The vertical drain is a clear winner compared to bar and beach nourishment.

After 2 years and a harsh winter on the west coast with no less than 5 storms from October 2006 to January 20 2007, sand loss on the beaches in the drained areas 1 and 2, as well as reference 3, has only been 69.000 m^3

As previously stated, the SIC system with its vertical drain provides lee side accumulation of washed sand, in contrast to hard constructions, which cause lee side erosion.

The storm in March 2007 falls outside of measurements for the first 2 years.

In contrast, 960.000 m^3 of nourished sand at Søndervig has been washed into the sea and it is estimated that the sea has taken approx. an additional 400.000 m^3 of the dunes at the beach nourished areas north and south of Søndervig, where there is major dune damage.

Bar and beach nourishment at Søndervig have cost approx. DKK 42 million including dune foot protection (revetment), which cost approx. DKK 8.0 million.

As described in *Geologisk Nyt 01/07*, the SIC system has stopped erosion in the lee side erosion area south of Hvide Sande harbour.

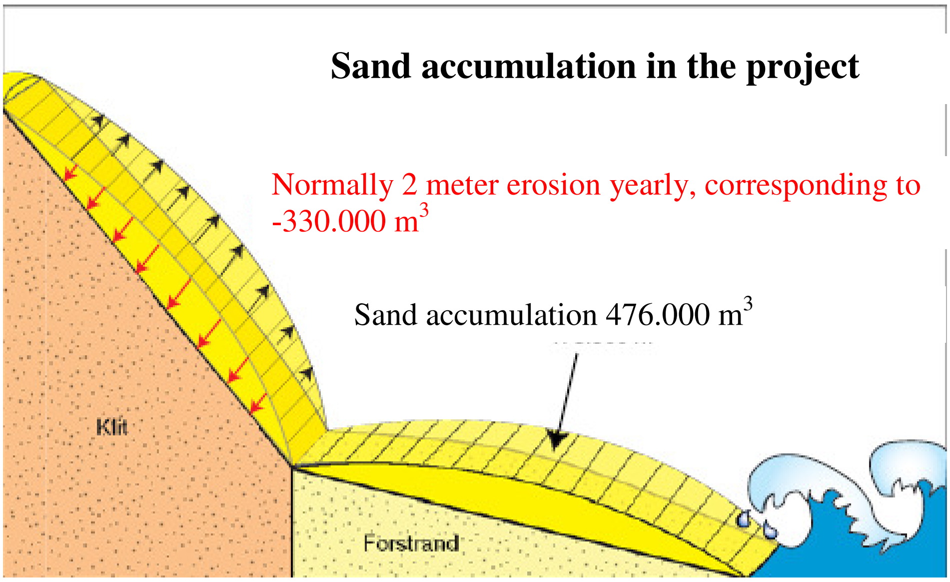


Fig. 1

At the same time, a sand accumulation of 476,000 cubic metres has occurred from the dune top and out to the coastline, so the total effect is 806,000 m^3 in the first year.

This calculation was made in order to avoid incorrect information about sand waves in the area as presented to Coastal Authority (KDI) by Professor Jørgen Fredsøe DTU.

If the sand quantity in the foreshore is calculated using this new calculation method based upon fixed reference lines, the accumulation of sand is 411.000 m^3 and a total effect of the drain system is 741.000 m^3 in the first year.

Søndervig.

05-07-2005 12:00 45 cm

Fig. 2

Søndervig the 5th of July 2005 after beach nourishment of

960.000 m^3 sand on the beach

16-01-2007 10:00 50 cm

<u>Fig. 3.</u>

Søndervig the 16th of January 2007 after an investment DKK 42 million

in bar and beach nourishment.

The nourished sand has washed into the sea and the sea has taken approx. 400.000 m^3 of the dunes.

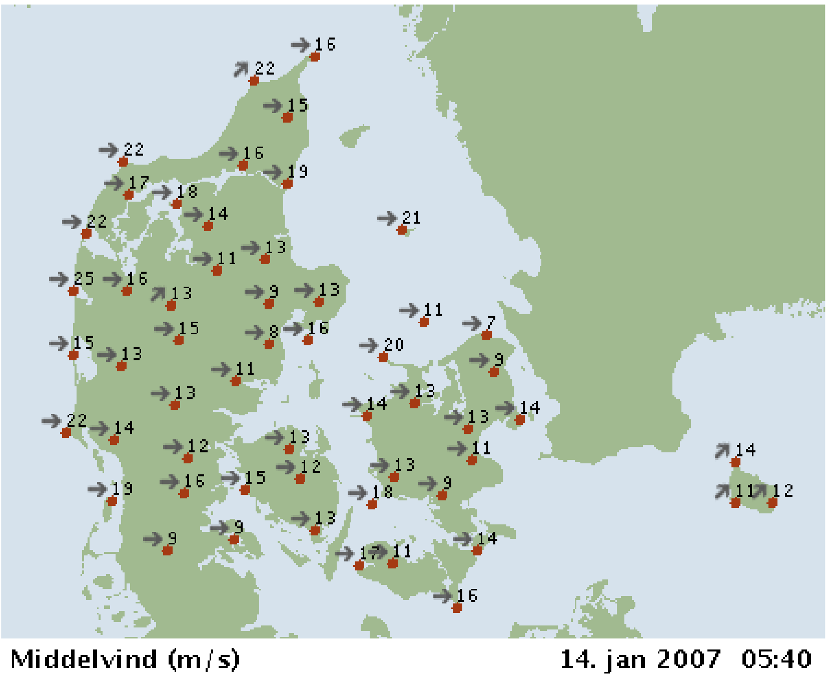
Krylen north of Søndervig.

Fig. 4

Fig. 5

Bunkers topple from the dunes following the winter storms from 2006/07, which we saw at Søndervig in 2005. Beach nourishment of 960,000 m^3 is washed out to sea.

Wind data



Wind speed m/sec
Fig. 6

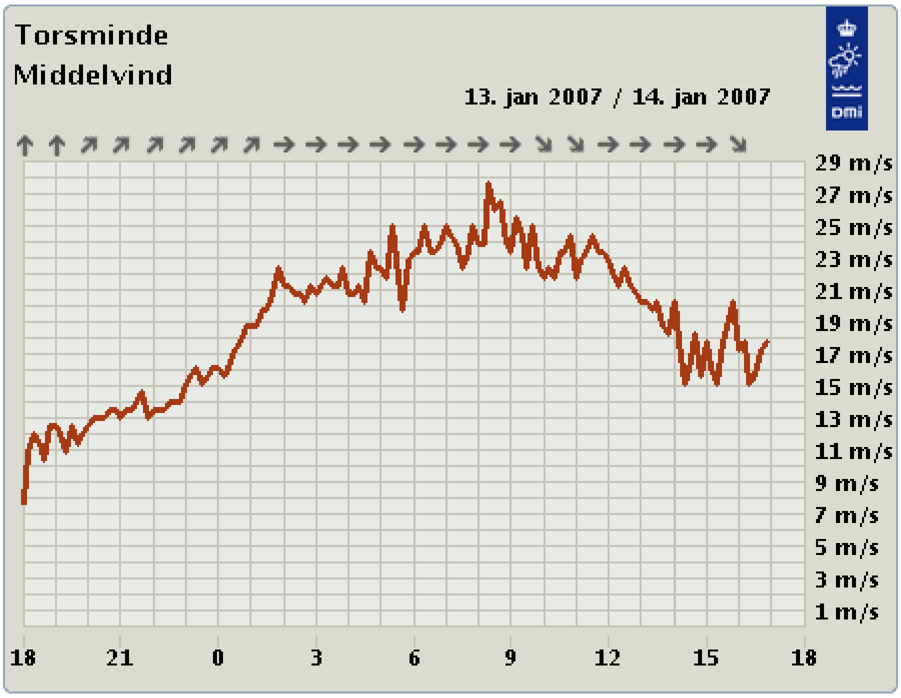


Fig. 7
Wind speed m/sec

As we see in fig. 6, the wind speed at Hvide Sande is significantly lower than the wind speed at Torsminde and Blåvandshug.

This is because DMI's (Danish Meteorological Institute) anemometer at Hvide Sande is located at the wastewater treatment plant behind the dunes at Hvide Sande.

Therefore the anemometer shows 7 – 10 m/sec. less in strong westerly wind.

We subsequently carried out quality assessments on KDI's wind data from Slusen in Hvide Sande, but this wind data also deviated significantly from Torsminde and Blåvandshug, as the anemometer was worn and finally blew down in the storm on 19- 20 January 2007.

Based upon wind data from Blåvandshug and Hvide Sande, the following storms were recorded on the west coast during winter 2006/07.

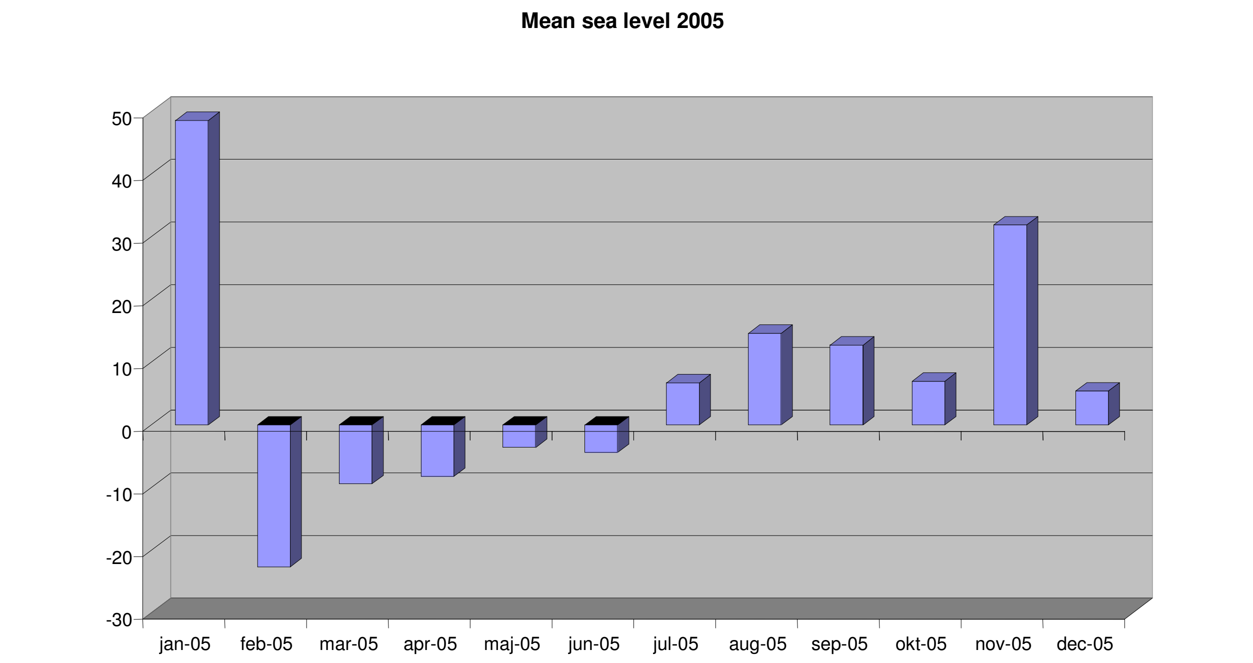
27. October 2006.	Max. sea level 1.54 metres.
1. January 2007.	Max. sea level 1.75 metres
11 – 12 January 2007	Max. sea level 2.14 metres.
14 January 2007	Max. sea level 1.78 metres.
19 - 20 January	Max sea level 1.78 metres.

Beach measurements began the 22nd of January and ended the 25 January 2007.

An error was made in not setting up an anemometer in the project area at the start of the project in January 2005.

DMI admits that the anemometer in Hvide Sande gives off incorrect data but has no plans to fix it. Therefore, it is necessary to interpolate wind data for Torsminde and Blåvandshug to subsequent scientific papers, which will be presented at international conferences.

Mean sea level

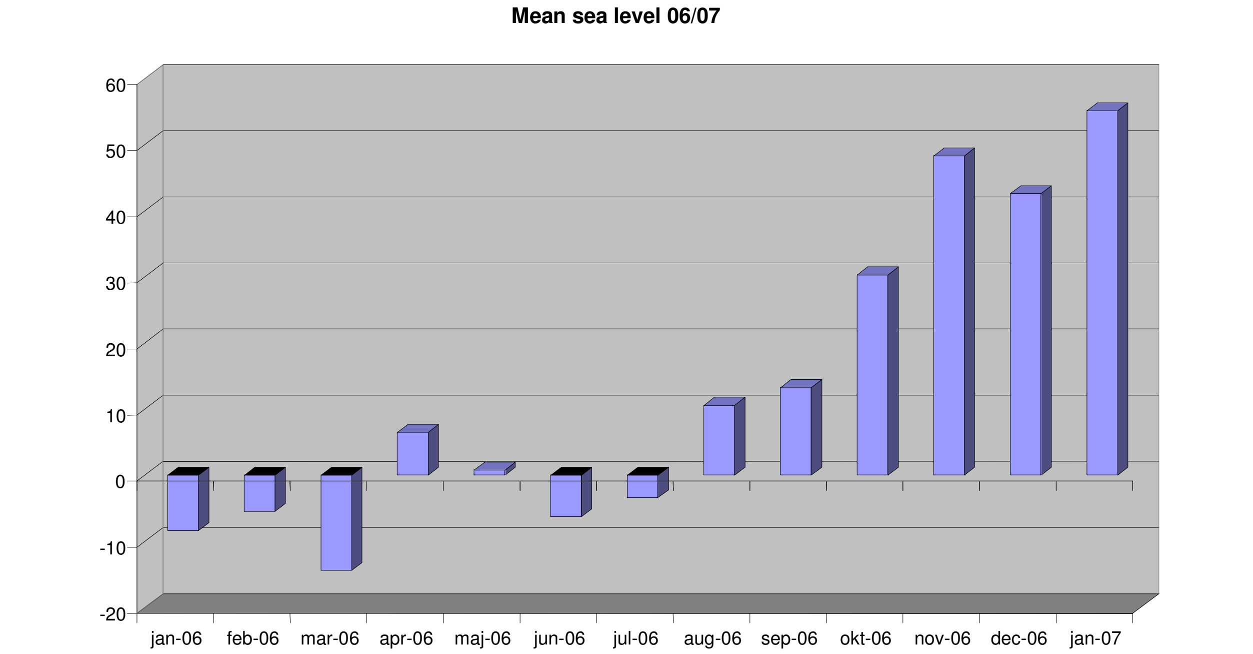


	jan-05	feb-05	mar-05	apr-05	maj-05	jun-05	jul-05	aug-05	sep-05	okt-05	nov-05	dec-05
Serie1	48,59	-22,65	-9,4	-8,25	-3,6	-4,4	6,7	14,6	12,74	6,94	31,89	5,4

Serie1

Fig. 8

In 2005, the mean sea level on the west coast was 6.55 cm above DVR 90.



	jan-06	feb-06	mar-06	apr-06	maj-06	jun-06	jul-06	aug-06	sep-06	okt-06	nov-06	dec-06	jan-07
Serie1	-8,4	-5,5	-14,4	6,5	0,77	-6,26	-3,41	10,57	13,24	30,3	48,3	42,6	55,13

Serie1

Fig. 9

In 2006, the mean sea level on the west coast was 9.53 cm above DVR 90. During the storm period, from 29 October 2006 to 12 January 2007, the mean sea level was 54.5 cm above DVR 90. Thus, the SIC system was tested under conditions corresponding to a mean sea level rise of 54.5 cm over 100 years in relation to the global sea level rise.

Waves

Average wave height 2005

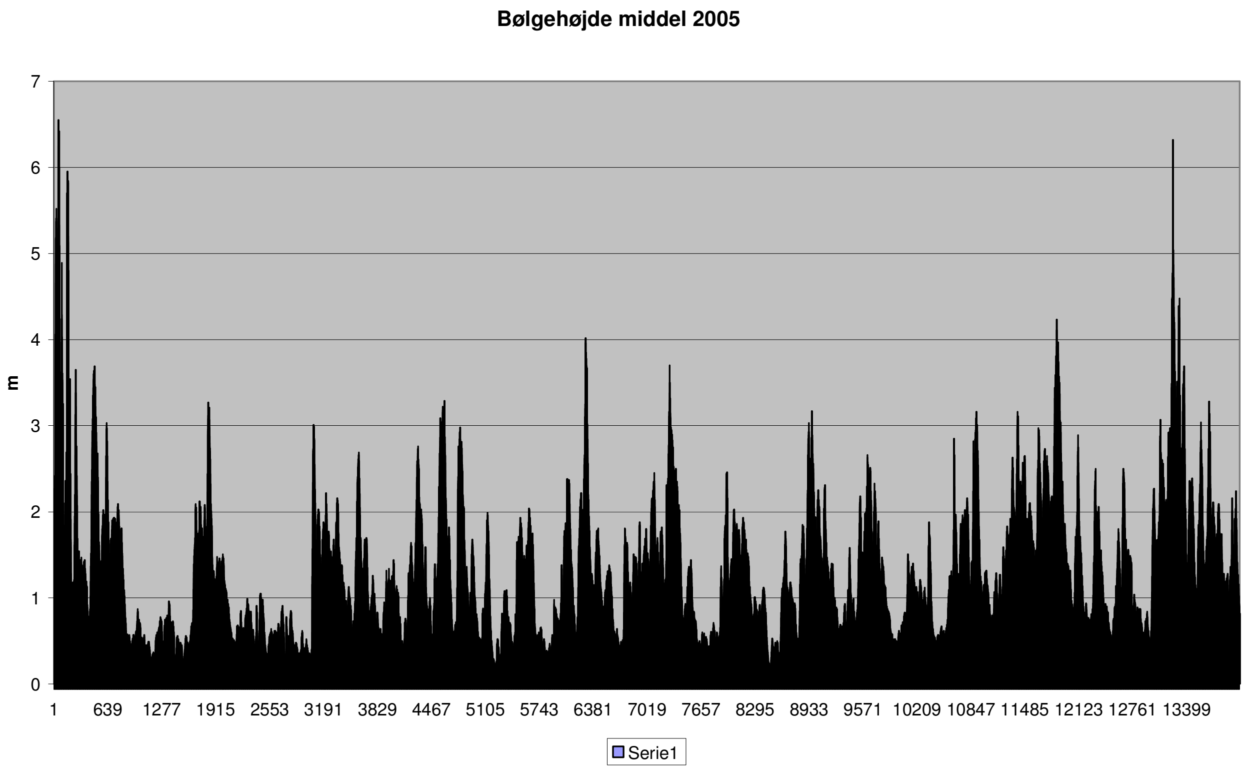


Fig. 10

Average wave height 2006/jan07

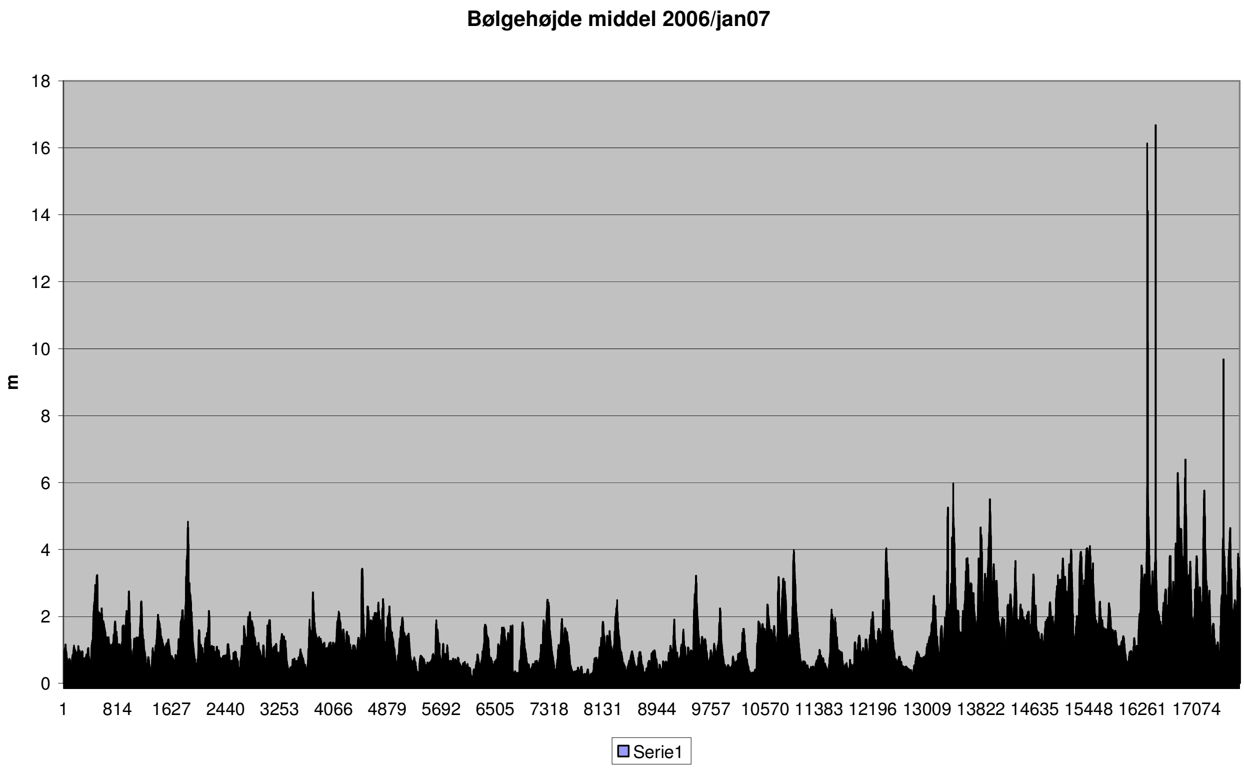


Fig. 11

The wave meter shows wave heights up to 14-16 metres in January 2007 and we can, therefore, conclude that there has been extremely harsh weather on the west coast in winter 2006/7. Wave data is recorded over periods of 20 minutes on the x axle. The data is supplied by KDI.

Evaluation Skodbjerge

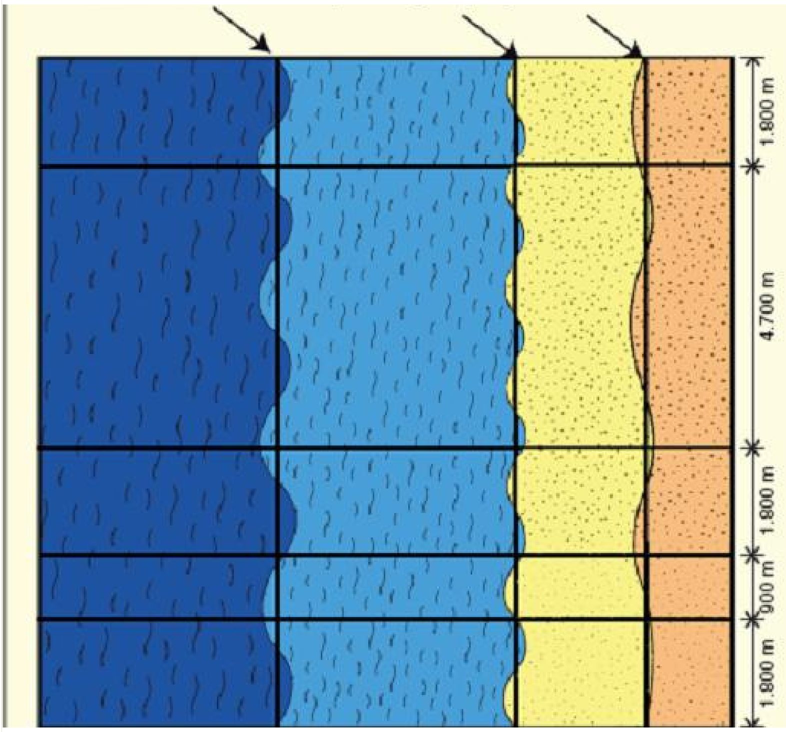


Fig. 12

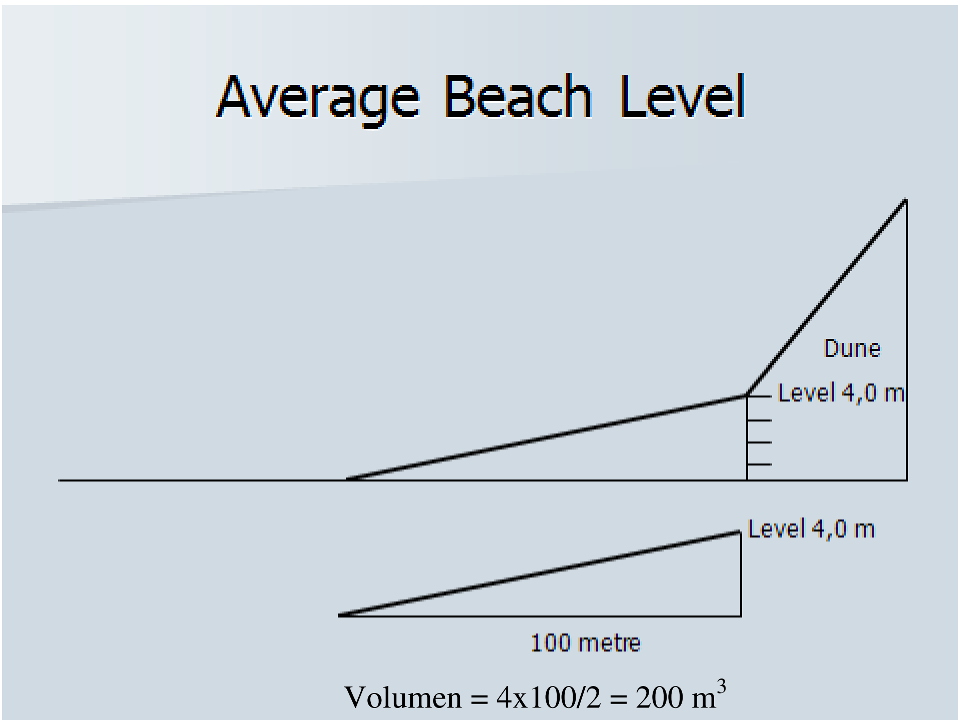


Fig. 13

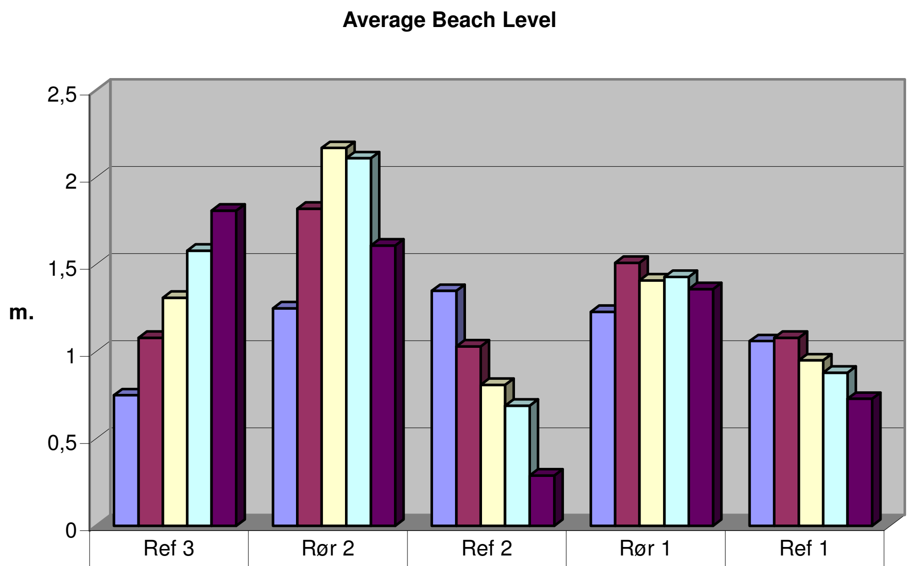
Average beach level – 2,0 meter is equal to 200 m^3 / metre

Average beach level – 1,5 meter is equal to 130 m^3 / metre

Design.

The goal of the project is to build a 70 – 100 metre wide sandy beach in front of the dunes in a equilibrium profile. A max. of 11 modules will be placed in the individual rows. The modules are submerged in the beach. The average beach level shall be greater than 1.3 metres. When the average beach level is greater than 1.3 metres, one cannot see sea erosion in the dunes should a storm occur. When the average beach level is 1.3 metres, one has a buffer of 130 cubic metres per metre along the beach. The coastline should be as straight as possible.

Results after 2 years



	Ref 3	Rør 2	Ref 2	Rør 1	Ref 1
jan-05	0,75	1,25	1,35	1,23	1,06
jul-05	1,08	1,82	1,03	1,51	1,08
jan-06	1,31	2,17	0,81	1,41	0,95
jul-06	1,58	2,11	0,69	1,43	0,88
jan-07	1,81	1,61	0,29	1,36	0,73

jan-05 jul-05 jan-06 jul-06 jan-07

Fig. 14

The average beach level is calculated from the dune foot at levels 4.0 and 100 metres out from the dune foot as shown in figures 12 and 13.

Analyses.

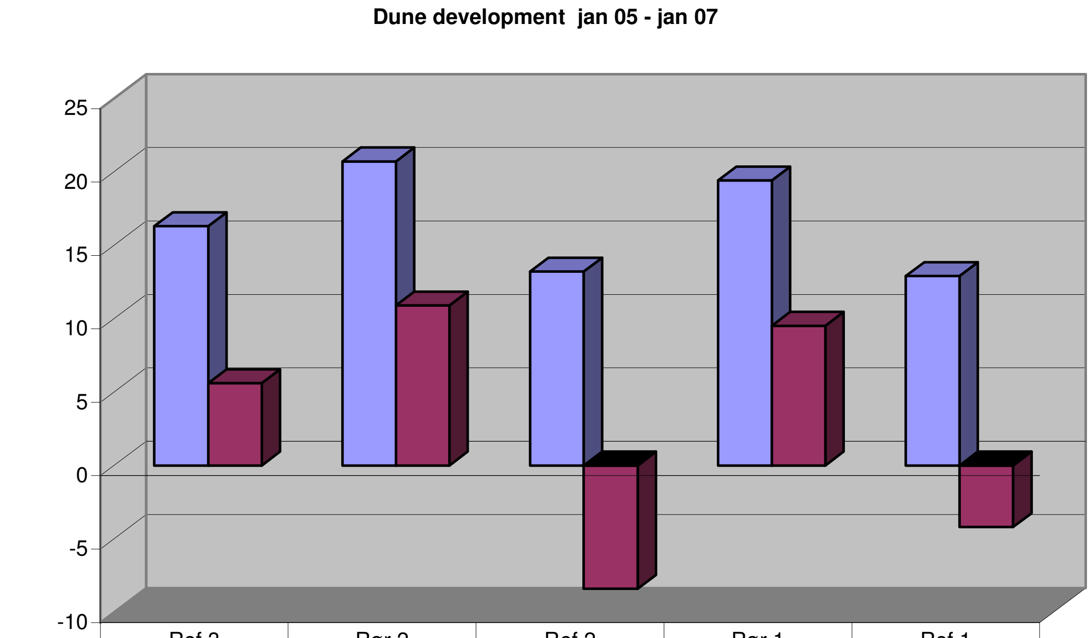
Measurements show that the average beach level is greater than 1.3 in both drained areas and ref. 3 where there is a lee side supplement of washed sand.

In contrast, the average beach level in ref.1 has fallen from 1.06 metres to 73 cm and in ref. 2 from 1.35 m to 29 cm.

The original beach in reference area 2 has eroded away; it was the strongest area in January 2005.

At the same time, we see significant wave erosion in the dunes from January 06 to January 07 in ref. 1 and 2 and the southerly part of ref. 3.

Dune development



	Ref 3	Rør 2	Ref 2	Rør 1	Ref 1
jan-06	16,3	20,7	13,2	19,4	12,9
jan-07	5,6	10,9	-8,4	9,5	-4,2

Fig. 15.

In ref. 1, the erosion from January 06 to January 07 is 17.1 cubic metres. I ref. 2 the erosion is 21.6 cubic metres pr metre.

Conversely, the erosion in drained area1 and 2 is 9.9 cubic metres and 9.8 cubic metres respectively.

That is, erosion at the dune foot is double as great as in ref. 1 and ref. 2 in relation to the drained areas.

In the drained areas, it is primarily wind erosion, while in the reference areas it is primarily wave erosion, as we see in figure 6, which shows location of the dune foot in Jan 06/Jan 07.

The dune foot is moved up to 12.5 metres back in reference area 1 and up to 17 metres back in reference area 2, where the sea has been deep into the dunes.

Dune foot movement in relation to average beach level

Jan 2005 – Jan 2007

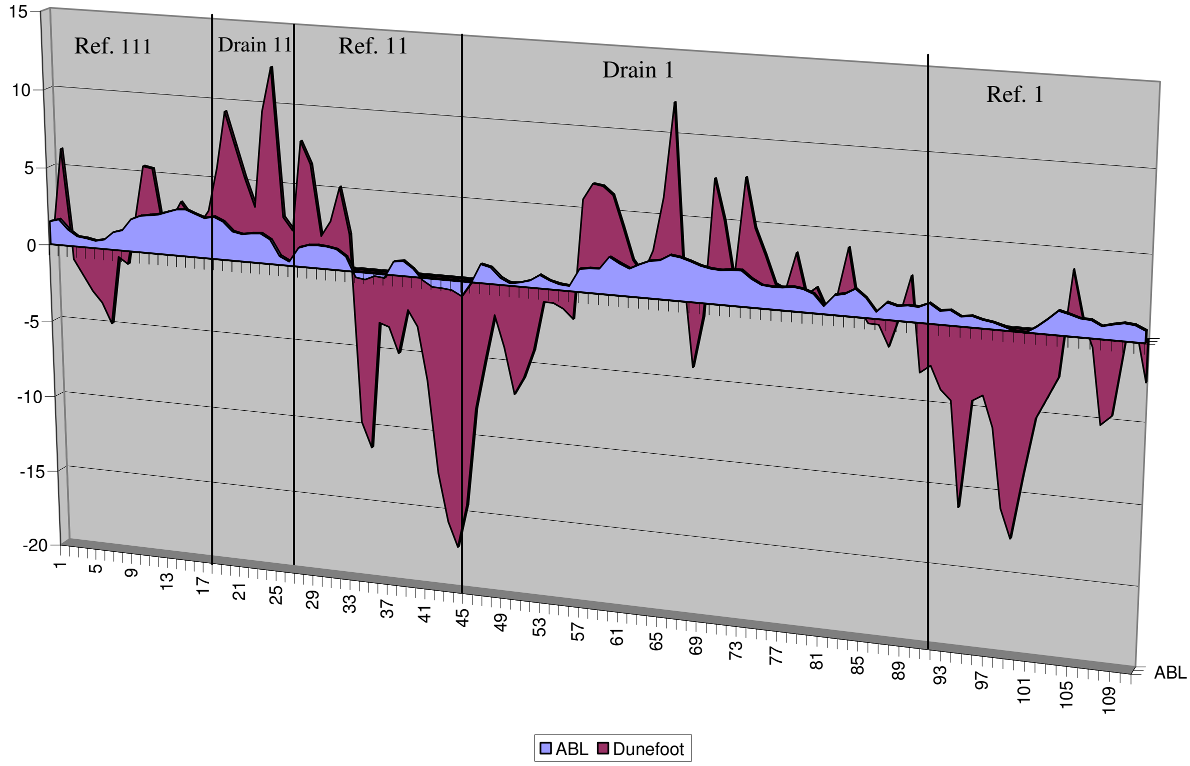


Fig. 16.

Fig. 16 shows the changes in the dune foot compared with the average beach level. One can clearly see that the dune foot is advancing in the drained areas, while there is wave erosion in areas with low average beach level.

The wave erosion returns the materials to the sea, while the sand is lost in the hinterland in the event of wind erosion.

Thus, there is an important difference between erosion at the dune foot in the drained areas and the reference areas.

Dune foot movement

dune foot movement jan 2005 – jan 2007

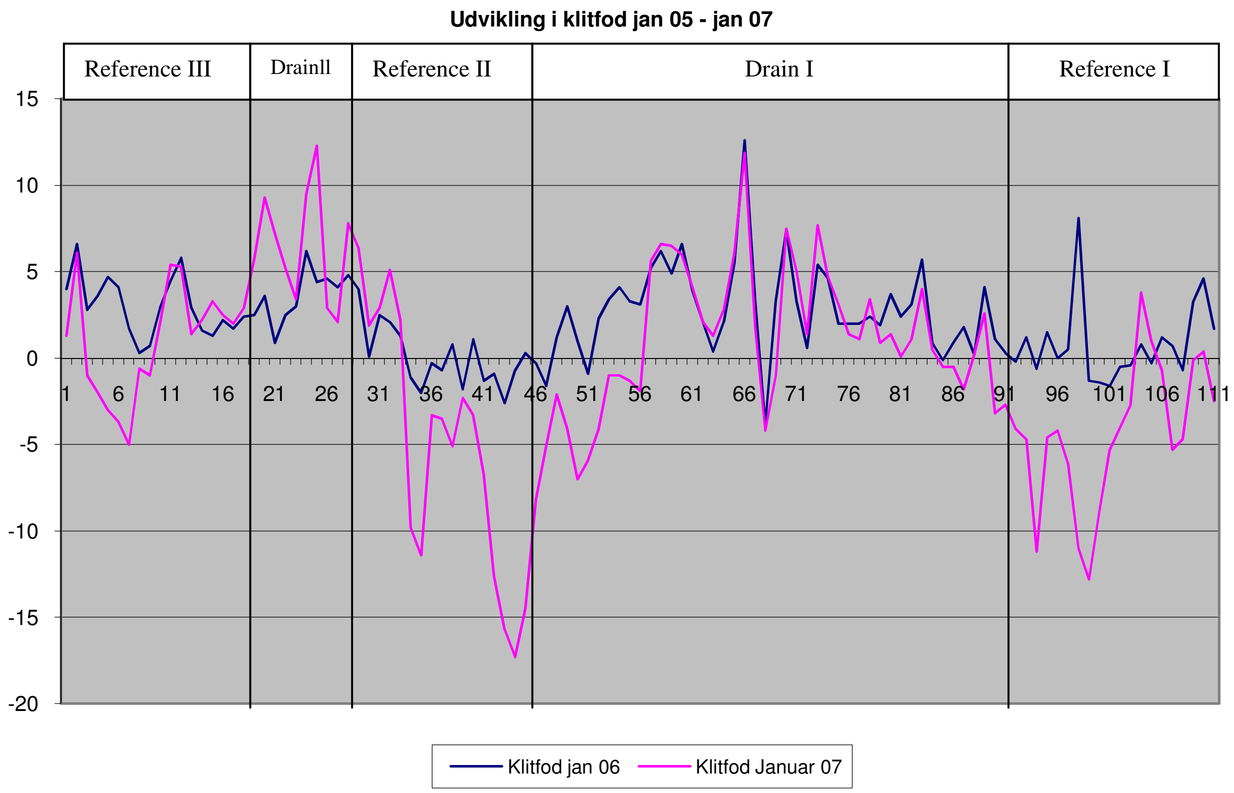


Fig. 17.

Wind erosion

In connection with drained beaches, it is necessary to focus on wind erosion in the foreshore.

Wind erosion on the drained beaches is roughly 30 – 40 cubic metres annually and is therefore a significant amount of sand over 3 years, as wind erosion constitutes 90 – 120 cubic metres per metre.

Thus, if the beach is 100 metres wide, wind erosion will reduce the beach level by 90 – 120 cm over the course of 3 years.

However, it is only the fine-grained materials that get blocked up in the dunes, while pebbles and stones will remain on the foreshore.

Wind erosion is a significant factor when we speak of the materials becoming coarser on the foreshore when the beaches are drained.

It is a fact that the wind sorts 90 cubic metres per metre over 3 years.

Subsequent analyses of the materials on the foreshore will show the total quantities that must be sorter in order for us to find the net result of 90 cubic metres in the dunes over 3 years.

Grain size analyses from the foreshore and dune

Grain size mm	<0.063	0.13	0.25	0.5	1	2	4	8	16	31.5
2500 Bar 8	0	0.1	12.7	43	54.3	58.5	62.8	84.5	84.5	100
2500 Bar 7	0	0	8.5	35.9	51.7	59	64.7	84.2	84.2	100
2600 Bar 7	0	0.1	10.8	40.9	57.6	66.7	74.5	94.1	94.1	100
2600 Bar 6	0	0.1	13.2	59	72.9	76.6	79.4	91.6	91.6	100
2700 Bar 7	0	0.1	8.5	40	54.5	61.8	67.8	95.1	95.1	100
2700 Bar 6	0	0	4.1	25.8	37.9	44.7	50.9	89	89	100
2650 Dune base	0	0.2	16	65.4	82.7	88,1	91	100		
2700 Dune base	0	0	4.1	27.1	43.3	59.9	76.1	100		
2700 Front edge dune	0	0	20.7	88.9	99.7	100				
2700 Rear edge dune	0	0.1	14	78.2	96.6	100				
2700 Rear edge dune	0.1	0.3	18.6	83.7	99.1	100				

Table 1

Material samples from the beach and dunes shows the following

33 % of the materials in the foreshore are coarser than 4.0 mm in grain diameter
39 % of the materials in the foreshore are coarser than 2.0 mm in grain diameter
45 % of the materials in the foreshore are coarser than 1.0 mm in grain size

At the same time, the dune samples show that:

98 % of the sand in the dunes has a grain diameter lower than 1.0 mm
84 % have a grain diameter that is less than 0.5 mm

Thus, we can conclude that the total amount of sand that is sorted by the wind on the foreshore is double the quantity, in relation to the quantities of sand we find in the dunes.

In the foreshore, the wind sorted quantity of sand per metre is somewhere between 180 and 240 m^3 per metre over 3 years.

Therefore, we can conclude that the materials in the foreshore become more and more coarse over time and that the beach generally develops significantly improved drainage ability, as the K value increases significantly in the drained areas.

Sand from the North Sea used for sand nourishment on the west coast, primarily has a grain diameter between 0.25 mm - 0.5 mm and according to American experts is actually unusable for sand pumping.

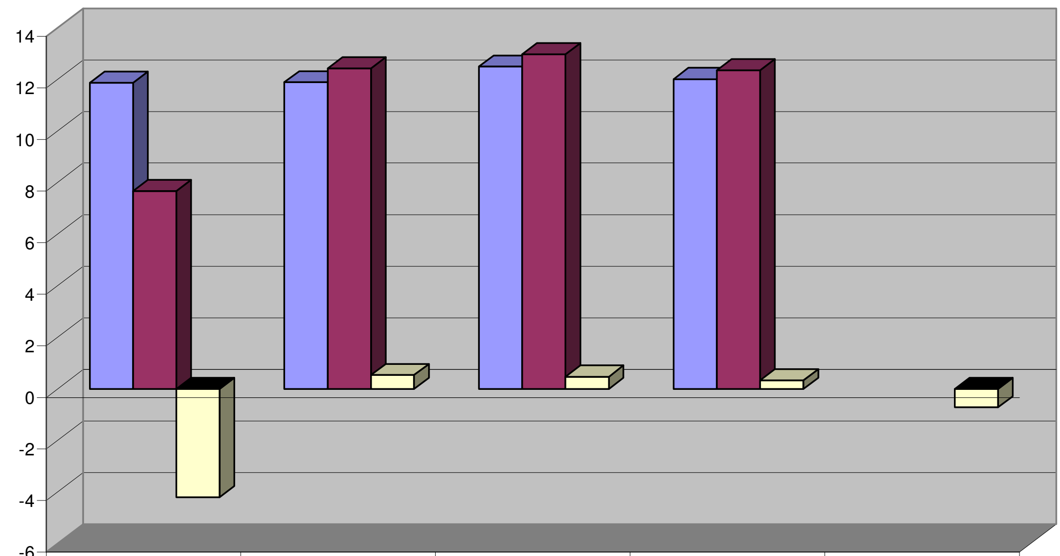
SIC views this as the background for the catastrophically poor effects of sand nourishment on the west coast.

However, there is an extremely large difference in the wind sorting for drained areas 1 and 2, and the reference areas where the average beach level is very low.

This is clearly illustrated in figures 18, 19, 20, 21.

Reference area 2.

4014300

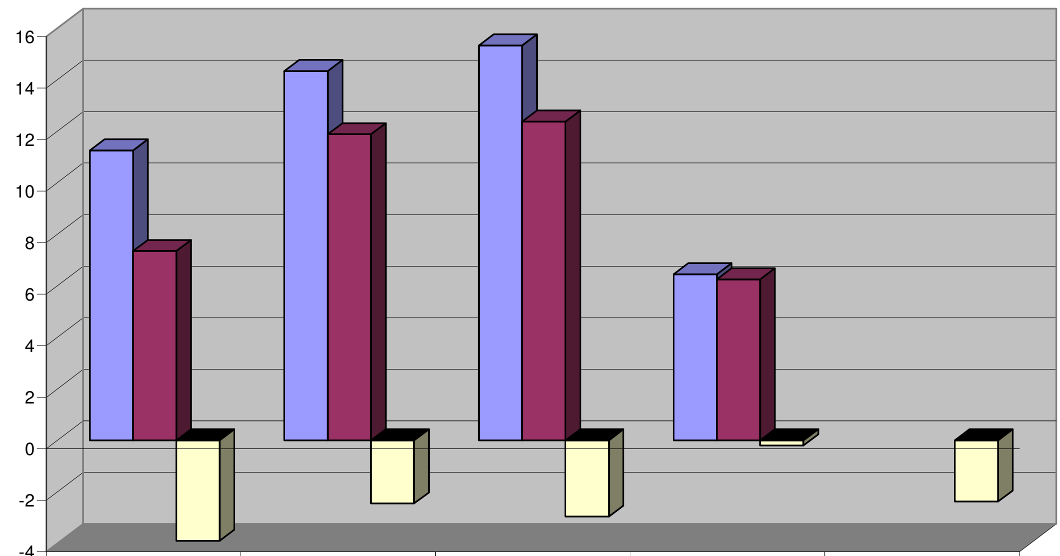


	Punkt 1	Punkt 2	Punkt 3	Punkt 4	
jan-05	11,88	11,89	12,5	12,02	
jul-07	7,68	12,43	12,98	12,36	
Udvikling	-4,2	0,54	0,48	0,34	-0,71

jan-05 jul-07 Udvikling

Fig. 18

Station 4014400



	Punkt 1	Punkt 2	Punkt 3	Punkt 4	
jan-05	11,25	14,33	15,33	6,45	
jul-07	7,35	11,88	12,37	6,25	
Udvikling	-3,9	-2,45	-2,96	-0,2	-2,3775

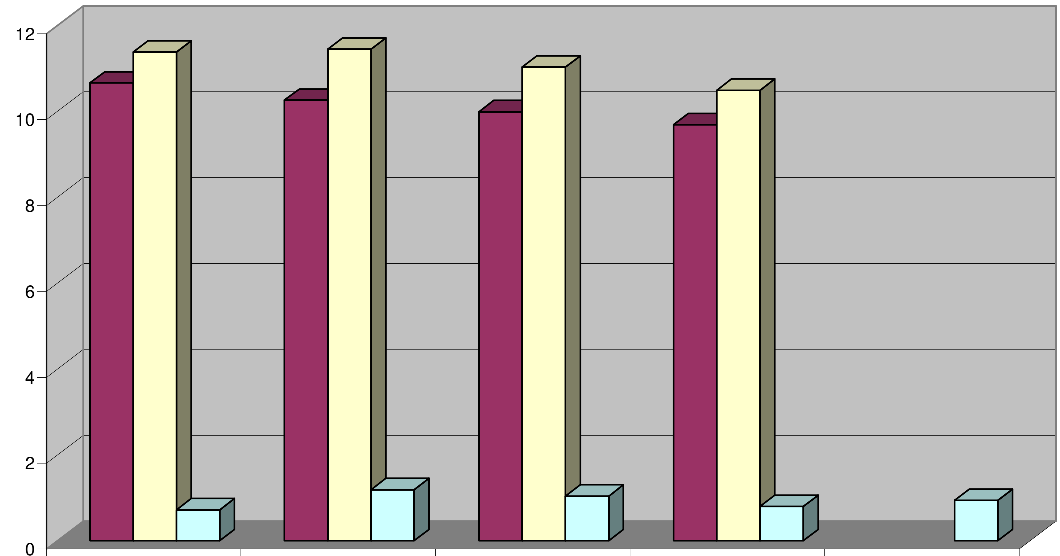
jan-05 jul-07 Udvikling

Fig. 19

Survey points on top the dunes.

Drained Area 1.

Station 4016100

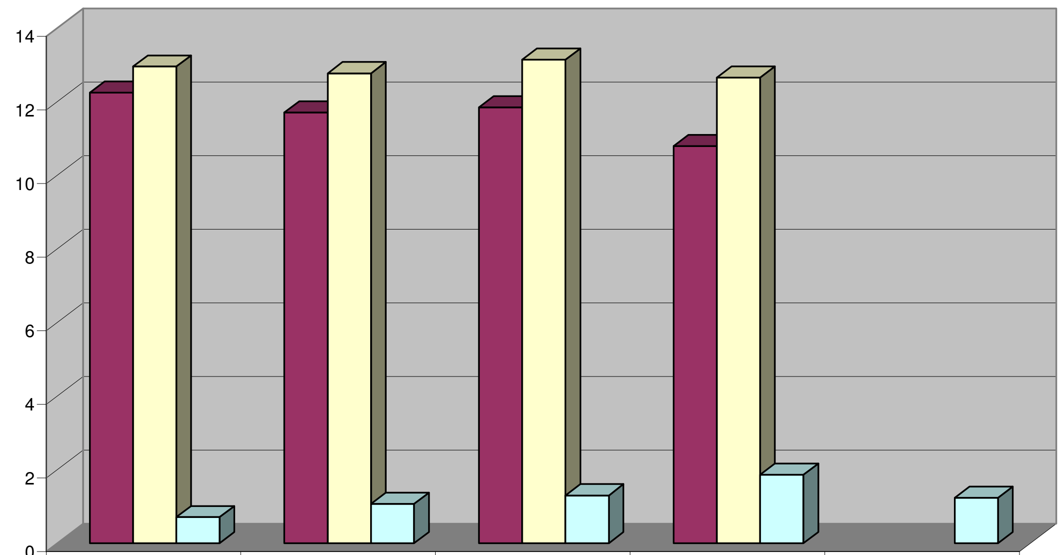


	1	2	3	4	5
jan-05	10,66	10,26	9,99	9,69	
jul-07	11,38	11,45	11,03	10,49	
Udvikling	0,72	1,19	1,04	0,8	0,9375

jan-05 jul-07 Udvikling

Fig. 20

Station 4016200



	1	2	3	4	5
jan-05	12,24	11,7	11,84	10,79	
jul-07	12,95	12,77	13,14	12,65	
Udvikling	0,71	1,07	1,3	1,86	1,235

jan-05 jul-07 Udvikling

Fig. 21
Survey points on top the dunes.

Station 4400

Fig. 22
Allan Christensen from Carl Bro A/S stands on the front edge of the dune, which was previously the top of the dune

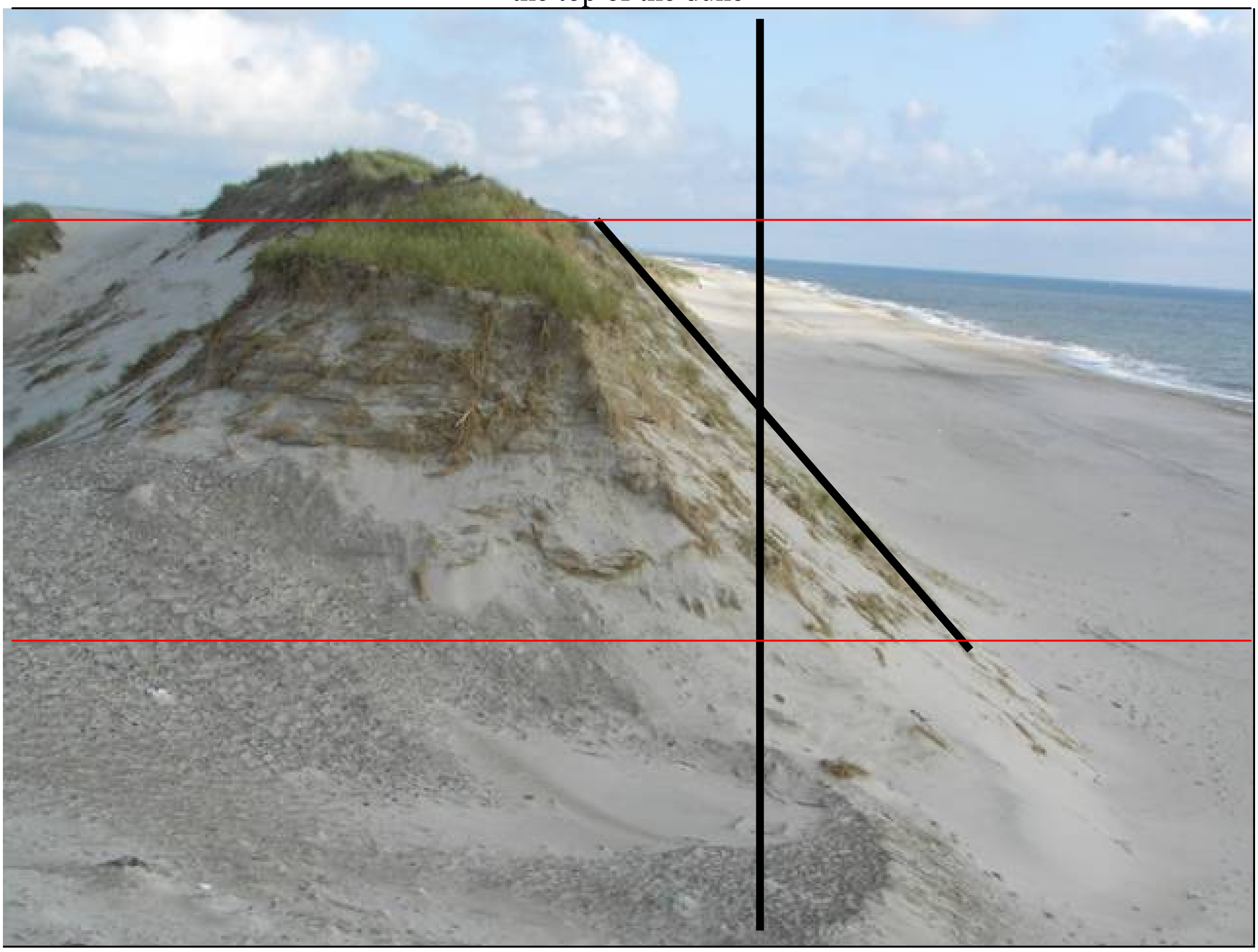


Fig. 22
Sand from the dune top rush down to the dune foot after wave erosion.

Dune structure in the drained areas

Fig. 24
Helm grass in the dune front in the drained areas.

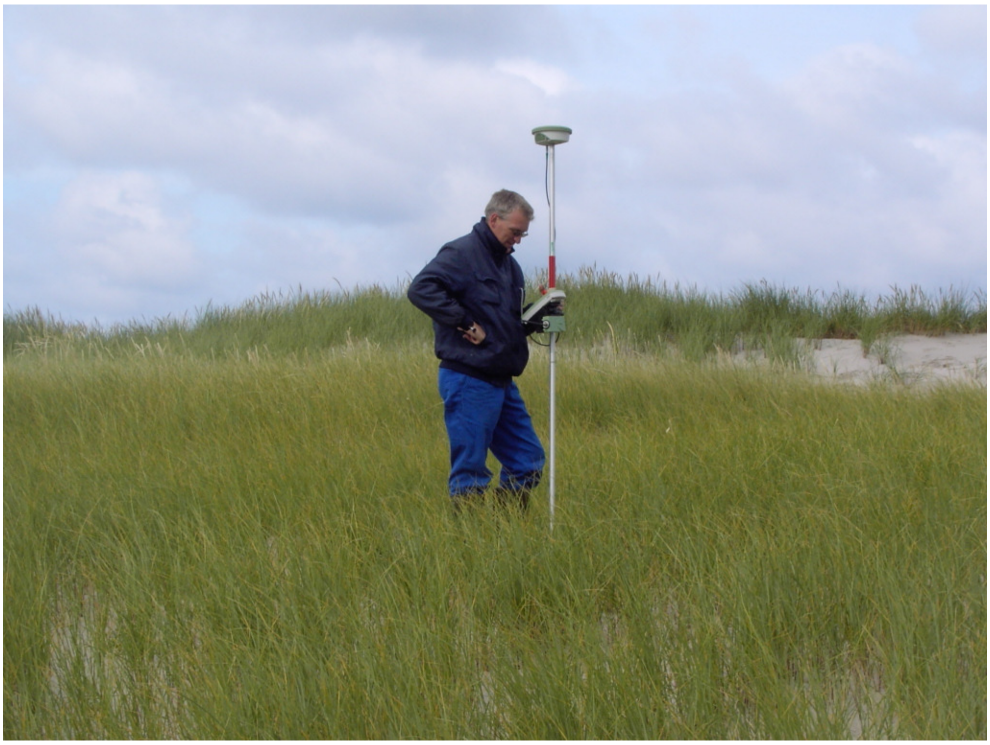


Fig. 25
In the drained areas, the dunes have been raised between 90 cm and 120 cm over 2.5 years in the four measuring points on the tops of the dunes, but the sand has also caused sand drift further along the dune system, as we see in figures 26 and 27

Sand drift in the hinterland

Fig. 26
Bjerregårdsvej before the project began

Fig. 27
Bjerregårdsvej March 2007.

Several properties are buried in sand.

Fig. 28
Bjerregårdsvej 435

Fig. 29
Bjerregårdsvej 437

Solution

The solution to the wind erosion problem is to plant helm grass from the base of the dune and 10-15 metres out in the foreshore so that the sand is retained in the foreshore and especially at the dune foot so that the coast is better secured against high water situations in the event of a storm or hurricane.

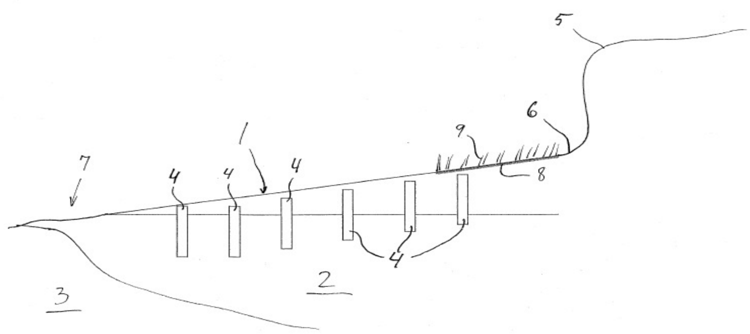
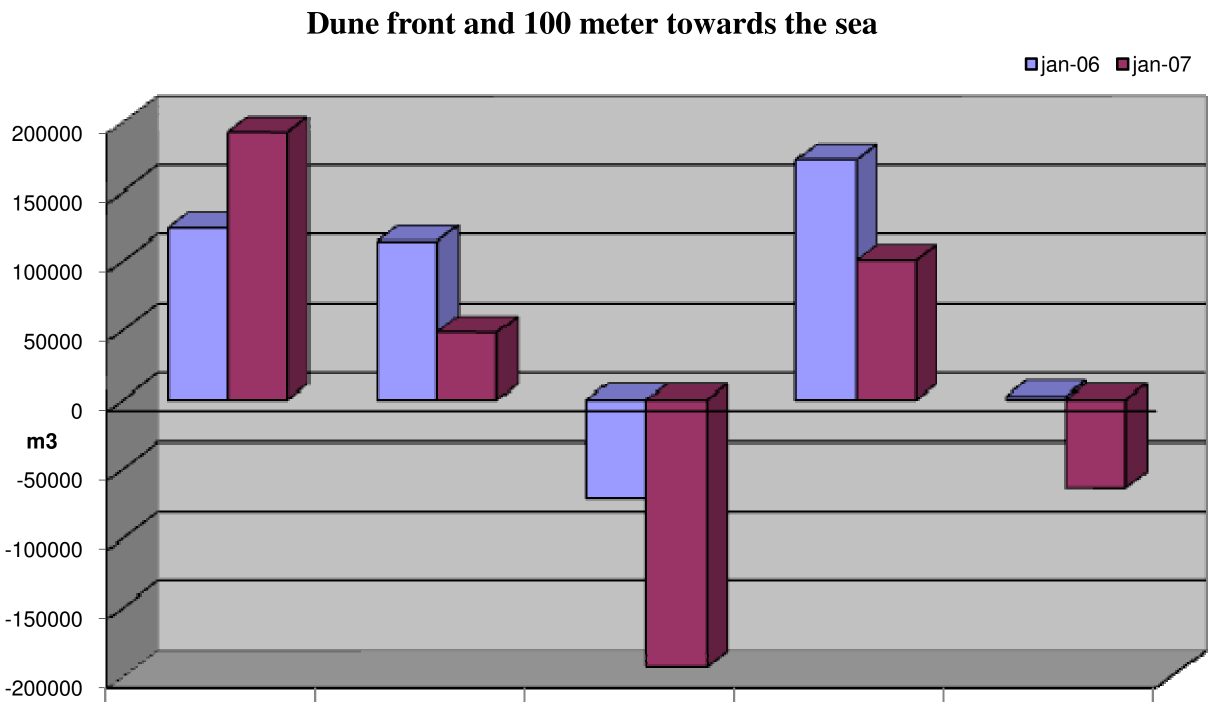


Fig. 30.

1 is the foreshore, 2 is freshwater, 3 is the salt water tongue in under the beach, 4 is the pressure equalising modules, 5 is the top of the dune, 6 is the dune base, 7 is the coastline, 8 is the planted area and 9 is the vegetation, which can be helm grass.

The foreshore

Jan 2005 – Jan 2007



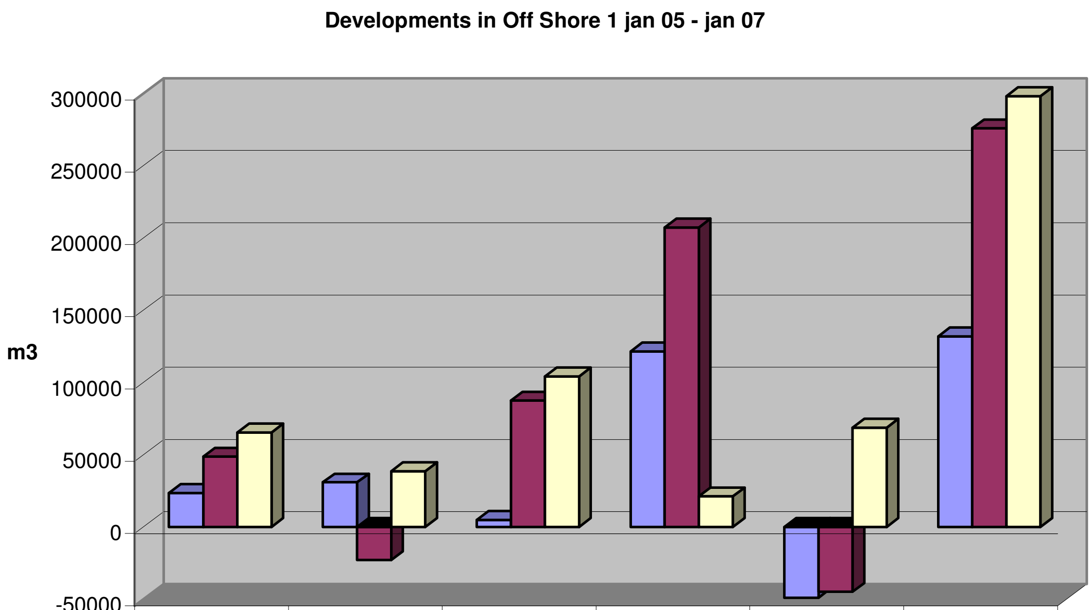
	Ref 3	Rør 2	Ref 2	Rør 1	Ref 1
jan-06	123725	114000	-70380	173280	2450
jan-07	192325	48400	-192440	100800	-64225

Fig. 31

The erosion has only been approx. 69,000 cubic metres in the drained area 1 and 2 plus ref. 3, where there is a lee side addition of washed sand.

Analyses show that erosion in the drained area1 and 2 is primarily wind erosion, so the sand has moved into the rear area and has not been lost at sea in the drained areas, in contrast to the sand that have been taken by the sea in ref. 1 and ref. 2.

Off shore 1



	Ref 3	Rør 2	Ref 2	Rør 1	Ref 1	Total
jan-06	23450	30900	4930	121440	-48825	131895
jul-06	48825	-22900	87550	207360	-44800	276035
jan-07	65450	38700	104210	21120	68775	298255

jan-06 jul-06 jan-07

Fig. 32

Fig. 32 shows that the coast profile is not steepened during the project period. At the same time, one can see that the large amounts of erosion in ref. 1 and ref. 2 are not repeated offshore following violent winter storms. When we look at the period between July 06 to 22 January 07, we see that storms do not create a reservoir of sand out at sea. Thus, sand that has eroded away disappears out of the project area during severe storms.

However, it is interesting to analyse the offshore data a little more closely for a specific area. Fig. 33 shows measurement data in ref. 3 of offshore 1.

As one can see, there is no system at all in the data measured out at sea and there are variations between +150 m^3 to minus 200 m^3 . We have therefore informed the experts that in the analyses one cannot simply put data from the beach together with offshore 1 and. 2

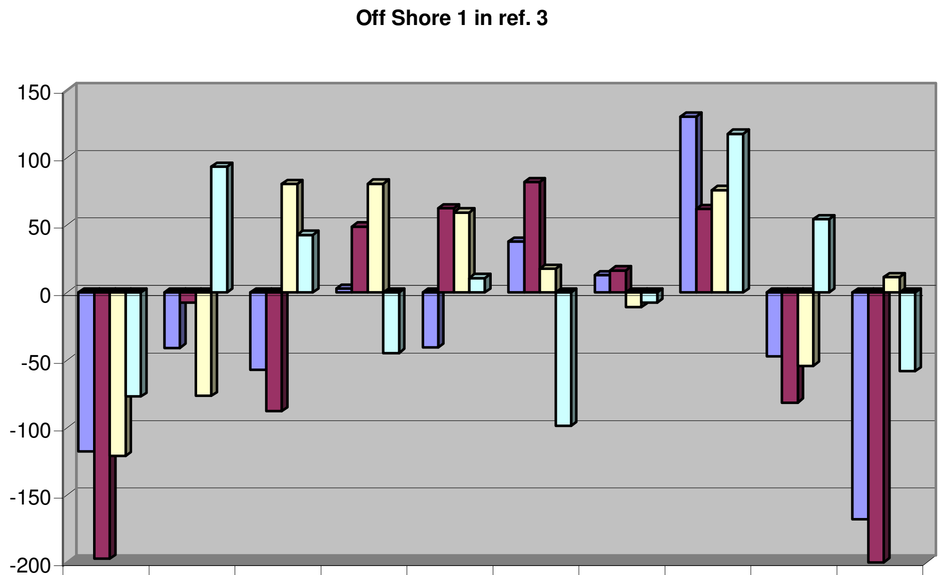
The longitudinal sediment transport is approx. 2.1 million cubic metres net annually in a southerly direction.

The seabed shall be viewed in a much greater perspective and we have shown average values for the entire 11.0 km stretch in table 2.

The analyses in table 2 show that the profile in off shore 1 has a rising tendency and is elevated by 9 cm over the course of 2 years, which is not related to the severe storms in the winter of 2006/07.

However, off shore 2 is unchanged, as 1-2 cm is less than the average tolerance on the equipment used for measurement.

Off shore 1 Ref 3



	0	200	400	600	800	1000	1200	1400	1600	1800
apr-05	-117,45	-40,89	-57,15	2,75	-40,58	38,04	12,87	130,36	-47,22	-167,74
jul-05	-197,08	-7,64	-87,94	49,01	62,36	81,89	16,37	61,97	-81,52	-199,74
okt-05	-120,96	-76,58	80,4	80,66	59,44	17,67	-10,9	75,97	-54,12	11,41
jan-06	-76,99	93,33	42,84	-44,58	10,73	-98,82	-7,55	117,55	54,31	-58,13

apr-05 jul-05 okt-05 jan-06

Fig. 33

Development of the offshore seabed

	Apr-05	July-05	Oct-05	Jan-06	July-06	Jan-07	
Offshore 1	1.44	9.57	24.84	11.80	24.91	27.21	m^3/m
Offshore 2	3,.4	5.01	8.23	-4,.9	-5.84	1.47	m^3/m

	Apr-05	July-05	Oct-05	Jan-06	July-06	Jan-07	
Offshore 1	0.48	3.19	8.28	3.93	8.30	9.07	cm
Offshore 2	1.8	1.7	2.74	-1.53	-1,.5	0.49	cm

Table 2

Table 2 shows erosion/additions in off shore 1 and 2 for the full stretch of 11 kilometres at a width of 2 x 300 metres out to sea

The top shows the development in m^3 pr. metres and below, the average raising or lowering of the seabed in cm.

Conclusion

The SIC system has now been tested in a scenario corresponding to the global sea level rise in 100 years as mean sea level was over 50 cm from the 20th of October and 2006 to the 20th of January 2007.

During the same period, the west coast was hit by 5 very powerful storms with average wind speeds of up to 27ms/sek. Four of these storms hit the west coast of Jutland between the 1st and 20th of January 2007.

The analysis shows sea erosion in the dunes has stopped in drained areas 1 and 2, as well as in the north coast of part 3, where there are leeside additions of washed sand.

This is because the average beach level in the drained areas has been increased significantly.

The buffer from the dunes, measured 100 metres wide at 411,000 m^3 , has been large enough to withstand 5 hard storms from the end of October 26 to January 20, 2007, when storm number 4 in January 2007 hit the western coast of Jutland.

The collective erosion in the drained area1 and 2 was only 69,000 m^3 in autumn 2006/07. There is primarily talk of wind erosion in the drained areas, with the sand moving into the dune system.

In contrast, there has been major wave erosion in ref. 1 and ref. 2, where the sea has taken more than 250,000 m^3 in a 3.5 km long stretch, which corresponds to 70 m^3 per m., even though the beach has been fed with approx. 2.0 million m^3sand over 10 years immediately north of ref. 1. and the bar nourishment 700 metres down in ref. 1 in the project period.

Sand waves have not been found in the project area and measurements off shore show that the coastal profile has not been steepened, but continues to rise.

Photo monitoring at Søndervig shows that beach nourishment no. 2 in 2005 of 960.000 m^3 was washed into the sea shortly after and it is estimated that dune erosion north and south of Søndervig has been approx. 400,000 m^3 during the same period.

Thus, the total erosion in the Søndervig project has been approx. 1,360,000 m^3 throughout the project duration. Sand loss in the drained areas and ref. 3 with washed sand was only 69,000 m^3.

A similar attempt of beach nourishment of 100,000 m^3 at Søndervig in 2004 also failed as the sand was washed into the sea after 1 month and the sea took an additional 400.000 m^3 of the dunes in the storm of January 2005.

Recommendations

SIC recommends that helm grass is planted from the dune foot and 10 metres towards the sea in the drained areas, in order to avoid sand loss to the hinterland with resulting damage.

SIC recommends that a 20 km area is set-aside at Søndervig, so that the SIC system can be directly compared with bar and beach nourishment on a large scale. Measurement in the dune areas at Søndervig will bee based upon aerial measurements, in order to provide better monitoring and a tool to avoid sand drift damage in the hinterland.

Skagen, the 24th of July 2007

Poul Jakobsen/Claus Brøgger.