Report

Work Package 3
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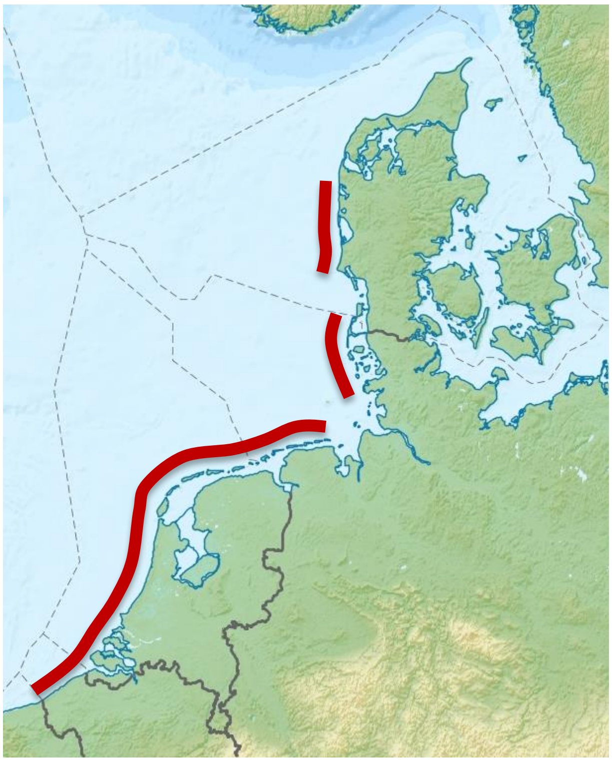
Date: 3 March 2017

Overall document

From flood prevention strategy to current practice nourishments

This document is a composition of six factsheets current practices from Flanders, the Netherlands, Lower Saxony, Schleswig Holstein, Denmark and Skåne (Sweden).



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1. Flanders

A. General flood prevention strategy

The Coastal Division is responsible for coastal flood protection in Flanders. In 2011 the Coastal Safety Masterplan (http://www.kustveiligheid.be/) was approved by the Flemish Government. This Masterplan aims to protect the coastal zone against a flood event with a return period of 1000 year: no fatal casualties are allowed due to such storm event, which means:

- no breaching of dunes and dikes
- max. allowed overtopping at the 'safety line' of 1 l/m/s
- no dune erosion landwards of the safety line

The safety line is a line that marks the area that needs to be protected. In urban areas it coincides with the seaward front of permanent inhabited buildings. In dune areas it coincides with the +7 m TAW height line at the landward side of the dunes, which approximately is the water level for a 1000-year storm.

The safety assessment of 2007-2008 revealed weak links, i.e. the coastal zones which can't withstand a 1000-year storm event. The Coastal Safety Masterplan provides flood protection measures at all weak links, see Figure 1. The general policy of this Masterplan is:

- 'hold the line': strengthen and maintain the current coast line (no retreat of the coast)

- 'soft when possible, hard when needed': soft flood measures (dune- and beach nourishments) are the preferable measures. Hard measures (strengthening and heightening of seawalls and quays, storm surge barrier) are chosen when soft measures aren't technically possible (in harbours). Sometimes hard and soft measures are combined to reduce nourishment costs: the beach in front of a seawall is nourished in combination with a heightening of the seawall.

The Coastal Safety Masterplan provides protection for 1000-year flood events till 2050, taking into account sea level rise. This means:

- dune- and beach nourishments will 'grow with sea level rise'
- hard measures are designed, taking sea level rise in to account depending on the lifetime of the hard measure. (50 year for a storm wall, 100 year for a storm surge barrier)

The estimated sea level is 30 cm till 2050 and 80 cm till 2100 (reference year 2000). Following this approach, in 2050, when the current masterplan ends, the coastal division is still able to nourish the coast and provide the safety level given the estimated sea level rise. Therefore sea level rise is indirectly incorporated.

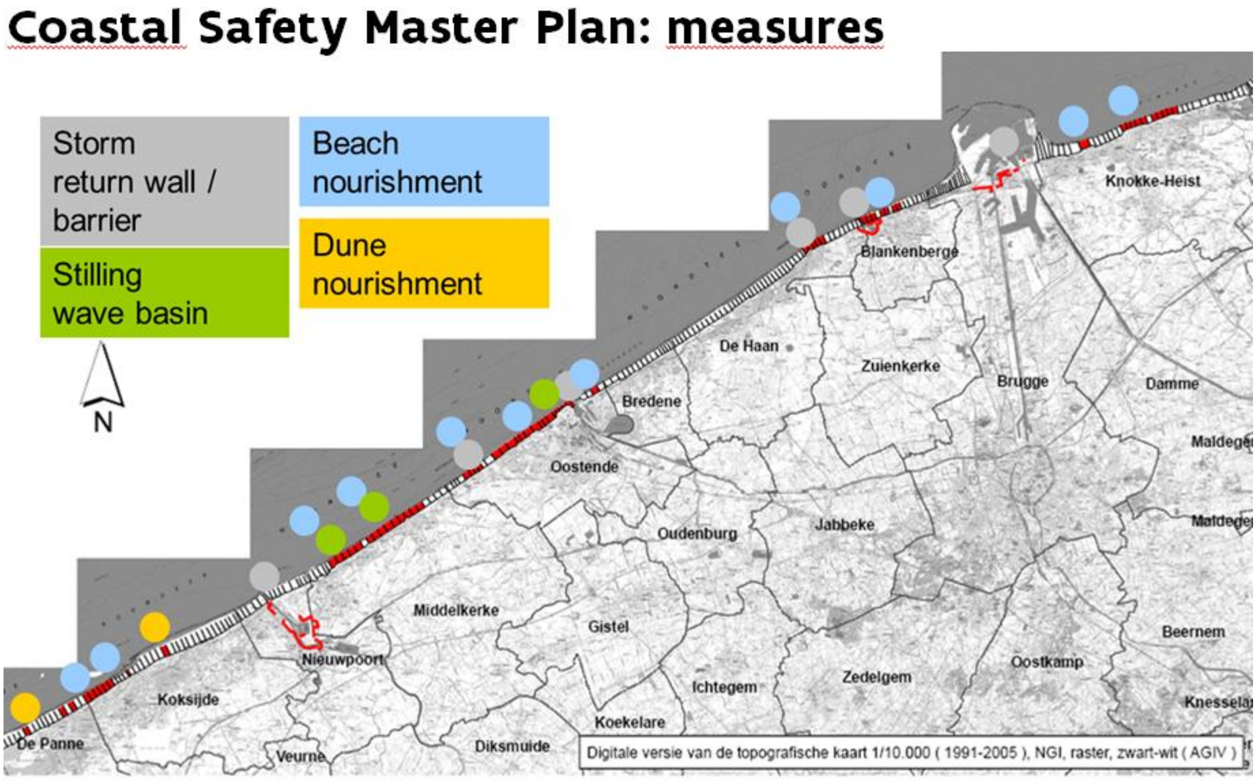

Figure 1: Weak links (red) and flood protection measures (year 2008)

B. Coastal management policy

In general, beach nourishments are executed including a 5-year maintenance buffer. This is an additional volume, so that safety will be provided during 5 years. This volume is calculated by the expected local erosion, based on historical data.

Every six year there is a safety assessment of the entire coast to test if the coast complies to the set of goals. For the moment there is a safety assessment going on. Results are expected in the beginning of 2017. After this safety assessment, new beach nourishments will be designed, depending of the result of the safety assessment.

When severe beach damage occurs due to storms, nourishments are executed to restore the beach.

C. Detailed design type of, location and volume nourishment

There are 3 types of nourishments executed at the Flemish coast:

1. Beach nourishments

   Beach nourishments are needed in the weak links of the sandy coast, this is mostly in front of the seawalls at the coastal towns.

The design of beach nourishments is mainly based on the overtopping limit of 1 l/m/s over the safety line. The design profile has typically a wide berm at +7 m TAW, the water level at a 1000-year event.

2. Dune nourishments

Dune nourishments are rarely executed at the Flemish coast because most dune areas are safe for a 1000-year flood event.

3. Shoreface nourishments

In 2014 a pilot shoreface nourishment was executed of 300.000 m³ at the area of Mariakerke, part of the town Oostende, see Figure 2.

This project aims the assessment of the contribution of underwater nourishments to extend the lifetime of beach nourishments. The experiment aims to compare the morphological response to a combined beach and shoreface nourishment and to a beach nourishment alone, in two adjacent coastal stretches. For the comparison an integrated approach including field measurement campaigns, video-monitoring, morphological numerical modelling and the definition and evaluation of a number of morphological indicators is adopted throughout the duration of the project (2014-2018).[1]

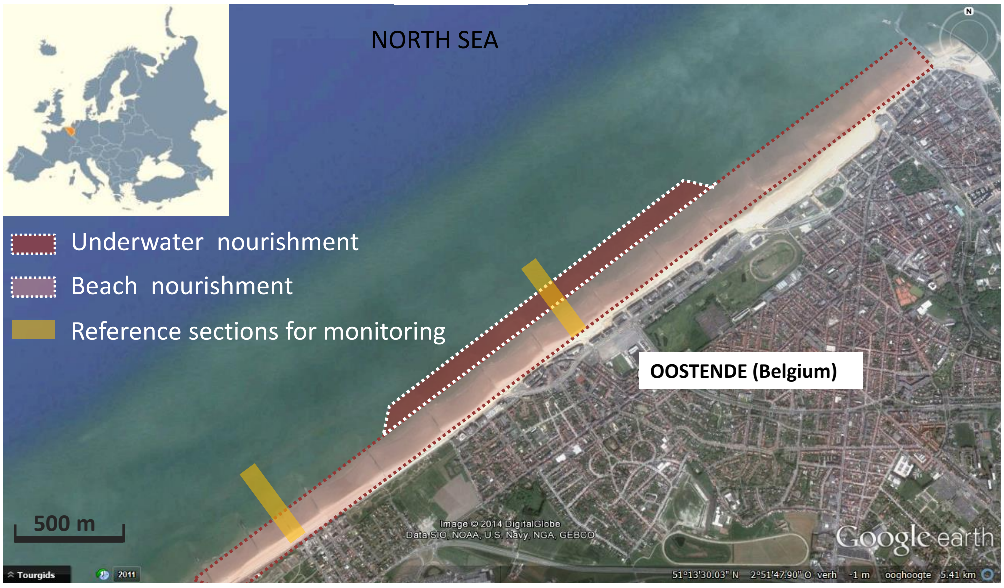

Figure 2: location shoreface nourishment [2]

D. Tendering and execution strategy

In Flanders, several types of contracts are tendered:

1. Contracts for small scale maintenance nourishments

These contracts are used for small scale ad hoc maintenance of the beaches on several locations along the coast. The typically duration of the contract is 1 year. The total volume of sand that can be nourished is around 200.000 m³. Sand can be transported to the beach by dumpers or vessels.

2. Contracts for large scale maintenance nourishments

These contracts are tendered for a nourishment to maintain the beach at 1 particular location. The nourishment volume depends on the maintenance need.

3. Contracts for nourishments of the Coastal Safety Masterplan

As can be seen in figure 1, the Coastal Safety Masterplan foresees the execution of several nourishments to upgrade the safety level to a 1000-year protection standard. These nourishments are tendered by separate contracts over several years. Most nourishments are finished. The maximum nourished volume was 1.6 million m³.

4. Contracts for urgent nourishments

During the severe December 2013 storm (called the ‘Sinterklaasstorm’ in Belgium), major sand losses were observed at several locations at the Flemish coast. To restore the beaches as soon as possible, there was a contract tendered using an urgent tendering procedure. The nourished volume was about 1 million m³.

The average price for nourishments on the Flemish coat is €11/m³, without VAT.

E. Evaluation of nourishments

As mentioned in chapter B, a safety assessment is executed very six year of the entire coast.

During this period, several intermediate evaluations are done of typical erosion spots and weak links. These evaluations are done in a graphical way, by making difference maps of the present beach topography and the designed nourishment (without maintenance buffer). Based on these evaluations, a decision can be made to perform maintenance on beaches.

To provide enough information for these intermediate evaluations, topography measurements by LIDAR are done twice a year (spring and autumn).

Especially for the shoreface nourishment project at Oostende - Mariakerke monitoring campaigns are conducted at the project site aiming the measurement of water levels, waves, current profiles, turbidity, sediment concentration, sediment grain size near the bottom, temperature, salinity and sediment concentration in the water column. Measurements are regularly conducted:

1. Six times a year, during 13 hours, at a location 500m offshore on section 104 at a depth of -7.5m TAW, temperature, conductivity and salinity are

measured (CTD), sediment concentration (OBS and LISST) and water samples are collected at an elevation of approximately 1m above the sea floor;

2. Twice a year, during 6 weeks, multi-instrumental frames (Hercules, Hylas I, Hylas II, Hylas III) are deployed in sections 100 and 104 at two reference depths, -6.5m and -3.5m TAW.

3. On a less regular basis, 8 to 24 hours, swash zone measurements are also conducted, using another multi-instrumental frame (Ellada), in sections 100 and 104, at the reference depth +1m TAW[1].

Two of the frames, Hercules and Hylas I, allow for simultaneous measurement of water level and waves (pressure sensors, AWAC), currents along the water column (Aquadopp), suspended sediment concentration, at 30cm, 50cm and 80cm above the bottom (OBS) and point velocity high frequency measurements (Vector). Hylas II allows for the same measurements except for waves. Hylas III does not measure sediment concentrations.

Topographic surveys available are conducted with high resolution LIDAR systems, allowing for the generation of 1m resolution Digital Elevation Models (DEM), covering the beach between the dike (if present) and the low water level (around 0m TAW). Bathymetric surveys are conducted by echo sounders, either single beam, with soundings spaced approximately 100m alongshore and 1-2m cross-shore, allowing for the generation of 33m resolution DEM, or high resolution multi-beam with soundings spaced approximately 1m. These surveys cover the shoreface between approximately -10m TAW and the coastline, 2m TAW. The topo-hydrographic and bathymetric surveys were not conducted simultaneously and do not always cover the same area, having different resolutions.

The field campaigns were initiated in September 2013. In 2013 one six week campaign and four 13-hours measurements were conducted. During 2014, the conducted campaigns were: two six week campaigns, six 13-hours measurements and one swash zone campaign (pressure sensors only). In 2015, two six weeks campaigns and four 13 hours measurements were conducted. In June 2014 an Argus video-monitoring system was installed by Deltares in the project site. [3]

References:

[1], [2] and [3]: Silva, Raquel;Montreuil, Anne-Lise;Delgado, Rosalia;Dan, Sebastian;Chen, Margaret;Verwaest, Toon;Mostaert, Frank (2016). Coastal

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[1] The Belgian datum level (TAW, Tweede Algemene Waterpassing, Second General Leveling) corresponds with the lower low water at Oostende (1839–1858); 0m TAW is 2.0m below mean sea level; 0m TAW is 2.33 m below the zero of NAP (Datum Level of the Netherlands), which corresponds to average mean sea level during the last 300 years.

Morphology at Mariakerke: Changes, evolution and trends, indicators and Argus monitoring – Concept Report. Version 1.0. WL Rapporten, 00_128. Flanders Hydraulics Research, Antea Group & VUB: Antwerp, Belgium

2. The Netherlands

A. General flood prevention strategy

The Netherlands is currently in a transition between two different approaches of flood risk prevention strategies. The former approach (that is legal up to the end of 2016) is that every section of a dike of a particular dike ring area should withstand an extreme water level that can occur once per X years. This definition of flood safety is expressed as a probability of exceedance $P(x)$ (start of damage to flood defence) of an extreme water level larger than once per X years for a particular dike section (with the most rigorous standard $P(x) > \frac{1}{10.000}$ year). The new approach (legal from 2017 on) does not focus on the probability of exceedance of an extreme water level but focusses on the mortality risk of an individual person and secondly (in case of a high valued economic and densely populated area) on the economic risk and group risk. The individual risk may not exceed the probability of 1/100.000 year of dying due to a flooding event, see Figure 3. This risk is translated into a maximum acceptable probability of failure of a (section of a) flood defence.

In both the former and new approach, the probabilities of exceedance are regulated by law (Water Act). The system in which a flood defence has to perform can change over time (e.g. sea level rise, autonomous changes, etc.). Authorities responsible for the flood defences have to assess the flood defence every six years if it still meets the flood risk standards.

B. Coastal management policy

Translating the flood prevention strategy to coastal management incorporates coastal maintenance. Extreme events (storm surges) will cause a severe instantaneous erosion. Because most of the Netherlands is situated below sea level, the beach and dunes should be able to withstand a storm surge with a

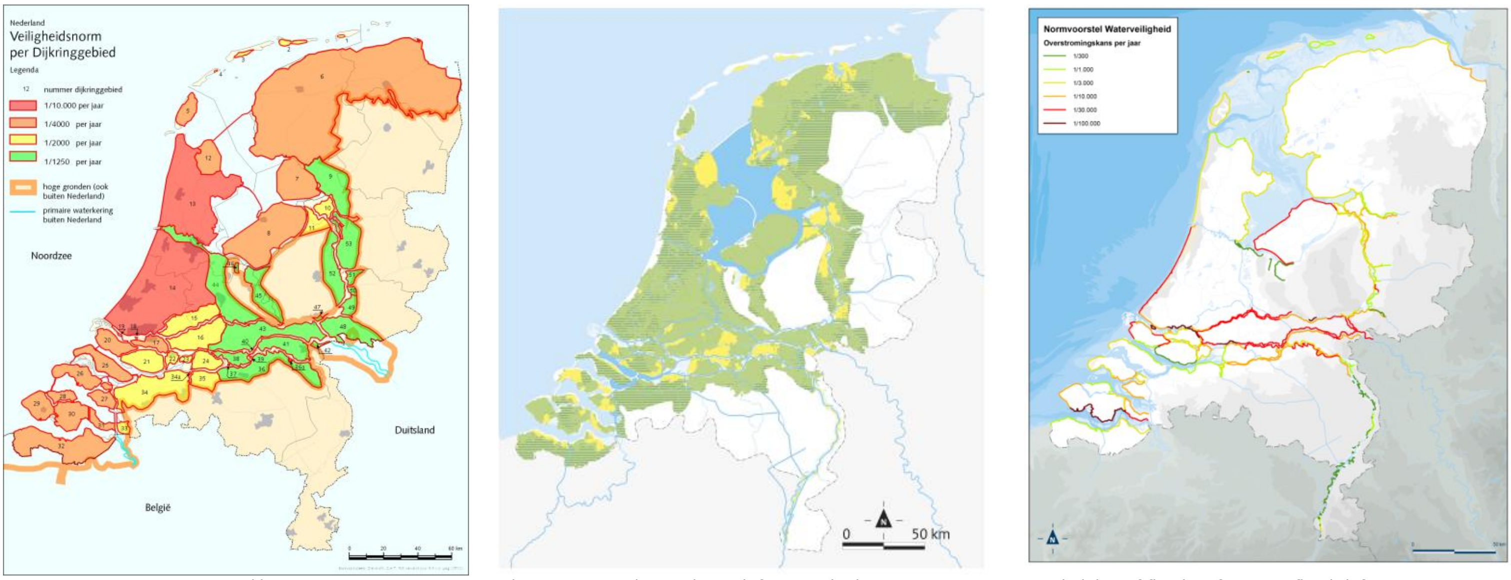

Figure 3 - From a system per dike ring area --> and given an equal mortality risk for everybody --> to a probability of flooding for every flood defence segment

probability of occurrence ranging from 1:300 to 1:30.000 years. This range is based on the defined individual risk and deviates per coastal section by factors like inundation depth and group risk (defined by a social cost-benefit analysis).

A reference coastline (Dutch: Basiskustlijn, BKL[2]) has been determined. This reference coastline should be maintained (hold the line) to preserve beaches, dunes and to preserve coastal functions. Since 1991 soft interventions are preferred over hard structures. Soft (sandy) interventions better match to the natural behaviour and layout of the coast. The amount of sand that needs to be added to the system to compensate the ongoing erosion is determined by a sediment mass balance approach using the schematization as shown in Figure 4 and visualized in Figure 5 for the Netherlands. The following formula expresses this mass balance approach, introduced in words by Nederbragt (Nederbragt, 2005):

$$Vsuppl = (Akf + Awz + Aws) * ZSSact \qquad (1)$$

in which:
- Vsuppl: Nourishment volume
- Akf: Surface area coastal foundation
- Awz: Surface area Wadden Sea
- Aws: Surface area Western Scheldt
- ZSSact: Actual sea level rise

Taking into account a sea level rise of 0.18 m per century (Baart et al., 2016), the current total sediment demand of the Dutch coast is ± 12 Mm^3 per year.

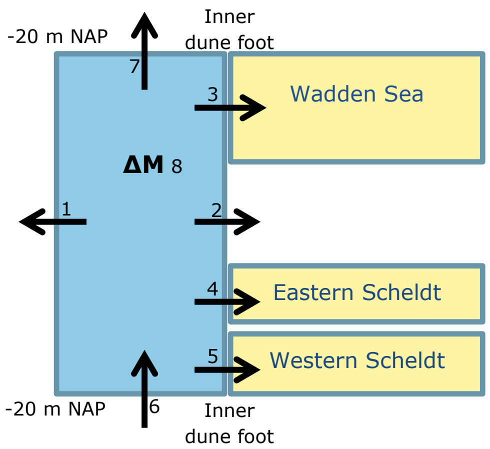

Figure 4 - Schematisation mass sediment balance coastal area

1.[3]: Net sediment transport over seaward boundary; negligible
2.[2]: Net sediment transport over inner dune foot; negligible
3.[2]: Net sediment transport towards Wadden Sea; area Wadden Sea * sea level rise
4.: Net sediment transport towards Eastern Scheldt; negligible
5.: Net sediment transport towards Wester Scheldt: area Western Scheldt * sea level rise
6.: Sediment import from Belgium North Sea; NL-BE = NL-DE
7.[2]: Sediment export towards Germany; NL-BE = NL-D
8.[2]: Sediment loss in total coastal foundation; mainly caused by sea level rise

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[2] This BKL is the average coastline between 1980 and 1989 in the Netherlands (start of sandy strategy) and is updated in 2001 and 2012. Besides the BKL, also the coastal foundation is taken into account in the sandy strategy since 2001. This area spatially is restricted by the -20m NAP line and the inner dune foot.

[3] There is currently discussion about the above mentioned assumptions. Main issues are the width of the dynamic coastal area (Is the boundary of the dynamic coastal area really situated at -20 m NAP (Amsterdam Ordnance Datum)?) and land subsidence caused by mineral extraction. It seems that the schematization will be updated incorporating these issues.

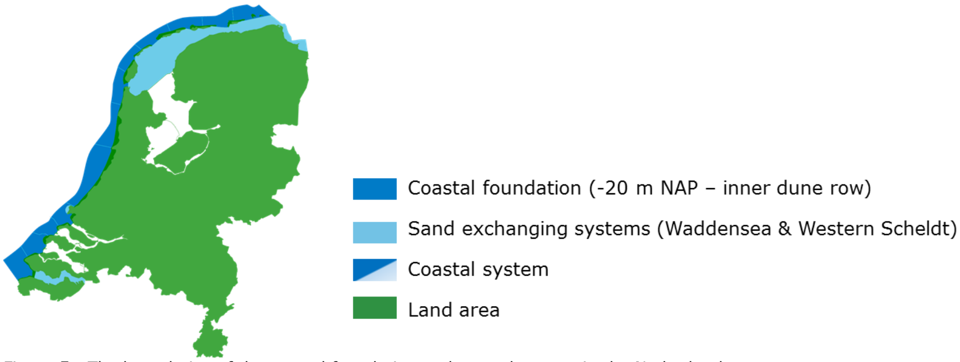


Figure 5 - The boundaries of the coastal foundation and coastal system in the Netherlands.

The current coastal management policy regarding soft interventions results in a program of sand nourishments. The nourishment program is redefined every four years, but is updated annually. A four year cycle is chosen because of the approximate lifetime of a nourishment. A longer lasting program is not desired. The effects of previous nourishments are not known yet when future nourishments have to be defined.

Approximately 75% of the nourishments (32 Mm^3 in four years) are programmed at the start of those four years at different coastal sections, prioritized by the need to directly maintain the BKL. The other 25% (16 Mm^3 for four years) can be projected during those four years for additional corrections to the BKL or for the preservation of the coastal foundation. The volume to be nourished at a particular location is determined by the expected sediment losses per year of the coast multiplied by the area and lifespan of the nourishment. The morphology of the coast can restrict or change the volume to be nourished due to for example existing bars and channels.

Several criteria are used to translate the policy into a nourishment program and planning. The most important criteria are summarized here:

- Nourishments to maintain the BKL take priority over coastal foundation nourishments. A BKL nourishment will be executed if 1. the BKL is exceeded in the forthcoming years (± 6 years), 2. structural erosion is the cause, 3. coastal functions are threatened by the erosion, 4. Coastal functions benefit from a nourishment and 5. the nourishment can be executed economically efficient.
- Shoreface nourishment are preferred over beach nourishments. Beach nourishments are only applied when shoreface nourishments do not have enough impact or are not feasible.

C. Detailed design type of, location and volume nourishment

The four year nourishment program is being verified and detailed every year in August, using the coastal transect measurements after the storm season of that year. In principal shoreface nourishments are performed. If shoreface nourishments are not applicable (due to the depth of the location or it takes too long to have a significant effect in enhancing the flood safety or other coastal functions), beach nourishments are applied.

The location(s) and demand of sediment (determined by erosion * lifetime) of the nourishments at the start of the four year program are verified every year.

For all expected nourishments in the forthcoming years of the nourishment program, general designs are made consisting of:

- Total volume
- Approximate location
- Nourishment type
- Approximate volume per running meter.

This general design entails the total volume to be nourished, indication of the volume to be nourished per transect (m^3/m), construction depth and angle of inclination. An example of which data is used to determine the amount of sand needed (m^3/m) is shown in Figure 6. Using the total expected erosion for the forthcoming years given structural erosion is going on (extrapolate trend), there can be calculated how much sediment is needed for the nourishment for its proposed lifespan. After determination of the volume of sand per coastal transect, a general design per transect is made, e.g. shown in Figure 7.

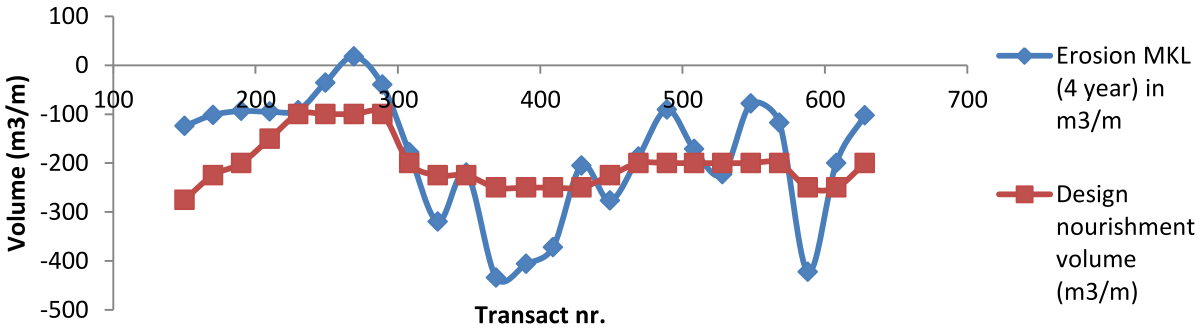


Figure 6 - Example of observed erosion for a coastal segment (MKL: Instantaneous coast line)

Shoreface nourishments are placed at the seaward side of the outer breaker bar or around -5m NAP (crest of nourishment). The nourishment is designed to resemble a natural breaker bar. No detailed designing is needed since the waves will reshape the nourishment quickly in to a “natural” breaker bar. The angle of inclination and construction depth are dependent on local variabilities of the coastal profile.

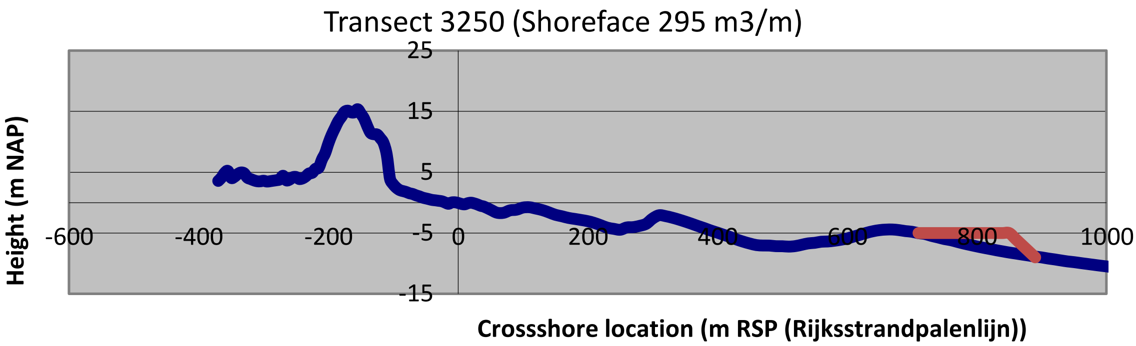


Figure 7 - Example of a shoreface nourishment design (Red) for a coastal cross shore (transect) profile (blue) Bergen aan Zee.

Beach nourishments generally are constructed from +3m/+3.5m NAP towards 0 or -1 m NAP. In general, the nourishment consists of a berm (about 10 to 50 meters) followed by a slope towards the sea with an approximate incline of 1/30 (matching the natural beach slopes in the Netherlands). In addition, requests of local authorities can be taken into account (more or less sediment, slightly different location or timing of execution) if no negative consequences are coupled to these requests. An example request is to execute the work outside the tourist season for beach nourishments.

The final design is made by the contractor six weeks before the work will start, based on the general design of Rijkswaterstaat and based on recent additional measurements. The final design is usually made for 50m transects (or 50x50m grid). A specialist of Rijkswaterstaat will check and approve the design or will suggest changes to the contractor. After approval of Rijkswaterstaat, the nourishment can be executed. Afterwards, the contractor surveys the "as build" nourishment to prove that the sediment was nourished correctly. For the contract however the bulk volume in the vessel is leading, not the volume that can be calculated from "pre" and "as build" surveys.

D. Tendering and execution strategy

The nourishment program is subdivided into separate work packages (sets of several nourishments) to tender on. These plots are composed based on specific characteristics of the nourishments like local depth, depth of the sand extraction pit, year of execution and vessel capacity. Most work packages are tendered once per four years. If needed, additional nourishments are added to the tendered contracts. Also new contracts can be tendered of nourishments that result from the yearly actualisations during the four year program.

Tendering four year in advance provides flexibility to contractors with respect to their other projects that can be anywhere around the world. The contractor already knows far in advance when a particular type of vessel is needed at the Dutch coast. Using this information the contractor can organize his vessels in a more cost economic way resulting in lower costs for maintaining the coast. In addition, durable competition is supported, including smaller dredging firms.

E. Evaluation of nourishments

The goal of evaluation of nourishments is multiple. Evaluating the nourishments can learn us how the nourishment develops on both the short and long term. In addition there can be checked or verified if the objectives set before the execution of the nourishment are achieved. If needed, the procedure for planning and designing nourishments can be adjusted. The choice whether a nourishment will be evaluated is mainly determined by the design and local conditions. Only if a nourishment is "special'' (i.e. a new design or new location), the nourishment will be evaluated.

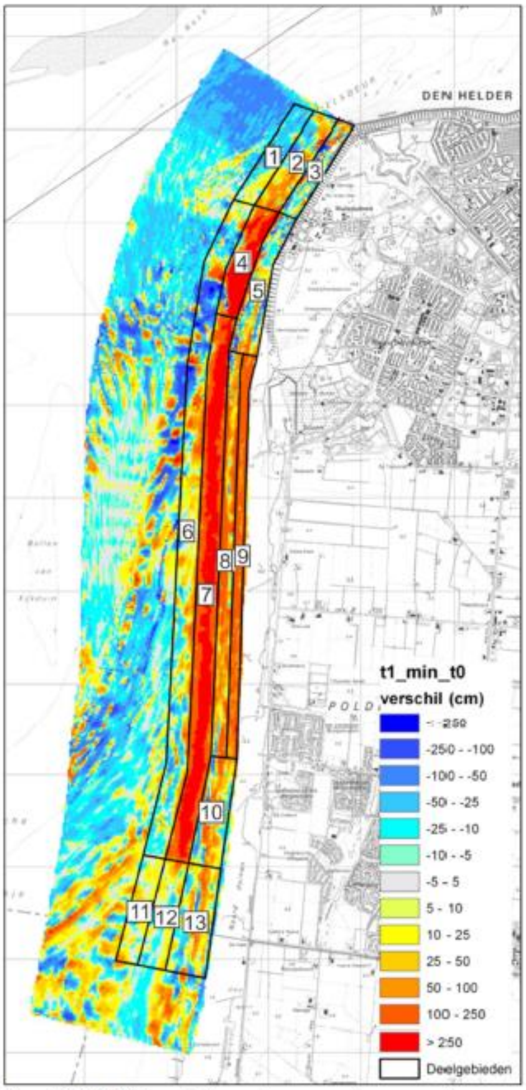
The evaluation takes place in a standardized way. First the motivation for the nourishment, the goal and the design are discussed. Besides the nourishment, the area in which the nourishment executed is discussed. The area description contains the morphological characteristics, long term developments and mechanisms (how does the system work). Also coastal defence works (hard and soft structures) of the past are described. A major part of each evaluation is the calculation of the volume changes in the area of the nourishment. These calculations are done in a standardized way using set 'sediment" boxes, see Figure 8.

Selected nourishments for evaluation are extra being monitored. Intensified bathymetric surveys are performed using the following schedule after construction (number of measurements per year) 2x, 2x, 2x, 1x, 1x, 1x (years). These measurements do have a double spatial resolution (transect measurements every 125 m instead of 250 m) and are monitored twice a year in spring and autumn. The measurements are performed partly by Rijkswaterstaat and partly contracted.

F. References

Baart, F., Leander, R., de Ronde, J., de Vries, H., Vuik, V., & Nicolai, R. (2016). *Zeespiegelmonitor 2014.* Delft: Deltares.

Nederbragt, G. (2005). *Zandvoorraden van het kustsysteem, onderbouwing van een conceptueel model met behulp van trends van de winst- en verliesposten over de periode 1973-1997. Rapport RIKZ/2005.033.* Rijkswaterstaat, Rijksinstituut voor Kust en Zee/RIKZ.



Figuur 4.13 Definitie zandbalans polygonen en volumes per polygoon (links) direct na aanleg (T1-T0) en na 3.5 jaar (T7-T1).

Volumeontwikkeling T0 – T7		
Poly goon	T1-T0 x1000m³	T7-T1 X1000M³
1	-43	152
2	97	36
3	3	27
4	1072	-824
5	51	-110
6	61	-306
7	3269	-460
8	463	-240
9	519	-352
10	112	-65
Totaal 1-10	***5603***	***-2142***
11	27	39
12	15	369
13	77	-62
Totaal 1-13	***+5723***	***-1796***

Figure 8 – Example of sediment box calculation based on volume changes directly after construction (T1) and after 3.5 years (T7)

3. Lower Saxony

A. General flood prevention strategy

In 1955 the Lower Saxony Coastal Programme (Niedersächsisches Küstenprogramm) for the enhancement of the protection of the coastal lowlands against flooding was established as a consequence of the catastrophic storm surge in the Netherlands of February 1953. The severe storm surges of February 1962, with more than 300 casualties and huge economic losses, and of January 1976 with the highest measured storm surge levels in Elbe Estuary were reason to intensify the programme for strengthening and upgrading the coastal defences and to improve the technical standards. In 1973, the status of execution and further needs for coastal defence works were determined in a 'Master plan coastal defence'. In 1997, this plan was updated for the Weser-Ems region.

In 2007 and 2010 the Master Plans Coastal Risk Management for Niedersachsen, Bremen and East Frisian Islands were issued (NLWKN 2007, NLWKN 2010). Primary objectives of coastal risk management are safeguarding of coastal areas against flooding due to storm surges and guaranteeing the existence of the inhabited islands. New embankments are not planned (Thorenz, 2008).

Since 1955, 2 billion Euro were invested in coastal defence measures. The primary dikes line along the mainland coast was significantly straightened and shortened from over 1100 km to 610 km. Seventeen storm surge barriers have been build in order to cut off the tributaries of the tidal rivers Ems, Weser and Elbe from the influence of storm surges, see Figure 9. Due to historical reasons, secondary dikes exist for only 20 % of this defence line. Wide-stretching coastal areas, which are not divided into polders, are protected. Hence an equal safety standard is defined for all flood protected areas.

(1) Leda-Sperrwerk (2) Emssperrwerk (3) Sperrwerk Leysiel (4) Hunte-Sperrwerk (5) Ochtum-Sperrwerk (6) Lesum-Sperrwerk (7) Geeste Sturmflutsperrwerk (8) Ostesperrwerk (9) Sperrwerk Freiburg (10) Sperrwerk Wischhafen (11) Sperrwerk Ruthenstrom (12)Sperrwerk Abbenfleth (13) Schwinge-Sperrwerk (14) Lühe-Sperrwerk (15) Este-Sperrwerk (16) Sperrwerk Seevesiel (17) Ilmenau-Sperrwerk

Figure 9 - Overview of main dikes and protected area in Lower Saxony (excluding islands) (NLWKN, 2007)

B. Coastal risk management policy at the islands

Main dikes and selected protective dunes on the East Frisian Islands are designed to protect defined areas against storm surges. These designated structures together with the main objectives for coastal risk management are defined by the Lower Saxony dike act (NDG) and are specified in the Master Plan Coastal Risk Management East Frisian Islands (NLWKN, 2010). On the islands of Borkum and Wangerooge massive bank protection systems and groynes also serve for the stabilisation of these islands since these are located close to the Ems and Jade rivers as important shipping routes. The legal basis is marked by the Federal Water Way Act. This Water Way Act specifies a deterministic approach to define water levels which the beach and dunes should be able to withstand.

On the islands main dikes and protective dunes jointly form a flood protection system. These flood protected areas mainly cover settlements and infrastructure. Protective dunes are also designated in order to preserve parts of the islands which are of importance for coastal risk management. Groynes, Groyne fields and revetments accompany main dikes and protective dunes as legal defined elements. Secondary dike lines are not present on the islands (NLWKN, 2010).

C. Detailed design type of, location and volume nourishment

The beach and shoreface may show natural material losses due to longer-term structural erosion or phases of sediment shortage e.g. in consequence of ebb delta dynamics. Due to these morphological developments, the functionality of dunes can be endangered. By applying beach and shoreface nourishments these material losses can be compensated. Due to an increase in the beach and shoreface level associated with widening of the beach, a well-balanced shoreface and beach profile will be achieved in order to prevent the protective dune ridges from eroding or establish an extra dune volume.

Nourishments have been executed at the islands Borkum, Norderney, Langeoog and Wangerooge.

On Norderney nourishments are performed to ensure the stability of the massive bank protection systems and thus to stabilize the islands base. The adverse point of arrival of tidal shoals (=Riffbogen) is located four to five kilometres east of the western end of the island. This induces a structural sediment deficit in western part of the island (see Figure 10).

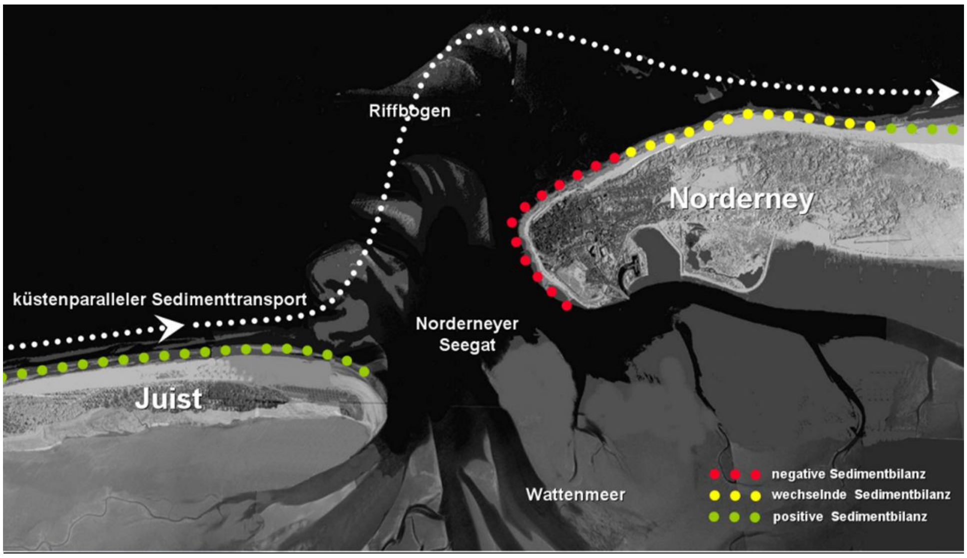


Figure 10 - Norderneyer Seegat – tidal inlet with ebb delta (Riffbogen) and indicated qualitative sediment balances of beach sections (negative, alternating, positive)

The first beach nourishment took place in 1951/52. Since then about a total of 5 million m³ of sand has been nourished to protect the western head of the island of Norderney. The borrow area is at short distance of the Norderneyer Seegat (inlet) Ebb tidal Delta. The unfavourable direction of transport and the landing point of the sediment can be corrected by an artificial bypass which supplies the west of the island with sediment by means of hydraulic filling (Thorenz, 2014). On Langeoog approximately 3.9 million m³ of sand have been nourished since 1971 to ensure the protection of dunes, to bridge temporary sediment deficient phases resulting from temporally and spatially varying approaching of tidal shoals. Also on Borkum and Wangerooge nourishments were necessary and therefore carried out by the Waterways and Navigation Authority, the responsible authority of the federal government.

To protect the inhabited areas against flooding and erosion, the beach-dune system or the beach-groyne system in front of the dune revetment must contain a sufficient volume of sediment. Due to the location close to the tidal channels with depth over NHN - 20 m, mostly beach nourishments are chosen to refill directly the beach sections. See Figures 11 and 12 for an overview of beach nourishments on Norderney and Langeoog. Figure 13 shows an example of a beach nourishment design.

The sand for the beach nourishments of Norderney and Langeoog are taken from shoals of the nearby tidal inlets Norderneyer Seegat and Accumer Ee, respectively. These areas were chosen because here sufficient amounts of sediment are available and the extraction point can regenerate rapidly. Using a cutter dredger or in some cases a hopper dredger the sand is excavated and pumped as a sand-water mixture via a pipeline to the beach. At the beach the sand is spread and profiled by bulldozers.

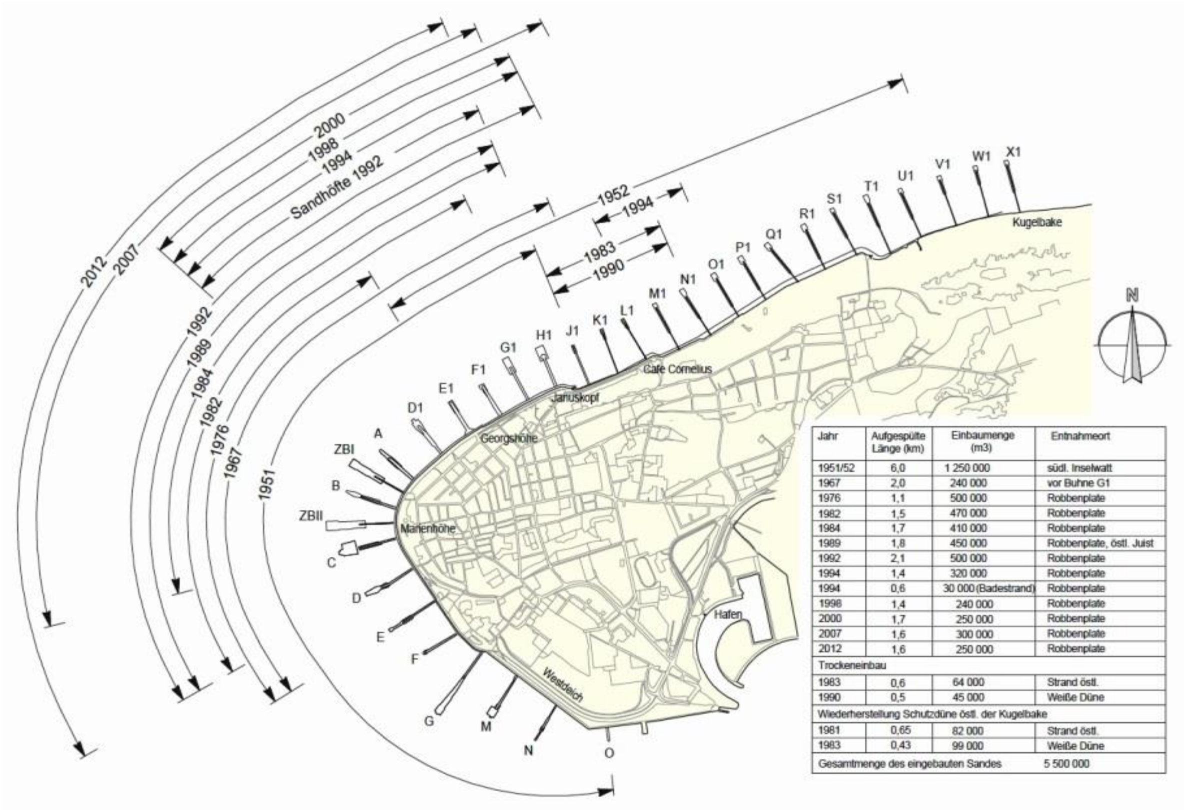


Figure 11 - Beach nourishments at western part of Norderneyer since 1951/52 – arrows indicate nourished beach sections, date and volume (Thorenz, 2014)

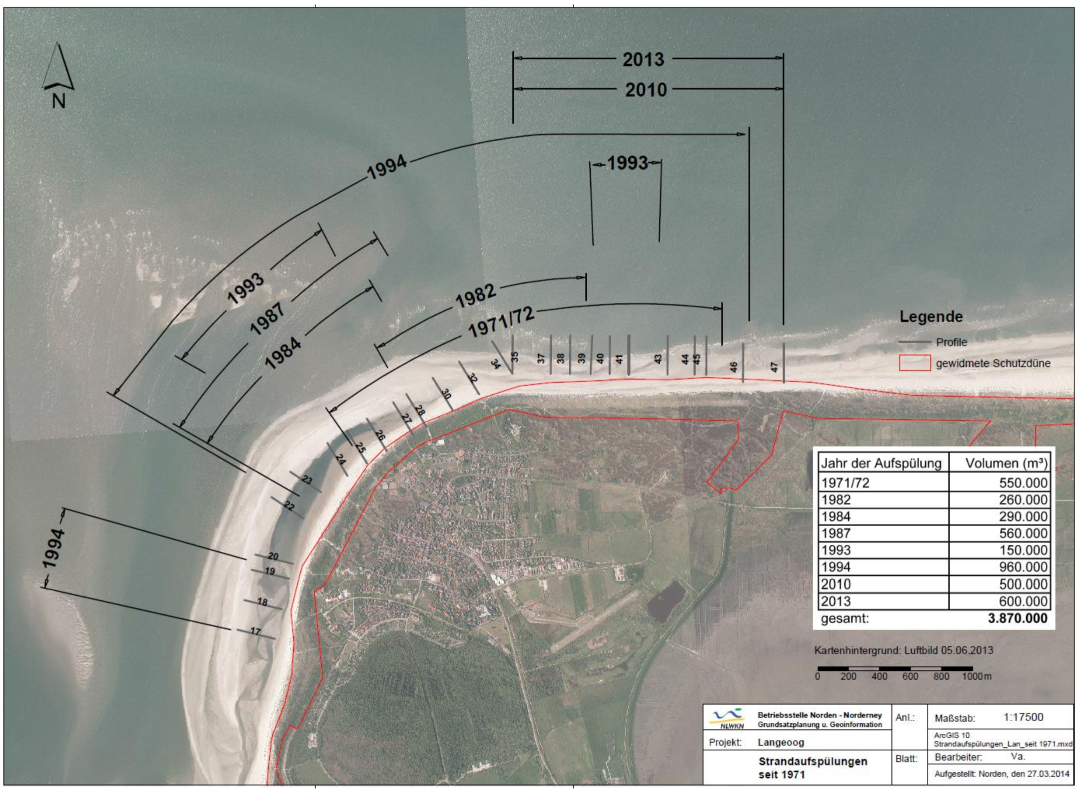


Figure 12 - Beach nourishments at western part of Langeoog since 1971/72 – arrows indicate nourished beach sections, date and volume**.**

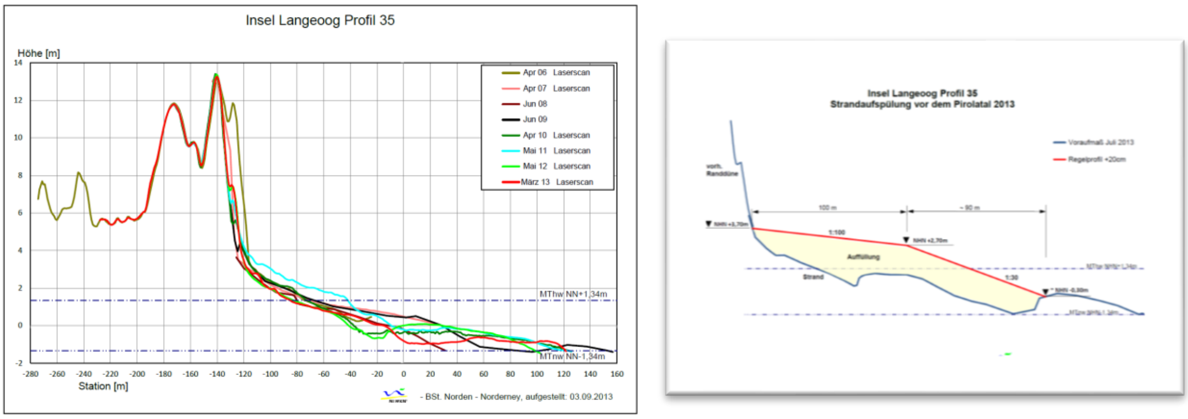


Figure 13 - Beach-dune cross section No. 35 – left: development of beach an dune in period 2006 -2013; right: cross section of beach nourishments taken from public invitation to tender (2013).

D. Tendering and execution strategy

The coastal stretches along the sandy beaches of the islands are monitored and assessed on a regular basis in order to evaluate whether the needed safety level is provided. Different options to deal with the specific situation, e.g. severe erosion caused by storm surges, will be analysed by NLWKN. If it turns out that the best solution is a nourishment, the works are designed, planned and published for public invitation to tender, according to contracting rules for awarding of public works contracts (VOB).

E. Evaluation of nourishments

The assessment of performed beach nourishments is based on combination of several methods. Terrestrial surveys and remote sensing technologies as well as hydrographic surveys are applied.

Transects are measured regularly with distances between 100 and 250 m. Additionally, remote sensing technics are applied in order to achieve at least once a year a digital terrain model of the intertidal and supratidal beach area including the adjacent dune ridge(s). One synoptically surveyed shoreface and beach bathymetry including the ebb delta is aimed to survey to a depth of approximately NHN -8m / NHN -10 m (profile distances approximately 150m and multibeam echo sounding in the deeper tidal channel).

The assessment focus of the performance of nourishments in this BwN project is on the islands of Norderney and Langeoog. This assessment is integrated in the annual safety check, taking place in spring when the storm surge season ends.

Due to overlapping of nourished beach areas, an assessment period is limited to the return period of beach nourishments which is in average between 3 and 6 years depending on location and morphological situation of the ebb delta. For each nourishment, the development of the nourishment volume is assessed within these periods (cp. Figure 14).

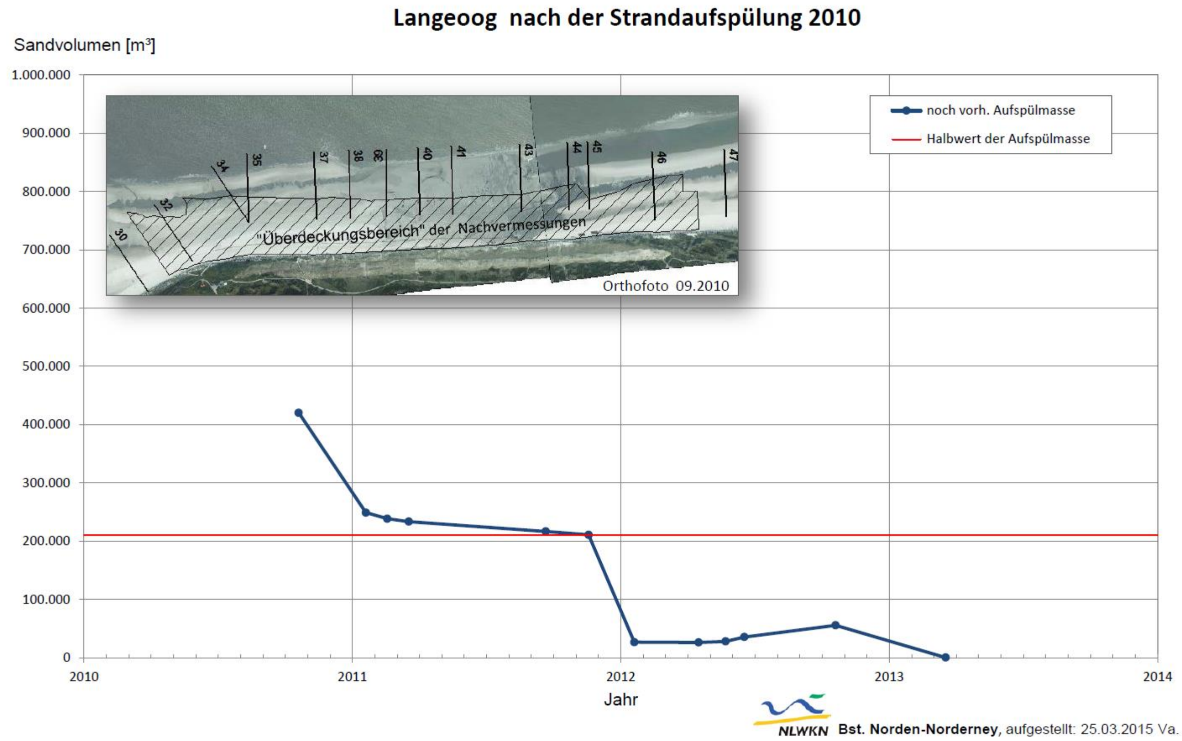


Figure 14 - Langeoog beach nourishment 2010 - Development over a period of 2.5 years

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4. Schleswig Holstein

A. General flood prevention strategy

In Germany the flood prevention and coastal risk management strategy is under responsibility of the federal states. In the federal state of Schleswig-Holstein the LKN.SH is the authority that plans, builds, maintains, approves and finances the measures along the coastal zone. The tasks of LKN.SH are dependent on the risk that can be accepted in a particular area. In the hinterland, water boards are mainly responsible for flood prevention. The flood prevention strategy is outlined in the masterplan for coastal flood defence and coastal protection ("Generalplan Küstenschutz des Landes Schleswig-Holstein" 2012) and for the flooding in the hinterland in the "Generalplan Binnenhochwasserschutz und Hochwasserrückhalt Schleswig-Holstein" (2007), see Figure 15. The risk areas are estimated and represented in context with the EU directives for flood defence. The main aspects of flood prevention strategy in Schleswig-Holstein are as follows:

- Avoid buildings in flood prone areas (polders) and around dikes (50 m for state owned dikes and 25 m for regional dikes)
- Enlarging measures up to a size that takes a possible higher sea level rise into account ("Klimadeich"), see Figure 16

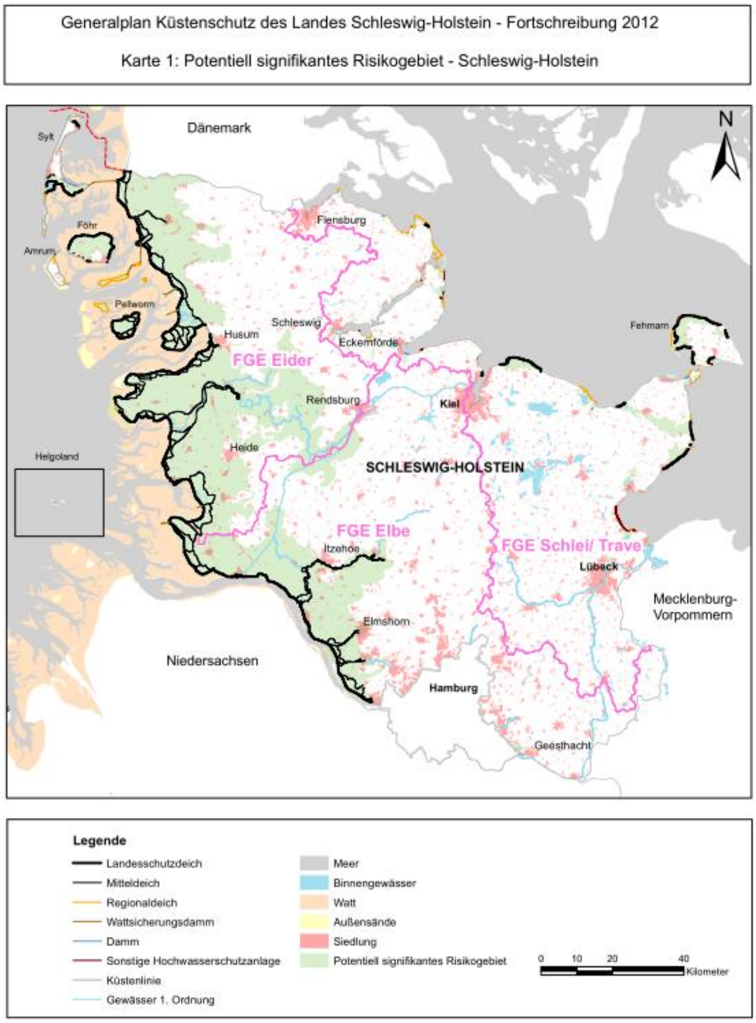

Figure 15 - Area of potential significant flood risk (Generalplan Küstenschutz, 2012).

B. Coastal management policy

The coastal risk management policy is generally described in the "Generalplan Küstenschutz". For the different areas there have been worked out more detailed plans called "Fachpläne Küstenschutz". These plans are published via Internet (www.schleswig-holstein.de/kuestenschutz) in order to be able to update as soon as possible.

Along the sandy coasts, nourishments are recognized to be the most effective way to protect the coast against erosion. Together with measures to keep the sand in front of the dunes by planting grass and setting brushes in the fore dunes, the safety of the coast was enlarged significantly (the dunes itself are high and strong enough nowadays). With nourishments the systematic and structural existing negative sediment balances can be equalized. As far as the sediment input is higher than the erosion, an additional sand buffer can be created so that heavy storm surges cannot affect the dunes. Due to the greater amount of existing sand in the system, beaches show abetter ability for recreation.

The law that determines coastal flood defence and coastal protection in Schleswig-Holstein is named Landeswassergesetz (LWG), meaning “the law of water”. In this law the tasks and responsibilities are named explicitly. Generally, coastal flood defence and protection is in the responsibility of those who benefit from it. But in §63, several exceptions are named where public institutions are responsible, for instance for the conservation of the islands and protection of the Wadden Sea.

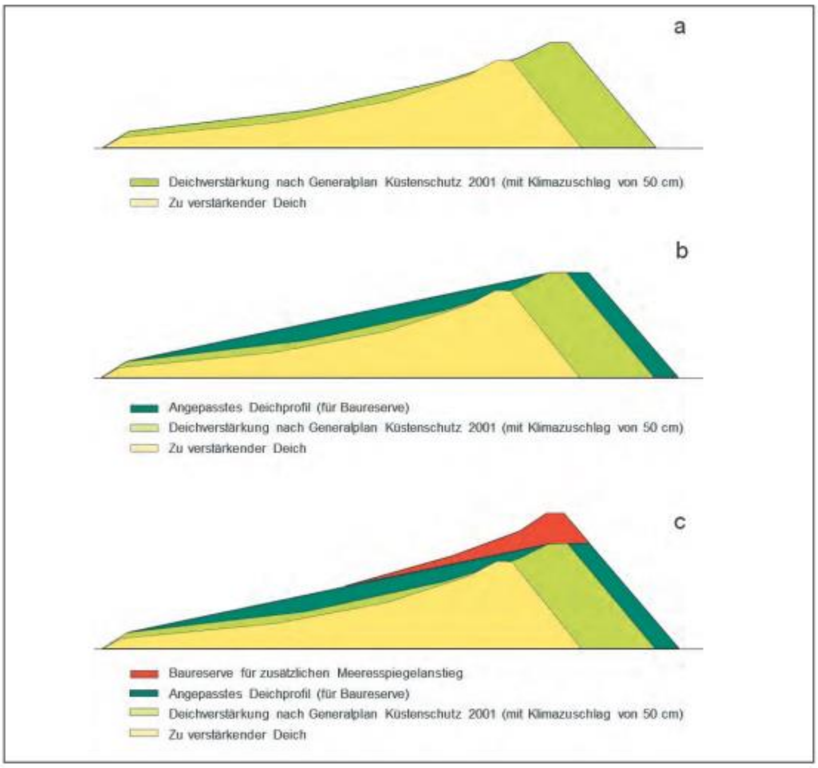

Abb. 17: Das Konzept Baureserve.

Figure 16 - Planning dikes (Generalplan Küstenschutz, 2012)

C. Detailed design type of, location and volume nourishment

The nourishments are carried out in Schleswig-Holstein since 1963 (Föhr) and 1972 (Sylt). The dune of Helgoland got a first supply of sand in 1954. In Schleswig-Holstein mainly combined beach and foreshore nourishments are performed. In some areas also shoreface nourishments are implemented.

The 1st nourishment on Sylt took place directly in front of the city of Westerland because the sea wall wasn’t safe enough. 1 Mio m^3 have been placed from the beach up to 500 m perpendicular to the coast line. The aim was to dam the bar-trough-system and thus to reduce the currents. The material was re-distributed in a short time and six years later a next nourishment with again 1 Mio m^3 was done, but now the sand was distributed along the beach. Another six years later (1984) a new nourishment was established, again with 1 Mio m^3. The geometric form looked like garlands. Since this time the nourishments fill up the beach and stretch along the coastline. In the first years the sand was nourished up to 8 m above MSL. However, in order to optimize the nourishments, the height of the nourishment was reduced successively. Now the height of the nourishment is up to 5 m above MSL and the slope of the berm reaches 1:10. There have been some trials with closed dumping areas instead of open dumping areas. Nowadays the sand is nourished in the latter way.

On Föhr, a first shoreface nourishment was placed in 1975. Directly afterwards, in January 1976, heavy storm surges occurred, the bar was spread out and the height reduced significantly. Nevertheless an additional supply on the beach was executed again in 1988, resulting in a lifespan of the first nourishment of nearly 13 years. On the island of Sylt, the first shoreface nourishment was executed in 1996 in form of a bar nourishment. The height of the bar increased and in the following months the trough deepened significantly, resulting in an increased beach erosion. That was the reason to make any further shoreface nourishment only at the seaward side of the breaker bars. This technique was used in 2004, 2006, 2009, 2011 and 2015. In 2016 another shoreface nourishment at the centre of the island (Westerland) is planned. It is the first time at the central part of the island aiming to increase the sand drifting towards north and south, equally.

The areas that need to be nourished are estimated by measurements (terrestrial and bathymetric). Depending on the natural dynamics, the measurements of the whole coast are done in a continuous matter. On Sylt the beach and dunes are surveyed each year by LIDAR (since 1999) and the bathymetry each five years (since 1999). The calculated differences between these (annual) measurements and the reference measurement (that is the state before the first nourishment took place in the respective area) determine the need of a nourishment (keeping the reference coastline, "Basisküstenlinie"). In order to calculate the demand of sand to be nourished, the sand balance between 5 m above MSL and 1 m below MSL is estimated. Usually there is a need of an additional sand buffer to prevent strong erosion at severe storm surges. Using all available data, a volume trend in the described layer can be calculated. However, the total nourishment volume must be accounted for. Together with the desired or proposed life span, the result of the calculations provides the total demanded sand volume to be nourished.

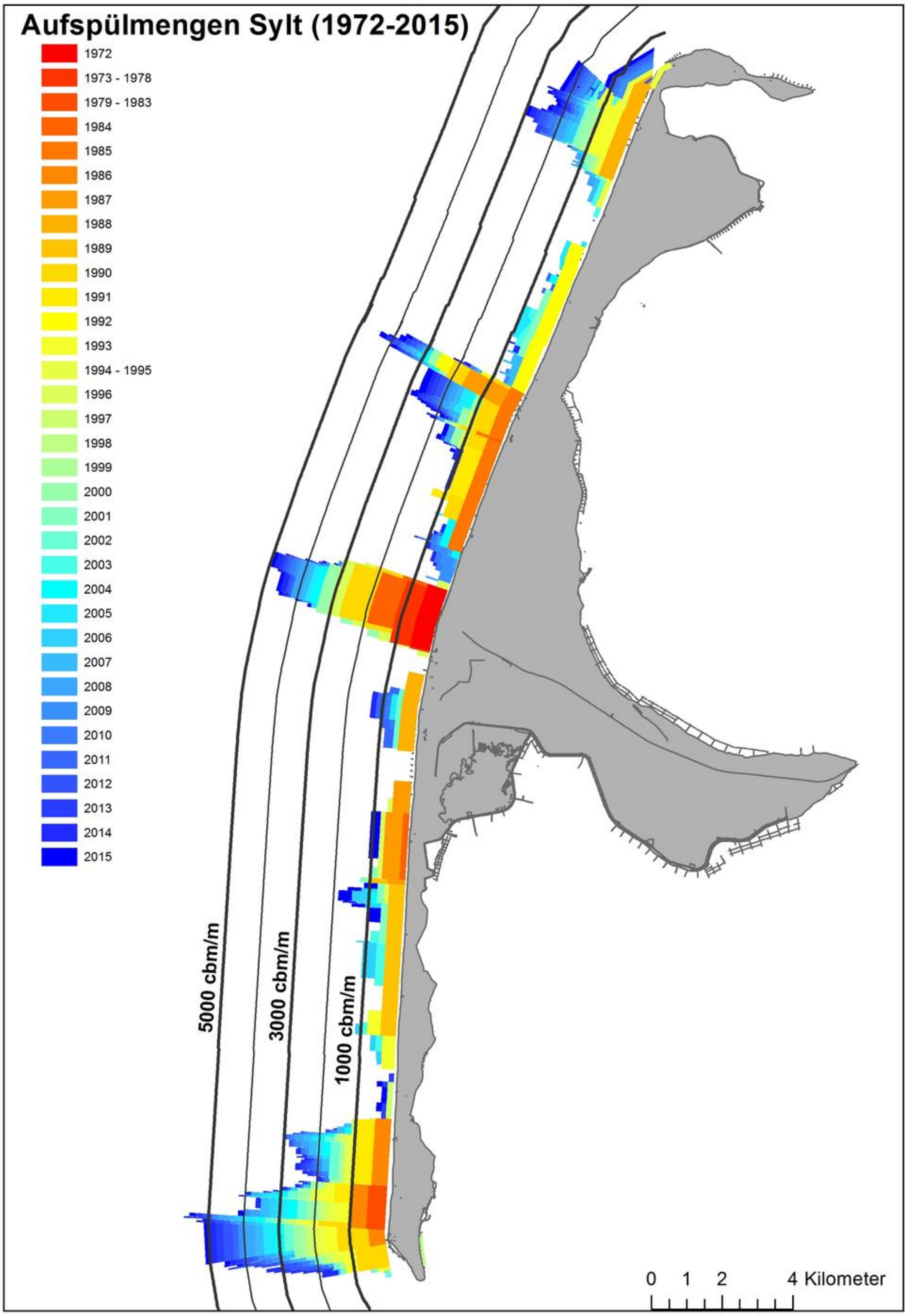

Figure17 - Cumulated amount of nourishments on Sylt (1972-2015)

D. Tendering and execution strategy

In Schleswig-Holstein framework contracts over a period of 4 years are used for nourishments. In the contracts yearly volumes and rates for beach and shoreface nourishments are specified with a total of 1.250 Mio m^3 for Sylt (total: 4 Mio m^3 beach, 1 Mio m^3 shoreface in the four year contract period). The costs of 1 m^3 nourished sand varies between 5.00 € and 8.50 € (2008-2015), the shoreface nourishment provides an additional sand volume of 40 % for the same money.

Other measures like the nourishments on Föhr are tendered additionally. The costs are largely dependent on the distance of the extraction site.

The sand is suctioned from the ocean bed 7 km western of the island of Sylt and nourished by pipelines on the beach where it is distributed by bulldozers. Shoreface nourishments are dumped at the destination, usually by split hoppers. The distance is about 500 m out of the coast.

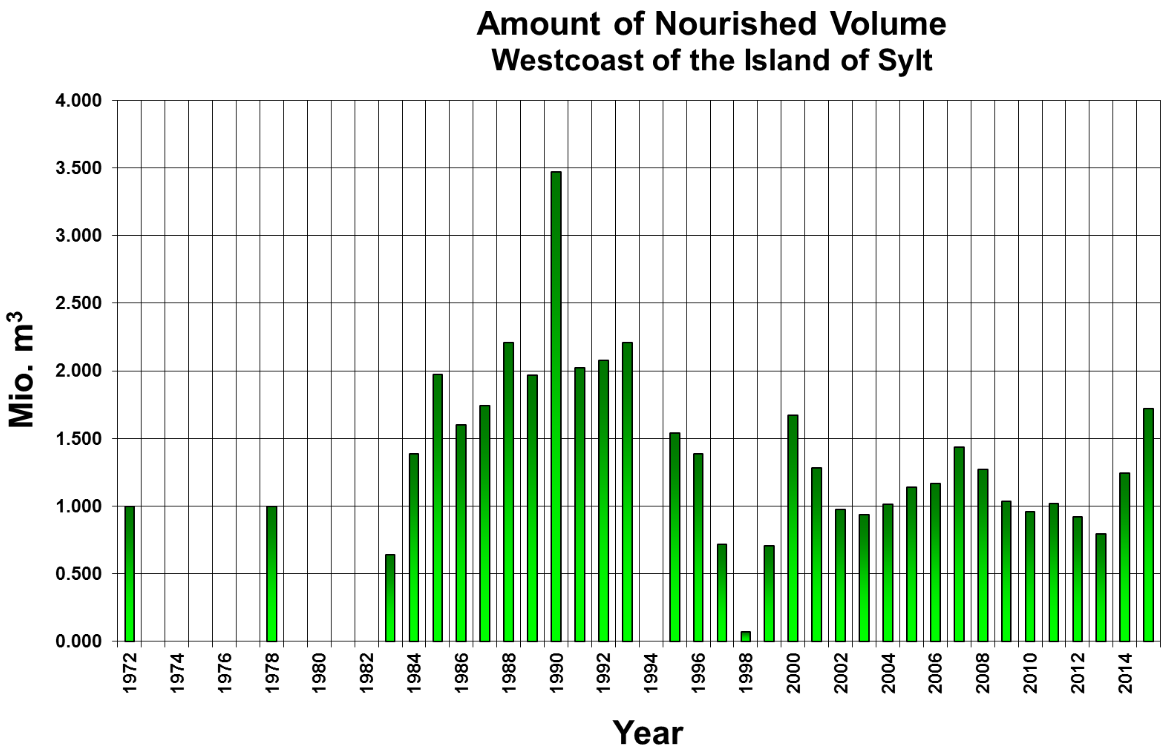

Figure 18 - Amount of annual nourishments on Sylt (1972 – 2015).

E. Evaluation of nourishments

The evaluation of nourishments is done by calculating the half-value time of the material loss. After a period of time, enough measurements and surveys are available to do analyses. Since the weather conditions and longshore transport affects the sand balance, even more parameters have to be used to describe indicators of effectiveness. On the other hand there are some hot spots along the coast where the supplied sand disappears in a short period of time. In order to protect these areas there is a steady need of sand. Due to longshore transports, the surrounding areas benefit and show stability. Additionally the aeolian transport on the beach influences the sediment balance.

The measurements are done on transects that have been defined in the 1950ies. The usual defined spacing is about 50 m. For echo sounding a distance of 50 m is needed, at least, in order to detect the bar-trough system. At some locations the opening of the bar-through system is less than 100 m. For terrestrial measurements often only a profile distance of 100 m is sufficient. Offshore the measured area ends at -8 m MSL. The dunes are measured up to +7 m MSL. Before the nourishments can start, bathymetric and terrestrial surveys are done. After the nourishment is completed, a terrestrial survey must follow. In the sites where shoreface nourishments have been placed, a bathymetric survey is performed additionally.

The temporal interval for the west coast of Sylt is annually (terrestrial) and 5 years (bathymetric). On Föhr the surveys are done every two years (only terrestrial). For areas with lower dynamics this interval is longer. The profiles are always defined with a spacing of 50 m.

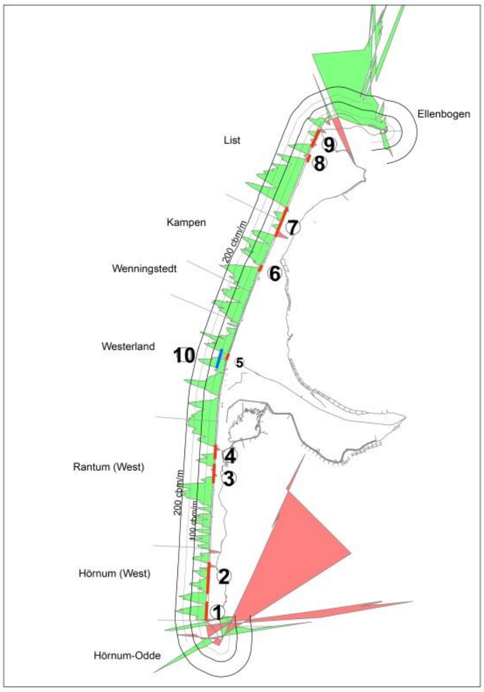

Figure 19 - Volume balance between reference state and 2015 (Plan for 2016).

5. Denmark

A. General flood prevention strategy

The general principle in Denmark is that each individual landowner is responsible for financing and planning of coastal protection. A permit must be obtained by the authorities. Therefore, it is each landowner individually who is responsible for setting up a strategy for flood protection and prevention of erosion.

In 2016 the Danish government issued a national coastal assessment, in which the risk of flooding of erosion in 2015, 2065 and 2115 were presented.

Furthermore 10 areas in Denmark have been pointed out as the most flood prone areas in Denmark when implementing the EU floods directive. In each of these areas the municipalities must compile a risk management plan which describes how the flood risk will be handled. The plans should be revised every six years.

In specific locations the state has a special role in flood protection and prevention of erosion. At the central part of the Danish North Sea coast between Lodbjerg and Nymindegab a common agreement exists on coastal protection between the state and four municipalities. The agreement was first initiated in 1982 after a severe storm that caused a breach of the dunes and flooding of the hinterland. This agreement has been negotiated every five year since. Similar agreements exist in Blåvand, Lønstrup and Skagen (figure 20).

Figure 20 - Locations where Danish coastal authority has a special role.

In Skagen and Lønstrup only coastal erosion is a challenge because the hinterland is higher than the storm water level. At the stretch from Lodbjerg to Nymindegab both erosion and flooding are challenges. The retreat rate at this coastal stretch is the highest in Denmark. This hinterland is the largest flood prone area in Denmark. The safety level for this area is to protect against a flooding from a 100 year storm event and at Thyborøn a 1000 year storm event. This level was chosen given it the possibility to evacuate all people if a flooding occurs. A flooding-preparedness-scheme is run under the responsibility of the Danish Coastal Authority (DCA). At Blåvand both erosion and flooding are challenges and no defined safety level exists at this location.

In the Wadden Sea the state has previously co-financed the building and strengthening of the sea dikes. The Danish Coastal Authority and the municipalities have previously agreed on the safety of each dike, based on a simple risk-based approach. The safety levels are based on return periods between 20 and 500 years calculated from water level frequencies. Here, also a flooding preparedness scheme is run under the responsibility of the Danish Coastal Authority

B. Coastal management policy

In this section the coastal management policy and the resulting determination of where the sand nourishment is placed, will be described.

Lodbjerg-Nymindegab

On this 110 km long stretch there are two overall aims. 1.: providing at least a 100 year safety level against flooding and 2.: nourish at the stretches where the estimated retreat and maximum allowed coastal retreat interfere. The aim is based on the safety level at the local stretch and the agreed finances for coastal protection. The present aim and natural retreat of the coastal profile can be seen in Figure 21. The active profile ranges from -10 m DVR90 to the dune top.

The safety level is maintained if the width of the dune above the 100 year return water level exceeds 40 m (Figure 22), and 30m if the dune is protected by a revetment. The safety assessment is based on analysis of dune erosion of past storm events.

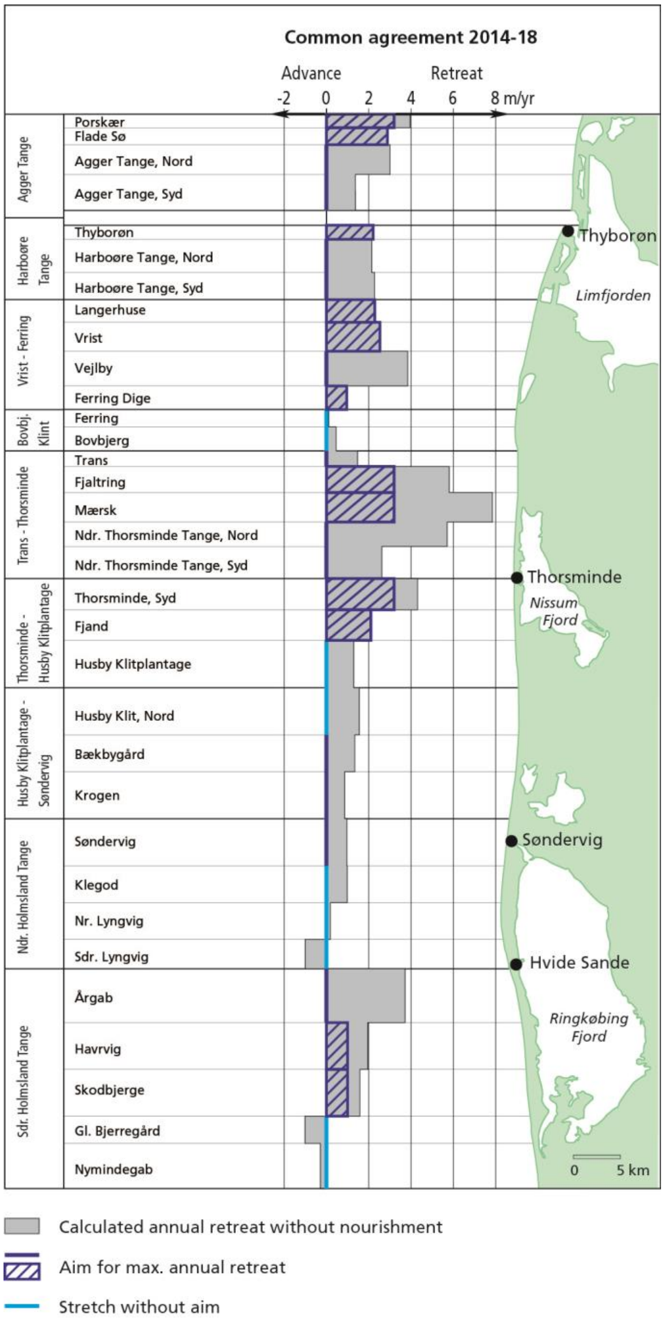

Figure 21: Natural retreat of coastal profile (grey) and aim for retreat of the profile (dark blue).

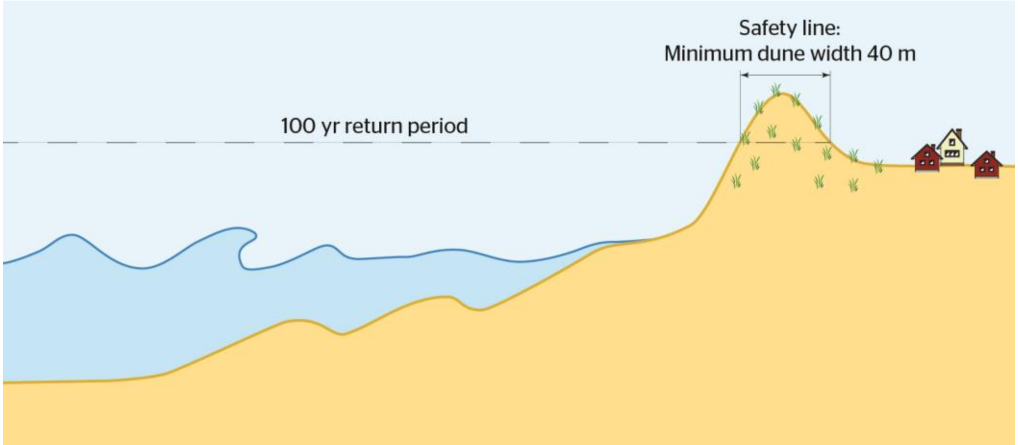

Figure 22: Definition of safety.

Blåvand, Lønstrup and Skagen
The policy at these locations are different from Lodbjerg-Nymindegab, but due to page limitations the policies are not described any further here.

C. Detailed design type of, location and volume nourishment

For each common agreement the Coastal Authority has established a nourishment strategy. The DCA prefers to nourish seawards of the outer bar and when the dune width is nearly smaller than 40 m, beach nourishments will be carried out. We aim to nourish 60% of the volume outside the coastline and 40% within the coastline to get the optimal effect of the sand nourishment.

In general the nourishment volume is about 100-200 m^3/m depending on the nourishment strategy. The minimum amount is 75 m^3/m. This amount is set to avoid humps on the beach.

D. Tendering and execution strategy

The Danish nourishments are performed after an EU-tendering restricted procedure. A five year contract is tendered. The contract combines nourishments with the Danish Coastal Authority dredging obligations.

The tendered contract is split in four parts. One part is for extraction of sand and shoreface nourishments. The second part is for the extraction of sand and beach nourishments. The third part is for the sailing distance. The fourth part is the dredging of navigation channels. In the Danish law the price has to be indexed once a year. Because of the nature of the contract only the part of the contract covering the sailing distance has to be indexed.

The contract is a fairly open. The contractor has a lot of freedom. The contactor knows what has to be done every year and that has to be finished in September. The contractor principally chooses the order of the nourishments. The only requirement is that he has to finish nourishments at a coastal stretch before starting a new one.

Regarding the shoreface nourishments the contractor is required to place the sand landwards of the 6 m depth contours. For beach nourishments the sand must be placed close to the dune foot. From here the sand will spread out naturally. The only requirements to the contractor are that he has to even out the sand.

E. Evaluation of nourishments

The Danish coastal authority evaluates the morphological behaviour of nourishments.

Definition of effectiveness

The effectiveness of nourishments is evaluated in a quantitative and qualitative approach.

The quantitative approach is based on volume calculations in different height intervals in the coastal profile. An example is shown in Figure 23 where 3 parameters are shown. The active coastal profile is defined by the volume from -8 to +5 m (DVR90). The coastline is defined by the volume from -1 to +1 m DVR90 and the dune face defined by the volume from +4 to +5 m DVR90.

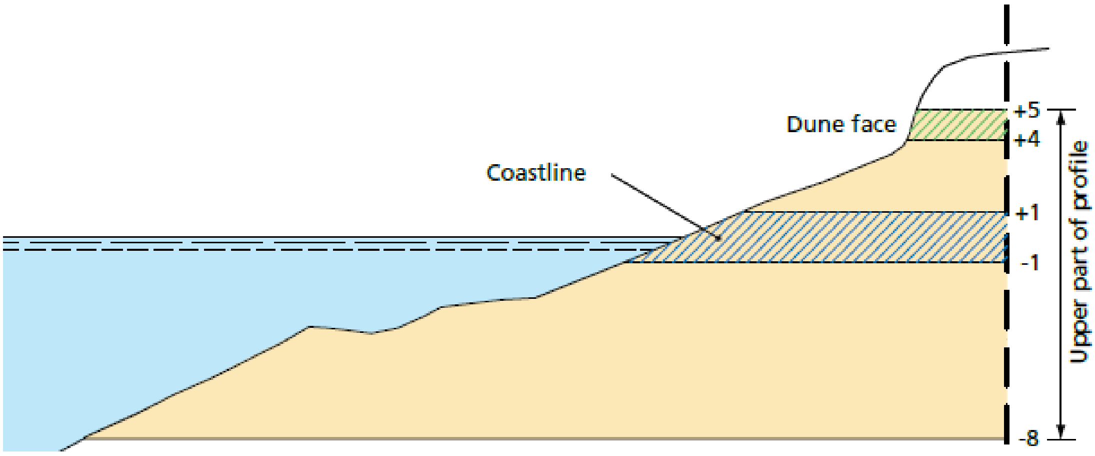

Figure 23 - Parameters used for calculation of effectiveness.

The volume calculations are done in boxes defined by a certain distance to a reference line onshore. The layout of the boxes varies according to the expected behaviour in the survey period. An example of a layout of the boxes assessing the impact of two shoreface nourishments is shown in Figure 24.

The qualitative approach is based on the nourishments impact on the morphology. A special focus is on the bar system and how the nourishments interact with the bar system. The reason for this is that bars control the wave breaking, hence likely the dune erosion during storm surges. Because the cheapest way to nourish sand in the active profile is to do it on the outer bar, special emphasis is on the determination of the effectiveness of shoreface nourishment on the dune safety. The aim is to understand the interaction between shoreface nourishments and the rest of the active profile.

As example of a morphological analysis on the impact of a nourishment on the bar system can be seen in Figure 25.

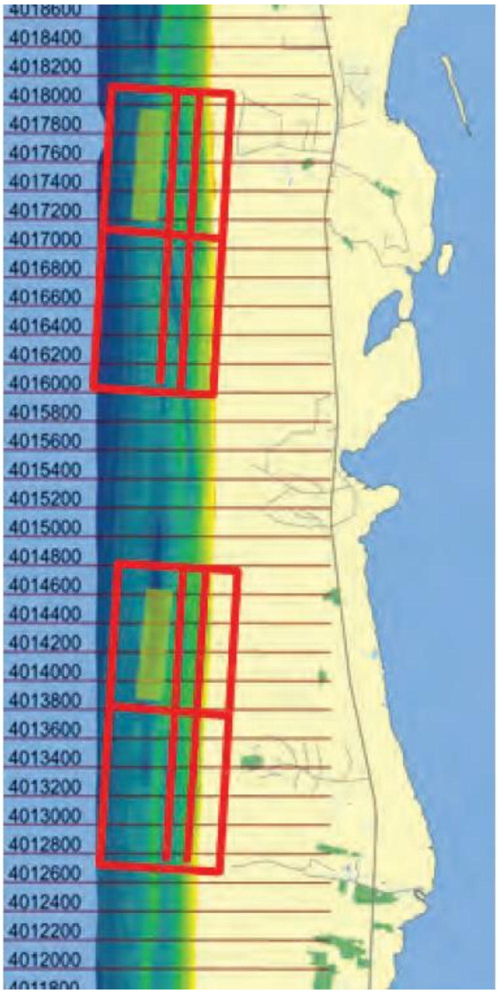

Figure 24 - Layout of volume calculation boxes (red boxes). The red lines layout of survey lines.

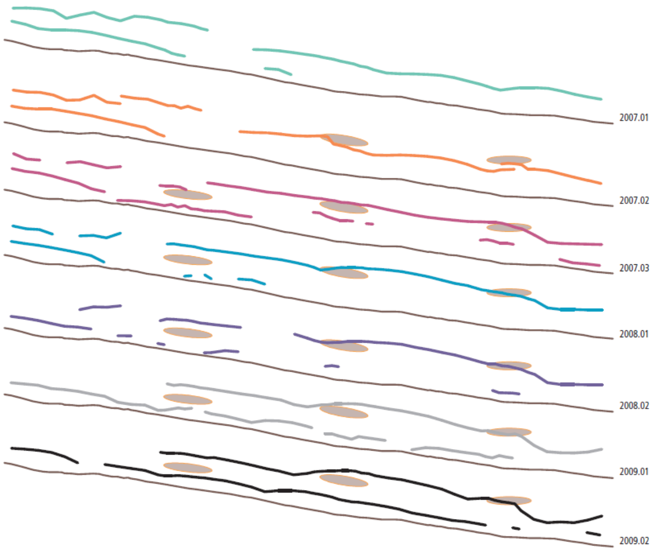

Figure 25 - Development of bar system.

Measurements

We aim to establish a baseline before the nourishment is placed by surveying prior to the execution. After the nourishment we aim to survey at least 4 times a year, primarily to reduce the error on the volume calculations and to get a more detailed understanding of the variability of the nourishment during different conditions.

It is a challenge to do measurements at the Danish west coast at wintertime due to the sea state that is often dominated by heavy swell.

The surveys are done in transects perpendicular to the coastline in order to resolve the rapid cross-shore variability of the active coastal profile. The survey lines start behind the top of the dunes and extends way beyond the wave dominated profile. There is sediment transport outside the wave-dominated profile, primarily caused by the northwards moving tidal current, secondarily by the larger waves. The transects in the dunes are supplemented by yearly LIDAR scans by plane.

The distance between the transects is normally 100 m, but the spacing can be varied. A survey layout with a distance between transects of 200 m can be seen in figure 24. A longshore control transect perpendicular to the cross shore transects is measured to be able to calculate the spreading of the survey. A multibeam system with RTK is used with one reference base station on land for water depths below approximately 1,5 m. A diver equipped with a GPS, or a jetski with singlebeam covers the shallow water part. On land handheld terrestrial GPS is used.

The hydrodynamic impact on the analysed stretch is always monitored using a directional offshore wave buoy. Also water levels are recorded. Sometimes additional measurements are done like current profiling.

Moment of evaluation

The lifetime of a shoreface nourishment has varied a lot from nourishment to nourishment. The understanding of these differences is one of the research questions addressed in the BwN project. Normally the lifetime is expected to be at least 3 years, depending on many parameters as wave impact and similar parameters.

We aim to have at least 3 years of impact on the nourishment before we evaluate the performance of the nourishment. That explains why the nourishment in the pilot site of Krogen was chosen. Now it will be possible to analyse the performance of the nourishment within BwN.

How many nourishments are evaluated and why

The numbers of nourishments that are evaluated are determined by the survey capacity of the survey section at the Danish coastal Authority. The present capacity is to survey two nourishments at the time. That is the number that will be evaluated. Former evaluations will be included in the conclusions.