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A new sediment budget for the Netherlands: the effect of 15 years of nourishing (1991-2005)

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Summary
In 1990, the Dutch government decided to halt structural coastal erosion with sand nourishments. This paper presents a sediment balance over the period 1990-2005, the first fifteen years of nourishing, in order to establish the results. The overall net sediment budget of the Dutch coast is still negative due to erosion of the lower shoreface and the ebb-tidal deltas: -159.8 million cubic meter (mcm). However, the budget shows that the accretionary status of the upper shoreface, beach and frontal dunes has changed to positive. The natural volume trend over the period 1990-2005 is -41.5 mcm. With a nourished volume of 118.6 mcm this zone has a net gain of 77.3 mcm. Especially the Holland coast has a very positive sediment budget: a gain of 23.3 mcm. The conclusion of this study is that the aim of the Dynamic Preservation policy is achieved: coastal recession has been stopped.

References

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Contents

1 Introduction

After continued losses of dune area in the nineteen seventies and eighties of approximately 20 ha per year (de Ruig 1998), the Dutch government decided in 1990 to halt structural coastal erosion. In order to do this, a reference coastline was defined, a yearly test procedure was designed (see Hillen and De Haan 1995, for details) and the Dynamic Preservation policy was introduced. This policy stated that coastal erosion should be compensated predominantly with sand nourishments, under the motto 'soft measures where possible, hard structures where necessary'. In 1991 the yearly nourishment scheme started with a total yearly sand volume of 5 to 7 million cubic meters (*mcm*) that was supplied mainly as beach nourishments at locations that failed the yearly test procedure. In 2000 the zone of attention was extended both into seaward and landward direction by including the lower shoreface and the dune area respectively. Non-deposition and erosion in the lower shoreface is expected to threaten the coastal stability in the long run and increase structural coastal erosion. An outline of the sediment budget for the Dutch coast over the period 1965-1995, see Figure 1.1, shows a negative trend for the lower shoreface all along the Dutch coast (except for the accretion zones directly north and south of the harbor moles of IJmuiden). This extended zone was baptized the Coastal Foundation. In order to maintain this foundation the yearly available sand volume was doubled to on average 12 *mcm* and shoreface nourishments were adopted as an efficient and effective way of nourishing. Over the period 1991-2012 a total volume of 207 *mcm* of sand has been supplied to the coast of The Netherlands, about half of this volume as shoreface nourishments. Shoreface nourishments are in general placed in the lowest part of the surf zone, between 5 and 8 m below MSL. In order to establish the result of these efforts and compare them to the situation before the introduction of Dynamic Preservation, a sediment balance over the first fifteen years of nourishing was calculated. This paper presents the results.

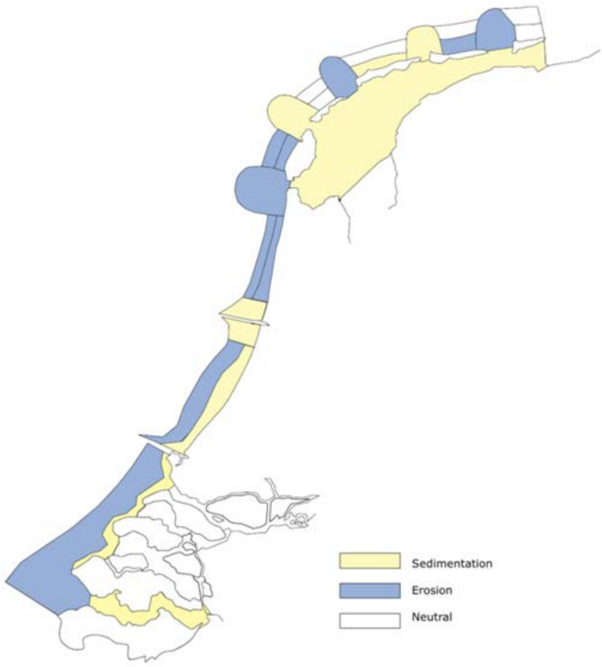

Figure 1.1 Sediment budget 1965-1995 (Ministerie van Verkeer en Waterstaat 2000)

2 The coast of The Netherlands

The coast of The Netherlands can be divided into 3 subsystems, the Wadden Sea in the north, the beach-dune coast of central Holland and the Delta area in the Southwest (Figure 2.1). The Wadden Sea consists of barrier islands and an extensive back-barrier intertidal flat area. The Delta area is formed by 4 estuaries, 3 of them distributaries of the rivers Rhine and Meuse and one of the river Scheldt. With exception of the latter, the Western Scheldt, these distributaries are partly or completely closed off from the sea and river by dams. This triggered large-scale changes in their ebb-tidal deltas, with both positive and negative effects on the coastlines of the adjacent islands.

The mean tidal range along the Dutch coast decreases from 3.86 m in Vlissingen at the mouth of the Western Scheldt in the southwest, to 1.39 m at Den Helder in the north and increases again to the (north-)east to 2.99 m at Delfzijl at the Ems estuary (source: Rijkswaterstaat). Waves are coming predominantly from the (west)southwest (200°-230°) with significant wave heights ranging from 0.75 to 1.88 m and periods of 5-6 s for almost 60% of the time (observation post Europlatform). The typical mean grainsize for the shoreface and beach is around 0.25 mm. Shoreface slopes range from 1:150 to 1:450 along the Holland coast (Spanhoff and Van der Graaff 2006).

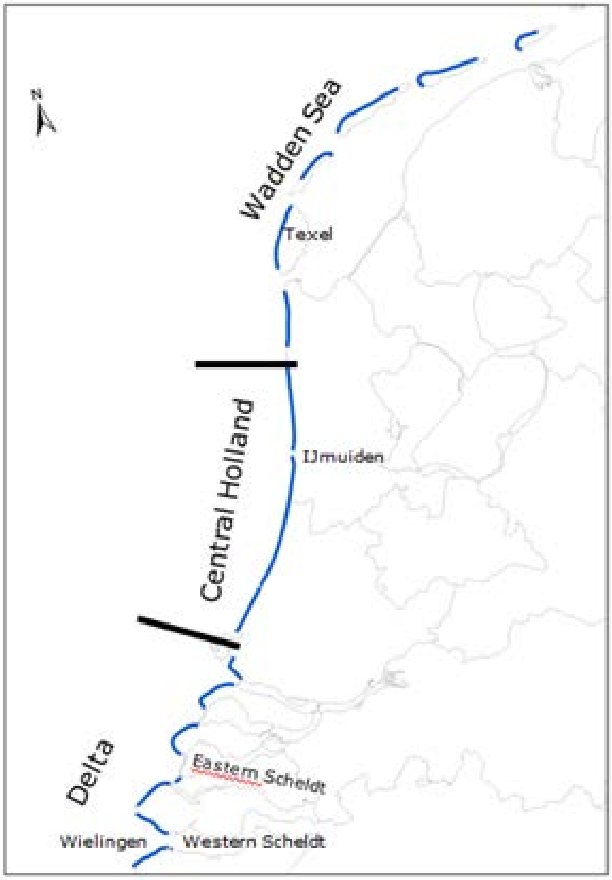

Figure 2.1 The three subsystems, Wadden Sea, Holland Coast and Delta Area. The blue line indicates all parts of the Netherlands where a reference volume is set

2.1 Coastal developments

The general trend in the Wadden area is erosion of the barrier-island shorelines and ebb-tidal deltas and sedimentation in the back-barrier basins. Nearly 600 *mcm* of sediment was imported between 1935 and 2005, which is a larger volume than needed for the compensation of the present rate of sea-level rise (Elias et al. 2012). The large infilling rates in closed-off channels and along basin shorelines indicate that this sedimentation is primarily a response to the damming of parts of tidal basins. The Holland coast is eroding at its northern and southern ends but more or less stable in its central part. The Delta area is strongly influenced by the damming of the estuaries, all ebb-tidal deltas are either eroding or about stable. Note that even when a subsystem is accreting as a whole, erosion can occur locally.

2.2 Coastal maintenance

The state of the coast is assessed yearly by surveying cross-shore profiles at fixed, typically 250 m spaced transects (Jarkus program). The sand volume in the vertical section between approximately the dune foot and the MSL - 5 m contour (exact depth varying over the coastal system) per cross-section is compared to a reference volume and when the actual sand volume is smaller than the reference volume, the cross-section qualifies for nourishment (see De Ruig and Hillen 1997, for a more detailed description of this coastal maintenance methodology). Whether a nourishment is actually placed depends, amongst other things on the persistence of erosion over the years, the longshore extent of the eroding section, local coastal functions, design options and the costs of the nourishment.

The reference volume per cross-section is in principle based on the shoreline position of 1990, taking into account the trend in shoreline evolution over the interval 1980-1990. However, the practicability of the reference is evaluated periodically (every decade or so), taking into account the local state of e.g. the beach and its typical local functions. For instance, in cases where the coast is reinforced by seaward extension of the beach, the reference volume has been increased which will result in more frequent nourishment of that particular stretch of coastline. Figures 2.2 to 2.5 illustrate the structural coastal erosion before 1985, indicated by the position of the red squares in Figure 2.2, and the coastal development since the introduction of periodic replenishment of the sand volume. Before 1985, structural erosion caused a coastline recession of about 60 m (trend A in Figs. 2.2-2.4), indicated by a diminishing cross-shore distance (trend A in Figure 2.2) and landward receding dune foot positions (A in Figure 2.3, Figure 2.4). Repeated beach nourishments resulted in progradation of the dune foot, followed by renewed erosion (B in Figure 2.2, Figure 2.3). The negative trends between the nourishments (Figure 2.2) show that coastal erosion continued. Since 2003 three nourishments have been placed on the shoreface, which resulted in stabilization of the dune foot (respectively C and D in Figure 2.3). Figure 2.2 shows a small but steady progradation since 2009. Figure 2.5 illustrates the overall progradation and dune growth since 1990.

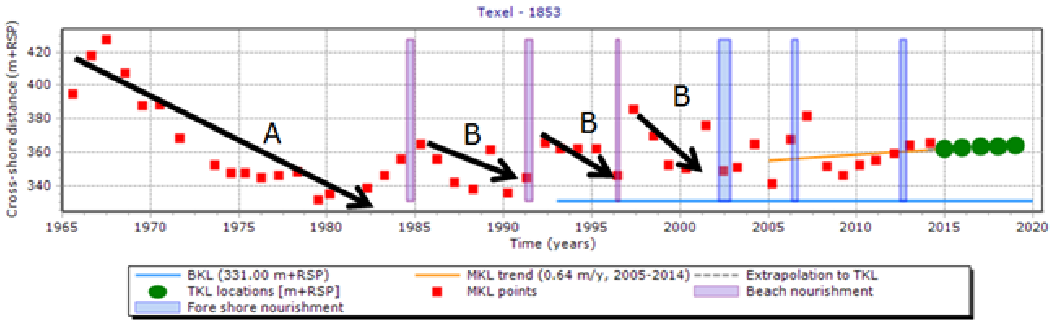

Figure 2.2 Example of the use of the reference volume for transect 18.53 at the island of Texel. The red squares indicate the coastal volume from year to year. The horizontal blue line is the reference volume, vertical blue and purple lines indicate nourishments. Note that the trends have been manually drawn for visualization. See text for further explanation

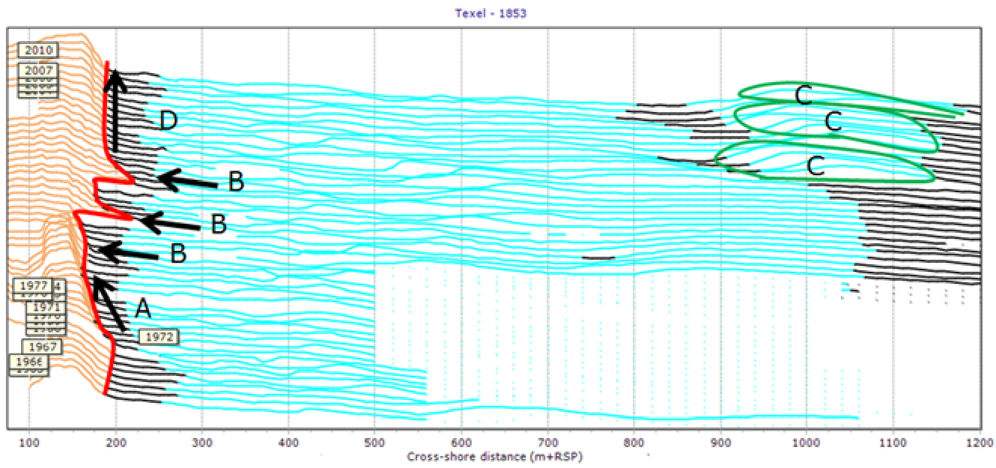

Figure 2.3 Timestack of yearly surveys of transect 18.53 at the island of Texel. The coastal development is indicated by the dune foot position (red line): erosion (A), repeated retreat-progradation (B) and stabilization (D) by shoreface nourishments (C); see text for further explanation

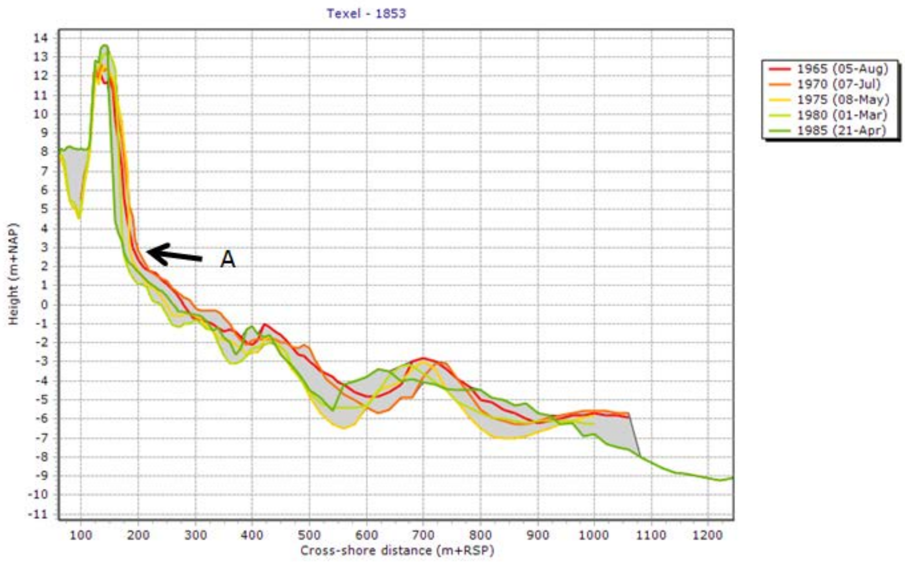

Figure 2.4 Coastal recession (A) between 1965 and 1985, transect 18.53, Texel island

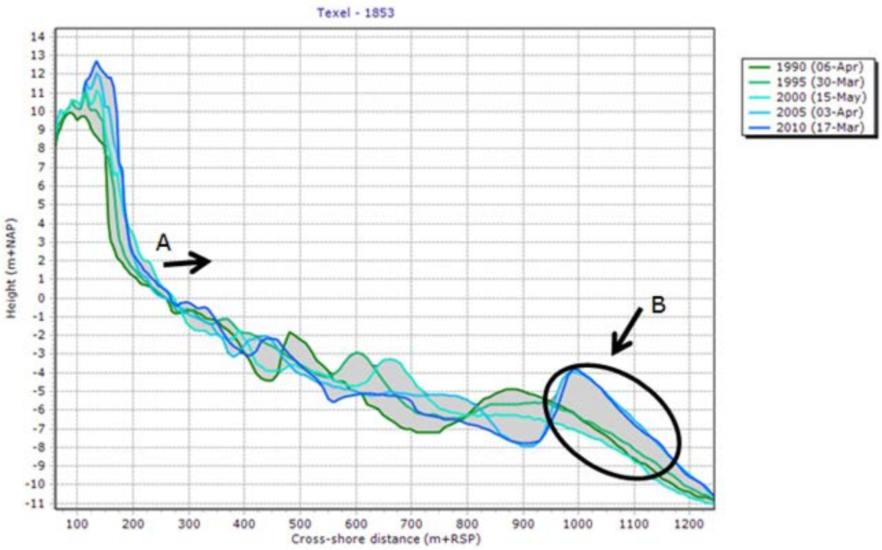

Figure 2.5 Coastal accretion (A) due to nourishments between 1990 and 2010, transect 18.53, Texel island. B: shoreface nourishment placed at the seaward side of the outer breaker bar

Nourishments are preferably placed on the shoreface where the construction is neither hampering the use of the beach nor creating dangerous situations for users. Moreover, larger volumes of sand can be put in place in comparison to beach nourishments, at generally lower expense per volume. Beaches are nourished either when there is an acute shortage of sand resulting in a severely eroded beach that is expected to disrupt coastal functions, or where the coastal profile is too shallow or too steep to place an shoreface nourishment. The latter is the case in the Delta region where large tidal channels occur inshore. In the last decade, large-scale nourishments in tidal channels have been applied successfully to stop landward channel migration and the accompanying erosion (Nederbragt and Koomans 2006).
The nourished sand is extracted from the North Sea bed, seaward the MSL – 20 m contour. This depth contour is considered the long-term lower boundary of the coastal system of the Netherlands.

3 Budget calculations 1990-2005

To calculate a sediment budget for the Dutch coast, the coastal zone in both Figure 5.1 and Table 1 has been subdivided in different zones for the subsystems Wadden, Holland and Delta. The Wadden subsystem consists of the zones (1) upper shoreface-beach-frontal dunes ('shallow'), (2) lower shoreface ('deep'), (3) dune areas, (4) ebb-tidal deltas and (4) tidal basins-estuaries. For the Holland subsystem the zones (1) and (2) are distinguished. The zoning of the Delta coast depends on the developments in the ebb-tidal delta; in all areas zone (1) was distinguished but the two northern ebb-tidal deltas were subdivided into a 'shallow' and a 'deep' subzone, whereas the Eastern Scheldt ebb-tidal delta was subdivided in a significantly changing part in the north and a comparatively stable part in the south. The Western Scheldt ebb-tidal delta consists of an inner subzone that is directly influenced by the sediment budget of the estuary, a northern subzone that is dominated by channel-shoal interaction southwest of Walcheren and a southern subzone that includes the shallow, more or less stable delta platform (Vlakte van de Raan) and the Wielingen channel where dredging and dumping are dominant.

3.1 Zone 1; upper shoreface-beach-frontal dunes

The yearly measured Jarkus data set depicts the development of the zone between MSL - 8 m and the frontal dune row. This zone has been subdivided in coastal sections with a more or less similar development, see Figure 5.1. For each section, the development of this zone between two nourishments is determined for all transects. This is assumed to be the autonomous trend in development of this zone. Subsequently, the yearly change in profile surface area is multiplied by the alongshore length of the section to derive the volume change per year. The latter is multiplied by 15, to arrive at the autonomous volume change over the interval 1990-2005. Finally, the volume of sand nourished in the years from 1990 to 2004 is added.

Example for the island of Texel (Wadden area):

- ✓ Representative trend 1990-2004: -0.800 million cubic meter per year.
- ✓ Volume change 1990-2005: 15 x -0.800 = -12.1 *mcm*
- ✓ Nourished volume 1990-2004: 24.3 *mcm*
- ✓ Net increase in sand volume: -12.1 + 24.3 = 12.2 *mcm*

3.2 Zone 2; lower shoreface

Volume changes of the lower shoreface of the Holland are based on the data of Vermaas (2010). The trend for the Wadden Sea barrier islands was estimated on the basis of the available changes in bathymetry. Here, data scarcity excludes the determination of distinct values.

3.3 Zone 3; dunes

The dune areas landward of the frontal dune row are part of the Coastal Foundation but there volume changes are very small since the frontal dune row catches almost all eolian sand transport. Therefore, the volume changes of the dunes have not been included in the budget.

3.4 Zone 4; ebb-tidal deltas

Volume changes in the ebb-tidal deltas are based on bathymetric maps. Changes for the Wadden Sea are given by Elias et al. (2012; Tab. 2). Volume changes for the subzones of the ebb-tidal deltas in the Delta area are based on the data given in Elias and Van der Spek (2014).

3.5 Zone 5; tidal basins

Comparison of bathymetric maps determines the changes in sediment volume in the tidal basins of the Wadden Sea. Elias et al. (2012; Tab. 2) present the numbers for the interval 1990-2005.

Table 1a. Sediment budget for the Dutch coast, including nourishments and sand extraction in the subsystems, in million cubic meters, over the period 1990-2005 *

Zone	Wadden	Holland	Delta	Total
Shallow	14.4	42.6	20.3	77.3
Deep		-19.3		-19.3
Dunes				
Deltas	-116.9		-155.6	-272.5
Basins	54.7			54.7
Total	**-47.8**	**23.3**	**-135.3**	**-159.8**
Nourished	37.3	54.3	27.0	118.6
Extracted	-2.9	-1.3	-11.5	-15.7
Net added volume	**34.4**	**53.0**	**15.5**	**102.9**

Table 1b. Autonomous sediment budget (total volume changes minus nourished and extracted volumes) for the Dutch coast, in million cubic meters, over the period 1990-2005

one	Wadden	Holland	Delta	Total
Shallow	-23.0	-11.8	-6.7	-41.5
Deep		-18.0		-18.0
Dunes				
Deltas	-114.0		-144.0	-258.0
Basins	54.7			54.7
Total	**-85.3**	**-29.8**	**-150.7**	**-262.8**

4 Sediment budget 1990-2005

The effects of the Dynamic Preservation policy are shown in the upper panel of Figure 5.1. The accretionary status of almost all upper shoreface-beach-frontal dunes segments has changed to positive. The natural trend over the period 1990-2005 is -41.5 *mcm* (Tab. 1b). With a nourished volume of 118.6 *mcm* this zone has a net gain of 77.3 *mcm* (Tab. 1a). Especially the Holland coast has a very positive sediment budget: a gain of 23.3 *mcm* (Tab. 1a). The overall sediment budget of the Dutch coast is still negative due to erosion of the lower shoreface and the ebb-tidal deltas. The total net budget is -159.8 *mcm*. The autonomous sediment budget, that is the volume change when the nourished volumes are left out, is still overall negative with exception of the tidal basins of the Wadden Sea (Tab. 1b).
The lower panel in Figure 5.1 shows these developments in detail.

5 Conclusion

The Dynamic Preservation policy maintains or increases the sediment volume of the shallow coastal zone between MSL - 8 m and the landward side of the frontal dune row. The eroding trend has changed into an accreting trend. The upper panel in Figure 5.1 illustrates this: two zones are slightly eroding (light blue color), 3 zones are about stable (green color) and all other zones are accreting (yellow or orange color). The nourished volume does not distribute over the entire coastal profile, the deeper shoreface is still eroding. In the ebb-tidal deltas in the Delta area, sediment is transported landward: the deep zones are losing sediment whereas the shallow zones are accreting. The tidal basins in the Wadden Sea are receiving sediment from the eroding ebb-tidal deltas and deeper shorefaces of the islands. Moreover, part of the sand volume nourished on the islands will be transported into the tidal basins. The westernmost basin indicates erosion (blue color), but this is due to the chosen basin boundaries (representative for the period 1935-2005; see Elias et al. 2012).

The final conclusion of this sediment budget study is that the aim of the Dynamic Preservation policy, to halt structural coastal erosion, is achieved. The coastline has been stabilized by nourishing regularly and in some places the coast is even building seaward. Coastal recession has been stopped. Only in places where natural dynamics are preferred, e.g. in nature reserves, and that are deliberately not nourished, the coastline is allowed to erode without interventions.

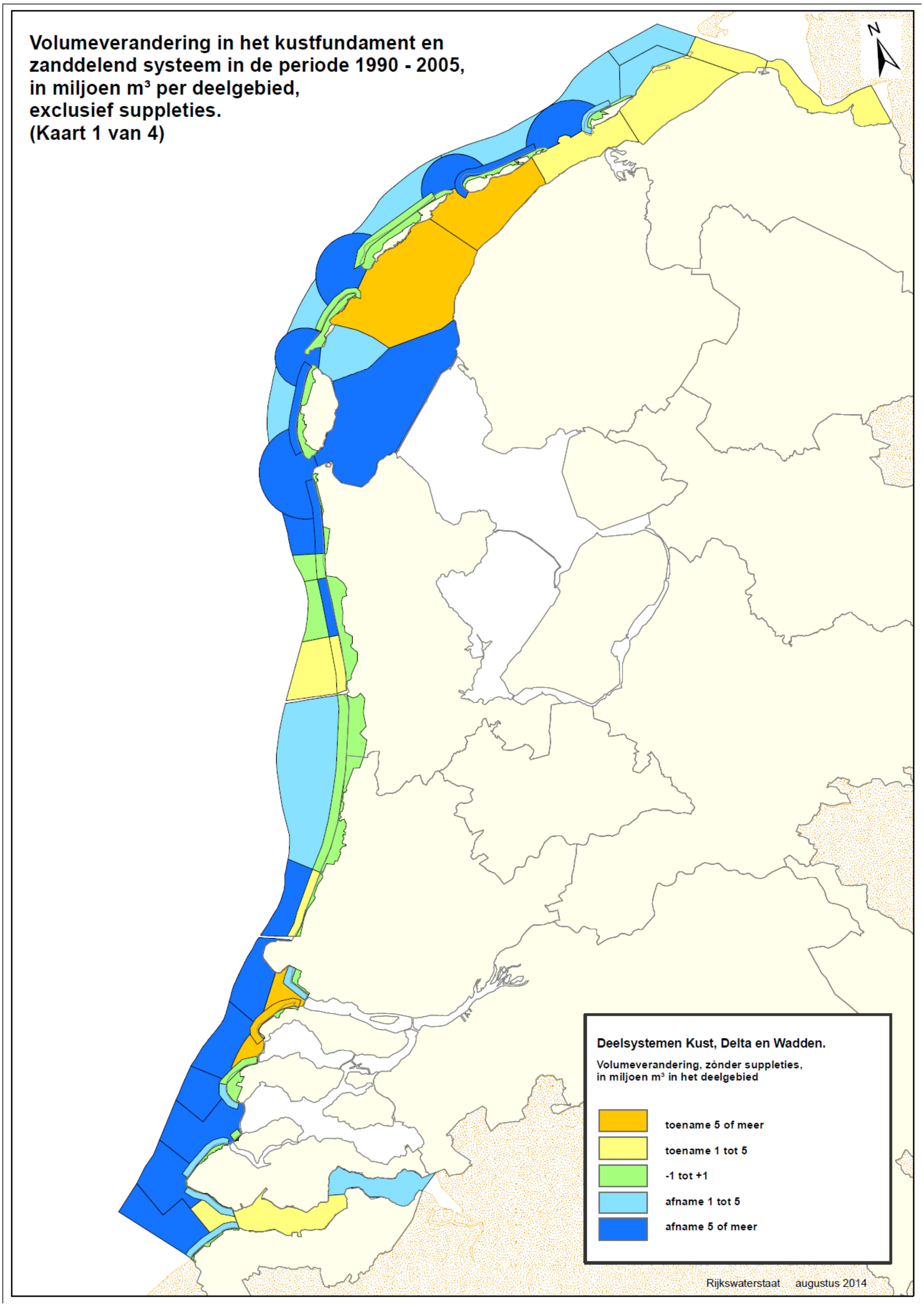

Figure 5.1 Volume changes per coastal section over the period 1991-2005, natural trend without nourishments Legend: orange = ≥5 mcm sedimentation; yellow = 1-5 mcm sedimentation; green = 1 mcm erosion to 1 mcm sedimentation; light blue = 1-5 mcm erosion; dark blue =≥5 mcm erosion

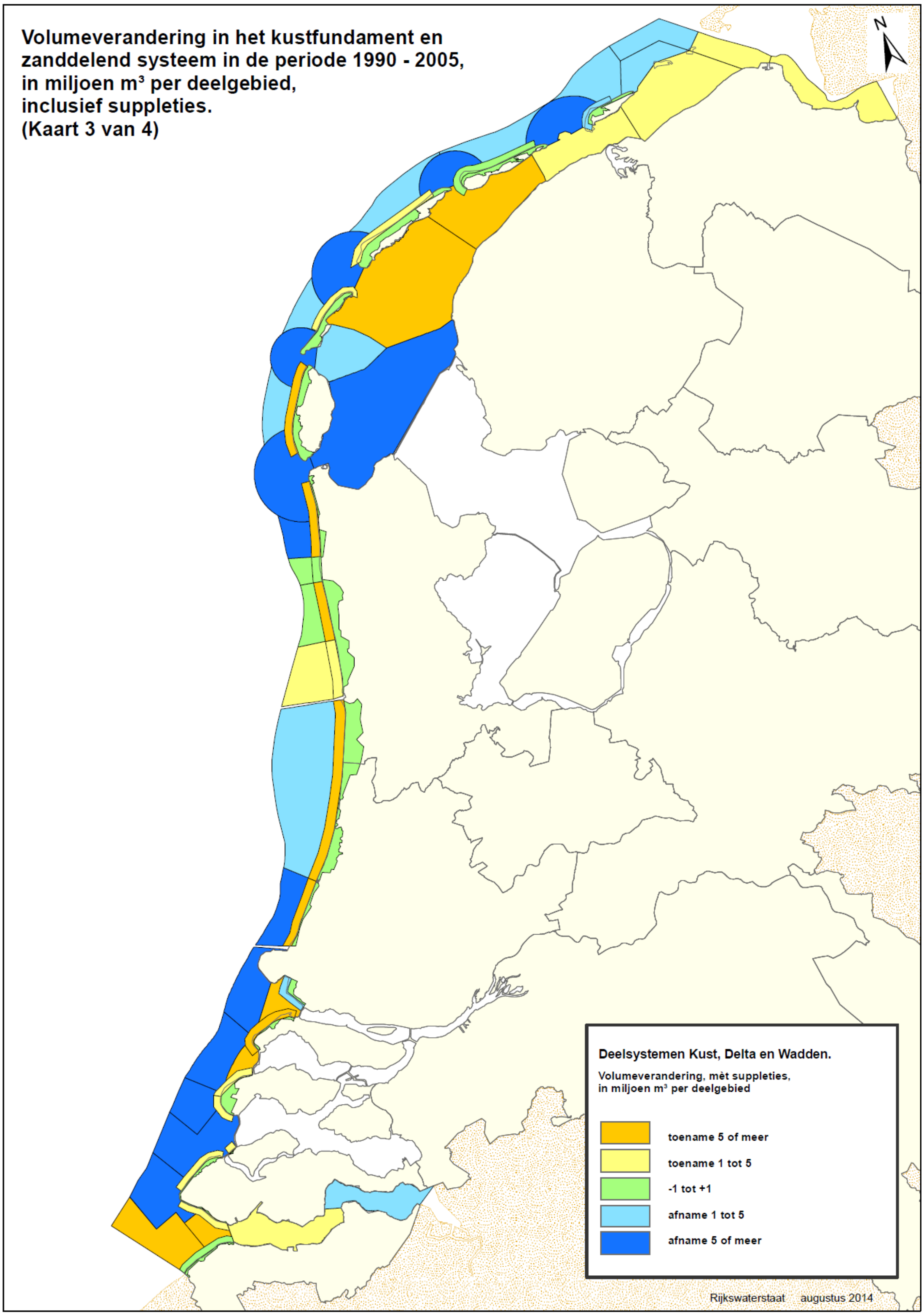

Figure 5.2 Volume changes per coastal section over the period 1991-2005, natural trend and including nourished volumes (upper panel). Legend: orange = ≥5 mcm sedimentation; yellow = 1-5 mcm sedimentation; green = 1 mcm erosion to 1 mcm sedimentation; light blue = 1-5 mcm erosion; dark blue =≥5 mcm erosion

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