DUNES: THE NETHERLANDS SOFT BUT SECURE SEA DEFENCES

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ABSTRACT

A major part of the Netherlands lies below or around sea level and has to be protected from flooding by the sea. Along the coast natural dunes are the first line of defence. Research in the 70's and 80's of the 20th century yielded methods to quantify dune strength for coastal safety assessments. This enabled coastal managers to engineer the soft and dynamic dune area to be a robust coastal defence of a predetermined strength. Further, research in the 80's yielded quantitative approaches to prevent structural coastal erosion. This enabled coastal managers to implement a national policy to counter structural coastal erosion by sand nourishment. The main objective of this paper is to explain the Netherlands' sandy coastal policies in order to convey the importance of sand nourishment as a coastal engineering measure in the Netherlands and its potential for other coastal areas. To illustrate how these policies are implemented in practice two case examples (both for the Delfland coast) are discussed.

The Dynamic Preservation case, dealing with coastline management, shows that annual coastline checks result in substantial nourishment efforts (1 Mm^3 with a 2-3 year return period). Nourishments of this order of magnitude are well capable to maintain the coastline position not landward of its established 1990 reference. The paper discusses the procedure that provided the trigger for intervention and outlines the order of magnitude of the intervention.

The Coastal Safety case, dealing with dune strength, illustrates how the five yearly review of criteria led in 2001 to the identification of a number of weak links along the North Sea coast. To meet the prescribed safety standards, strengthening measures have been designed and discussed publicly. The plans not only focus on safety from flooding but also account for aspects like natural values and spatial quality. The currently preferred alternative for the weak link of Delfland is a sandy intervention involving approximately 20 Mm^3 of sand, to be dredged in the North Sea. Execution is scheduled to start in 2008.

Based on experiences in the Netherlands we can see that working with sand works. Sand based coastal management strategies are clearly effective, sustainable and flexible. Years of research and experience have shown that sandy coasts, although soft and dynamic, can in fact be engineered to provide predefined safety levels while supporting other functions as well.

Keywords: coastal policy, safety, coastline preservation, coastal defences, sand nourishment

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INTRODUCTION

Although the Dutch are famous for their large hydraulic engineering structures, in alongshore scales these make up a relatively small part of the Dutch coastal flood defence. Some 15% of the Dutch coast consists of sea dikes and other man made sea barriers, 10% consists of beach flats along the tips of the northern Wadden islands and 75% consists of dune areas of varying widths, ranging from less than 100 meters to several kilometres. The primary function of these sandy dunes is to protect the low-lying hinterland from flooding. Without the dunes and dikes a large part of the Netherlands would vulnerable to periodic or permanent inundation (Figure 1).

The sandy coast, however, represents important value to other functions as well besides flood protection: e.g.

interventions) two case examples are discussed: one related to the policy of Dynamic Preservation, in particular dealing with coastline maintenance, and one related to coastal safety.

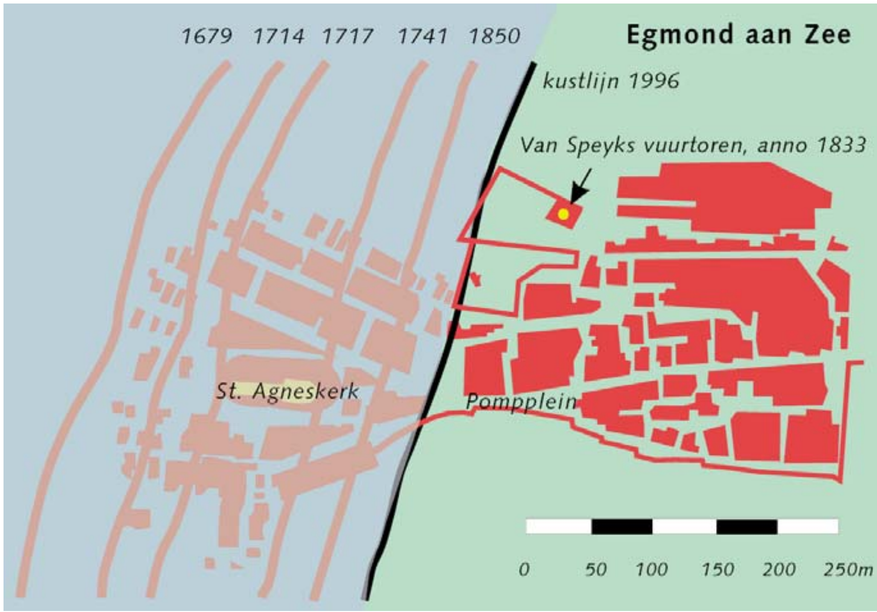

Figure 2. Coastline retreat at Egmond aan Zee (Min V&W, 2000).

SANDY COAST RELATED POLICIES

Traditionally, coastal policy in the Netherlands primarily is aimed at safety from flooding. After the storm surge disaster of 1953, coastal policy was dominated by the objective to bring all sea defences to a predefined safety level: the Delta strength. Implementation of these safety measures took place in the Delta Project. During the 1960's, 70's and 80's, dikes and dunes were strengthened and tidal inlets in SW Netherlands were dammed. Important research was done over the last decades to better understand the response of dunes to storm surges (cf. Jelgersma, 1961, Van de Graaff, 1977, Vellinga, 1982, 1986, Steetzel, 1993, Jelgersma et al. 1995). The work by Vellinga and Van de Graaff, amongst others, resulted in the Guideline for Dune Erosion (TAW, 1984). This guideline facilitates strategies for engineering of the dynamic sandy dunes to behave as the primary flood defence of a predetermined strength.

From the mid 70's the policy perspective of the Delta Project gradually widened, including ecological arguments in decision making. As a result, closure of the Eastern Scheldt tidal inlet in 1986 (climax of the Delta Project) was decided to be an open storm surge barrier. Similarly, during the 80's, the scope of coastal policy gradually extended towards other functions. Once the Delta safety levels had largely been established, the background coastal erosion problems received increasing attention. The need to maintain structural integrity of the coast in order to ensure sustainability of all coastal functions called for a new coastal policy. In the late 80's, in order to counteract further structural recession of the coastline, the Dutch government initiated the development of a new coastal policy. Several large studies, (e.g. the Coastal Genesis project (Stive, 1987) and other projects (cf. Van Koningsveld *et al., 2003)*) involving many of the Dutch coastal researchers were commissioned contributing to the decision by the Dutch Government on a national policy of "Dynamic Preservation" (Min V&W, 1990). Basic characteristic of the coastal policy is a multi-scale approach (cf. Table 1 and Fig. 3). This can be demonstrated using the Frame of Reference method for policy analysis (Van Koningsveld, 2003; Van Koningsveld and Mulder, 2004; Van Koningsveld and Lescinski, 2007) showing insight in the coherence of the various elements of the Netherlands sandy coastal policies. The Frame of Reference method facilitates structured policy analysis by providing a 'basic' template prescribing the specification of clear strategic and operational objectives supported by a matching decision recipe, which consists of:

1. A quantitative concept of the actual state of the system;
2. Procedures for objective benchmarking;
3. Procedures for preferred interventions; and
4. Procedures for evaluation (against operational as well as strategic objectives).

Recasting existing or new policies in terms of this basic frame of reference helps to identify if the policy as a whole is well-defined enough to be effectively applied and evaluated.

Applying this method to the current (dune oriented) Coastal Safety policy yields the following. The strategic policy objective is to guarantee the safety against flooding during extreme events. The focus is typically on the small scale: the dunes should be kept at sufficient strength to withstand hydraulic boundary conditions with a predetermined exceedance probability (to be tested every five years officially). The protection level is a political choice, laid down in Flood Defence Act (TK, 1996), based on a cost-benefit analysis. For the densely populated Holland coast the dunes should be able to withstand hydraulic boundary conditions with an exceedance probability of 1•10-4 times per year; the Wadden coast 5•10-4 times per year with the exception of Texel (2,5•10-4 times per year); the Delta coast 2,5•10-4 times per year. The decision recipe is based on the Dune Erosion Point (DEP), a quantitative state concept that helps determine the dune strength under certain hydraulic boundary conditions (TAW, 1984). Both the method and the hydraulic boundary conditions are officially reviewed five yearly. Water boards, dedicated regional water management authorities, are responsible for executing this Coastal Safety policy.

Table 1. Dutch coastal management strategies recast into the 'basic' frame of reference (modified after Van Koningsveld and Lescinski (2007)).

Management context:	**Coastal safety** **Small scale (< ~ 1 years)**	**Dynamic Preservation** **Medium scale (~ 10 years)**	**Large scale (~ 50-100 years)**
Strategic objective:	Guarantee safety levels provided by the dunes	Guarantee a sustainable safety level and sustainable preservation of functions and values of the dune area	Guarantee safety against flooding and preserve spatial quality of the coastal zone
Operational objective:	Dunes should be kept at sufficient strength to withstand hydraulic boundary conditions with a predetermined probability of occurrence.	To maintain the coastline not landward of its position of 01/01/1990	Preserve and improve the coastal foundation
Quantitative State Concept (CSI):	The dune erosion point (DEP): developed to unambiguously quantify the effects of dune erosion under design conditions per profile	The momentane coastline (MCL): developed to unambiguously quantify the position of the coastline per profile	The coastal foundation: the area between the inner dune edge and the (modified) NAP -20 m depth contour.
Benchmarking:	**Current state:** Extrapolation of a linear regression of all erosion points results in the testing dune erosion point **Reference State:** The reference state is a predefined critical position of the erosion point at which the dunes are assumed to have a sufficient rest strength.	**Current state:** Extrapolation of a linear regression of 10 previous MCL positions estimates the testing coastline position (TCL) **Reference State:** The TCL for 1990 is the Basal Coastline (BCL) and the reference state.	**Current state:** No procedure available yet **Reference State:** The TCL No procedure available yet
Intervention	**Procedure:** If the dune test returns 'unsafe', strengthen dune according to the measured shortfall (design life 5 years)	**Procedure:** If TCL exceeds the BCL position replenish according to the measured shortfall in volume (design life 5 years)	**Procedure:** Preferred intervention method is sand nourishment. No procedure available yet.
Evaluation	**Procedure:** Review strategy effectiveness by repeat benchmarking process	**Procedure:** Review strategy effectiveness by repeat benchmarking process	**Procedure:** No procedure available yet

The strategic objective for Dynamic Preservation is to guarantee sustainable preservation of safety and of values and functions in the dune area. The term 'sustainable' is interpreted as 'long-term' (in the order of several (~ 10) years), which is explicitly intended to be longer than in the above-mentioned strategic objective for the coastal safety policy, for example. The operational objective is that the coastline should be maintained at a position not landward of the 1990 reference. The decision recipe for this policy is based on the Momentane Coastline (MCL), a quantitative state concept used to determine structural coastline retreat (reflecting the longer term scope of the strategic objective) with respect to a certain reference value (TAW, 1995; Van Koningsveld and Mulder, 2004). The reference value, for the most part based on physical arguments, is formally established in a political process. The ministry of transport, public works and water management is responsible for executing the dynamic Preservation policy.

After implementation of Dynamic Preservation in 1990, various studies into the large scale sediment budget of the Dutch coast (Van Rijn et al., 1994, Van Rijn, 1997), taking into account various scenario's for sea-level rise, indicated that the coastal system as a whole was losing more sediment (~ 12 Mm^3/year) than was put in by Dynamic Preservation (~ 6 Mm^3/year) (Mulder, 2000, Mulder et al. 2006, Nederbragt 2006, Elias et al. 2006)). Consequently Dynamic Preservation was not considered sustainable, at time scales larger than the above-mentioned several (~ 10) years. In 1995, the Dutch Government decided on an extended, large-scale approach: additional compensation of sand losses at deeper water (Min V&W 1996, 2000). The recent National Spatial Strategy (NSS, 2005) reconfirmed the strategic objective of the large-scale coastal policy in the Netherlands, rephrasing it as: to guarantee safety against flooding and to preserve spatial quality of the coastal zone. As an additional large scale operational objective, NSS (2005) defined the preservation and improvement of the Coastal Foundation: the area between inner dune edge and the (modified) NAP –20 m depth contour. The Coastal Foundation is a new large-scale quantitative state concept. The frame of reference for this large scale coastal policy, however, is not yet fully developed (cf. Mulder, 2000; Van Koningsveld and Mulder, 2004 - see also Table 1, column 3). Nonetheless, acknowledging sand as 'the carrier of all functions', NSS (2005) underlines the importance of sand nourishments as principle component of the Dutch coastal policy on all scales.

A concise overview of Dutch coastal management strategies recast into the 'basic' frame of reference terms is presented in Table 1.

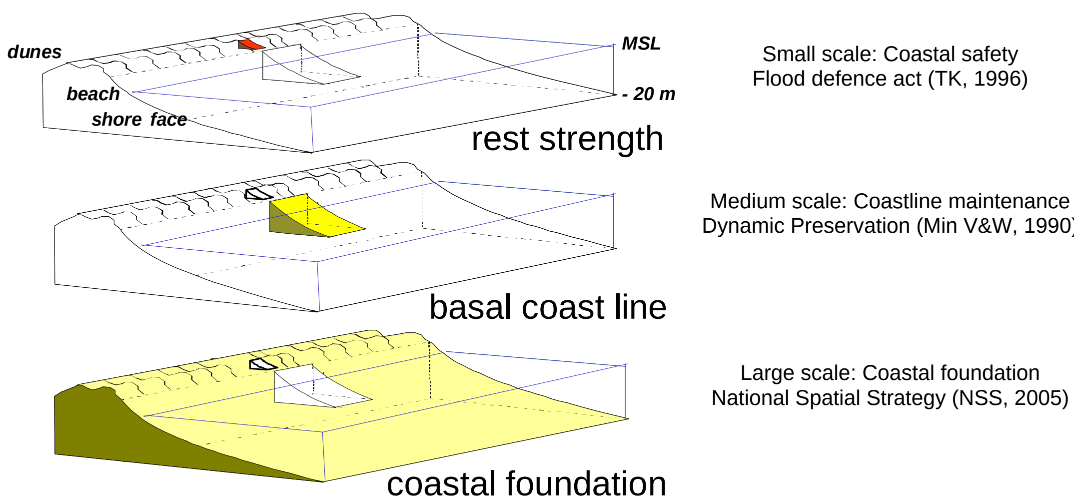

Figure 3. Schematic representation of the spatial scales associated with the coastal management concepts for dune strength (1 year), coastline preservation (5 – 10 years) and preservation of the Coastal Foundation (50 – 200 years) (Mulder *et al.*, 2006).

Figure 3 illustrates the spatial scales of the abovementioned elements of the Netherlands sandy coastal policy: maintaining the coastal foundation, coastline preservation and rest strength maintenance of the dunes. Rijkswaterstaat (the Dutch national coastal management authority) applies strategies at different time and space scales in order to promote interventions for larger scale operational objectives to have as much of a positive effect as possible on the other smaller scale objectives (Mulder *et al.*, 2006). The next section elaborates in more detail the quantitative methods supporting successful implementation of these sand based coastal policies with a focus on the medium scale (coastline maintenance branch of Dynamic Preservation) and smaller scale (coastal safety policy) respectively.

APPROACHES

Dynamic Preservation

The operational objective for the coastline maintenance branch of Dynamic Preservation is to prevent any further structural retreat of the coast beyond a predetermined reference coastline. To make this policy operational, criteria were developed to objectively determine whether or not a problem exists. First of all one needs to be able to describe the current (or momentane) state of the system and compare it with a predefined reference state. To enable practical implementation of this policy, three quantitative concepts have been defined (TAW, 1995, 2003, Van Koningsveld and Mulder, 2004):

- The Momentane Coastline (MCL) – basic building block
- The Basal Coastline (BCL) – reference state
- The Testing Coastline (TCL) – current state

Quantitative State Concept: The Momentane Coastline

The first element of the decision recipe for coastline management is an objective assessment of the state of the system. For this purpose the concept of the Momentary Coastline (MCL) has been developed, defining the coastline position as a function of the volume of sand in the near shore zone. The calculation of the MCL in any given cross-shore profile, is based on the area (or volume per unit length) of sand between two horizontal planes (MIN V&W, 1991). The upper and lower boundaries are each located at a distance 'H' from the Mean Low Water Level (MLWL), where 'H' denotes the vertical difference between the dune foot and the mean low water level (see Figure 4 - left panel).

The 'actual' calculation of the MCL is based on data from the Dutch yearly coastal monitoring program (JARKUS), which has been operational since 1963. JARKUS measures coastal depth profiles from the first dunes up to 1 km in a seaward direction, at alongshore intervals of 250m.

Benchmarking Procedure

The benchmarking procedure aims at an objective assessment of erosion problems of a structural nature, comparing the observed (or predicted) system state (TCL) with a predefined reference state (BCL). Basic building block of these state descriptions is the above mentioned quantitative state concept: MCL.

The operational objective to maintain the coastline at its 1990 position, implies a reference state related to the 1990 coastline. As such the Basal Coastline (BCL) has been defined as the estimated position of the coastline on January 1st of 1990. The BCL position is derived from an extrapolation of the linear trend in positions of the 10 MCL-points during the years 1980 to 1989 (Figure 4). The choice for a 10 year linear trend extrapolation, was inspired by the objective to counter structural, rather than incidental erosion. Even though the BCL is based on physical arguments for the most part the actual BCL position is established in a political process which means that locally the established reference may deviate from the calculated value.

Similarly, accounting for structural erosion, the description of the actual state of the system is based on a so-called Testing Coastline (TCL). The position of the TCL is determined, in a similar way as the BCL, by linearly extrapolating the trend of coastline positions (MCL) of ten previous years. Thus the position of the TCL in the year T can be determined by linearly extrapolating on the calculated MCL positions in the years (T-10) until (T-1) (Figure 4). For nourished sections it is no longer feasible to take an undisturbed 10 year trend. In such cases the MCL of the previous year is taken as TCL.

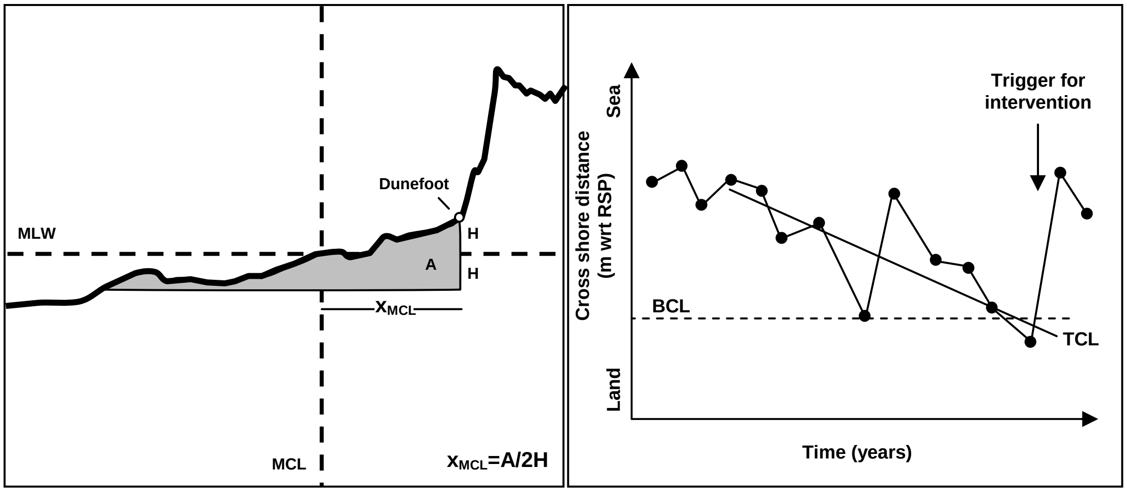

Figure 4. Left panel: definition sketch of the quantitative state concept MCL. Right panel: illustration of how for a given transect a number of MCL positions is used to compare the TCL (10 year trend) with the BCL. Intervention is considered if the TCL moves landward of the BCL.

The state of the system can now be compared with the reference state, by comparing the TCL position with the BCL position. This comparison provides an indication for the (expected) coastal state in the year T. A TCL that lies landward of the BCL provides a signal to the responsible coastal authority to consider intervention (see right panel Figure 4).

Annually the results of the testing procedure are shown on charts for every cross shore profile (Figure 5). The height of each plotted bar provides an indication of the size of the local TCL-trend slope (compare right panel Figure 4). A bar in offshore direction indicates an offshore directed or accretive trend and an onshore directed bar indicates an onshore directed or erosive trend. A threat of exceedance or indeed an actual exceedance of the local reference value, provides a trigger to Rijkswaterstaat, the responsible coastal management authority, to consider intervention (beach or shoreface nourishment). Aided by this system of triggers Rijkswaterstaat determines the nourishment schemes on an annual basis.

Coastal Safety

The strategic objective of the Flood Defence Act (TK, 1996) is to guarantee the safety of the hinterland against flooding. The operational objective of the Flood Defence Act is that the strength of the dunes satisfies the legal safety limits. The dunes of the most densely populated part of the country representing the highest economic value, have to resist a storm flood with a probability of occurrence of 1:10,000 a year. The associated probability of dune failure (breach) is a factor 10 smaller, viz. 1:100,000 a year.

Guaranteeing the legally determined level of safety of the hinterland is the most important function of the coastal zone. In the Netherlands the responsibility for this task is decentralized and delegated to regional Water boards. To operationalise the safety policy in areas where dunes form the back barrier, a method to assess the state of this barrier and a criterion for intervention are needed; similar to the above-described method supporting coastline maintenance. Because of the number of erosion processes and their intrinsic uncertainties, a probabilistic approach is appropriate.

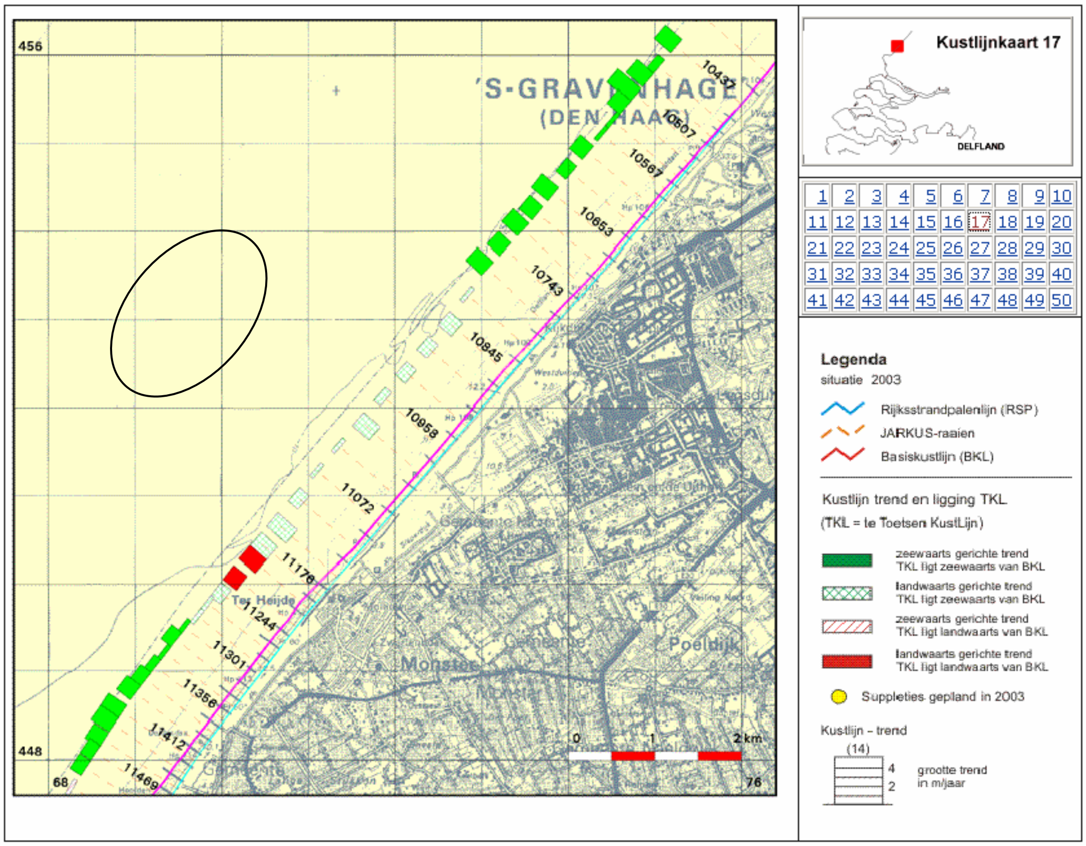

Figure 5. Coastline chart (2003) coast of Delfland. The oval highlights the area surrounding the village of Ter Heijde where in 2003 a trigger for intervention occurred.
http://www.kustlijnkaart.nl/kustlijnen/klk2003/index1.html

A first deterministic step in coastal safety assessments is the calculation of dune erosion based on water level, wave height, wave period and sediment fall velocity. With these parameters, an equilibrium erosion profile can be determined (see Figure 6). This equilibrium profile should then be 'fit' into coastal profile at hand. The position of the erosion profile in the vertical sense is determined by the computational water level (In Dutch: Rekenpeil). The position in the horizontal sense is determined by iteratively positioning the erosion profile over the coastal profile in such a way that an erosion-sedimentation balance is obtained in the direction perpendicular to the coast. The resulting profile is assumed to be the equilibrium profile after the storm.

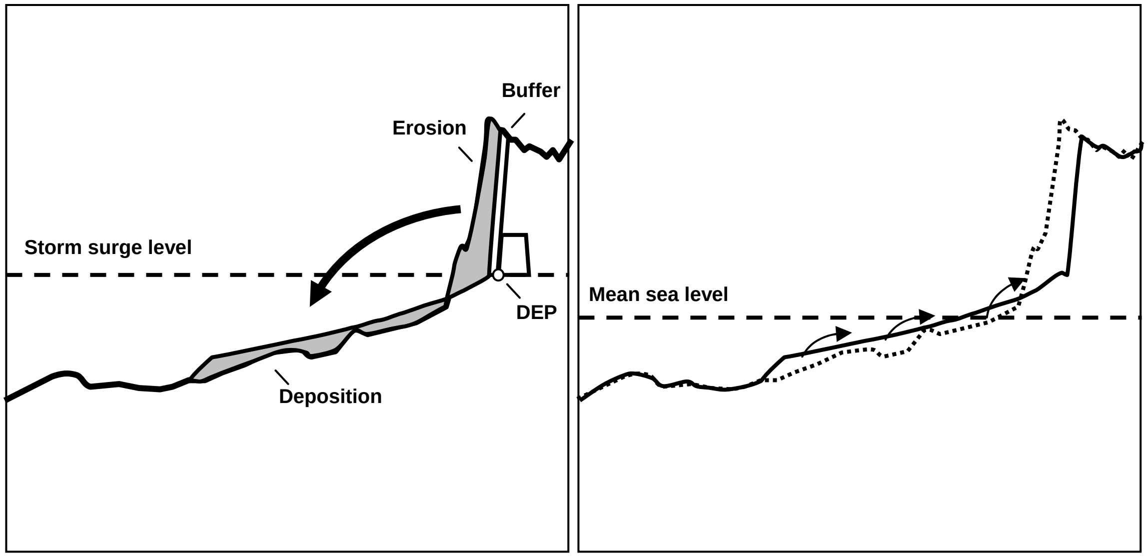

Figure 6. Left panel: Dune erosion point (DEP) definition sketch (time scale hours). Right panel: Coastal profile regeneration under calm conditions (time scale months)

Intuitively the shape of this equilibrium profile can be understood as follows. During the storm surge wave attack and run-up erodes sediment from the dune face. This sediment accumulates on the beach and foreshore. Storm waves break earlier on the now shallower beach profile thus slightly reducing the wave attack to the dune face. An equilibrium is reached when so much sand has been moved from the duneface to the beach that all waves have broken before the dune face is reached. In calm periods natural processes (wind and waves) transport the material deposited on the shoreface back to the dunefront, restoring the pre-storm situation in a matter of months to years.

To compensate for uncertainties in the model and the forcing conditions, the calculated effect (erosion above storm surge level) is exaggerated (based on a probabilistic approach), applying an uncertainty surcharge or buffer. The additional retreat of the dune face depends on the actual shape of the dune profile. The calculated erosion plus the uncertainty surcharge yield a so-called dune erosion point (DEP) (see Figure 6). The location of the DEP is defined as the most landward position of the predicted dune erosion on storm surge level. The dune is considered strong enough as long as behind the buffer volume a so-called 'boundary profile', a virtual sandy dike, can still fit in the coastal profile. The most landward position of the erosion point where a boundary profile still just fits under the dune profile is called the critical erosion point.

The Flood Defence Act (TK 1996) prescribes that every five years the dunes have to be checked to see if they have sufficient strength for the next 50 years to resist the predefined design storm. The dune erosion method as well as the hydraulic boundary conditions used for the calculations should also be reviewed five-yearly.

CASE DELFLAND: DYNAMIC PRESERVATION

This section illustrates the working of the Dynamic Preservation policy based on the actual case of the re-nourishment in 2005 of the Delfland coast near Ter Heijde, located in the southern part of the central Holland coast (see Figure 1). Figure 7 provides an aerial picture of the coast in front of the village of Ter Heijde. The picture clearly illustrates the location of the village behind a very narrow dune row. Furthermore it can be observed that the coast in this area is also protected by groins. These groins have been constructed in the previous two hundred years.

Due to the narrow dune row and the large economic values that are present in the hinterland (the highly developed province of South Holland is protected by this dune row), this coastal area has always received increased attention. Structural erosion here can clearly not be accepted.

Verification procedure

Due to several nourishments that were executed in this area since 1990 and due to the fact that there are groins in this area the TCL in 2003, is not exclusively based on the ten year trend of calculated MCL positions. The TCL here is supported by expert judgement taking the MCL of 2002 as a starting point. This TCL is then compared with the

BCL. Figure 5 shows the test results as a diagram. The diagram shows that between km 108,600 and km 113,000 the plotted bars are shoreward directed and solid red. The latter is a sign that on top of the fact that the TCL trend is directed landward, the actual TCL itself is located landward of the reference value (BCL).

Figure 7. Photos of the case area around Ter Heijde just before noon at low tide on October 18th 2005 (source: Rijkswaterstaat - www.kustfoto.nl).

The test results gave rise to the formulation of a new beach nourishment programme. The suggested programme was presented to the consultative committee on coastal affairs (POK) of the province of South Holland. In 2004 the programme was discussed by the provincial committees and eventually approved.

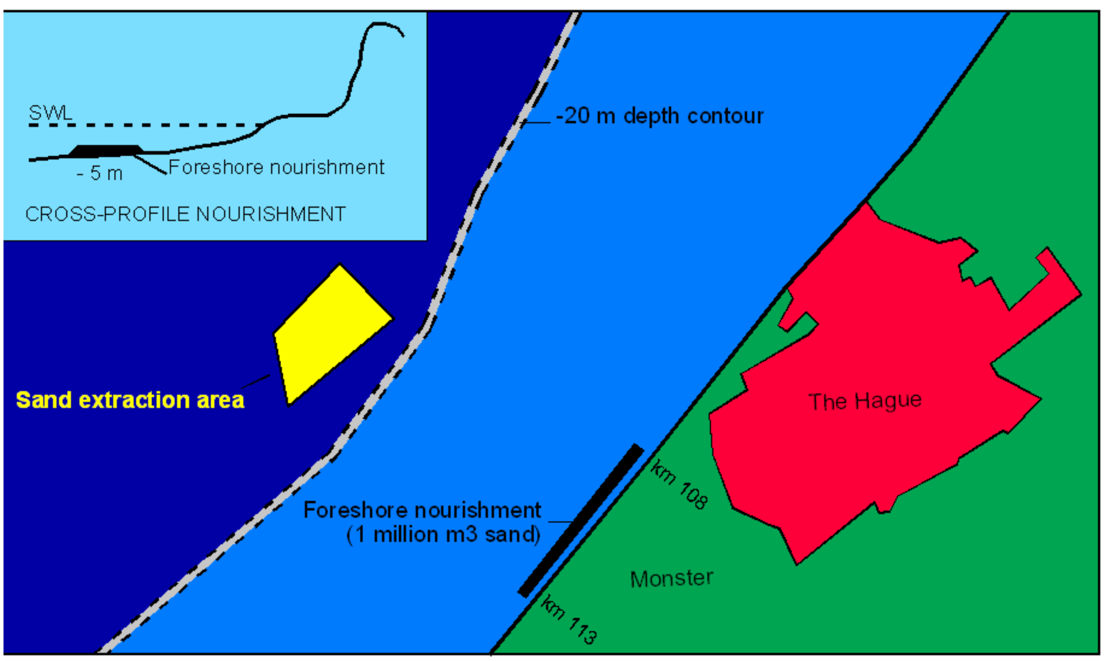

Figure 8. Shoreface nourishment, coast of Delfland.

Execution of Beach Nourishment

In 2005 the planned shoreface nourishment was executed between km 108,600 and km 113,000 commissioned by Rijkswaterstaat Directorate North Sea. In total 1 million m^3 of sand was dredged out of the North Sea (Table 2 contains a factsheet of the nourishment applied). The sand was extracted outside the coastal foundation, which limit is the –20 m depth contour. The sand was dumped in front of the coast of Monster on the –5 m depth contour (see Figure 8). As a result of the shoreface nourishment applied, the TCL should in the next measurement be located seaward of the BCL.

Table 2. Fact sheet Delfland 2005 shoreface nourishment.

Project		**Sand extraction area**	
City	Monster	Geographic name	Q16F
Location nourishment	km 108,600 – km 113,000	Depth	-20 m
Execution year	2005	Grain size bed material	407 µm
Execution period	October 10th until November 14th		
Design volume	1 million m^3		
Dredged volume measure at foreshore	0,9 million m^3 (loss of 10%)		
Construction depth	-5 m MSL		
Berm width	200 m^3/m		
Grainsize after nourishment	400 µm		
Slope nourishment profile	1:10		

Figure 9 shows that, as a result of the foreshore nourishment, the TCL has moved seaward of the BCL, although a landward trend is still suspected.

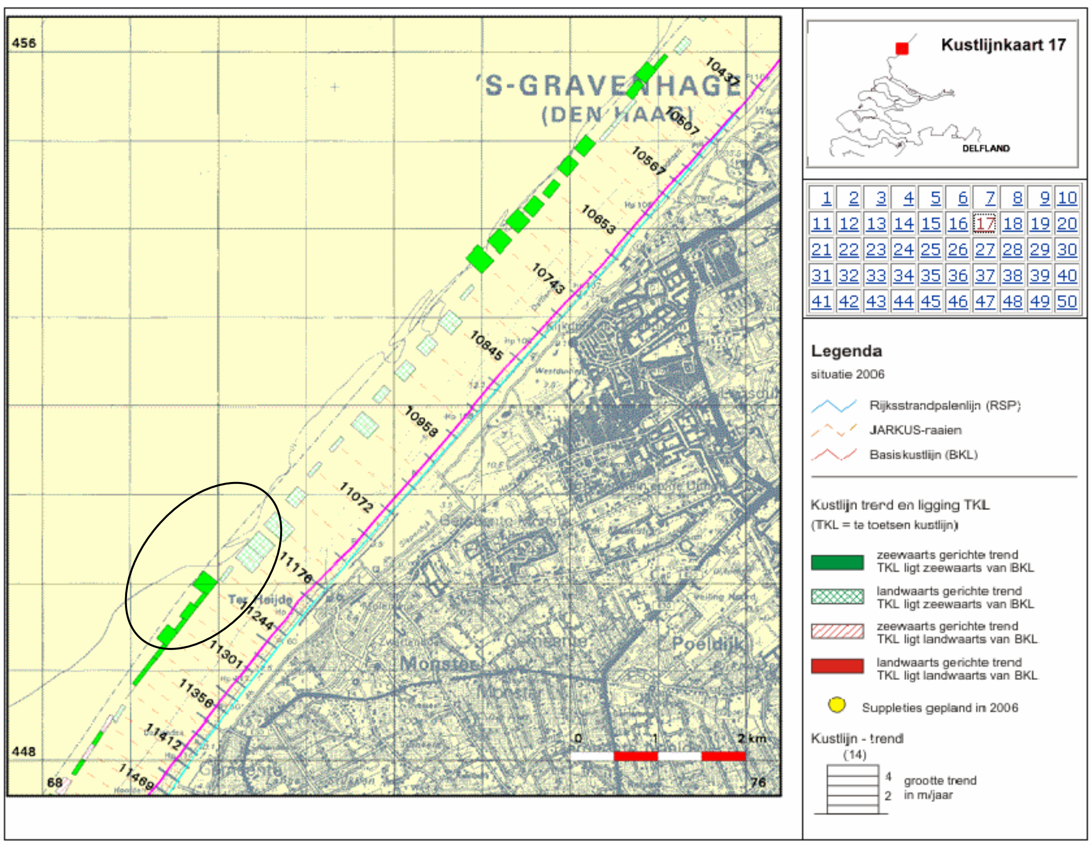

Figure 9. Coastline chart (2006) coast of Delfland. http://www.kustlijnkaart.nl/kustlijnen/klk2006/index1.html

CASE TER HEIJDE: COASTAL SAFETY

In 2002 new data became available suggesting that design conditions for dunes and dikes were more severe than previously suspected. In particular the wave periods for extreme conditions were found to be longer. This was expected to result in more energy reaching the coast under design conditions, causing sea defences to suffer more during extreme events. In anticipation of more detailed information on hydraulic boundary conditions and a new rule for dune erosion that included explicitly the wave peak period as a parameter, the flood defence system had to be checked by the water boards in 2003 to identify vulnerable sections (Hoogheemraadschap van Delfland, 2005). The test results indicated that several locations along the coast did not satisfy the safety limits under the expected heavier wave attacks on the long term (Figure 10). The coastal areas that did not meet the safety standards where labeled ‘weak links’.

Figure 10. Overview of identified weak links in the Dutch coastal flood defence system. The box indicates the location of the weak link of Delfland near Ter Heijde.

One of the weak links identified is located on the Delfland coast in between Hoek van Holland and Kijkduin (location indicated by frame in Figure 10). Especially the dunes of Ter Heijde do not provide sufficient protection against heavier wave attacks. Currently the Hoogheemraadschap Delfland (waterboard responsible for the Delfland coast), Rijkswaterstaat, the province of South-Holland and the municipalities Westland and The Hague are working together on a study to reinforce the Delfland coast structurally. Besides safety, spatial quality of the coastal zone and nature values are taken into account also in this study. The process towards reinforcement of the Delfland Coast is divided in the following phases (Hoogheemraadschap van Delfland):

- Phase 1 (2005): Generating alternatives to be assessed in the Environmental Impact Assessment (EIA). Alternatives to reinforce weak links are described in a starting note
- Phase 2 (2005 – 2007): Formulation of the EIA, review of alternatives, selection of an alternative, approval procedure, detailing the selected reinforcement measures, cost estimate, specifications and tendering terms.

- Phase 3 (since 2008): International tendering and execution of the reinforcement measures.

Characterisation coast of Delfland

To better understand the nature of the problem and the potential intervention alternatives a brief description of the coastal stretch at hand is presented in this section. The Delfland coast consists of two types of landscape. At some locations the coast consists of relatively natural dunes with a green interior border while at other locations the dunes are no more than a sandy dyke, with urban areas and green houses bordering the sea defence (Hoogheemraadschap van Delfland, 2005) (see Figure 11). The sandy dyke is a narrow dune, which is mainly manmade. The Delfland coast is characterised by narrow beaches and a raised dune toe, which is created by repeated beach nourishment. Figure 11 shows the coastal profiles of 3 locations along the Delfland coast.

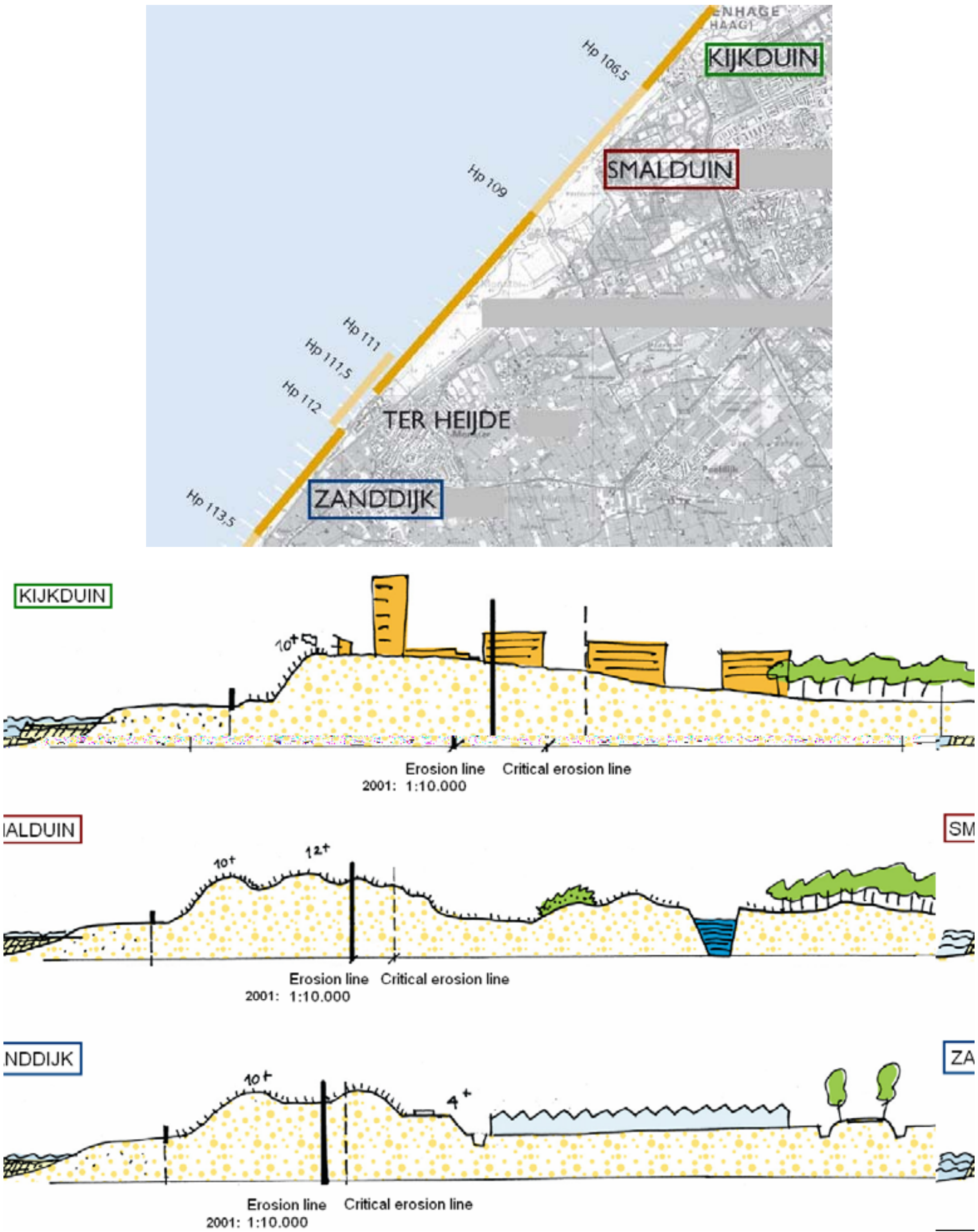

Figure 11. Cross-sections coast of Delfland and locations.
http://www.kustvisiezuidholland.nl/index_rebuild.html?http://www.kustvisie.nl/zwakke_schakels/delflandse_kust/nieuws.html

Strengthening Weak Link

The solution for the strengthening of the weak link must meet the boundary conditions which are determined by the government:

1. The solution must be able to withstand, during a minimum of 50 years, the legally imposed design conditions that occur 1:10.000 per year;
2. The solution must have an integrated character. This means that beside security also spatial quality and natural values must be taken into account;
3. The solution in sand is preferably carried out within the coastline maintenance branch of the Dynamic Preservation policy;
4. The alongshore shape of the solution must be optimized for minimum erosion.

Based on these boundary conditions three alternative measures have been suggested in the Environmental Impact Assessment (Hoogheemraadschap van Delfland, 2005) (Figure 12). Each alternative consists of sandy dune reinforcement measures engineered to manipulate the position of the dune erosion point.

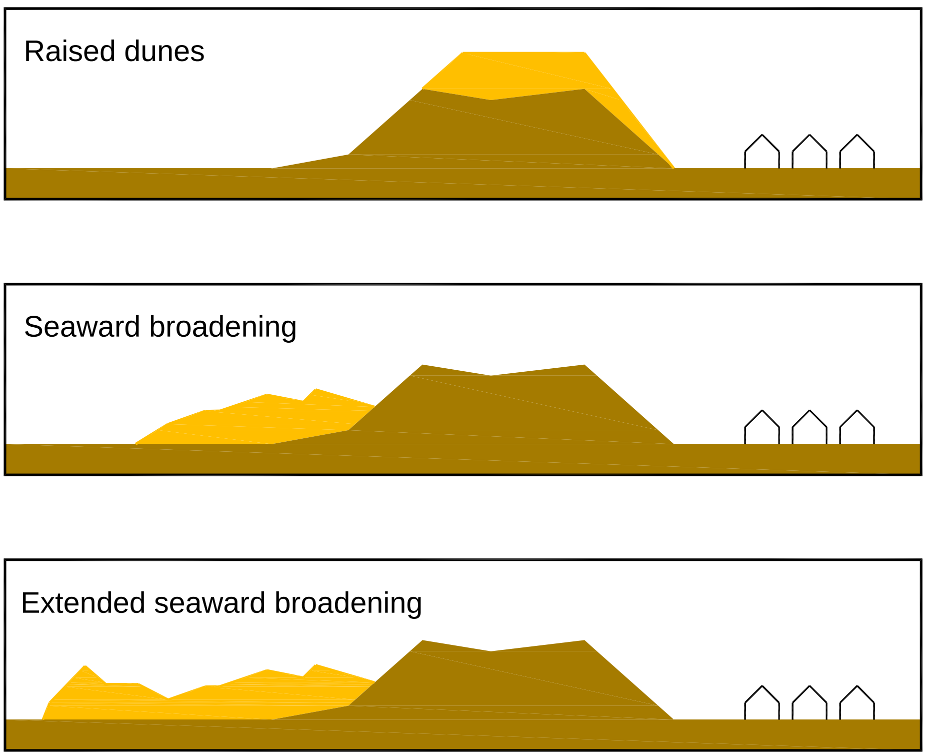

Figure 12. Strengthening alternatives.

http://www.kustvisiezuidholland.nl/index_rebuild.html?http://www.kustvisie.nl/zwakke_schakels/delflandse_kust/nieuws.html

The first alternative suggests to raise the dunes. On the weak spots a banked-up bed is introduced. A disadvantage of raising the dunes is the negative impact on the natural values currently present in the dune area.

The second alternative includes seaward broadening of de dunes. With this measure the existing dune area is kept in tact. An important advantage of this alternative is that is smoothes the coastline near the weak spots, which is expected to reduce the coastline maintenance efforts.

Alternative three suggests an extended seaward broadening of the dunes; an extension of the second alternative. This solution leads to broader beaches and dunes, something that improves the spatial quality and natural values of the dune area.

In May 2006 the three basic alternatives have been reviewed and the selection of the preferred alternative took place. The alternative 'raised dunes' was rejected because of its limited advantages and associated impact on the current dunes. The 'extended seaward broadening' alternative was rejected as it was considered to be too expensive. As a result, the 'seaward broadening' alternative became the preferred alternative. Figure 13 shows three cross-profiles of the preferred alternative while Table 3 provides a fact sheet with more quantitative detail.

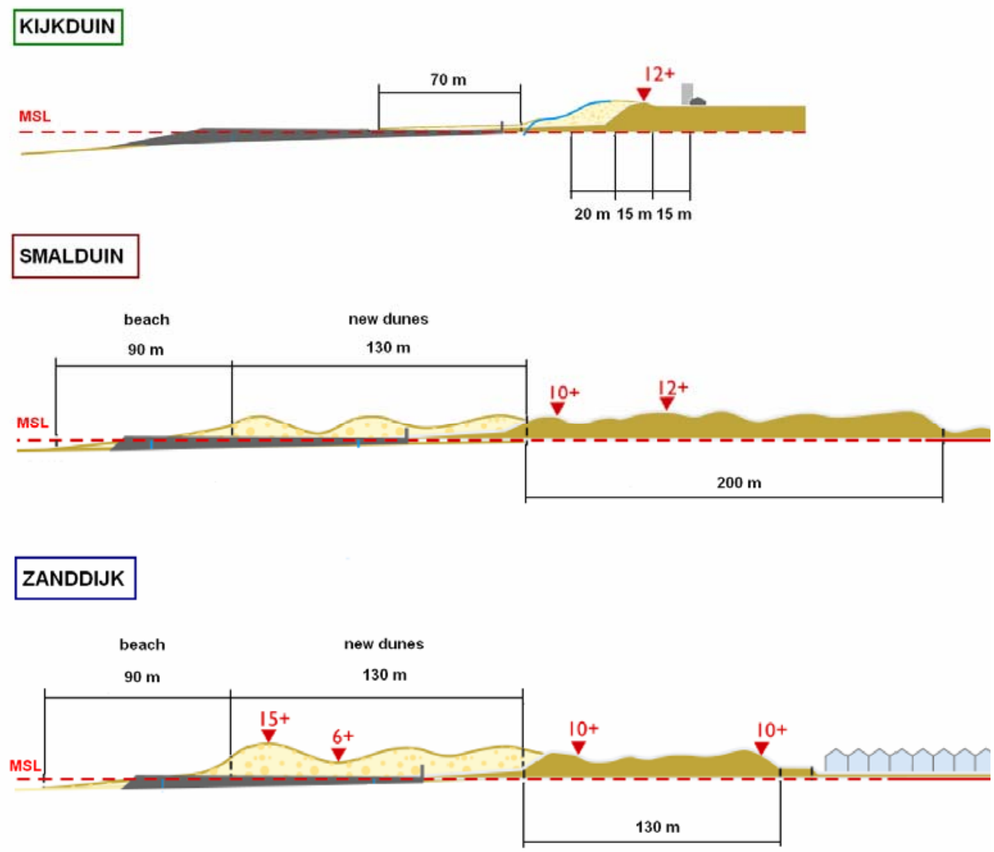

Figure 13. Cross-sections preferred alternative 'broadening seawards'.
http://www.kustvisiezuidholland.nl/index_rebuild.html?http://www.kustvisie.nl/zwakke_schakels/delflandse_kust/nieuws.html

In the design process several aspects of the current situation where taken into consideration. Developing a wide area of dunes, at the Kijkduin location, was considered undesirable as it requires extra large amounts of sand at Delfland in order to maintain a smooth coastline. Also the characteristic Kijkduin seaside views needed to be preserved. At the Kijkduin location a small sand parcel is introduced, conserving the current sea view. For the other parts of the Delfland coast, the dunes would be broadened seawards. The dune extensions have a width of 130 m with top altitudes up to MSL + 15 m. For the project as a whole, approximately 20 million m^3 of sand has to be dredged in the North Sea.

Table 3. Factsheet shoreface nourishment.

Factsheet Seaward broadening	**Weak Link Delfland**
Design criteria	Safe for next 50 years against 1:10.000 storm conditions and 0.30 m sea level rise in 50 year and more severe wave conditions
Dune area	increase of 0.9 Million m2
Beach area	increase of 0.5 Million m2, broadening until 150 – 200 m
Sand volume	19 Million m3, average D50 ca. 250 µm
Expected costs	100 M€
Execution	2008 – 2010

The case Ter Heijde shows that beside the safety aspect, other aspects such as spatial and natural quality can be taken into account in the design procedure of the dunes. The alternative 'seaward broadening' increases the safety level of the Delfland coast while at the same time it provides increased space for nature and more opportunities for recreation. The formal decision on whether or not the preferred alternative will actually be constructed is scheduled to be taken mid 2007. Following this decision, the selected alternative will be detailed further to facilitate a successful international tendering procedure. After tendering, execution of the work will probably start in 2008.

DISCUSSION AND CONCLUSIONS

- Based on experiences in the Netherlands we can see that working with sand works. Sand based coastal management strategies are clearly effective, flexible and - given the immense sand resources in the North Sea (see e.g. www.noordzeeatlas.nl) - above all sustainable.
- Years of research and experience have shown that sandy coasts, although soft and dynamic, can in fact be engineered to provide predefined safety levels while supporting other functions as well. The large scale approach of Dynamic Preservation further exploring the potential of different strategies to maintain and improve the coastal foundation, effectively creates boundary conditions for sustainable preservation of Coastal Safety.
- This approach can be of use in other coastal areas as well, when necessary parameters are or can be sufficiently documented. A main boundary condition is obviously the availability of sand.
- Relying on sand as main coastal management intervention requires that it is available in sufficient quantities and of sufficient quality against reasonable cost.
- If sediment for nourishment is scarce it is ever more important to manage sediment budgets. The best way to do this is to keep the coast as natural (sandy) as possible. Implementation of hard structures triggers a process that is very hard to reverse.
- Also if sediment sources are few, new technologies should be considered to mobilize deeper or further sediment sources against reasonable cost.

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