall of more than one order of magnitude. The medium term safety has improved, as shown by an average shift of the MKL indicator of 30 m in seaward direction. The dune foot has also been migrating seaward in average of about 18 m since 1990. Moreover, the erosive trends, which were quite common at most locations before 1990, have been replaced starting from 1990 by accretive trends.

Relations between indicators were identified at Jarkus transect level and at the scale of sub-areas. Indicators appeared to be, in general, well correlated. At the scale of sub-areas, relations between nourishment volumes and shift in indicators have been derived as well: nourishments of approximately 1000 m^3 per meter coast per 10 year can result in a seaward shift of MKL of approximately 25 meters per 10 year and a decrease in probability of failure of the first dune row with a factor 10 per 10 year.

A complete database of indicators has been developed, and is now freely available through the Open Earth system. This database can be used as support tool for several projects dealing with coastline morphology in The Netherlands.

The same dataset can now be easily visualized by a number of interfaces which are under development at Deltares (The coastal viewer and Morphan) and be a user friendly support tool for coastal managers.

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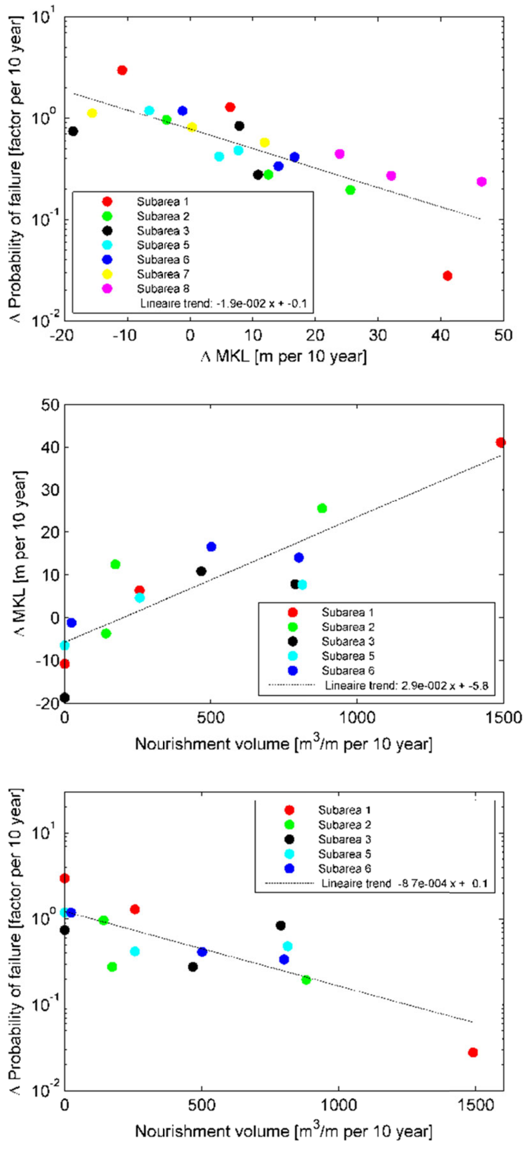

Figure 3. Upper panel: change in probability of failure (factor per 10 year) versus change in MKL position (meter per 10 year). Middle panel: change in MKL position (meter per 10 year) versus nourishment volume (m3 per m per 10 year). Lower panel: change in probability of failure (factor per 10 year) versus nourishment volume (m3 per m per 10 year). Plots for sub-areas in North Holland (see Table II).

Nourishment volumes in sub-area 7 and 8 are negligible and therefore not included in the two lowest panels.

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