PRESSURE EQUALISATION MODULES FOR ENVIRONMENTALLY FRIENDLY COASTAL PROTECTION

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Abstract

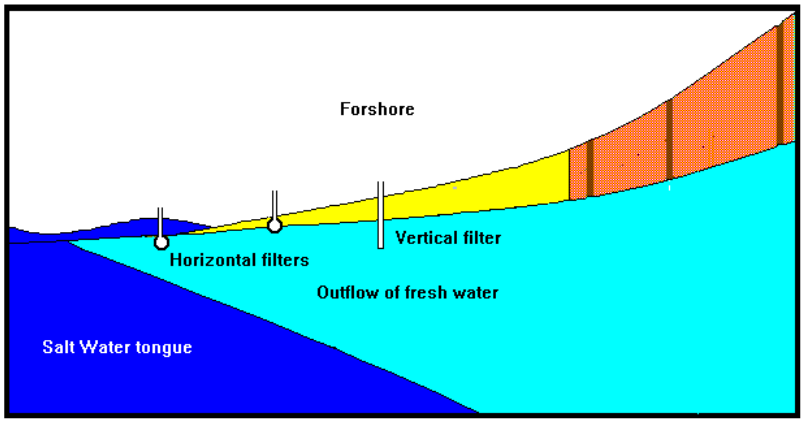
Land-based activities and natural physical processes have resulted in significant modifications of the shorelines in many countries, with drastic effects on the coastal geomorphology as well as on the coastal infrastructures. There is an urgent need to introduce new and cost-effective measures that can reduce and mitigate the impacts on the shorelines.
SIC Skagen Innovation Centre has invented an environmentally friendly coastal protection system. The SIC system is based on pressure equalisation modules and fascines. A long-term and comprehensive test of the efficiency has been carried out on the west coast of Denmark. Furthermore, a twelve-month scientific research programme was performed in 1999. The obtained results shows that the system is far more efficient than conventional methods such as groynes, breakwaters and sand nourishment. Due to the well-known lee side erosion effect, groynes and breakwaters create even greater erosion in adjacent coastal areas. Sand nourishment by dredging is in general terms a very expensive approach (about 130,000 USD / km / year in Denmark), but unfortunately it is an inefficient solution since usually the sand will disappear during the first spring tide.

INTRODUCTION

The SIC system is radically different to the dredging, sand nourishment and groynes building methods hitherto being employed. The SIC System makes the lowest impact on the aesthetic beauty of the beach area without disfiguring it with boulders etc. It also precludes sand nourishment activities since it basically traps the sediment transported by the sea on to the beach and thus starts the beach rehabilitation process by extending the beach further into the sea. The basic principle of the SIC system is pressure equalisation of the hydrodynamic forces along the coastal stretch it is being implemented on.

Pressure equalisation modules build up a wide balanced coastal profile. This has the significant advantage of causing the waves to loose their destructive energy while running uphill during high tide situations. Thus, the erosion of the coast profile is mitigated even in spring tide situations compounded by effects of hurricanes.

During the tests as carried out in Skagen it was recognised that the groundwater table was 2 metres above the sea level in a distance of only 70 metres from the coastline. Due to the gravity there is a considerable groundwater pressure from the land side. Thus, it can be illustrated that the sea water in the swash zone percolates through the sand and runs back into the sea "on top" of the groundwater discharge area. This promote the erosion process compounded with the back run of the sea water in the swash zone.



Equilibrium Profile.
As a result of SIC's research and experiments over the last 6 years, we now experience wide equilibrium coastal profiles at locations where SIC has installed pressure equalisation modules. At the same time the local people tell us that they have never seen wider sand beaches.

Theory.
Pressure equalisation modules are vertical filters that are placed in a matrix along the coastline. The filters equalise the pressure of the ground water basin and an increased circulation of seawater in the coastal profile will take place. This will promote sedimentation of materials on the coastal profile.

During our work we have developed the following theory (in short): The pressure equalisation modules increase the drop of the water level in the coastal profile in the period from high tide to low tide. Thus, the beach will be more effectively drained of water. When the water level is low on the coast during the period from low tide to high tide, the water circulation in the swash zone increases, which again increases the depositing of materials on the foreshore, thereby building up the beach from the sediments transported along the coast. Over time the new materials in the coastal profile are increasingly coarse, due to a higher speed of the underlying water in the coast profile.
The result of deploying the pressure equalisation modules inside a coast profile, is a strong and very wide equilibrium profile. To build up the dunes on the beach, fascines are used to collect the sand blown along the beach by the wind.

MONITORED AND CONTROLLED FIELD RESEARCH

Based on the very positive experiences from Gammel Skagen, a full-scale field research programme was performed south west of Gammel Skagen.

The supervising and controlling team comprised the following persons:

Mr. Hans Falk Burcharth	Professor Dr. Tech., Aalborg University
Mr. Frede Jensen	State Forester, Northern Jutland
Mr. Bjarke Jensen	North Jutland County
Mr. John Jensen	Engineer, The Danish Coastal Authorities
Mr. Poul O. Jørgensen	Carl Bro Consulting Engineers A/S
Mr. Stig Trollebø	Teknologisk Innovation A/S
Mr. Poul Jakobsen	Skagen Innovation Centre

The research project was executed with professor Hans Falk Burcharth as research advisor for SIC, whereas the other team members were supervising the research project. The team members have participated in all conferences concerning the research project and has agreed that professor Hans Falk Burcharth, as an independent scientific expert should evaluate the procedures and the obtained data from the research programme, on behalf of the team. All measurements during the field research programme was recorded and controlled by a reputed independent consulting company; Carl Bro Consulting Engineers, Denmark.

Controlled field research.
The field research was performed along a coastline 8 km long S.W. of Gammel Skagen (please se the map on the next page). Before the pressure equalising plant was implemented, a baseline measurement of the selected coastline was made with laser equipment. The distance between each of the stations/ equalisation modules is 100 metres. The total distance from station 113200 to 114250 is 1050 metres.

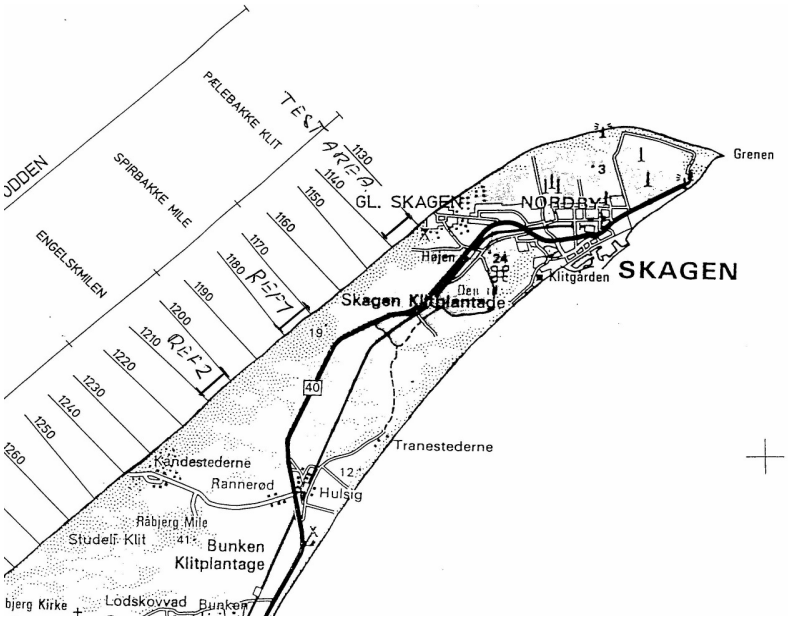
Flank areas.
Adjacent flank areas, without pressure equalisation modules, on either side of the test area, were monitored with the same procedures as the test area.

Reference area I.
Reference area I was located 4,0 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 research period of the coastal profile in a nearby site without pressure equalisation modules.

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 pressure equalisation modules during the research period

Test area, flank and reference areas are shown on the following sketch.

Overview map



Test, flank and reference areas

Flank 1	112800 - 113200
Test area	113200 - 114250
Flank 2	114250 - 114650
Reference area I	117000 - 118000
Reference area II	120134 - 121134

FIELD RESEARCH REPORT	
Issued by	**SIC** Skagen Innovation Center Østre Strandvej 33 a, DK - 9990 Skagen Denmark
Subject	Coastal Protection
Method	Pressure Equalisation modules
Location	Old Skagen.
Duration of research	27th January 1999 - 18th January 2000
Executing Consultants	Professor Dr. Tech. Hans Falk Burcharth Carl Bro Consulting Engineers, Denmark

SIC, Skagen Innovation Centre has established a demonstration/research pressure equalisation module plant at Old Skagen (Gammel Skagen), a small town on the West Coast of Jutland. The town is located in the extreme north of Denmark by the North Sea, at the position 10° 32,38' E - 57° 44,22' N. The site is recognised as a generally very windy location with heavy lateral currents.

The objective of the research program was to demonstrate, monitor and examine the efficiency of the SIC Pressure Equalisation System as a feasible solution to control coastal erosion. Professor Dr. Tech. Hans Falk Burcharth and Carl Bro, Consulting Engineers, Denmark carried out the research programme, during an all-season period of twelve months (27 January 1999 – 18 January 2000).

Summary

The efficiency of the pressure equalisation modules is unambiguous. After 12 months with 4 spring tide situations and 4 hurricanes, the average increase of the coastal profile in the 1000 metre long research area, was measured as 6,54 cubic metres per metre.
In reference area 1 (4 km SW of the research area), without pressure equalisation modules, a loss of 10,3 cubic metres (average) per metre was measured. In reference area 2 (7 km SW of the research area), without pressure equalisation modules, a loss of 3.45 cubic metres (average) per metre was measured.The function of the pressure equalisation modules has created a wide balanced coastal profile, with the significant advantage that the waves are losing their destructive energy while running uphill during high tide situations. Thus, the erosion of the coast profile is mitigated even in high tide situations combined with hurricanes.

Methodology

1.0 The current situation after twelve months of research is shown in diagram 1. It should be recognised that during this period 4 events with spring tide and hurricanes had taken place at this location.

2.0 The efficiency of the pressure equalisation modules is shown in diagram 2, which illustrates the efficiency and density of the coastal profile, compared to the adjacent reference areas.

3.0 The dynamics of each of the monitored coastal profiles during the twelve months research period is shown in diagram 3.

4.0 Comparison of conventional nourishment by dredging and the SIC pressure equalisation module system is shown in diagram 4. The Danish Coastal Authorities have back-filled a 3 km long coastline with 20 cubic metres of sand per metre at a cost of several million DKK.

The results of the twelve-month research programme.

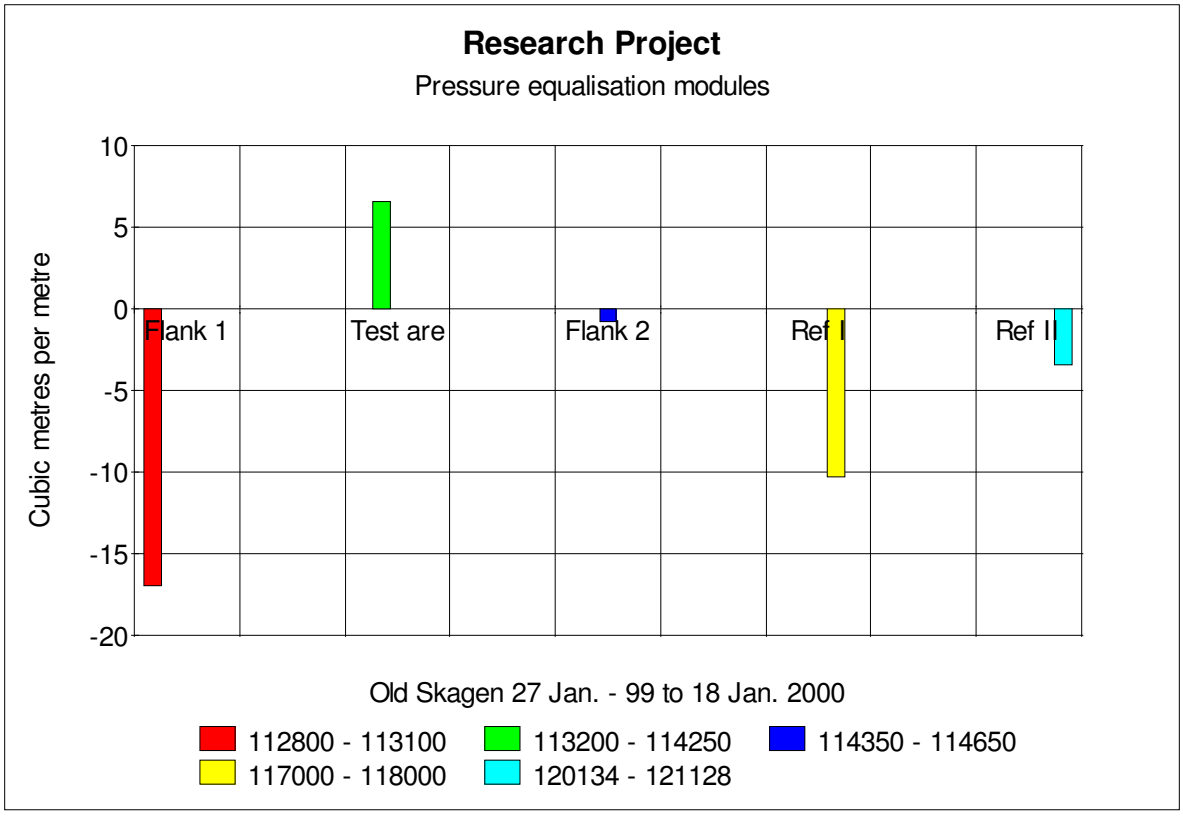


Diagram 1. The current situation after twelve months research.

The current situation after twelve months research is shown in diagram 1. It should be recognised that during this period 4 events with spring tide and hurricanes took place at this location.

After one year with heavy hurricanes the following results were observed.

Area	Measured impact	result
Flank 1	-16,95 cubic metre per metre	Erosion
Test area with modules	+ 6,54 cubic metre per metre	**Increase**
Flank 2	- 0,75 cubic metre per metre	Erosion
Ref. area I	-10,30 cubic metre per metre	Erosion
Ref. Area II	- 3,45 cubic metre per metre	Erosion

Table 1. Situation after twelve months research (including hurricanes).

The results of the test are unambiguous, but it is of greater importance that the density in the pressure equalised profile is significantly higher, compared with the adjacent areas.

Efficiency of the pressure equalisation modules.

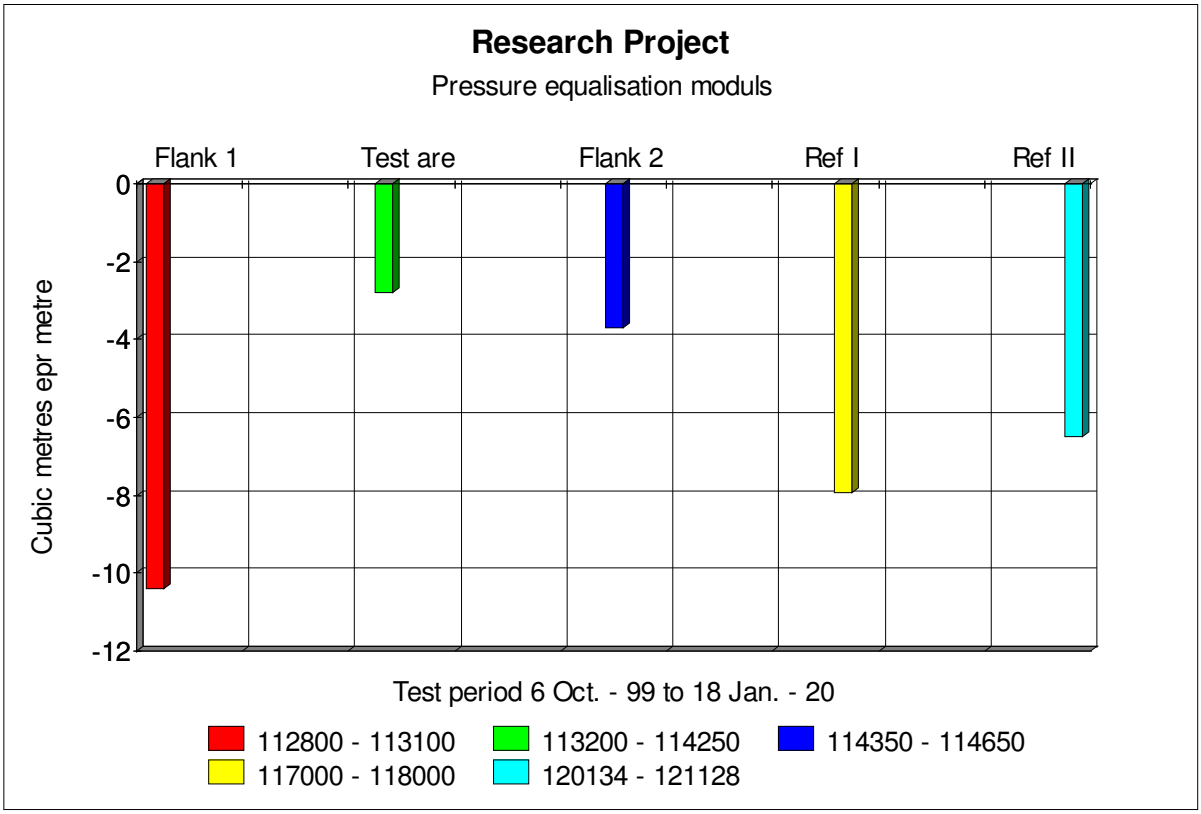


Diagram 2. The efficiency of pressure equalisation compared with the adjacent reference areas

The efficiency of the pressure equalisation modules is shown in diagram 2 which illustrates the efficiency and density compared with the adjacent reference areas.

The average erosion per metre caused by the two hurricanes in December 1999

Area	Measured impact	result
Flank 1	-10,41 cubic metres per metre	Erosion
Test area with modules	- 2,8 cubic metres per metre	Erosion
Flank 2	- 3,8 cubic metres per metre	Erosion
Ref. area I	- 7,93 cubic metres per metre	Erosion
Ref. Area II	- 6,48 cubic metres per metre	Erosion

Table 2. Erosion impact from hurricanes in 1999

Note:
The efficiency and density in the pressure equalised area with modules is more than 100 % higher than in the adjacent areas without modules when disregarding the upstream effect in Flank 2.

Development of the profiles during twelve months

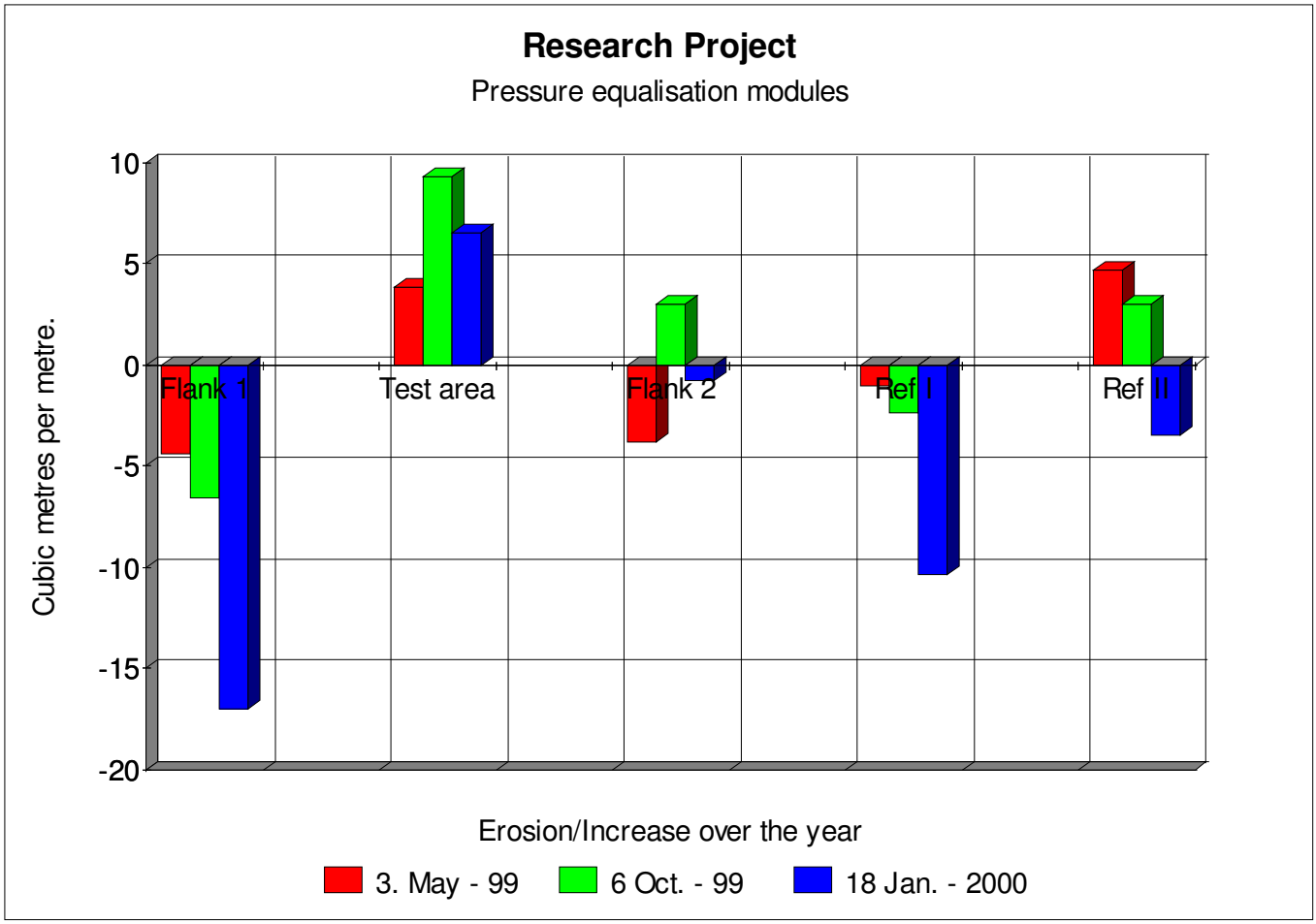


Diagram 3. The development of each of the monitored profiles over the twelve-month period.

The measurements were made between January and October of 1999 and January 2000 and comprise the test area with pressure equalisation modules as well as the nearby reference areas, each 1 kilometre long. The following results were observed:

Site	Results	Quantity	Unit
Test area	accumulation	9350.00	cubic metres
Reference area I	erosion	2363	cubic metres
Reference area II	accumulation	3035	cubic metres

Table 3. Erosion and accumulation over twelve months

Gain and loss factors immediately after the hurricanes:

Site	Results	Quantity	Unit
Test area	Remaining	6543 *	cubic metres
Reference area I	Loss / erosion	10295 *	cubic metres
Reference area II	Loss / erosion	3446*	cubic metres

Table 4. Gain and loss of coastline after the hurricanes

* (The observed measurements from 27th January 1999 are used as base line values).

It can be concluded that the pressure equalisation modules have not only mitigated the erosion, but also created a balanced coastal profile.

Comparison of efficiency between systems

The efficiency comparisons are made between; (i) the SIC environmentally friendly system based on pressure equalisation modules and (ii) the conventional approach as executed by the Danish Coastal Authorities with dredging/nourishing of a 3 kilometre coastline with 20 cubic metres of sand per metre, at a cost of several million DKK.

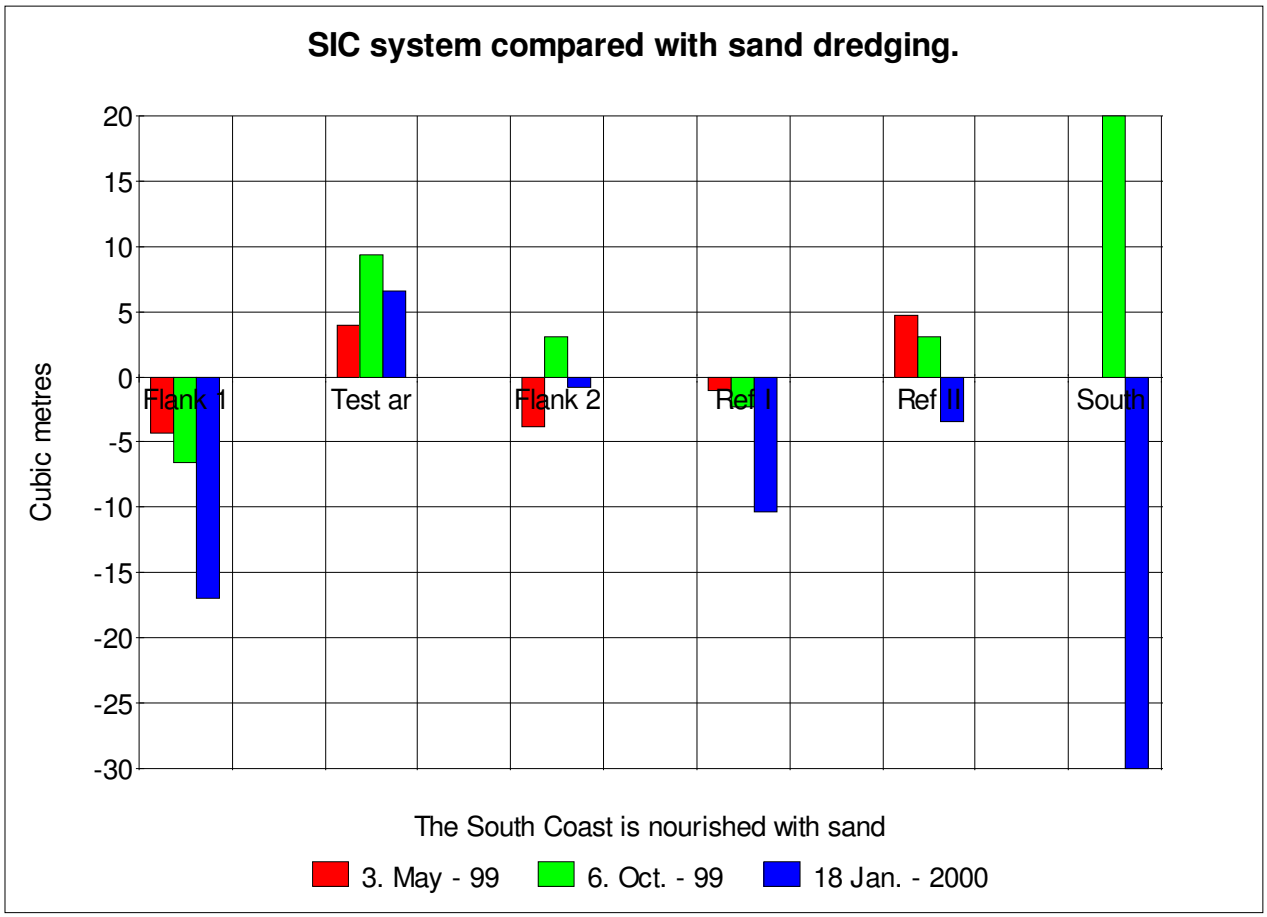


Diagram 4. Comparison of the SIC System and conventional dredging.

Conclusion

With reference to the above-mentioned observations during the research period, it has been proved that conventional dredging / nourishing with sand as performed by The Danish Coastal Authority during the past 17 years is inefficient.

Furthermore, it can be seen that the SIC environmentally friendly system based on pressure equalisation modules is a feasible and sustainable solution for coastal protection.