COADAPT

- The evulution of a beach nourishment at Blåvand

Blåvand, Denmark

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Coastal Authority

Project information

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Contents table

Chapter 1

Introduction

This project consists of an analysis of a beach nourishment executed near Blåvand, Denmark in 2010. This report is part of the COADAPT project. [1]

Firstly, the project objectives will be presented, in connection to the broad objectives set by COADAPT. Secondly, an introduction will be made to the location and nourishment.

The analysis part of this report consists of an overview of the site conditions, which includes water level, wave and bathymetric data interpretation. This will be followed by the analysis of the nourishment evolution, by interpreting the changes in sediment volume over time. The measured development of the nourishment will be compared with theoretical models for nourishment behaviour prediction.

Finally, a conclusion of this report is presented, in Chapter 2.

1.1 Project objectives

The main objective of the COADAPT project is to develop technical and shoreline management tools to meet the additional threats that an increased sea level rise and changes in storm conditions impose on coastal areas [1]. As part of that project, the aim of this study is to investigate the effect of beach nourishment on an exposed beach.

The main features of this nourishment are that it is purely a beach nourishment (all sediment deposited between the shoreline and the dune foot), and that there are groynes present. The applicability of two different nourishment decay formulas will be tested.

1.2 Description of coastal stretch

The stretch in question is located in the northern part of the Danish Wadden Sea, between the headland, Blåvandshuk and the barrier spit, Skallingen (Figure 1.1).

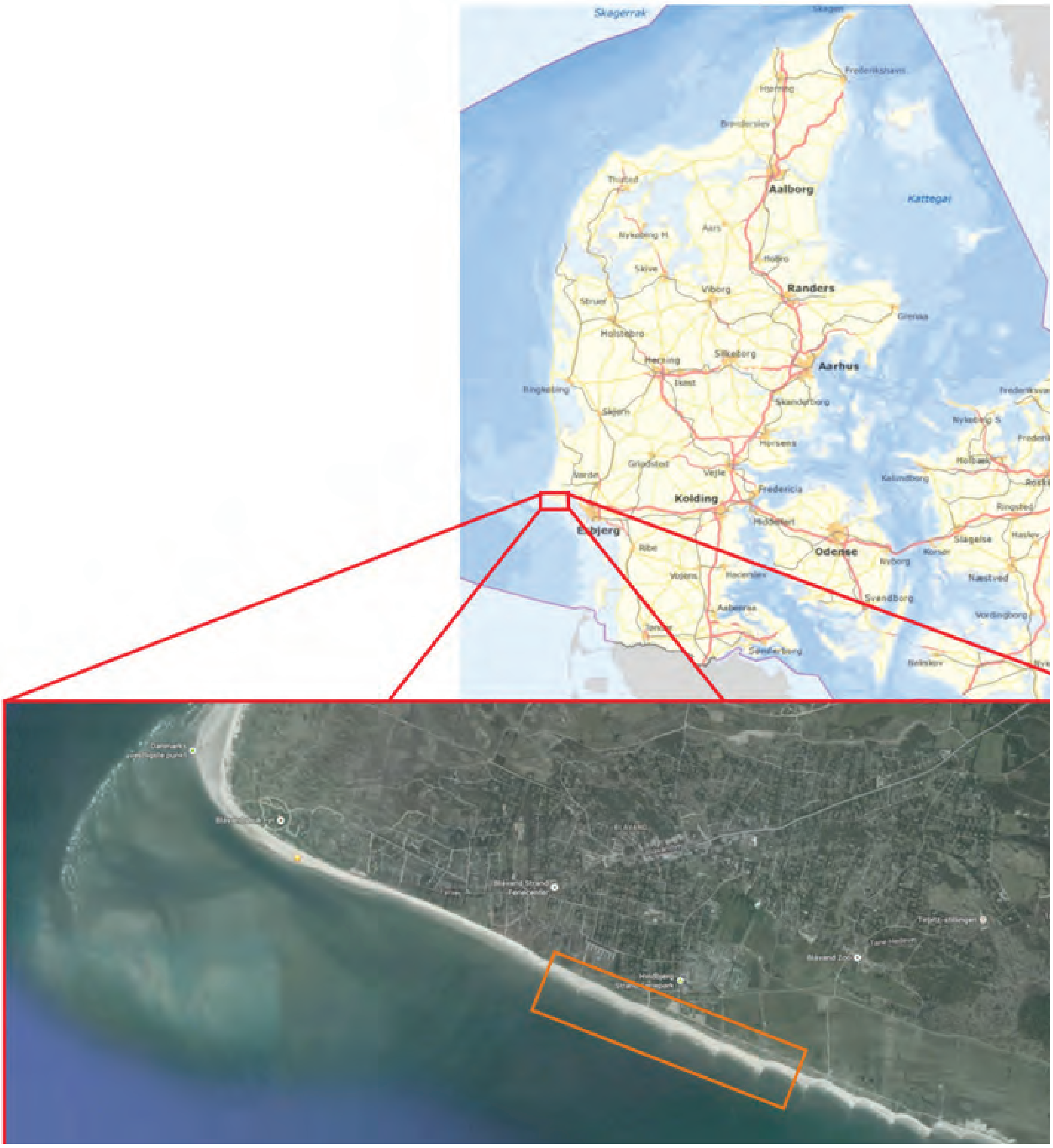

Figure 1.1 Location of the nourishment.

This barrier beach is exposed to moderately high energy wind-wave dominated North Sea. The beach normal is 204°. The mean annual significant wave height is 1.3 m, with a wave periods of 4-6 sec. With wind and waves primarily from the west, the longshore sediment transport is considered from Blåvandshuk (W) to Skallingen (E). Tides are semidiurnal with a mean tidal range of 1.5 m and approximately 1.8 m at spring tides. The beach is approximately 60-100 m in width, and the dune goes up to +6 m elevation. An unnourished mean slope if 1:26 is measured from the foot of the dune to the water line. The mean erosion rate is 2-3 m/year. [2]

1.3 Description of nourishment

The beach at Blåvand has been nourished 4 times, with 5 years between nourishment activities. The nourishment that is the subject of this analysis was executed between 30.08.2010 and 13.10.2010 and was preceded by a survey (2010.01). A volume of 125454 m³ (is situ volume) sand was deposited on the beach. Just after the nourishment, another survey was conducted (2010.02). Four other surveys follow; 2011.01, 2012.01, 2013.01 and 2014.01. The completion dates for the surveys can be seen in Table 1.1.

Survey	Date
2010.01	30-06-2010
2010.02	26-10-2010
2011.01	09-02-2011
2012.01	05-11-2012
2013.01	02-10-2013
2014.01	11-06-2014

Table 1.1. Survey dates.

Chapter 2

Conclusion

The main objectives of this report, under the COADAPT project frame, are to study the effect of beach nourishment at Blåvand and to compare the decay of sediment volume with theoretical models. The analysed nourishment is a beach nourishment executed between 30.08.2010 and 13.10.2010 in an area with groynes.

Analysis is performed within the constraints of 5 surveys which measure the beach between -0.5 m and +5 m or +6 m, The intervals between surveys vary between 106 and 635 days.

The theoretical models chosen for nourishment decay comparison are Dean [3] and Silvester&Hsu [4]. The measurements do not follow the predictions, mismatch which is attributed partly to the hard shore protection structures on the beach. Moreover, the declared applicability range of these formulas is exceeded. Both formulas assume rectangular beach nourishment placed on an infinitely long, straight shoreline, undisturbed by artificial structures.

The nourishment goes through an initial adjustment phase, where the sediment quickly rearranges and the beach reaches an equilibrium profile. From this point the area erodes naturally, not following the exponential decay predicted by the theoretical nourishment decay formulas. The sediment moves further out in the profile after the first winter period, after which it comes back to the beach contributing to the equilibrium profile. The nourishment benefits both the area directly downstream (on the beach) and the downstream beach face. These areas both acquire significant quantities of sand. The groynes have a significant impact on the beach processes.

Chapter 3

Background data

The available wave data is provided by the offshore wave buoy at Fanø Bay. For sea level data, the gauge at Esbjerg harbour is used.

The survey data consists of 22 survey lines (lines 6064800 to 6067200), with spacing of 100 m over 2000 m. The area has been surveyed 5 times.

Figure 3.1. Nourishment site with survey lines (red), nourished area (on the beach in length marked by yellow line) and DCA survey lines 6310 - 6330 (black).

To use all survey data in a uniform way, an investigation of the total usable length of all the lines is made. By finding the lowest height of the lines in the dunes and the highest measured level of the surf zone, the cut-off level of the volume calculations can be found, see Figure 3.2. The so called minimum common area for volume calculation is determined to be from elevation 0 m to +5 m.

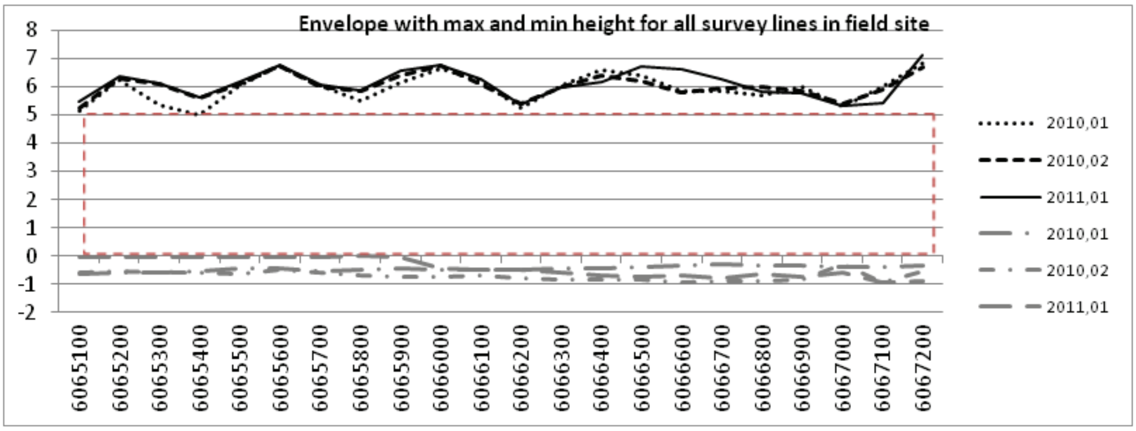

Figure 3.2. Cut-off of survey lines for volume calculation.

The range of length for the cross-sectional profiles is from -0.94 to 7.12 m. The considered envelope, describing the maximum common area includes measurements from 0 to 5 m. The variation in distance of the profiles is from 51.11 m to 117.22 m and indicates the disturbance of the groynes.

The standard variation of the measurement uncertainty is 5 cm. With an area of interest inside the envelope of circa 200000 m², the variation in volume calculations with this uncertainty may yield errors as much as 20000 m³, which may be amplified when combined with the relatively small amount of sediment scattered over a large area.

3.1 The nourishment

The sediment was distributed between the six groynes, each segment receiving circa 25000 m³ of sand with the following parameters:

D50 = 0.426
D60 / D10 = 2.415

The profile before the nourishment was relatively steep and the beach was narrow. The shoreline-dune top distance was 60 m. The sediment was transported to the location in ships, pumped through pipes, and deposited near the dune face. A more gentle slope was obtained from the dune to the shoreline, and the beach width after the nourishment was measured at 105 m. Because of the use of water as a means to get the sand on the beach, some of the sand may escape the envelope and become part of the intertidal beach process.

3.2 Water level and wave data

Sea level measurements are provided by the water level gauge located at Esbjerg Harbour, 22 km south east of the site. Since the Blåvand beach is much more exposed than the harbour, the water levels locally can be higher due to wave set-up. On the other hand the damping of the tidal wave from south to north can make the water level fluctuations and the mean level lower. Table 3.1 shows the extreme sea levels for Esbjerg Harbour.

Return Period	Level [cm]
100 years	405
50 years	388
20 years	362
1 year	247

Table 3.1. Sea levels for different return periods for Esbjerg harbour.

Neither of the 100, 50 or 20 year sea levels is exceeded in the period 30.06.2010 – 11.06.2014. The 1 year sea level is exceeded 5 times within that period, as it can be seen in Table 3.2.

Date	Level [cm]
12/11/2010	265
05/02/2011	275
14/12/2011	259
06/12/2013	302
31/01/2013	345

Table 3.2. Sea levels over that of a 1-year return period for Esbjerg harbour.

Wave heights are measured by a DCA wave buoy in Fanø bay, 23 km south of the site. Measurements from another buoy, located at Fjaltring (100 km north) supplement in case of missing readings from Fanø. Figure 3.3 to Figure 3.7 are wave roses. The different colours represent wave heights, the circles represent percent intervals.

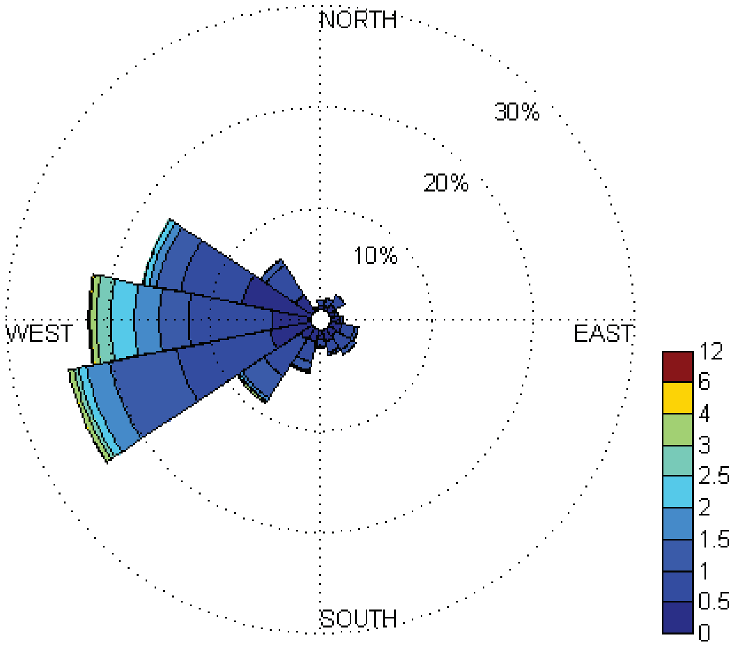

Figure 3.3. Wave Rose Fanø Bay 30/06/2010 - 26/10/2010.

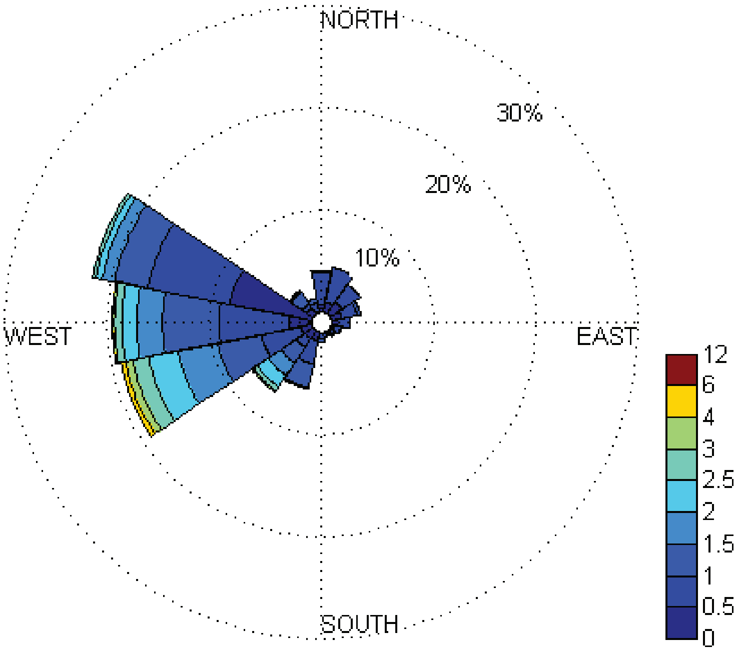

Figure 3.4. Wave Rose Fanø Bay 26/10/2010 - 09/02/2011.

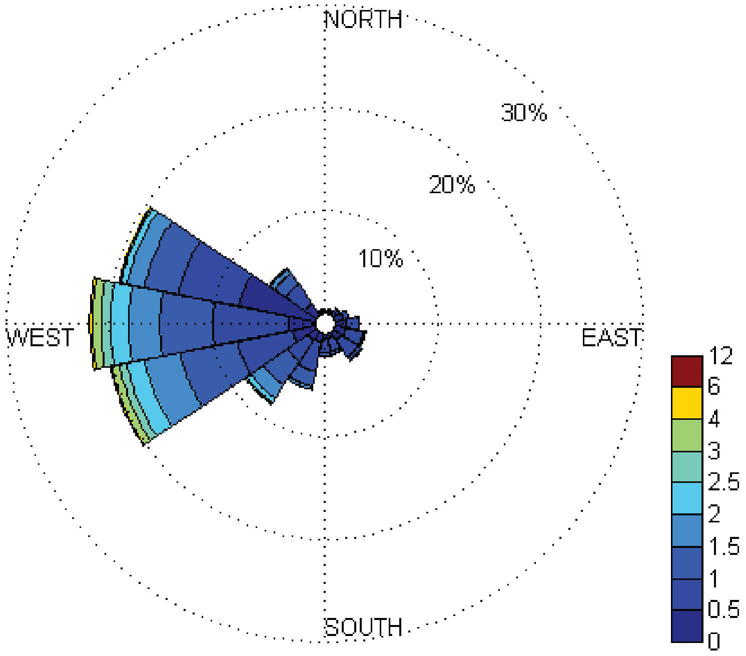

Figure 3.5. Wave Rose Fanø Bay 09/02/2011 - 05/11/2012.

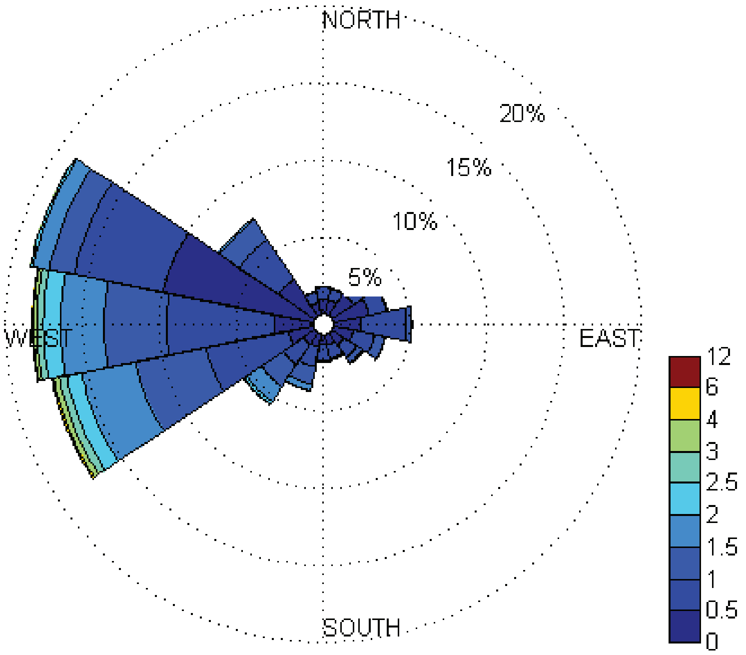

Figure 3.6. Wave Rose Fanø Bay 05/11/2012 - 02/10/2013.

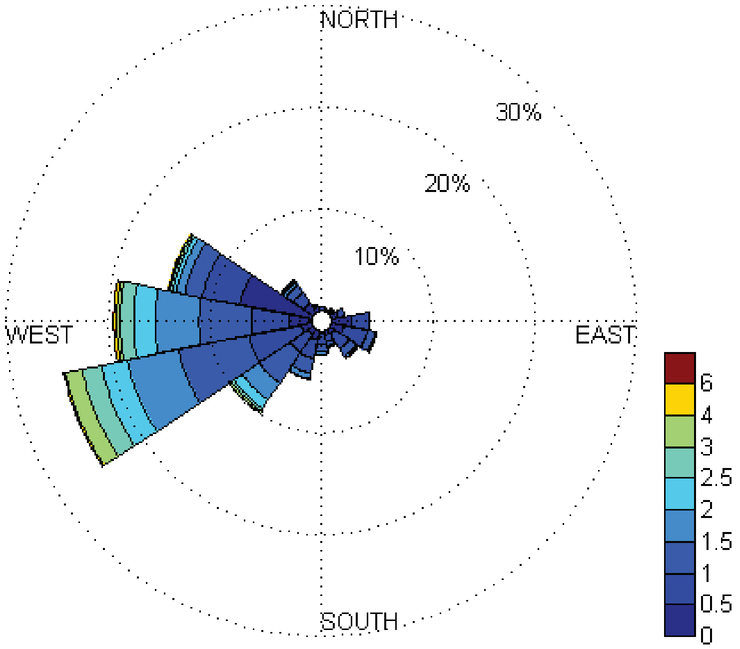

Figure 3.7. Wave Rose Fanø Bay 02/10/2013 - 11/06/2014.

In wave roses, the compass circles show the direction from which waves with the respective heights come. Waves at Fanø come typically from the WNS, W or WSW, while the highest waves come from W, WSW or SW directions.

Chapter 4

Volume analysis

This chapter consists of an analysis into how the nourishment impacts the nourished area and the surroundings areas. Firstly, the decay in nourishment volume will be calculated and compared to two theoretical models. For this, only the area where the nourishment sand is deposited is considered.

Secondly, the downstream and offshore areas will be included in the analysis. The sediment is expected to rearrange itself, eventually reaching an equilibrium profile. Moreover, the sediment is expected to migrate downstream and benefit that area.

4.1 Sediment volume decay

In this section, an analysis is made of the variations in the volume of sediment present in the area. This analysis is performed with the help of KI-Menuen, software developed by The Danish Coastal Authority. For this analysis, only the nourished beach (between lines 6065200 and 6067200) is considered.

Because of the distance along-shore between the survey lines, the volume calculations are sensitive to variations in the vertical component of the surveys, and thus rely on the accuracy of the measurements. KI-Menuen interpolates between the survey profiles.

When nourishing a beach closer to the dune face, the migration of sand is expected to be more active during storm conditions. This aspect cannot be thoroughly analysed because, apart from the pre- and post-nourishment studies, there is too much time between the surveys, and the intervals between them vary too much.

Nourishment decay is predicted by two empirical models proposed by Dean [3] and Silvester&Hsu [4]. Dean uses Equation 1 to predict decay. The theoretical decay in this case is an exponential curve controlled by an empirically determined site parameter.

$D_D(t) = \exp(-k_D t)$ (Equation 1)

where:	D_D	*decay according to Dean*
	k_D	*empirical site parameter*
	t	*time after nourishment*

Dean's formula does not include the long-term erosion rate. This is added to the formula later.

The non-dimensional empirical site parameter k_D has a value of 0.00251.

Silvester&Hsu use some previous studies and experience to predict nourishment decay based on a number of parameters including beach width and yearly erosion. The formula is presented in Equation 2.

$$D_{SH}(t) = \left(0.2 + \frac{0.8}{10^{k_{SH}t}}\right) \cdot Y - t \cdot \tan\alpha \qquad \text{(Equation 2)}$$

where:	D_{SH}	*decay according to Silvester&Hsu*
	k_{SH}	*rate of exponential decrease*
	Y	*beach width*
	$\tan\alpha$	*long term erosion rate*

The term tan α from Equation 2 is clarified in Figure 4.1. The long term erosion rate at Blåvand is 2.5 m/year [2] and the rate of exponential decrease according to Silvester&Hsu is 0.64. The beach width is calculated as the average distance between the shoreline and the coastline across the width of the nourishment at the time of the first survey after nourishment (2010.02).

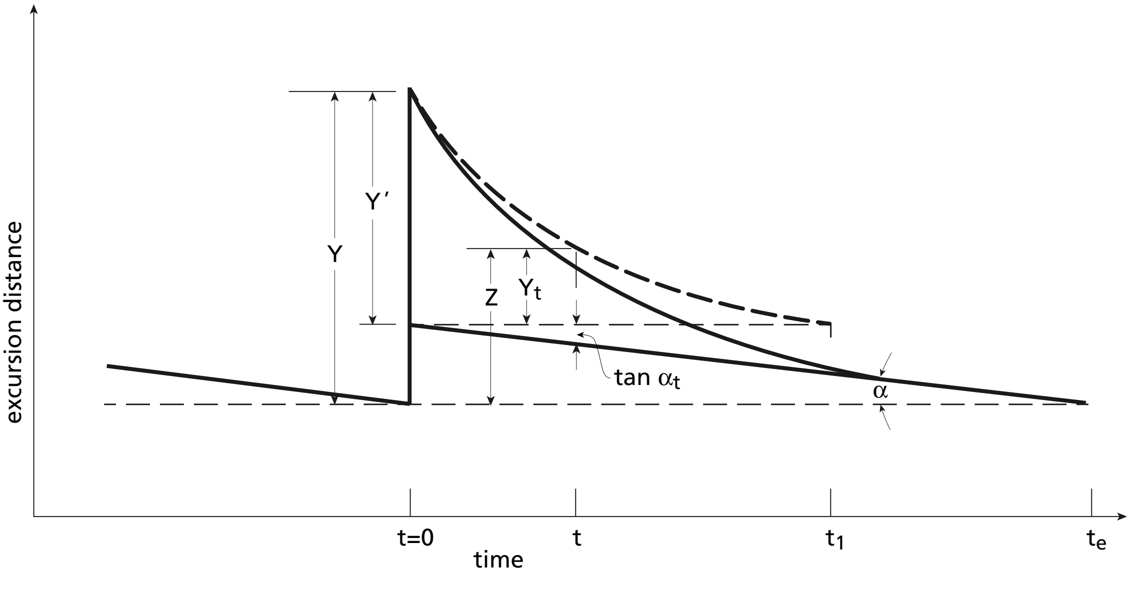

Figure 4.1. Long-term erosion rate model for a renourished beach. [5]

where:	$t=0$	*time of nourishment*
	t_1	*nourishment eroded back to long-term erosion rate [yrs]*
	t_e	*besch with reaches original demnation limit [yrs]*
	Y_t	*excursion distance [m]*
	Y'	*nourishment contribution [m]*

For both predictions methods, the values are normalised and presented as percent values of the initial nourished quantity. The results are plotted in Figure 4.2, together with the measurements at the site.

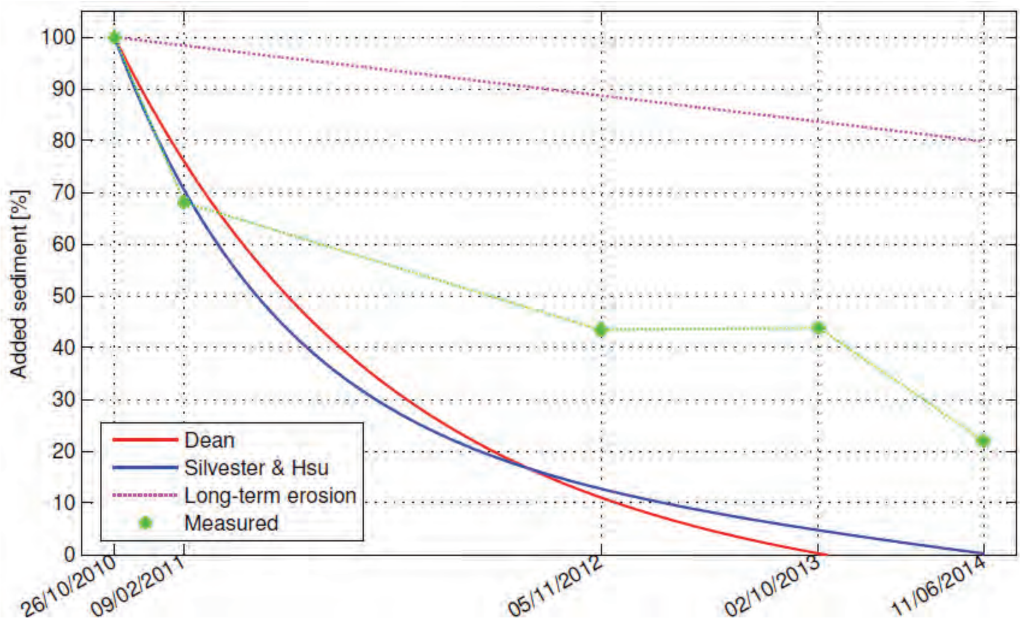

Figure 4.2. Volume decay.

As it can be seen, the measurements do not follow the theoretical curves. The nourishment decays quickly in the first interval. This happens because the deposited sediment gives the beach an unnatural profile. The period between the post-nourishment survey and the next one is a winter period, where sand migration is expected to be more active.

After the beach reaches the equilibrium profile the decay of the nourishment stops following the exponential decay predicted by the two methods. The February 2011 survey is executed after a storm period, whereas the subsequent surveys are executed during or after calmer weather seasons. After seasons of rough weather, more sand will lay further out in the profile, and after seasons of mild weather more sand will be brought to the beach area. Remember that the surveyed area is the beach; the area beyond the shoreline is not measured. This means that it is impossible to measure where the eroded sand goes.

The varying direction of cross-shore sediment transport does not explain the large difference between theoretical predictions and measurements. It is necessary to look at the assumptions and conditions associated with the theoretical models in order to explain this gap. Both formulas assume rectangular beach nourishments placed on straight shorelines. The beach at Blåvand is affected by the presence of groynes, which influence sediment transport.

4.2 Impact of nourishment on its surroundings

In this section, the entire surveyed area is taken into analysis. In order to evaluate the nourishment's impact on the surrounding areas, the surveyed stretch is divided into four areas, as shown in Figure 4.3. The limits of the nourishment are used to divide the stretch. Lines 6067200 and 6065200 delineate the nourished stretch, while elevation 0 m and +5 m (at survey 2010.01) are the lower and upper limits of the nourishment (box 1). Box 2 is the area cross-shore from the nourishment, down to elevation -0.6 m. Box 3 is the long-shore area located directly downstream from the nourishment, lines 6065200 to 6064800. Box 4 is the cross-shore area of Box 3, and is located downstream from Box 2. The approximate areas of the boxes are shown in Table 4.1.

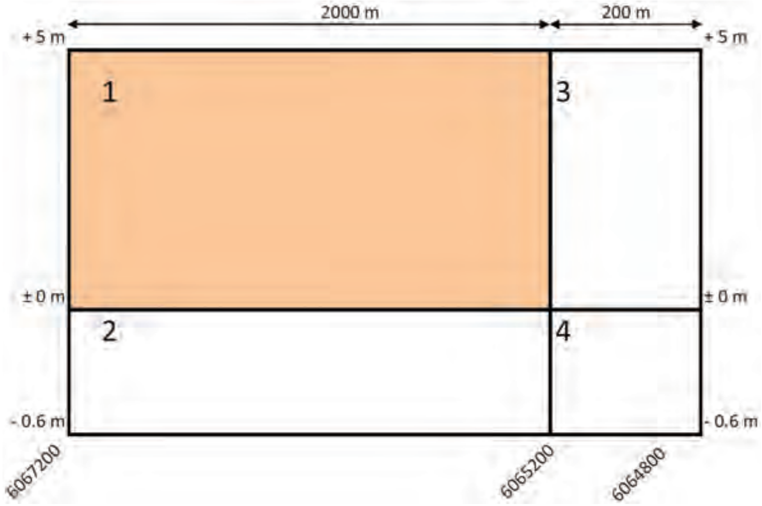

Figure 4.3. Volume Boxes

Box	Approximate area [m²]
1	224500
2	70000
3	16860
4	7650

Table 4.1. Approximate areas of the boxes from Figure 4.3.

The areas of the four boxes differ greatly; even by orders of magnitude (see Table 4.1). Therefore it is perhaps easier to follow the changes in sediment values as percent of the initial value after the nourishment in each box instead of looking at the volumes directly. This is done in Figure 4.4, where the values at survey 2010.02 (S2) are taken as initial values (100% sediment) for each box. Volume changes detected at surveys 2011.01 (S3), 2012.01 (S4), 2013.01 (S5), 2014.01 (S6) are plotted thereafter.

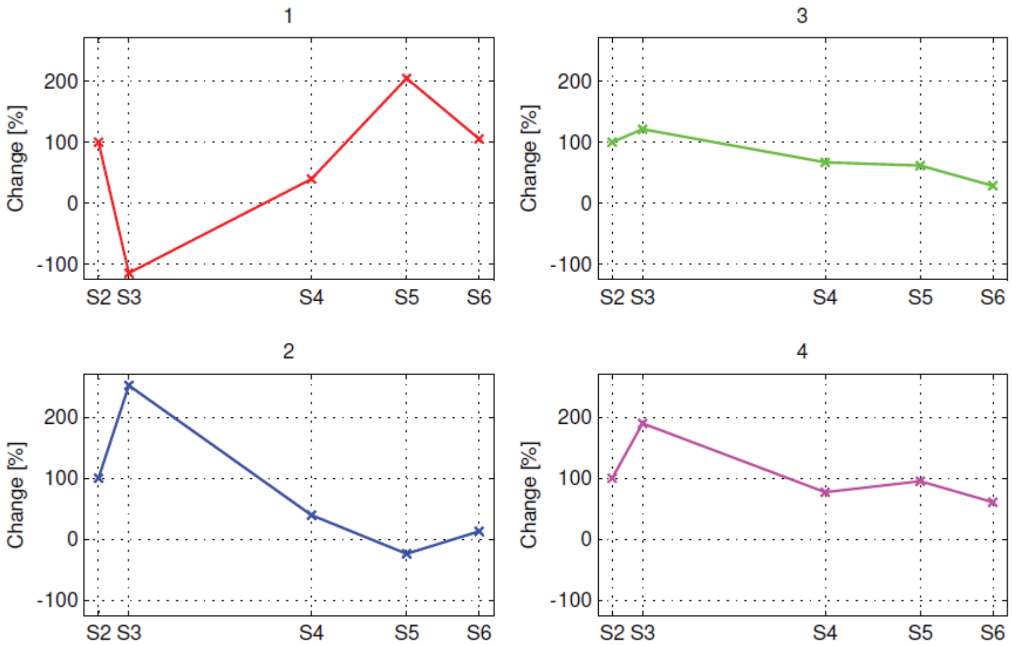

Figure 4.4. The evolution of sediment volume in each box, relative to the initial volume.

As expected, the nourished area erodes in the first period. It should be noted that the first survey post-nourishment is carried out 26/10/2010 (S2). The next survey after that is executed on 09/02/2011, after a winter season. It is normal for the sand placed at higher elevations to be dragged down the profile. At survey 2011.01, apparently all the sand placed in box 1 disappears. By looking at the other boxes, it is clear that the sediment gets redistributed. The biggest changes occur in boxes 2 and 4. The sand is dragged down to box 2, and downstream to box 4.

Measurements taken in November 2012 (survey 2012.01 – S4) show that some of the sediment has returned into nourished area. An explanation of this is that sand is dragged down the profile under bad weather, and then returns under milder weather. This could also be the case of survey 2013.01 (S5), executed in October. Erosion occurs in box 2, and sand is deposited in box 1 and 4.

References

[1] *DHI. Danish Coasts and Climate Adaptation. [Online]. http://coadapt.dhigroup.com/*

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