Cost Efficient & Environmentally Friendly Coastal Protection

With

Pressure Equalisation Modules

An old groyne has become part of a broad sandy beach since 1997 – when the Pressure Equalisation Modules were established by SIC.
This is one of many locations where the superiority of the SIC system over traditional coastal protection is clearly demonstrated.

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Abstract

In many locations, coastal erosion is a significant problem with dramatic effects on the coastline. The impact on coast-near infrastructures and property can be massive. Until now the urgent need for coastal erosion protection, has forced society to use costly solutions with bulky constructions and beach nourishment, where the dredging part of the process is very hostile to the marine environment.

Skagen Innovation Center (SIC) has invented an environmental-friendly, cost-efficient solution to this problem with a technology called Pressure Equalisation Modules (PEM).

The PEM system is based on vertical drain tubes, draining the beach, so the saline water circulation in the wash-zone increases and deposits the sediment from the sea in form of an equilibrium profile.

This paper describes the results obtained in Gl. Skagen after an official three-year field test in relation to traditional coastal protection based on groynes and breakwaters combined with beach nourishment.

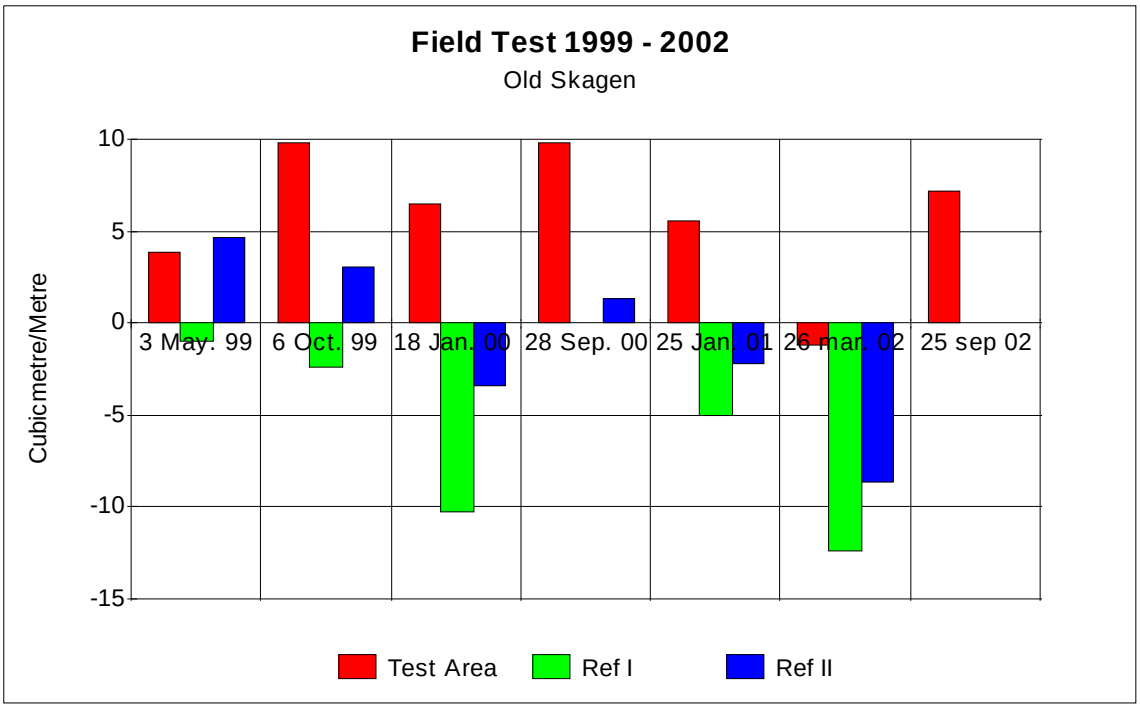


Fig. 1

The official three-year field test has proved that the PEM system is a very efficient way to establish coastal protection. The average increase/erosion in the test area with PEM's - and reference areas 1 and 2 without PEM - are shown in the fig. 1.

As shown the average accumulation of sediment inside the test area is 5,5 – 9,5 cubic metre per metre in the period 1999 – 2002 and we can conclude the profile is stable.

On other locations (e.g. coastlines in Ghana) with bigger tides (up to 2,0 metre) we have registered an increase of 17,0 cubic metre on average along the coastline.

The survey in January 2002 was delayed to the end of March against a background of high water level and gale in the area.

During the period from 1999 - 2002 the nearest reference area 1 has lost 12,4 cubic metres per metre. The difference is so significant that it is beyond any doubt, that the new PEM method is producing extraordinary results.

Introduction

With a five-year test period (including an official three-year field test), SIC has demonstrated that the technology and methodology, developed by the company, can create outstanding results.
The pressure equaliser technique has been proven to be an efficient method for coastal protection. From an economical as well as an environmental point of view, it is the preferred solution against coastal erosion.

The result from the first test with the Pressure Equaliser Modules (PEM) is clearly seen on the photo in Fig. 2 below. This picture from Gl. Skagen beach shows old sand covered groyne, which has been placed – inshore and passive on a new broad sandy Beach, in the five years the PEM system has been installed.

Fig.2 SIC test area Gl. Skagen North

The PEM protection was established on this site in November 1997. Shortly hereafter, it was possible to walk outside the groynes in periods with normal tides.

At low tides it was observed, that a sand groyne was building up outside the PEM. With this observation, it was realised that the PEM technology could be developed into a new method of protecting the coastline from erosion. Further information about this test installation is found in Appendix 2. "Gl. Skagen North Test Installation".

The PEM system has now been tested on several locations in Denmark and abroad. The development work and test locations have consistently shown very positive results.

During the test period it has been possible to compare SIC's PEM method with the traditional protection methods like groynes, breakwaters, sand dredging / beach nourishment. From an environmental and economical point of view, the PEM method is far superior to the traditional methods.

The Official Field Test

Based on the promising results observed in the first test installation, it was decided to establish an official field test in order to verify and document the results obtained with the PEM modules.
The official test site was established in January 28th. 1999, at Gl. Skagen beach, where a 1050-metre long well defined part of the beach was selected as the PEM test area.
A project group was appointed, to supervise and monitor the work, and a independent consultant was chosen to perform the measurement and survey work at the site.

The Project Group

The following people are participating in the project group:

Mr. Hans Falk Burcharth	Professor Dr. Tech., Aalborg University
Mr. Frede Jensen	State Forester, State Forestry North Jutland
Mr. Bjarke Jensen	Surveyor, North Jutland County
Mr. John Jensen	Engineer, M.Sc. The Danish Coastal Authorities
Mr. Poul O. Jørgensen	Engineer, M.Sc. Carl Bro Consulting Engineers A/S
Mr. Stig Trollebø	Danish Technological Institute, Innovation A/S
Mr. Poul Jakobsen	Managing Director, SIC

Controlled Test

The field test was executed under controlled conditions. Professor dr. tech. Hans Falk Burcharth has served as supervisor for SIC and the project group. He and the other team members have participated in the project throughout the entire field test period. The team members have participated in the conferences concerning the test project and have agreed that professor dr. tech. Hans Falk Burcharth, as an independent scientific expert, should evaluate the procedures and the obtained data from the field test program, on behalf of the team. During the field test program, all measurements were recorded and controlled by a reputable independent consulting company; Carl Bro Consulting Engineers, Denmark.

Field Test Area

The field test was performed along an 8 km long coastline S.W of Gl. Skagen (please see Fig.3)
Before the Pressure Equalising Modules was implemented, a baseline survey of the selected coastline was performed. Modern laser equipment was used for the measurements.

PEM Test Area

The distance between each line of PEMs is 100 metres, within the line a PEM is installed for each 10-metre. Initially the width of the beach made room for two PEMs only in each line, as the beach over time got wider, additional PEM were installed. The total distance from station 113200 to 114250 is 1050 metre.

Flank Areas

Adjacent flank areas, without PEM, on either side of the test area, were monitored with the same procedures as the test area.

Reference Area I.

Reference area I was located 3,0 km SW of the test area, ranging from station 117000 to station 118000. The objective of this reference area was to compare the development during the field test period of the coastal profile in a nearby site without PEM.

Reference Area II.

Reference area II was located 7,0 km SW of the test area, ranging from station 120131 to station 121134. The objective of this reference area was to compare development of the coastal profile in a nearby site without PEM during the research period

Test area, Flank areas and Reference areas

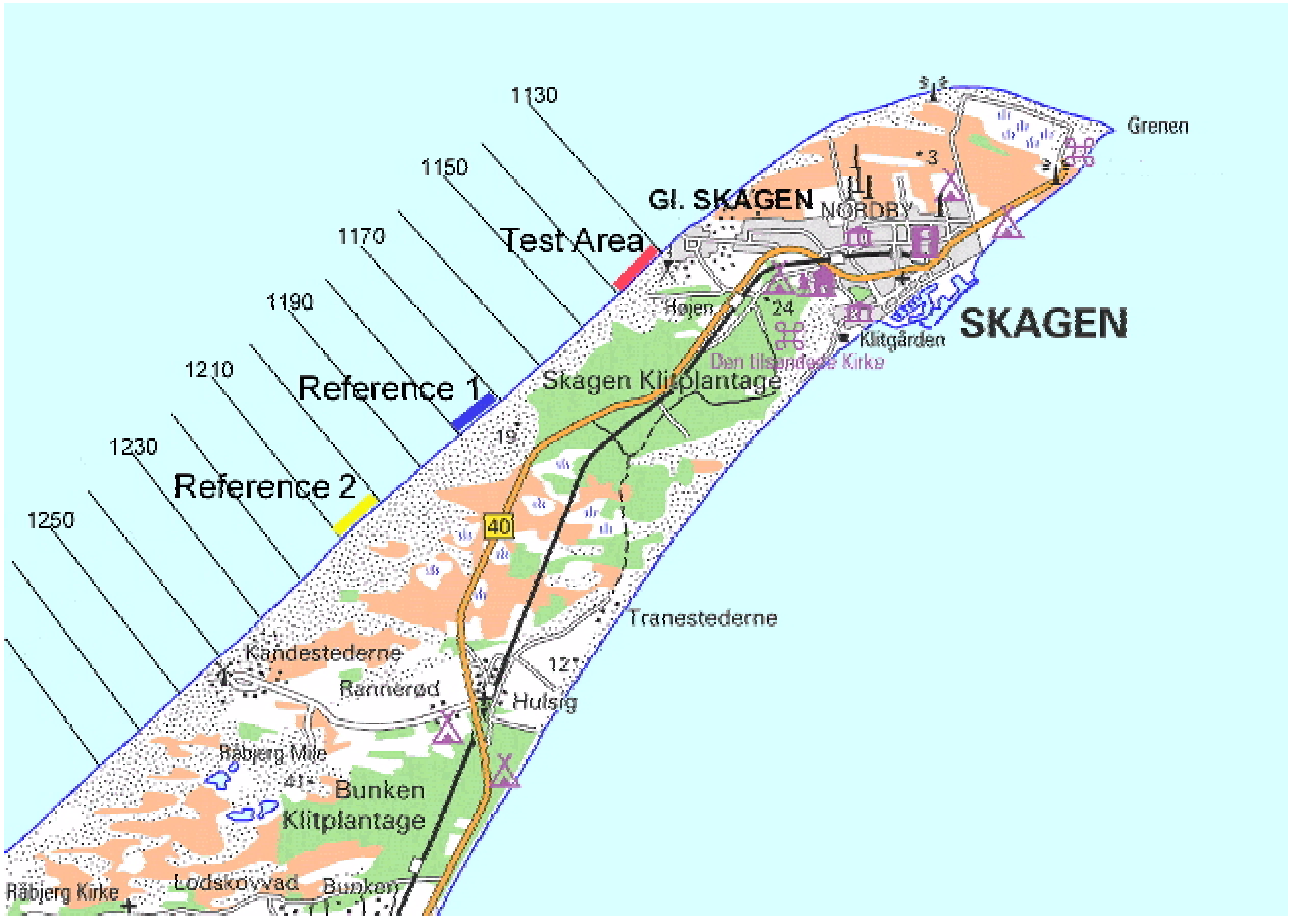


Fig. 3 Test and reference area

The Survey Schedule
The project group established the survey schedule during the first year of operation. The coast profile in the test area has a cyclic nature, with accumulation in the summer time and erosion during the winter. With this in mind, the measurements are scheduled to be performed late September and late January each year.

The actual dates were:
28. January 1999 reference level survey and start of field test
3. May 1999 initial survey to verify that the installation is working
6. October 1999
18. January 2000
28. September 2000
25. January 2001
xx. January 2002 (impossible because of storm in the area)
26. Marts 2002 (substitute for planed survey)
25. September 2002 (extra survey in the test area.)

Field Test Results
Test Area

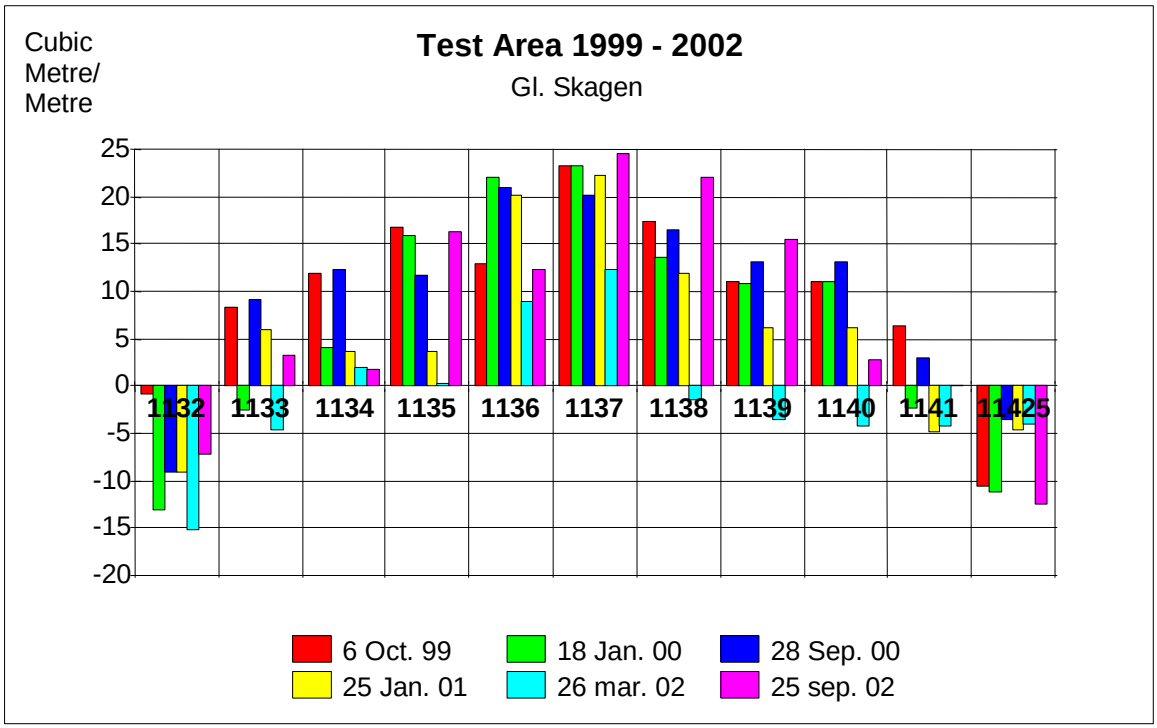


Fig. 4
Test Area Sediment Accumulation

In Fig. 4 the results from the test area are shown for each survey. The result is significant, the beach profile is in equilibrium and it recovers fast after storm and flood periods. The average sand accumulation in the area is app. 5,5 – 9,8 cubic metre per metre.

Reference Area 1

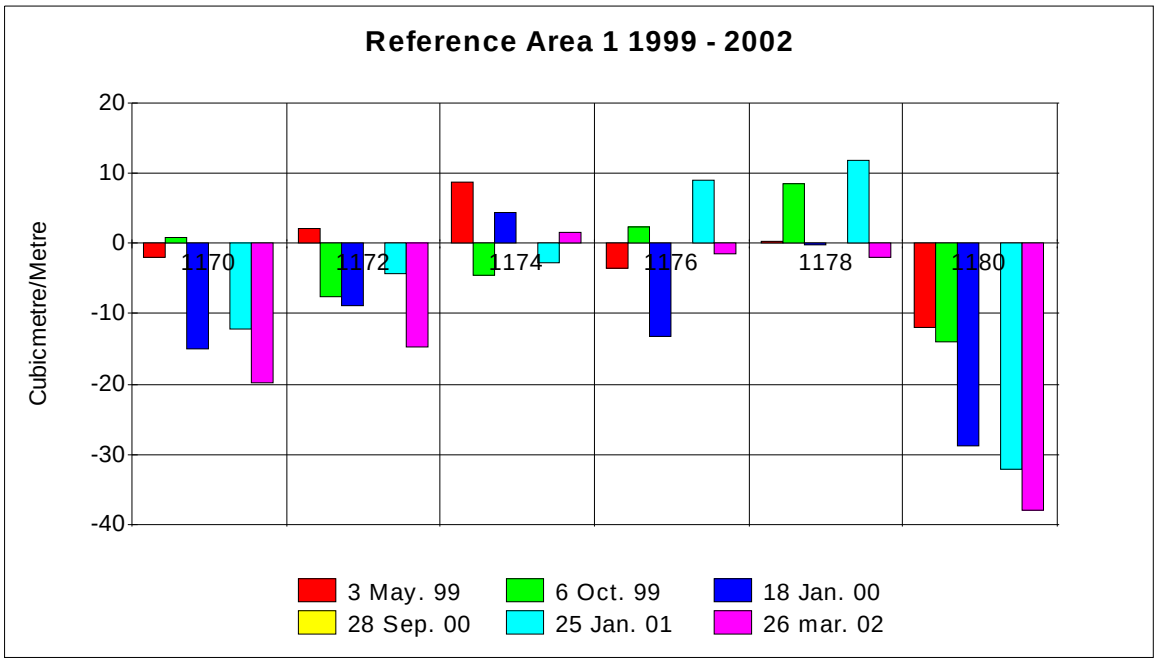


Fig. 5 Reference Area 1

In the test period, Reference area 1 had erosion of 12 cubic metre per metre and a shoreline decline of 9,2 metres.

Reference Area 2

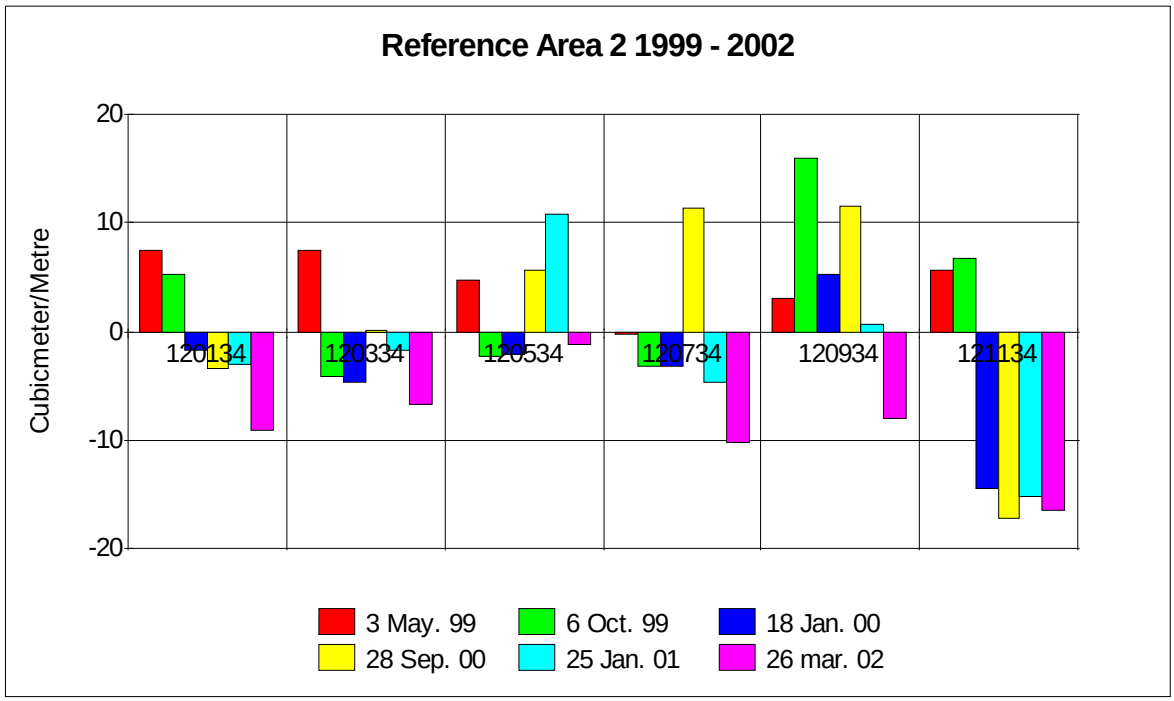


Fig. 6 Reference Area 2

During the test period Reference area 2 result was erosion of 8,6 cubic metre per metre and a decline of the coastline of 14 metres.

Comments on the Results

The accumulation of sediment in the test area is observed to be consistent. The accumulation is not found in the reference areas or flank areas. The most extreme values found were erosion of 40 cubic metre per metre in Reference area 1 and accumulation of 24 cubic metre per metre in the test area.

With three years of uninterrupted service of the PEM installation, the beach profile has developed significant in the test area. The Reference areas have in the same period followed the average erosion seen over the last 150 years, with a decline of the coastline of 1,5 metre per year.

The beach profile stabilised itself and was in equilibrium after the first 7 month of the field test. The resulting accumulation of sediment was 5,5 - 9,8 cubic metre per metre.

The beach profile has been stable in the field test period of three years. The coastline has gained 2,1 metre in the test area.

The reference area coastlines has lost 3,9 metres per year average during the period. This is more that the general average and is caused by unusually rough weather in the test period.

A 100 year storm hit the west coast of Denmark in December 1999.

Conclusion

The conclusion from this three-year of field test and the previous years of tests is unambiguous. The PEM system from SIC is an environmental-friendly and very efficient solution to protect against coastal erosion.

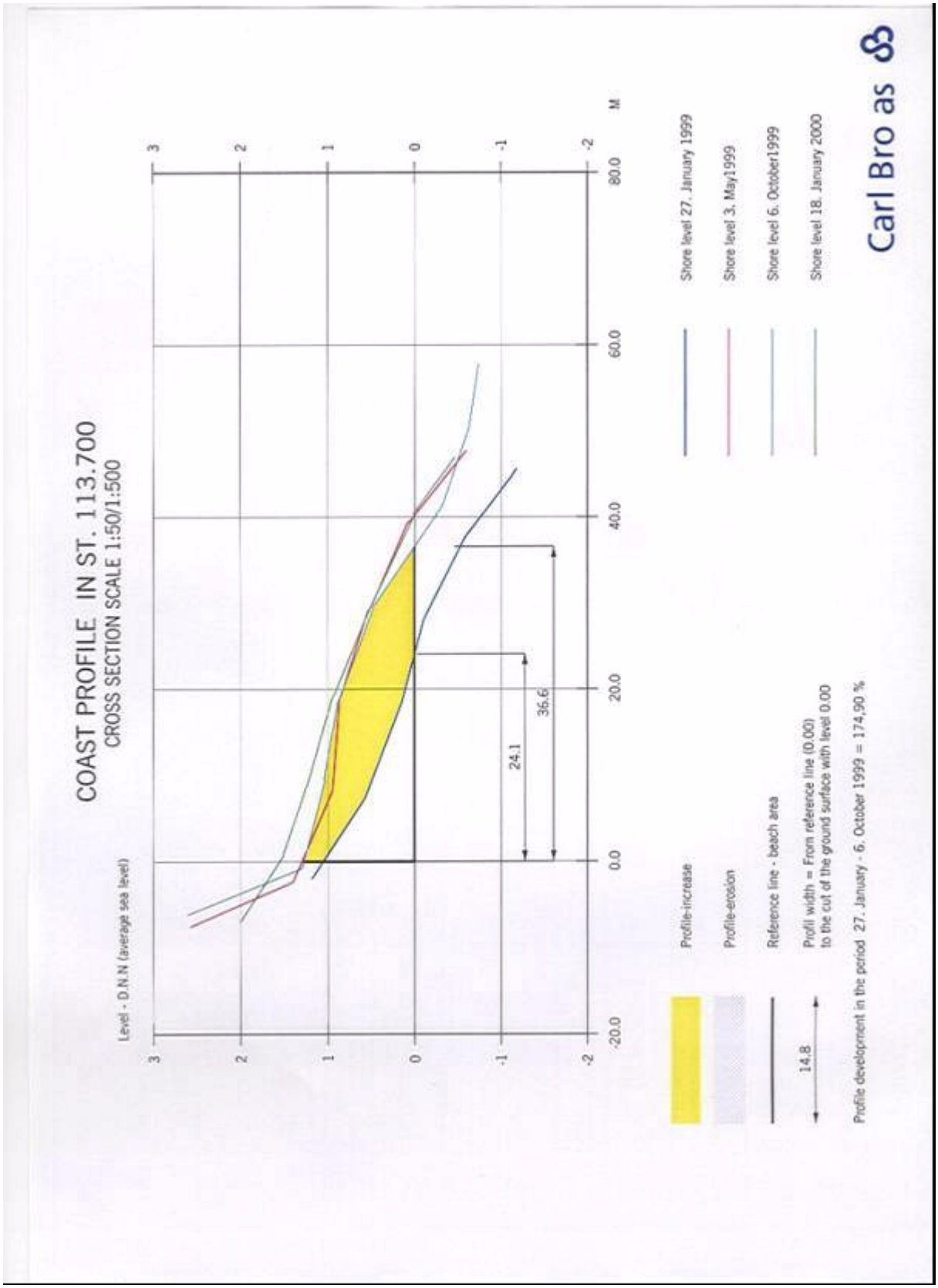
2th April 2003.

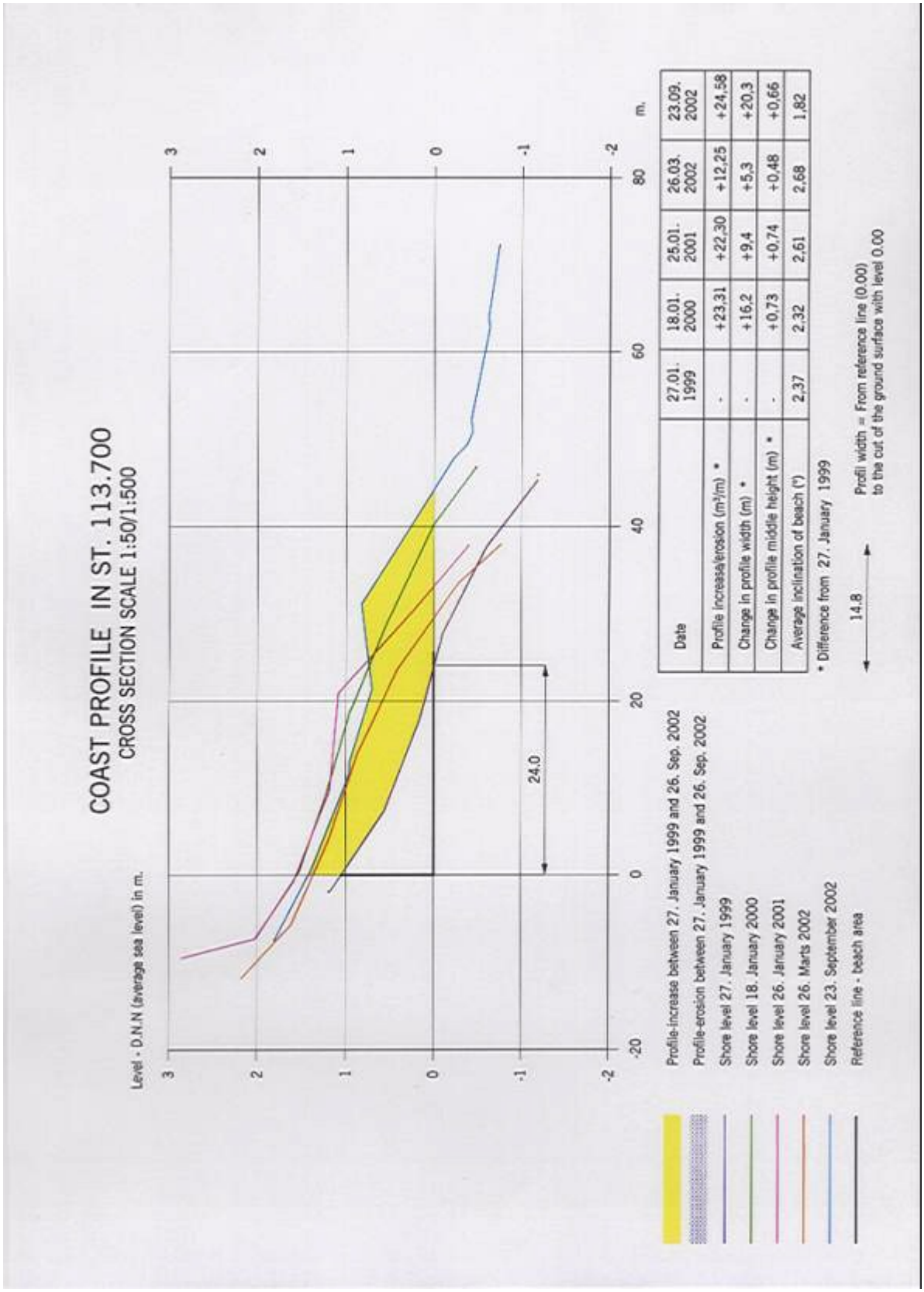
Poul Jakobsen
Managing Director, SIC

Appendix 1. Field Test Data

Strandvolumenændringer i kubikmeter i perioden jan 1999 - sep 2002							
Flank 1	3 May. 99	6 Oct. 99	18 Jan. 00	28 Sep. 00	25 Jan. 01	26 mar. 02	25 sep. 02
1128	0,29	-4,19	-12,38	-16,4	-22,67	-25,85	-22,89
1129	-3,67	-3,99	-17,24	-11,95	-16,15	-25,73	-19,9
1130	-4,17	-7,8	-18,05	-12,14	-19,02	-21,02	-19,97
1131	-9,92	-10,88	-20,12	-17,77	-20,31	-22,69	-22,98
Average	-4,3675	-6,715	-16,9475	-14,565	-19,5375	-23,8225	-21,435
Test Area	3 May. 99	6 Oct. 99	18 Jan. 00	28 Sep. 00	25 Jan. 01	26 mar. 02	25 sep. 02
1132	-1,72	-0,88	-13,02	-8,95	-9	-15,19	-7,13
1133	2,73	8,35	-2,51	9,15	5,99	-4,6	3,26
1134	4,99	11,96	4,07	12,34	3,64	2,03	1,82
1135	5,09	16,77	15,89	11,77	3,76	0,26	16,28
1136	6,75	12,99	21,99	20,95	20,13	8,9	12,4
1137	18,63	23,31	23,31	20,24	22,3	12,25	24,58
1138	13,15	17,31	13,68	16,62	11,82	-1,46	21,99
1139	1,34	11,07	10,79	13,1	6,14	-3,51	15,57
1140	1,45	11,06	11,03	13,14	6,16	-4,23	2,86
1141	-2,57	6,44	-2,21	3	-4,7	-4,14	0,14
114250	-6,62	-10,48	-11,05	-3,48	-4,58	-3,94	-12,46
Average	3,9290909	9,8090909	6,5427273	9,8072727	5,6054545	-1,2390909	7,21
Flank 2	3 May. 99	6 Oct. 99	18 Jan. 00	28 Sep. 00	25 Jan. 01	26 mar. 02	25 sep. 02
114350	-6,41	-9,85	-0,6	5,82	-2,16	-4,08	-5,96
114450	1,62	8,87	10,63	1,4	1,17	-0,38	-1,81
114550	-1	11,56	-1,42	-12,03	-4,55	-1,05	6,26
114650	-9,49	1,56	-11,61	-16,09	-10,19	-1,19	-3,18
Average	-3,82	3,035	-0,75	-5,225	-3,9325	-1,675	-1,1725
Ref. 1	3 May. 99	6 Oct. 99	18 Jan. 00	28 Sep. 00	25 Jan. 01	26 mar. 02	
1170	-1,89	0,9	-14,97		-12,2	-19,8	
1172	2,04	-7,54	-8,96		-4,3	-14,62	
1174	8,88	-4,48	4,31		-2,6	1,53	
1176	-3,44	2,29	-13,24		8,98	-1,57	
1178	0,26	8,61	-0,27		11,94	-1,91	
1180	-11,79	-13,96	-28,64		-31,97	-38	
Average	-0,99	-2,3633333	-10,295	0	-5,025	-12,395	
Ref. 2	3 May. 99	6 Oct. 99	18 Jan. 00	28 Sep. 00	25 Jan. 01	26 mar. 02	
120134	7,44	5,17	-1,7	-3,39	-3,04	-9,13	
120334	7,54	-4,18	-4,61	0,01	-1,78	-6,68	
120534	4,74	-2,23	-2,08	5,55	10,77	-1,13	
120734	-0,29	-3,22	-3,14	11,42	-4,75	-10,16	
120934	3,12	15,9	5,29	11,43	0,69	-8,01	
121134	5,68	6,77	-14,44	-17,27	-15,16	-16,5	
Average	4,705	3,035	-3,4466667	1,2916667	-2,2116667	-8,6016667	

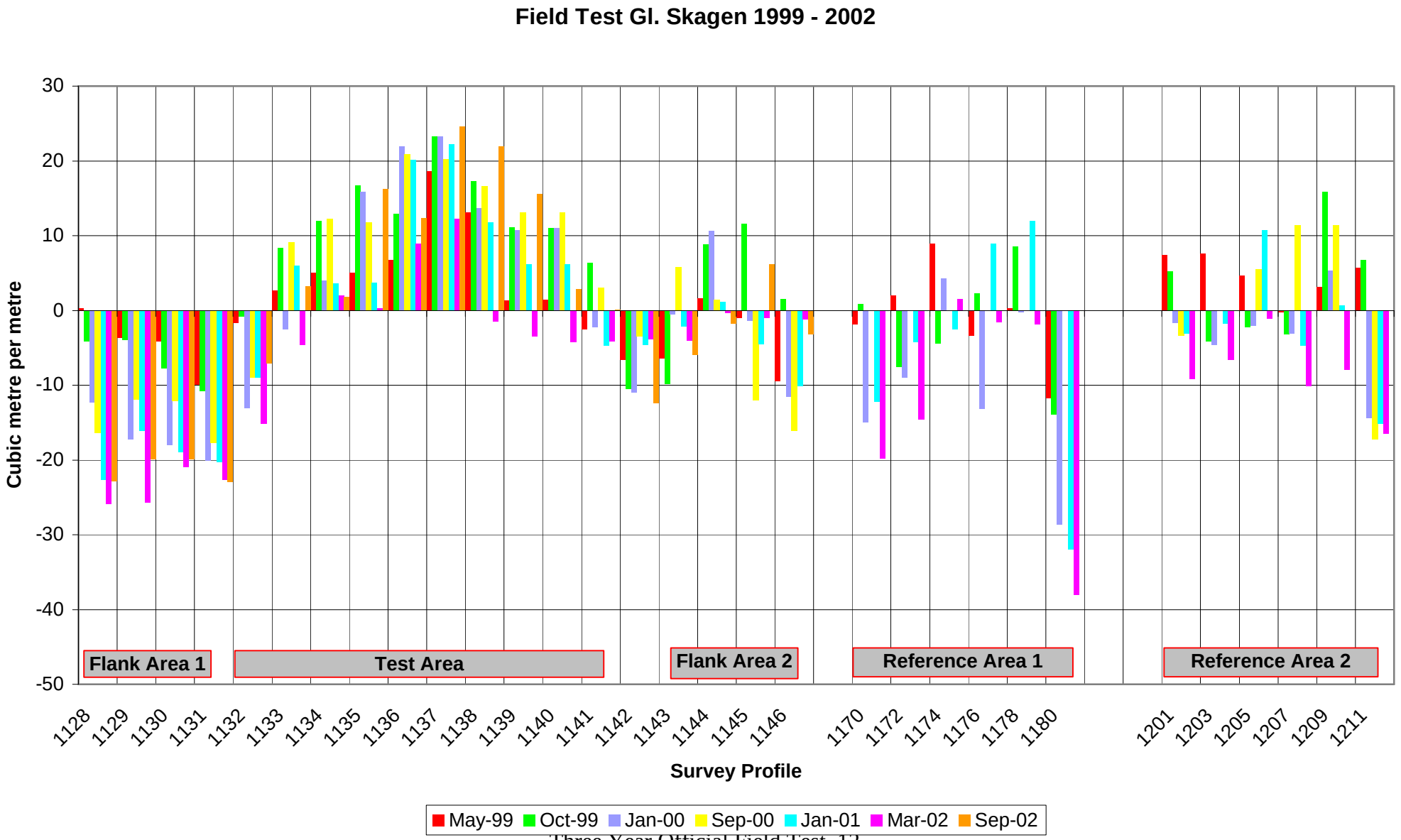
Survey Carl Bro A/S





Date	27.01. 1999	18.01. 2000	25.01. 2001	26.03. 2002	23.09. 2002
Profile increase/erosion (m³/m) *	-	+23,31	+22,30	+12,25	+24,58
Change in profile width (m) *	-	+16,2	+9,4	+5,3	+20,3
Change in profile middle height (m) *	-	+0,73	+0,74	+0,48	+0,66
Average inclination of beach (°)	2,37	2,32	2,61	2,68	1,82

* Difference from 27. January 1999


Field Test Gl. Skagen 1999 - 2002
Cubic metre per metre
30
20
10
0
-10
-20
-30
-40
-50
Flank Area 1
Test Area
Flank Area 2
Reference Area 1
Reference Area 2
1128
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1201
1203
1205
1207
1209
1211
Survey Profile
May-99
Oct-99
Jan-00
Sep-00
Jan-01
Mar-02
Sep-02

Appendix 2. Other Results with Pressure Equalisation Modules

Location Gl. Skagen North

Just North of the official Field Test Area in Gl. Skagen, SIC made one of the first PEM installation. The groynes reached 10 – 15 metres out from the shoreline before installation

Fig 9
The groynes at Gl. Skagen before installation of PEM system by SIC

Fig 10
The groynes at Gl. Skagen one year after the PEM installation.

As the aerial photo illustrates the groynes are completely covered in sand 5 to 10 metres inshore, one year after installation of the pressure equalisation modules.

Gl. Skagen North (cont.)

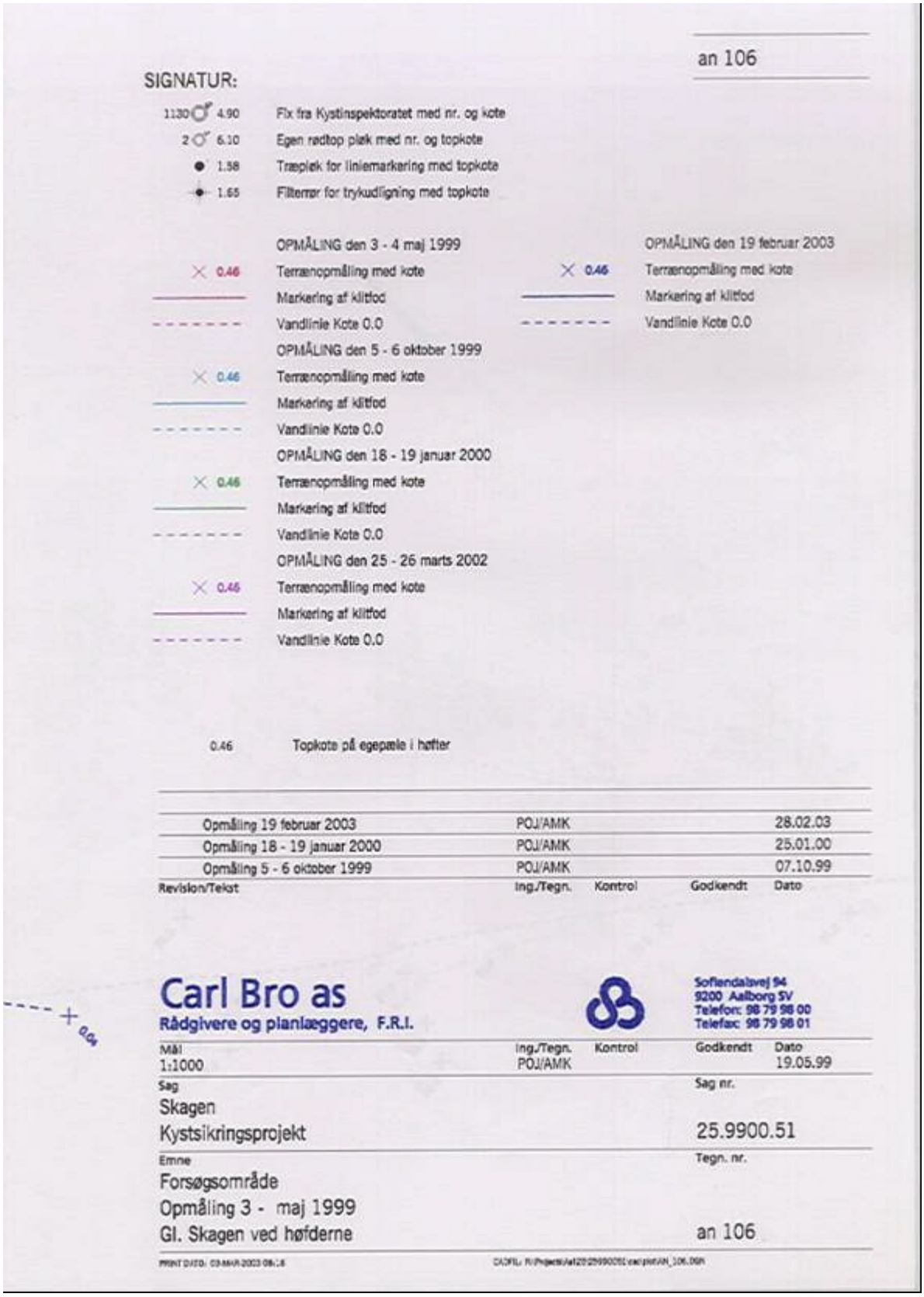
Fig. 11 Gl. Skagen PEM installation removed in 2001

After a dispute with the local authority SIC was ordered to remove the PEM installation in November 2001. The photo from July 2002 shows erosion has moved the coastline 15 to 25 metres back. The groynes are out in the sea and the sand has disappeared between the groynes.

Fig. 12
Gl. Skagen one PEM was accidentally left

SIC forgot to remove one set of PEM from the site in November 2001. On this photo from July 2002 the effect is seen there has been no erosion right on this spot. This is maybe the best proof of concept for SIC's unique coastal protection system

Survey Old Skagen 1999 – 2003.



an 106

SIGNATUR:

1130 4.90 Fix fra Kystinspektoratet med nr. og kote
2 6.10 Egen rødtop pløk med nr. og topkote
1.58 Træpløk for liniemarkering med topkote
1.65 Filterrør for trykudligning med topkote

OPMÅLING den 3 - 4 maj 1999
0.46 Terrænopmåling med kote
Markering af klitfod
Vandlinie Kote 0.0

OPMÅLING den 5 - 6 oktober 1999
0.46 Terrænopmåling med kote
Markering af klitfod
Vandlinie Kote 0.0

OPMÅLING den 18 - 19 januar 2000
0.46 Terrænopmåling med kote
Markering af klitfod
Vandlinie Kote 0.0

OPMÅLING den 25 - 26 marts 2002
0.46 Terrænopmåling med kote
Markering af klitfod
Vandlinie Kote 0.0

OPMÅLING den 19 februar 2003
0.46 Terrænopmåling med kote
Markering af klitfod
Vandlinie Kote 0.0

0.46 Topkote på egepæle i høfter

Revision/Tekst	Ing./Tegn.	Kontrol	Godkendt	Dato
Opmåling 19 februar 2003	POJ/AMK			28.02.03
Opmåling 18 - 19 januar 2000	POJ/AMK			25.01.00
Opmåling 5 - 6 oktober 1999	POJ/AMK			07.10.99

Carl Bro as
Rådgivere og planlæggere, F.R.I.

Sofiendalsvej 94
9200 Aalborg SV
Telefon: 98 79 98 00
Telefax: 98 79 98 01

Mål	Ing./Tegn.	Kontrol	Godkendt	Dato
1:1000	POJ/AMK			19.05.99

Sag
Skagen
Kystsikringsprojekt

Sag nr.
25.9900.51

Emne
Forsøgsområde
Opmåling 3 - maj 1999
Gl. Skagen ved høfderne

Tegn. nr.
an 106

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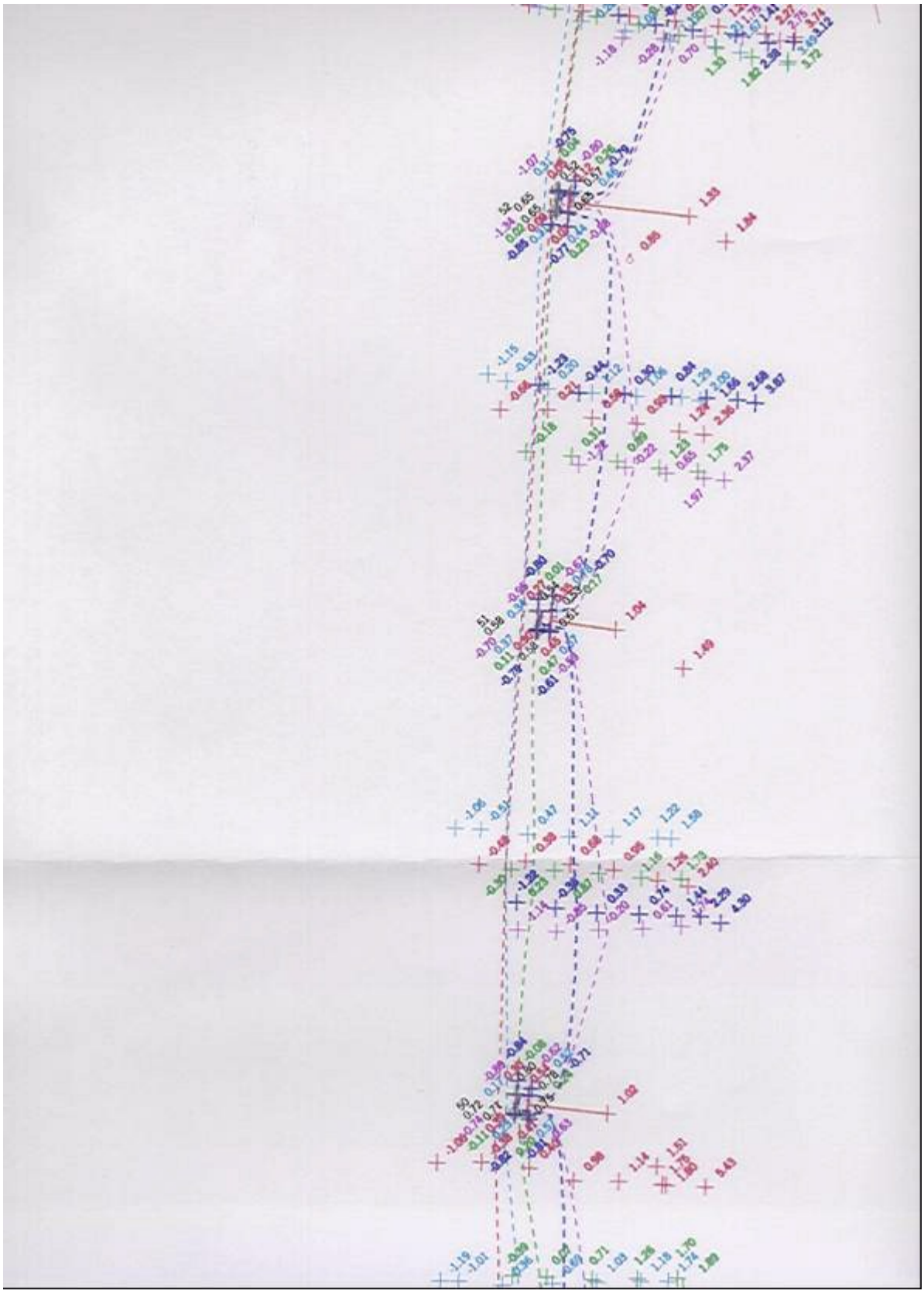
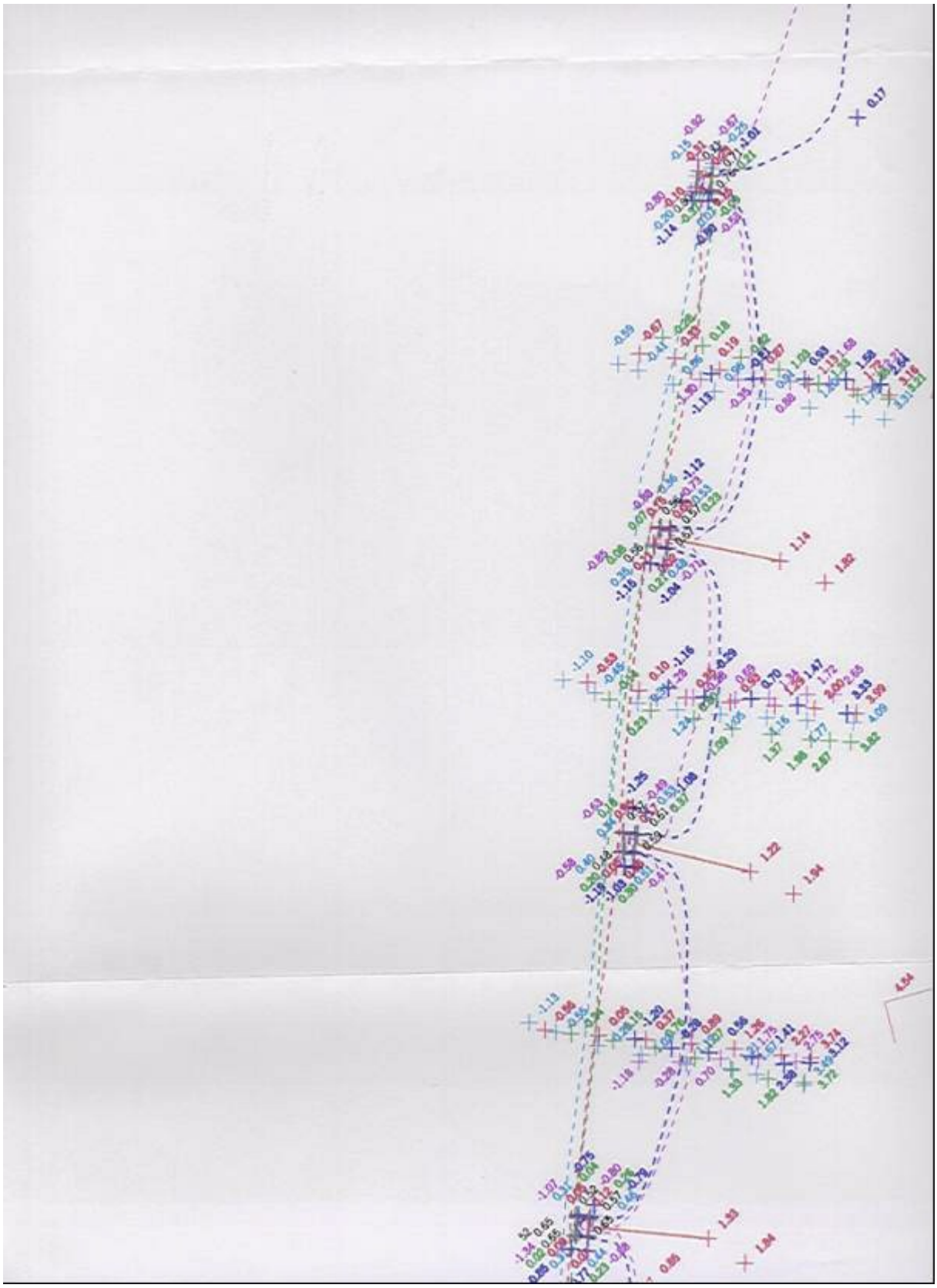


The PEM modules are taken away November 2001.



The PEM modules are taken away November 2001.

Location Lønstrup

Fig. 13
Lønstrup after PEM installation 1999

SIC installed a PEM system at Lønstrup beach in April 1999. Shortly after the breakwaters are completely covered in sand as seen on the photo from 1999 in Fig 13. The beach recovered with up to 90 cm over the area.

Fig. 14 Lønstrup 2002

The PEM installation was removed in August 1999, and the beach is back to the previous stage, with serious erosion.
The breakwaters are maintained with beach nourishment. Every year 25.000 cubic metre of sand is supplied at a cost of 160.000 € per year.

Lønstrup (cont.)

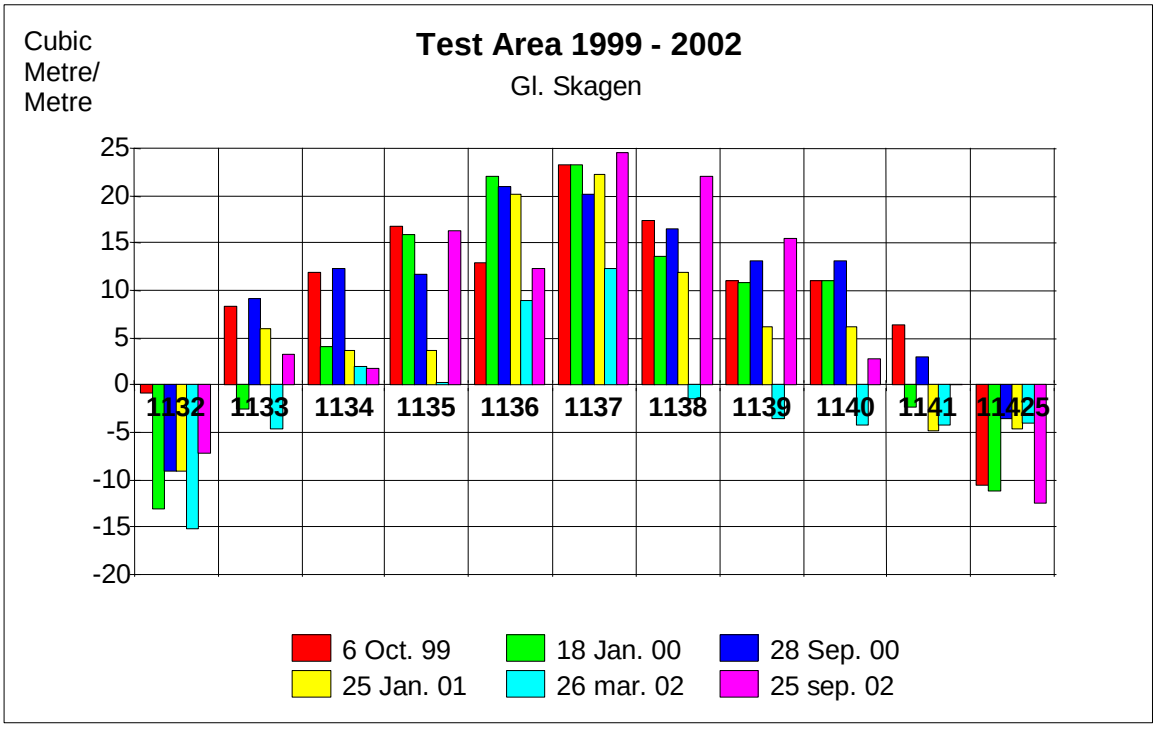
Fig.15 Lønstrup, July 1999
When the beach was protected by a SIC PEM installation, you could drive with cars on the beach.

Fig.16 Lønstrup, Marts 2002.

The same beaches after the PEM installation was removed. It is not longer possible to drive with cars on the beach. We just lost a company car trying to drive here.

Appendix 3

The SIC System compared with beach nourishment on the West Coast of Jutland.



Coastal development at Gl. Skagen - fig. 1

As illustrated in fig. 1, the SIC System has a systematic building effect on a beach profile.

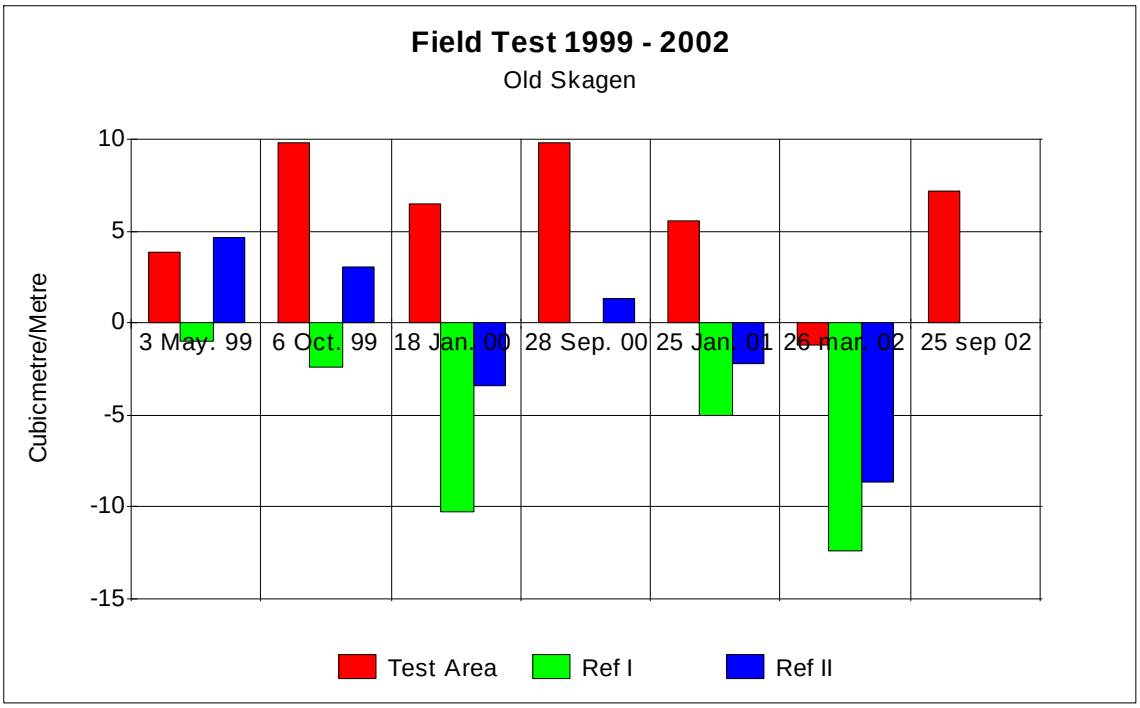


fig 2

The longtime effect is shown in fig. 2, where the Test Area fitted with pressequalization modules has a coastal increase of 5 – 10 m^3 per metre as opposed to the reference areas, which show an erosion of 3.5 – 10 m^3 per metre.

Erosion/Beach nourishment on the Danish West Coast.

Sediment Calculation West Coast of Jutland				
Distance Stenbjerg - Nymindegab			130000	Metre
Erosion				
Erosion direction north	Stenbjerg	-600000		Cubic metre
Erosion Agger Point		-330000		Cubic metre
Erosion Thyboroen Point		-900000		Cubic metre
Erosion south	Nymindegab	-2300000		Cubic metre
Erosion Total Per Year			-4130000	Cubic metre
Erosion per metre per year			**-31,7692308**	Cubic metre
Beach Nourishment				
Beach Nourishment north		775000		Cubic metre
Beach Nourishment south		1625000		Cubic metre
Beach Nourishment Total			2400000	Cubic metre
Beach Nourishment per metre per Year			18,4615385	Cubic metre
Netto Result			-1730000	Cubic metre
Erosion per metre per year			-13,3076923	Cubic metre

fig. 3

As it appears in Appendix 3.2, the West coast of Jutland is Beach Nourished every year with 2.4 mill. m^3 sand; however the yearly erosion is 4.13 mill. m^3 which is shown in Appendix 3.1 and fig. 3.

Thus, the result of the beach nourishment on the West coast of Jutland is overall negative with a yearly erosion rate of –13,3 m^3 per metre as opposed to the SIC System which is showing a positive profile of 5 – 10 m^3

The SIC system is creating a naturally balanced profile whereas beach nourishment is causing steep profiles prone to increased erosion. The erosion on the West coast of Jutland is now approximately 32 m^3 per metre per year – whilst beach nourishment is implemented.

In addition to the erosion comes a significant strain on the environment which is causing declining fish populations and a substantial CO^2 pollution.

Value for Money

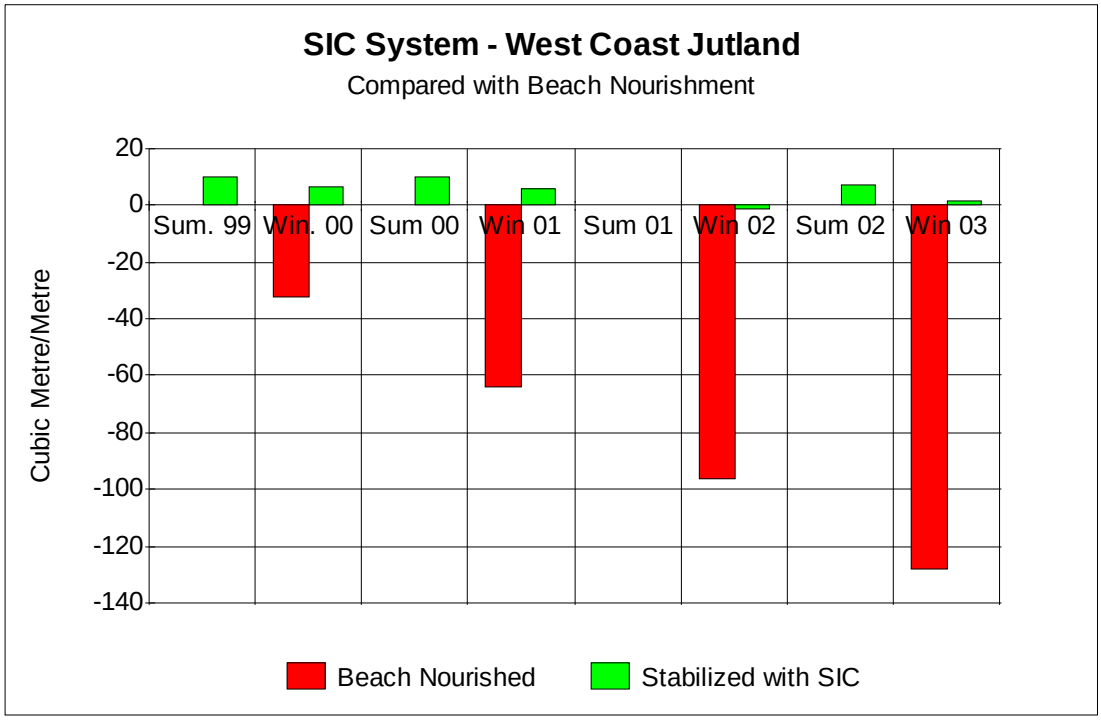


Fig 4

As illustrated in fig. 4 the SIC-treated beach is stabile due to the fact that during the summer season a “buffer” is built up which is sufficient to withstand the winter storms.

Contrary to the SIC-treated beaches, erosion is occurring at a rate of 32 m^3 per metre in the beach nourished areas according to the KDI record of sediment movement, Appendix 3.1.

Subsequently the erosion on the Jutland West Coast amounts to 4.130.000 cubic metres per year, which will cost 22.6 million USD to maintain through beach nourishment in order to keep the beach stabile.

The SIC system therefore has a real value of 22.6 million USD per year if implemented on the Jutland West Coast, because it is far more effective in stopping erosion than the present beach nourishment of 2.4 million cubic metres per year. As the SIC system only costs 3.8 million USD to operate and maintain, the savings would be 18.8 million USD and thus a far greater asset to society than previously estimated.

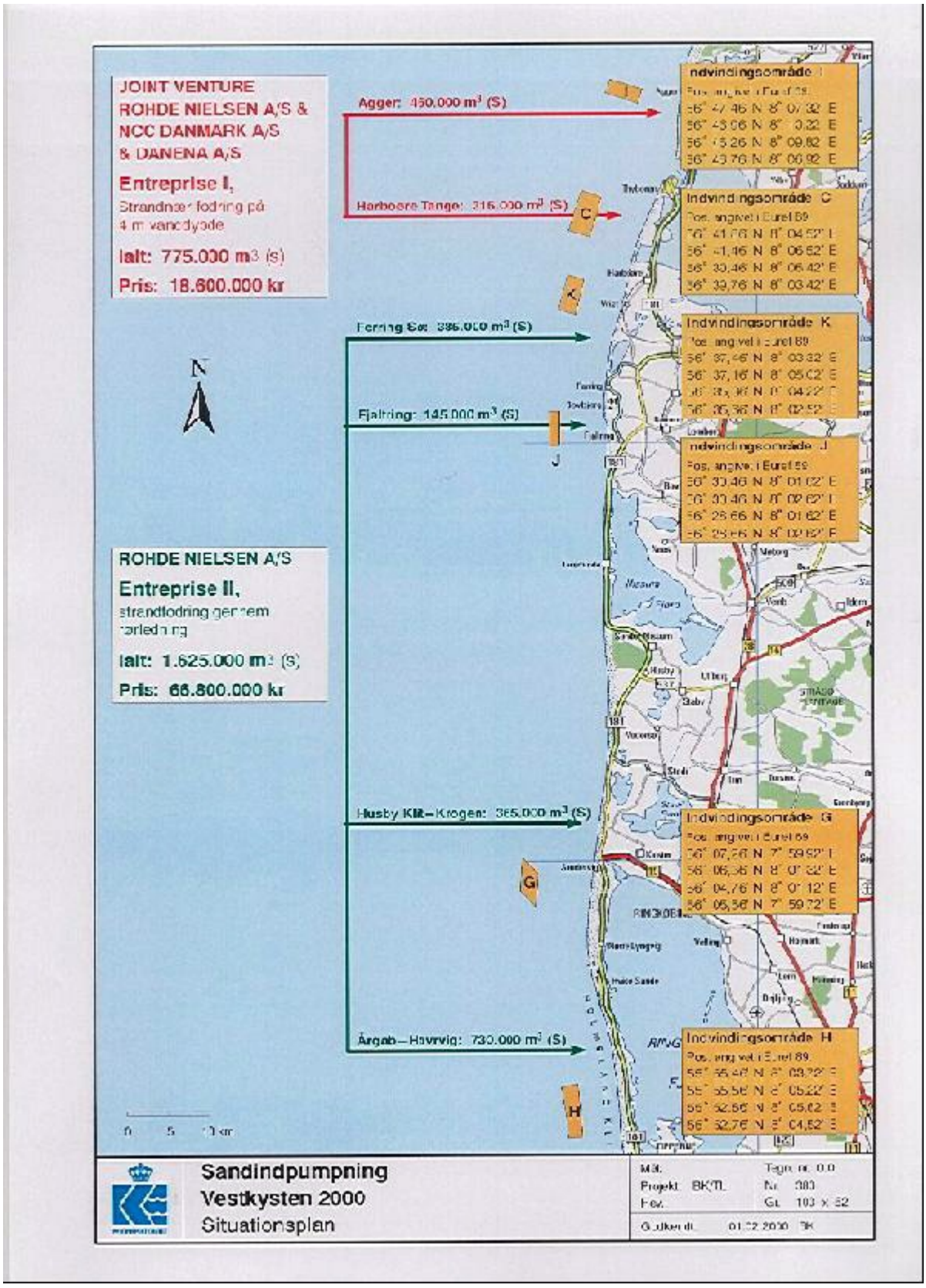
Skagen, 14. September 2003.

Poul Jakobsen

Appendix 3.1


1.550.000
900.000
Skagen
Kande-
stederne
Hirtshals
Lønstrup
Løkken
540.000
Blokhus
400.000
Lild Strand
Hanstholm
Klitmøller
Stenbjerg
0
Lodbjerg
330.000
Flade sø
900.000
Thyborøn
0
Ferring Sø
Fjaltring
1.400.000
Thorsminde
1.750.000
2.100.000
Hvide
Sande
Nymindegab
2.300.000
Blåvands Huk
Skallingen
N
250.000
300.000
1.000.000
Skagen
Rev
Skagen
500.000
Vejers Banke
600.000
Blåvands Huk
1.000.000
Skallingen
Horns Rev
200.000
570.000
340.000
0
10
20
30 km

Appendix 3.2.


JOINT VENTURE
ROHDE NIELSEN A/S &
NCC DANMARK A/S
& DANENA A/S
Entreprise I,
Strandfodring på
4 m vanddybde
Ialt: 775.000 m3 (S)
Pris: 18.600.000 kr
ROHDE NIELSEN A/S
Entreprise II,
strandfodring gennem
rørledning
Ialt: 1.625.000 m3 (S)
Pris: 66.800.000 kr
Agger: 450.000 m³ (S)
Harboøre Tange: 315.000 m³ (S)
Fjaltring: 145.000 m³ (S)
Husby Klit–Krogen: 365.000 m³ (S)
Årgab–Havvig: 730.000 m³ (S)
Indvindingsområde C
Indvindingsområde K
Indvindingsområde J
Indvindingsområde G
Indvindingsområde H
N
Sandindpumpning
Vestkysten 2000
Situationsplan

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