Prepared for:

Rijkswaterstaat

Ecobeach monitoring project

Phase 1

Report

January, 2007

WL | delft hydraulics

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CLIENT:	Rijkswaterstaat, Rijksinstituut voor Kust en Zee
TITLE:	Ecobeach monitoring project, Phase 1

ABSTRACT:

A drainage technique called Ecobeach has been developed in Denmark. There is no physical understanding yet of the functioning of the system, based on existing knowledge. A field experiment will be carried out in Egmond aan Zee, starting at the beginning of the storm season (fall 2006) and lasting three years. RIKZ has asked WL|Delft Hydraulics to set up a monitoring strategy for the field experiment in Egmond. This generation of a monitoring strategy is called Phase 1 in the Ecobeach project. Phase 2 is the actual experiment, with its monitoring.

The approach in Phase 1 is as follows:

- literature study on the vertical drainage system and the natural behaviour of the coast near Egmond
- Definition of research questions
- Definition of coastal state indicators (based on research questions)
- Development monitoring strategy

The overall objective is to define a monitoring strategy for Ecobeach Phase 2 that facilitates an objective evaluation of the Ecobeach drainage system. For this purpose, interviews are carried out to incorporate the existing knowledge and expectations about the system in the monitoring plan. Because of controversy existing about the drainage technique and the project set-up (carrying out an experiment without understanding the technique that is being tested), it is important that the monitoring and analysis strategy is defined before the start of Phase 2, to make objective analyses during and at the end of the project. The resulting monitoring plan is given in the report.

REFERENCES: RIKZ/2006/05512 dd 7 August 2006

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1 Introduction

The Dutch government is challenging businesses to stimulate innovation. This has led to a proposal by BAM (largest construction firm in The Netherlands) to the Minister of Public Works to protect the Dutch coast in an innovative way with the Ecobeach technique (see Appendix A). The Ministry of Public Works (RIKZ) is now investigating the added value of the proposed technique. This is done under the framework of the WINN program (WAter INnovatiebron). A field experiment will be carried out in Egmond aan Zee, starting at the beginning of the storm season (fall 2006) and lasting three years.

The Ecobeach technique is developed in Denmark by the Skagen Innovation Centre (SIC). It is an easily installable system that consists of vertical (passive) drainage pipes (diameter approximately 7 cm) that are regularly spaced on the beach (spacing approximately 10 m cross-shore and 100 m alongshore). There is no physical understanding yet of the functioning of the system, based on existing knowledge. RIKZ and BAM would like to find out more about the functioning of the system and its effects on the coast. For this understanding, good and thorough monitoring is needed, in order to quantify the possible effects of the drainage system. Identification of the effects of the system as opposed to natural variations in the coast is important in that sense. RIKZ has asked WL|Delft Hydraulics to set up a monitoring strategy for the field experiment in Egmond, with which this distinction can be made. This generation of a monitoring strategy is called Phase 1 in the Ecobeach project. Phase 2 is the actual experiment, with its monitoring.

Through letter RKZ-1755 “Uitvoering Pilot Monitoringsprogramma Ecobeach”, RIKZ has asked WL|Delft Hydraulics to make a proposal. We refer to letter RIKZ/2006/05512 dd 7 August 2006.

The monitoring strategy resulting from this study (Phase 1) will be the starting point for the actual monitoring in Phase 2 of the project. The approach in Phase 1 is as follows:

- literature study on the vertical drainage system and the natural behaviour of the coast near Egmond
- Definition of research questions
- Definition of coastal state indicators (based on research questions)
- Development monitoring strategy

The overall objective is to define a monitoring strategy for Ecobeach Phase 2 that facilitates an objective evaluation of the Ecobeach drainage system. For this purpose, interviews are carried out to incorporate the existing knowledge and expectations about the system in the monitoring plan. Because of controversy existing about the drainage technique and the project set-up (carrying out an experiment without understanding the technique that is being tested), it is important that the monitoring and analysis strategy is defined before the start of Phase 2, to make objective analyses during and at the end of the project.

2 Vertical beach drainage: knowledge and experience

A technique has been developed using vertical drains, called Pressure Equilibrium Modules (PEM), that is presumed to control beach erosion (Jacobsen and Brøgger, 2006). The vertical drains consist of a 10 cm diameter pipe with a 1 m long screen. The functioning of the PEM is not known, but one hypothesis is that the effective permeability of the beach is increased. In this chapter, the present 'knowledge' of the system will be described, as well as three field tests that have been carried out in Denmark. In the next phase of the Ecobeach monitoring project (Phase 2), BAM will initiate further research with respect to the understanding of the functioning of the drainage system.

2.1 Present knowledge PEM drainage system

Not much is known about the real physical operation of the PEM drainage system. The system is a passive drainage technique, which means that it is a system without pumps. The pipes are about 2m long with a diameter of the order 7cm, they are perforated near the bottom and allow air to enter at the top. The typical spacing of the modules is 10 m cross-shore and 100 m alongshore, where the modules are placed from the dunefoot to the low water line.

The idea behind PEM is that the pipes will drain the beach and make the watertable drop, therefore enhancing infiltration and sediment deposition. There is evidence that lowering of the watertable in beaches can have some beneficial effects, mainly enhancing accretion in fair weather rather than protecting against erosion during storms, see Turner & Leatherman (1997). There is also some data, which quantify the underlying effect of infiltration rate on sediment mobility, Nielsen et al (2001). However, the evidence is that a very strong drainage effect is needed in order to give a significant effect. Until now, no evidence exists of a (strong) drainage effect of the PEM system and the reason why the watertable should drop because of the PEM pipes is not entirely clear.

As explained by the inventor in the U.S. patent (2003):
A possible explanation as to why coastal accretion takes place is that the very fine sand which is fed to the profile partly by the sea and partly by the wind and which is packed with silt and other clay particles, reduces the hydraulic conductivity. Deeper layers in the coastal profile, which have exclusively been built by the waves of the sea, are primarily coarse in the form of gravel and pebbles which have a greater hydraulic conductivity. The difference in hydraulic conductivity will be seen clearly when digging into a coastal profile, it being possible to dig a hole in the profile, and the groundwater will then rise up into the profile once the water table is reached. The reason is the very different hydraulic conductivity and that the freshwater is under pressure from the hinterland. Thus, the coastal profile may be compared to a downwardly open tank where the tank is opened at the top with the pressure equalization modules which extend through the compact layers of the profile so that the water runs more easily and thereby more quickly out of the profile in the period from flood to ebb. This means that a pressure equalized profile is better emptied of freshwater and salt water in the fall period of the tide. When the tide then rises from ebb to flood, a greater fluctuation occurs in the foreshore, as the salt water in the swash zone is drained in the

swash zone so that materials settle in the foreshore during this period of time. Conversely, coastal erosion takes place if the freshwater is under pressure in the foreshore, as the salt water will then run back into the sea on top of the freshwater and thereby erode the foreshore. In reality, the pressure equalization modules start a process which spreads from the pressure equalization modules, as the silt and clay particles are flushed out of the foreshore when the fluctuation is increased because of the draining action of the modules. Further, a clear connection has been found between the amount of sediment transport on the coast and the rate of the coastal accretion. It has been found that the pressure equalization modules create a natural equilibrium profile with a system of about 1:20, so that the waves run up on the beach and leave material, as water in motion can carry large amounts of material which settle when the velocity of the water decreases. The profile must therefore have a given width with respect to the tide and a maximum water level in the area. Coastal profiles with pressure equalization modules naturally become very wide, which results in a very great sand drift on the foreshore. This great sand drift is utilized by establishing longitudinal fascines high up in the beach and transverse fascines with an increasing height toward the foot of the dune, the fascines forming the upper part of the beach profile.

The complete US Patent text is given in Appendix A.

2.2 Field experiment Skodbjerge

Several tests have been carried out to investigate the effects of the PEM drainage system on the beach. An overview of the set-up and first experiences of a PEM field experiment at Skodbjerge (Denmark) is given below, together with its most important conclusions. From this we can learn lessons about which types of data are needed to be able to give conclusions about the effects of the drainage system on the natural behaviour of the coast. Most information and text in Paragraphs 2.2.1 to 2.2.3 is taken from Burcharth and Fredsøe (2005). The information in Paragraph 2.2.4 is taken from Engesgaard (2006).

2.2.1 Site description and layout

A field test with the purpose of demonstrating the efficiency of the SIC vertical drain method as a mean for coastal protecting was initiated in 2004 by the Skagen Innovation Center (SIC) and the Danish Governmental Coastal Authority (KDI). The test period is three years after which a final report has to be presented. The report shall contain an evaluation of the drain system with respect to qualitative and quantitative efficiency and environmental impact, as well as a related comparison with conventional coastal protection methods. Besides the final report yearly reports have to be presented as well as a report half a year after the start of the field test. For the evaluation the following two experts were retained Prof.dr.techn., dr.h.c. Hans Falk Burcharth (HFB) Prof.dr.techn. Jørgen Fredsøe (JF).

The main basis for the evaluation of the tests will be a comparison of the morphological changes in stretches with and without drain pipes. The total length of the Skodbjerge test site was limited to approximately 11 km in order not to come too close to the beach breakwaters to the North and the accreting coast to the South. KDI and JF preferred a spilt of the site in a number of relatively short stretches (say 2 km) with alternating drains and no drains. SIC could not accept this as – based on experience – they wanted longer stretches, basically a 6 km stretch with drains and a 4 km stretch without drains. However, due to the gradient in erosion along the test site this was not acceptable and HFB proposed as a minimum stretches with no pipes on both sites of the drained stretch. A compromise as shown in Fig. 2 was found in which two stretches of 4.7 km (Rør I, chainage 4019200 - 4014500) and 0.9 km (Rør II, chainage 4014500 - 4012700) respectively were drained, and three stretches of 1.8 km (Reference I, chainage 4021000 – 4019200), 1.8 km (Reference II, chainage 4014500 – 4012700) and 1.8 km (Reference III, chainage 4011800 – 401000) respectively were left undrained. The drains were installed in January 2005. The positions of the drains are shown in Figure 2.

2.2.2 Surveying

Profiling per 100 m of the beach including the dune front four times per year was decided as well as soundings per 200 m of the seabed within 600 m from the shoreline. The first profiling took place in January 2005 just after placement of the drains. The second and third in April and June 2005. Also, ground water levels are monitored, as well as the composition of the beach material.
Surveying is carried out with the objective of gaining information on the development of the coast with respect to the following beach properties:

- beach width
- width of beachface
- volume of accreted/eroded material
- average height of beach
- average slope of beach
- average slope of the beachface

The coastal profile was divided into four zones defined as shown in Figure 1. The quantities a1, a2, a3, A1, A2, A3, A4 will be calculated from the coastal profiles and compared from survey to survey. Based on the experience from the April and the June surveys the definition of these quantities will be adjusted in order to obtain the most relevant interpretation of the data with respect to the above mentioned beach properties.

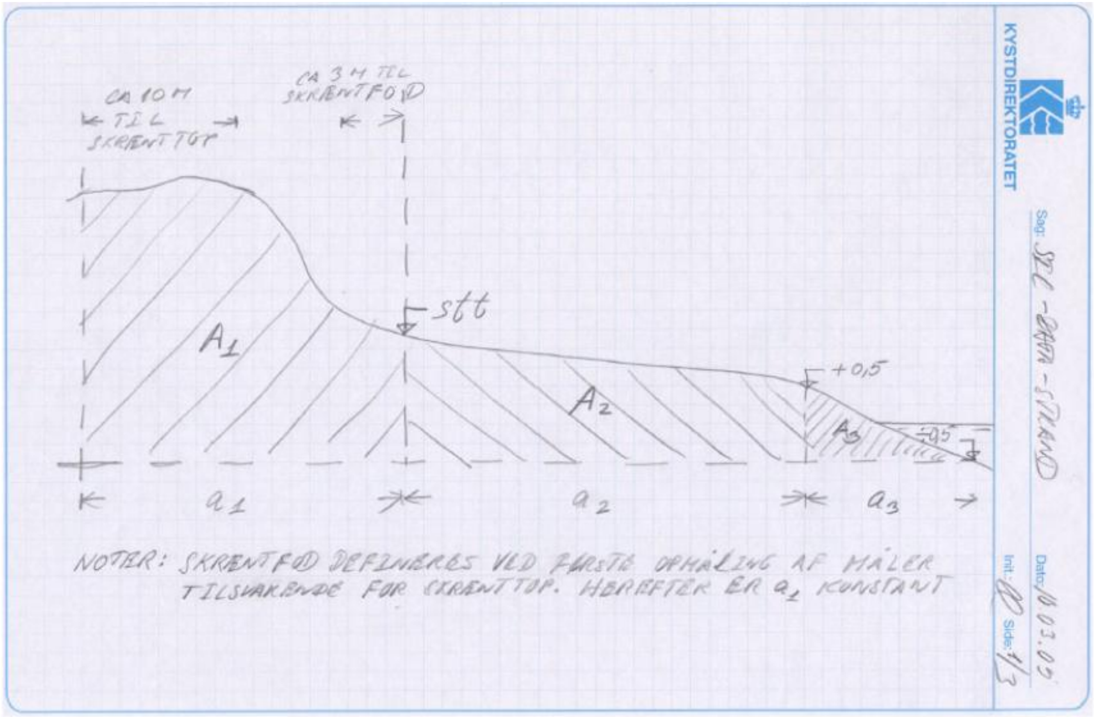


Figure 1 Illustration of geometrical properties extracted from the surveyed beach surface profiles.

2.2.3 Preliminary observations and conclusions

In the period ultimo January – primo July no significant changes have taken place in the beach platform as the coastline ondulations have more or less maintained their positions. Despite this it can be observed that significant accumulation of sand has taken place within the two areas with drains, Rør I and Rør II, i.e. the beach level has been raised. The same development is however observed in Ref. III with no drains, whereas Ref. I and Ref. II -also with no drains- exhibit both erosion and accretion. This observed development has taken place in a period with no severe storms and extreme high water levels since the very severe storm around 8 January 2005 occurred. At that occasion large quantities of sand were probably eroded from the beach. Usually part of this sand will be transported back to the beach in periods with milder wave climate, normally occurring in the spring and the summer. The changing wave climate causes large natural fluctuations in the beach planform and volume. Moreover, coastline ondulations moving along the coast in the direction of net sand transport might contribute to these fluctuations. The effect of the drains has to be detected from such "background noise" which is not easy during a short period, even if the drains might have a significant effect. For this reason the following conclusions are of preliminary character.

During the first six month of tests the beach has increased its volume significantly in the stretches where the SIC-drain system has been installed. In the three stretches without drains accretion has taken place in one stretch and erosion in two stretches. Thus there seems to be a certain correlation between areas with deposition and areas where the drains are located. The beach planform and thereby the beach width has not changed significantly. No migration of the coastline ondulations along the coast has been detected.

Figure 2 Reference area 1 st. 9200–11000, PEM area 1 st. 4500–9200, Reference area 2 st. 2800–4400, PEM area 2 st. 1800–2700, Reference area 3 st 0–1700, Burcharth and Fredsøe (2005).

2.2.4 Hydraulic mini-experiment March/April 2006

A two-week experiment was conducted in March/April 2006 at the test site described in Paragraph 2.2.1 in order to investigate the hydraulic functioning of the PEMs. The experiment was divided into two periods. Period 1 where only 10 cm diameter wells (10 cm screen) were installed with pressure transducers (divers; measurement every 2 minutes) and period 2 where both wells and PEMs were installed, the PEMs also with pressure transducers. Three transects were established. One transect with just wells and no PEMs, which then acted as a reference site, one transect with both wells and PEMs, and then one transect with a few wells and mostly PEMS, which was designed primarily for the PEM-scale experiment. This makes a before-and-after comparison possible, where the tidal response in the wells during period 2 can be compared with the tidal response in period 1 and finally can be compared with the reference site.

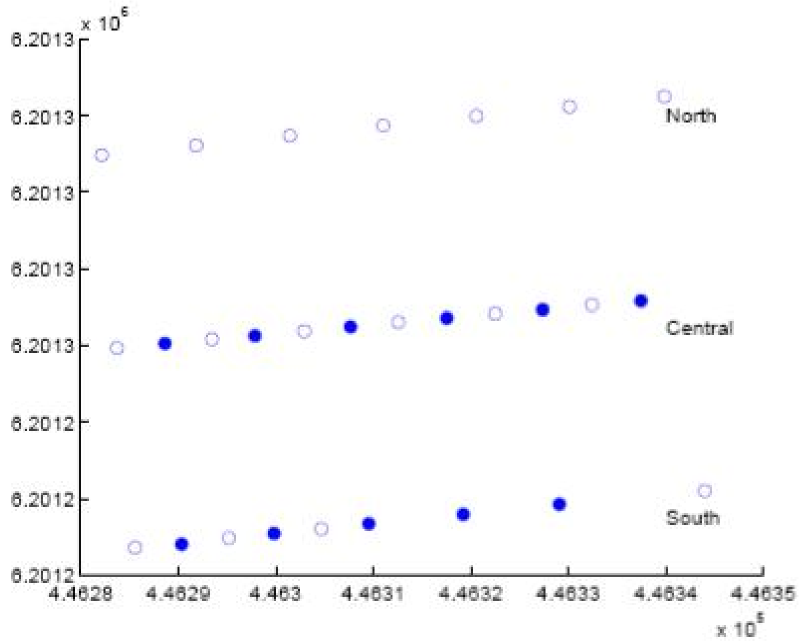


Figure 3: Location of wells with divers (open circle) and pressure equilibrium modules (filled circles), Engesgaard (2006).

An analysis on tidal response in a beach was performed on data from the two-week field-scale experiment at Holmsland. The analysis is primarily based on a before-and-after situation, where PEMs were installed in week 2. The hydraulic functioning of the beach during week 2 can be compared with week 1 and also compared with a reference site, where no PEMs were installed. The PEMs may result in a more permeable beach because the long screens can intersect several small gravel layers making the whole beach more conductive. Infiltrating water could thereby drain better away. The analysis is exclusively performed on tidal data where the high frequency waves have been filtered out. The hydraulic behaviour of the beach in damping the tidal signal was investigated and compared between week 1 and week 2. The analysis is based on similar principles as applied by Carr [1971], model predictions by Nielsen [1990] for beaches of different permeability, and observations in laboratory and field experiments by Cartwright et al.[2003, 2004]; Raubenheimer et al. [1999].

This leads to the following conclusions;
• The damping is less in period 2 (week 2), which is explained by the fact that the mean sea level moved 5-20 m more inland due to a combination of increase in water level at Hvide Sande and a change in beach profile.

• The temporal mean hydraulic heads increased in reasonable correspondence with the observed water levels at Hvide Sande and the fact that a sloping beach leads to an extra water table over height at inland wells.
• A comparison of the mean hydraulic heads in the wells and PEMs suggest that there is a downward flow in the tidal active zone. This is in agreement with laboratory and other field-scale findings.
• In all cases the transect with both wells and PEMs (Central) act very similar to the transect with just wells in both period 1 and 2. Any differences can be explained by the differences in beach profile.

In summary, it is concluded that, for this beach-scale analysis, the PEMs seem to have little effect on the tidal dynamics. The observed differences between periods 1 and 2 and between the Central and North transects can be explained by the physical situation (beach profile) and physical flow processes.

2.3 Recommendations

It can be seen that it is still difficult to come to conclusions regarding the effects of the PEM drainage system. The following points have to be kept in mind when designing a monitoring plan for the proposed experiment in Egmond aan Zee, 2006-2009:

- Measure groundwater levels, near the PEM modules, but also in the nearest dune. Previous research has shown that the groundwater level in the dune(foot) is mainly responsible for the horizontal groundwater flow from the dune to the (wet) beach. The gradient in the groundwater table due to this effect is much larger than the local groundwater effects observed around the PEM modules (Engesgaard, 2006).
- The effects of the system have until now only been evaluated based on the sediment budget of the dry and intertidal beach. It is recommended to also take into account the breaker/MCL zone and the interaction (cross-shore sediment redistribution/gain/loss) between these three zones. The natural behaviour of the nearshore sand bars before implementation of the PEM modules should be studied.
- Alongshore sand waves exist in the test area, which should be taken into account when analysing the effects of the drainage system.
- The spatial scheme of the pipe locations seems to be chosen rather arbitrarily in the previous tests of the PEM system. For a better understanding of the working of the system, special attention should be paid to this spatial installation scheme during the proposed experiment in Egmond, to get a feel for the spatial effect of the PEM system.

3 Field experiment Egmond 2006-2009

Starting in November 2006, a field experiment with PEM modules will be carried out in Egmond aan Zee (The Netherlands). The proposed duration of the experiment is three years in total. After one year, an evaluation report will be made, on the basis of which will be decided to complete the test for the full three year period or to remove the modules (in case of negative effects of the system on the coastal behaviour).

The test areas are shown in Figure 4. The test areas are chosen in such a way that both areas can clearly be monitored with the Argus cameras present in Egmond. There are two Argus video station located in Egmond, marked with red stars in the figure, the northern one in the Jan van Speijk lighthouse and the other approximately 3 kilometres to the south at the Coast3D tower (built especially for the Argus cameras during the European Coast3D project). The northern test area (marked in red) is located in a region which is heavily nourished during the past years (shoreface and beach). The southern test area (marked in yellow) is located in a fearly undisturbed region.

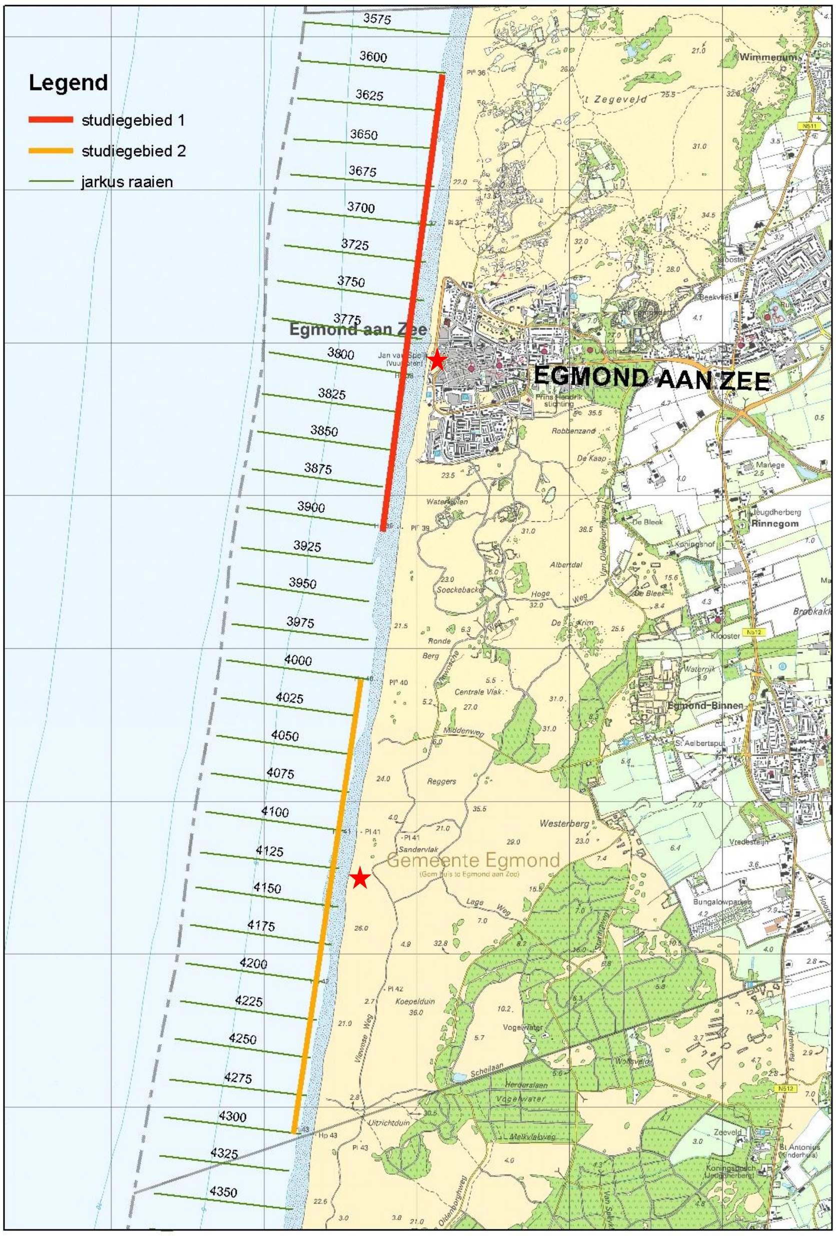


Figure 4 Map of the coastal area near Egmond aan Zee. The two test areas are marked in red and yellow, the two Argus stations are shown with red stars.

4 Natural morphological behaviour Egmond

To be able to come up with a good monitoring strategy for the Ecobeach project, a good understanding of the historical evolution of the coast in the test areas is needed. An overview of the natural behaviour of the Egmond coast is given below.

4.1 Central Dutch Coast

The central Dutch coast is a straight sandy coastline. The beach slope varies between 2˚ and 7˚. The median grain diameter at the dry beach lies between 250 and 350 μm (Kroon, 1994). The morphology is characterized by a dynamic bar system. The subtidal morphology generally consists of two nearshore bars exhibiting a cyclic behaviour in which a bar generated near the beach migrates seaward, grows and subsequently fades away when it reaches the outer surf zone. The period of this cyclicity varies between 4 and 15 years along the entire central Dutch coast (Wijnberg, 1995). The intertidal area also is characterized by the presence of bars. These are more dynamic than the subtidal bars and their lifetime depends on storm frequency and intensity. During a storm the beach erodes and the intertidal bars disappear. Under calm conditions a new subtidal bar is formed near the low water line, which migrates landward under continuous calm circumstances (e.g. Kroon, 1994; Quartel et al, subm).

4.2 Intertidal beach

4.2.1 Study area and definitions

The study area in this chapter is located near the village of Egmond aan Zee along the central Dutch Coast. We will focus on an intertidal beach area between beach poles RSP 40.100 and 41.100, which was studied extensively by Quartel and Grasmeijer (2006). They quantified the dynamics of the intertidal beach based on the position of the dune foot (x_D), mean high-water coastline (x_{GHWK}), mean low-water coastline (x_{GLWK}), beach width (B_S) and beach volume (V_S). A definition sketch of the various parameters is presented in Figure 5.

Quartel and Grasmeijer (2006) defined the beach as the area between the dune foot and the mean low-water coastline. The beach width is then the distance between these and the beach volume the volume integrated over this distance. The intertidal beach width is the distance between the mean high-water coastline and the mean low-water coastline and the intertidal beach volume the volume integrated over this distance. The position of the dune foot and the mean high- and low-water coastlines are based on vertical boundaries, i.e. z-levels. For the dune foot this is z_D = +3.0 m NAP, where NAP is the Dutch Ordnance Level. Taking account of the effect of breaking waves and swash processes, the z-levels for the mean high- and low-water coastline are z_{GHWK} = +1.34 m and z_{GLWK} = -0.76 m NAP. For details on the calculation of these z-levels we refer the report by Quartel and Grasmeijer (2006).

Data used by Quartel and Grasmeijer consist of monthly dGPS surveys by the University of Utrecht in the Netherlands during a period of 2 years between May 2002 and June 2004, and yearly surveys by Rijkswaterstaat over a period of more than 40 years between 1964 and present. The latter are commonly referred to as the JARKUS data.

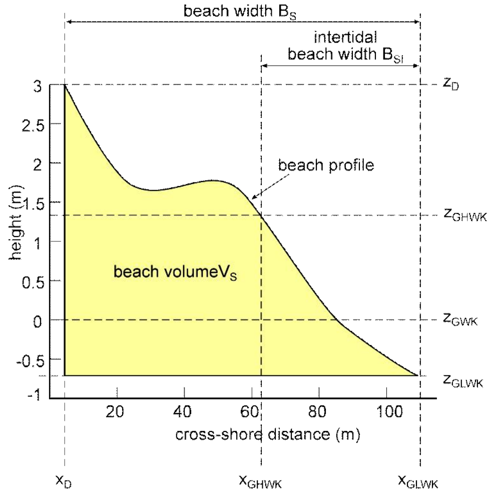


Figure 5: Beach profile with definitions of various parameters

4.2.2 Temporal variation on a monthly scale

Quartel and Grasmeijer (2006) found that the alongshore-averaged beach width near Egmond aan Zee shows a natural variation of about 5 m/month and the alongshore-averaged beach volume about 5 m^3/m/month. Although larger volumes of sand are transported from upper to lower beach during storms and vice versa during calm conditions this has little effect on the entire beach volume.

4.2.3 Spatial variation

Spatial variations in beach width and volume are due to sand waves. Quartel and Grasmeijer (2006) found variations in beach width of about 40 m over a distance of roughly 300 m, although these variations were not always present. A sand wave crest (large beach width) may contain 5000 m^3 of sand. Sand waves were found to migrate with an alongshore velocity of roughly 250 m/year, but not necessarily in one predominant direction. Figure 7 shows an example of the alongshore variation of the different beach parameters revealing the presence of a sand wave.

Figure 6 shows a time stack of the alongshore variation of beach volumes near Egmond aan Zee over a period of two years. The alongshore migration of a sand wave can be observed between 6 January and 22 December 2003. A relatively large beach volume (warm colours) around RSP 40.250 migrates 250 m south during this period. Due to the limited spatial and temporal scales in their study Quartel and Grasmeijer (2006) could only give a rough estimate of the dimensions and migration rates of sand waves. The southward migration of the sand wave in Figure 6 might for example be incidental. More data over larger alongshore distances and longer periods is necessary to draw firm conclusions about dimensions and migrations rates of sand waves. To exclude the effect of sandwaves in analyses, averageing should take place over a stretch of coast with a length larger than 1.5 km.

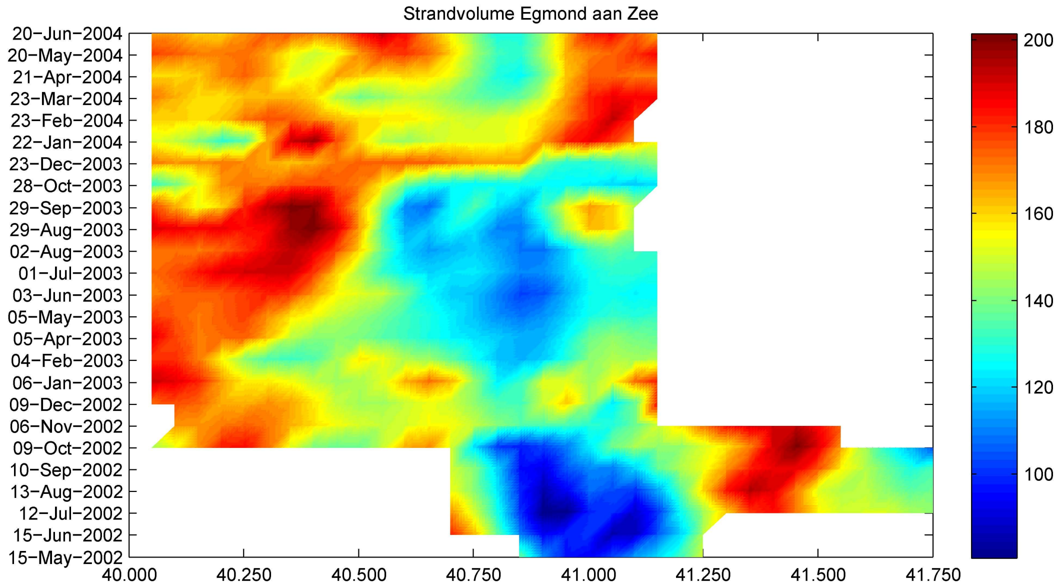


Figure 6 Time stack of alongshore variation of beach volume (between low water coastline and dune foot) near Egmond aan Zee. Warmer colours indicate larger beach volumes.

4.2.4 Temporal variation on a yearly scale

Quartel and Grasmeijer (2006) studied the long term variation of beach width and volume of six neighbouring beach compartments between RSP 37.000 and 43.000 and compared the trends before and after 1990. Table 1 shows the trends in beach width and beach volume for the different beach compartments for the periods 1964-1989 and 1990-2005. It is interesting to see that beach volume trends between 1990 and 2005 are all positive (accretion) for the beach compartments between RSP 37 en 40 with an average trend of +2.2 m^3/m/year and those between RSP 40 and 43 all negative (erosion) with an average of -1.2 m^3/m/year.

As an example, Figure 8 shows the alongshore-averaged beach widths and volumes for beach compartments RSP 37-38 and RSP 41-42. The 1990-2005 trends are shown also and the uncertainties of these trends are presented as a bandwidth. The left panels clearly show the increasing trend in beach width and volume for compartment RSP 37-38 between 1990 and 2005. This increase is likely due to the beach and shoreface nourishments implemented in this compartment. In contrast, the right panels in Figure 8 show a decreasing trend of beach width and volume in compartment RSP 41-42. No nourishments took place in this compartment.

Table 1. Annual beach width and beach volume trends for the periods 1964-1989 and 1990-2005

Beach compartment	Trend beach width 1964-1989	Trend beach width 1990-2005	Trend beach volume 1964-1989	Trend beach volume 1990-2005
37-38	-0.5 m	+1.5 m	-0.2 m^3/m	+3.8 m^3/m
38-39	+0.3 m	-0.9 m	+0.5 m^3/m	+0.1 m^3/m
39-40	+0.2 m	+1.1 m	+0.4 m^3/m	+2.7 m^3/m
40-41	-0.1 m	-0.7 m	-0.7 m^3/m	-0.9 m^3/m
41-42	+0.6 m	-0.5 m	+0.4 m^3/m	-0.8 m^3/m
42-43	+0.5 m	-0.5 m	-0.2 m^3/m	-1.9 m^3/m

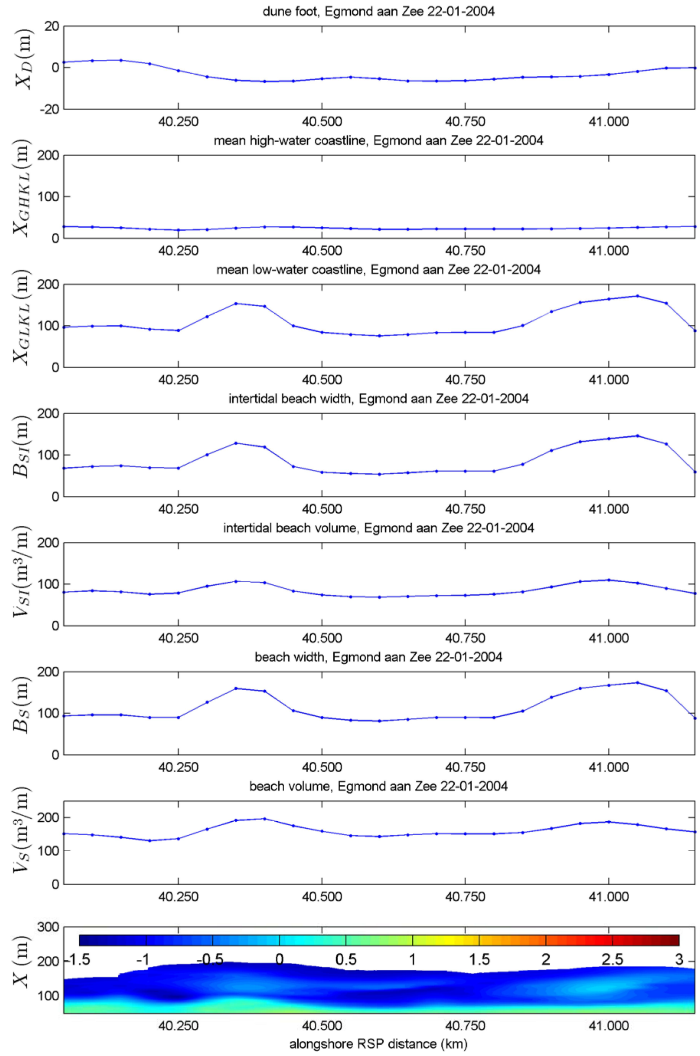


Figure 7: Alongshore variation of dune foot position, mean high- and low-water coastline, intertidal beach width and volume and total beach width and volume near Egmond aan Zee on 22 January 2004.

It is important to be aware of the effect of the nourishments in the RSP 37-38 compartment when quantifying future effects of other coastal protection measures. Quartel and Grasmeijer (2006) show that 7 or 8 years after implementing a relatively large shoreface nourishment (~ 400 m^3/m) the beach has returned to its original width and volume. This means that, under similar conditions, effects of the shoreface nourishment constructed in 2004 in the RSP 37-38 compartment can only be neglected after the year 2011.

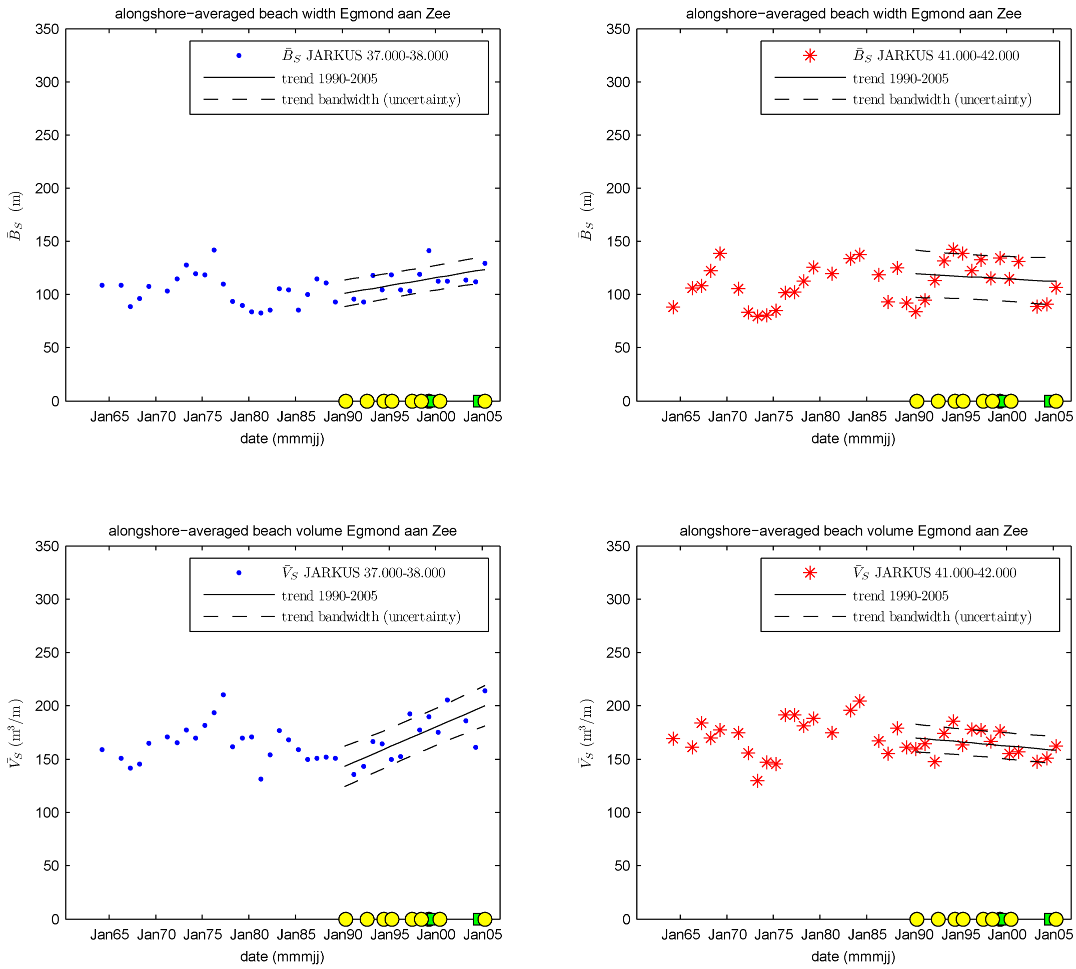


Figure 8: Alongshore-averaged beach widths and volumes for beach compartments RSP 37-38 (left) and RSP 41-42 (right). The trends for the period 1990-2005 are presented as a solid line and the uncertainties in this trend as a bandwidth between the dashed lines. Beach nourishments are indicated with a yellow circle and shoreface nourishments with a green square. Most nourishments were implemented roughly between RSP 37 and 39. No nourishments were made in the beach compartment between RSP 41 and 42.

4.3 Total beach (wet and dry)

Coastal policy in the Netherlands has primarily been aimed at the protection against flooding of the lowland areas situated landward of the coastline. Since 1990 it has been official policy to stop any further coastal retreat by maintaining the coastline at the position of that date, adopting a new policy called ‘Dynamic Preservation’. The objective of this policy is to provide safety against flooding in combination with sustainable preservation of the functions and values of dunes and beaches. As it aims to take advantage of natural dynamic processes, the principal intervention measure is sand nourishment. Implementation of the Dynamic Preservation policy demands an objective assessment of the state of the coastal system. For this purpose, the concept of the Momentary Coastline (MCL) has been developed (e.g., Hamm et al., 2002).

4.3.1 Momentary coastline definition

The MCL (see Figure 9) represents the momentary horizontal position of the coastline, determined from the sand volume in a cross-shore profile between the dune foot at an elevation *H* above mean low water (mlw) and the depth contour at an equal depth *H* below mlw. The MCL is computed every year on the basis of annual surveys of bathymetry (named JARKUS for “JAaRlijkse KUStmetingen” or “Annual Coastal Surveys”) along cross-shore profiles with 250 m alongshore spacing. The anticipated position of the MCL for the next year is predicted from the ten-year trend in the evolution of the MCL and compared to the location of the so-called Base Coastline (BCL), which reflects the 1990 coastline and acts as the reference state. If the anticipated MCL is located shoreward of the BCL, an intervention by means of sand nourishment is necessary at that location. The MCL and BCL parameters are calculated using the UCIT Toolkit (Van Koningsveld et al., 2004).

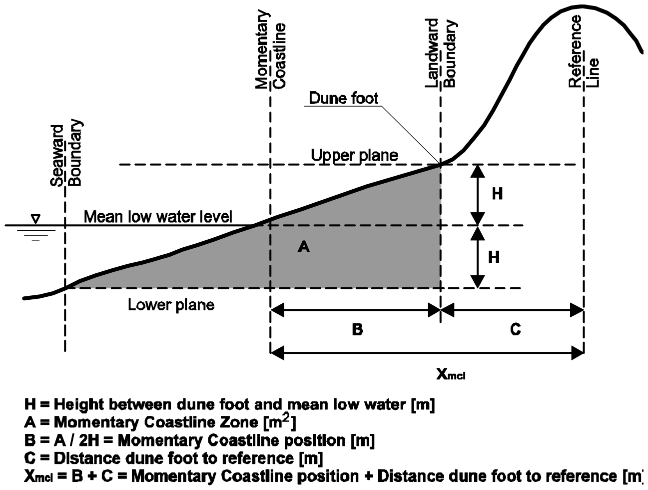


Figure 9 Definition sketch of the Momentary Coastline, MCL (Van Koningsveld and Mulder, 2004).

The Universal Coastal Intelligence Toolkit (UCIT), is an instrument that facilitates communication between decision makers and experts in coastal zone management problems. It does so by integrating various types of measurement data, morphological models and coastal state indicators (i.e. specific parameters on which decisions are based). A primary benefit of this approach is an increased efficiency in dealing with the 'traditional' coastal problems for which long standing approaches are used. A secondary but by no means lesser benefit is the creation of an environment where innovative technologies can be employed to supplement the traditionally derived information or even to generate new, previously unavailable, information in support of coastal management. Within the framework of the Beach Wizard project, the model results of the Egmond application are implemented in the UCIT environment, to facilitate simple comparison between model results and measured bathymetries, through derivation of several coastal state indicators from these bathymetries.

4.3.2 Temporal variation on a yearly scale

The measured MCL is shown at several transects in the test areas (see Figure 10 to Figure 15). Beach and shoreface nourishments are shown with vertical green and red lines. The BCL is shown as a horizontal red line. The trendline TCL is shown in blue, together with its uncertainty bands. We see that there is not a structural growth or decay of the MCL at all transects. Also, an upward trend is expected in all nourished transects, but this is not the case. The trends that are seen are well pronounced, so any possible effects of the Ecobeach system on the position of the MCL should be clearly vissible in these trends.

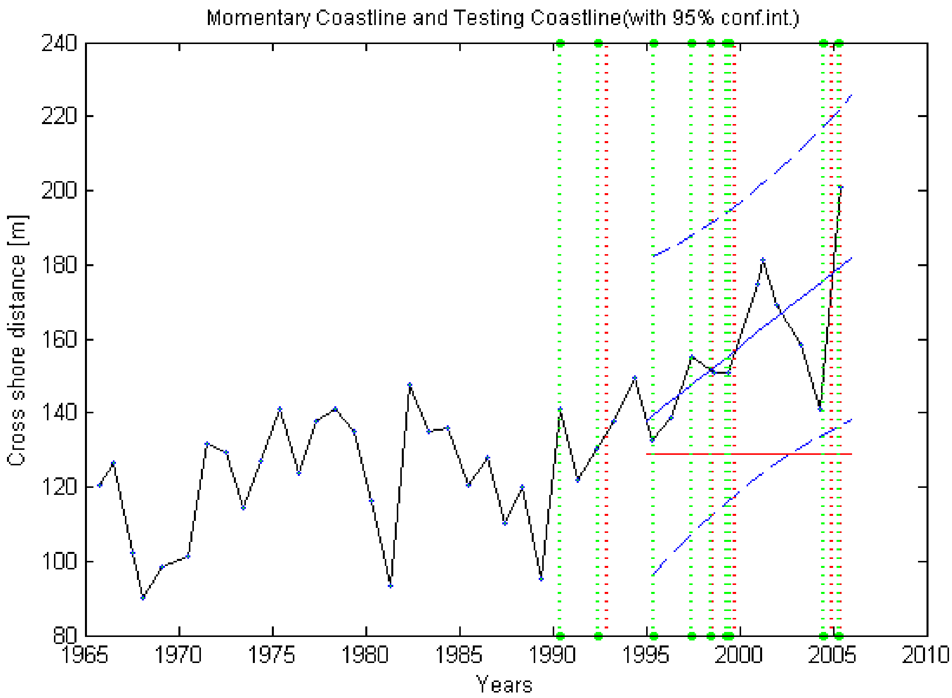


Figure 10 MCL and TCL in transect 3750

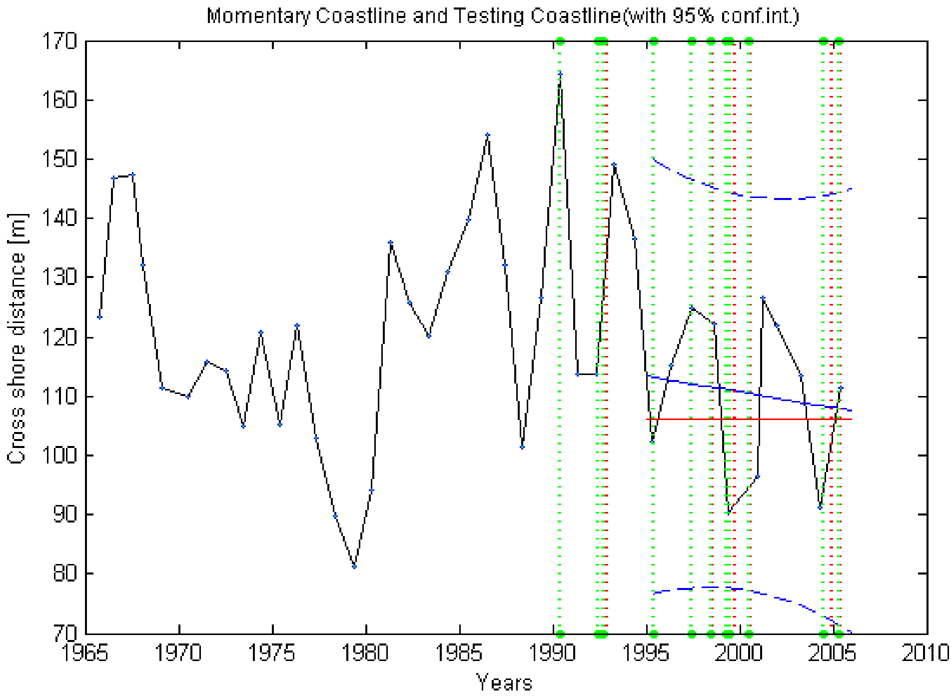


Figure 11 MCL and TCL in transect 3850

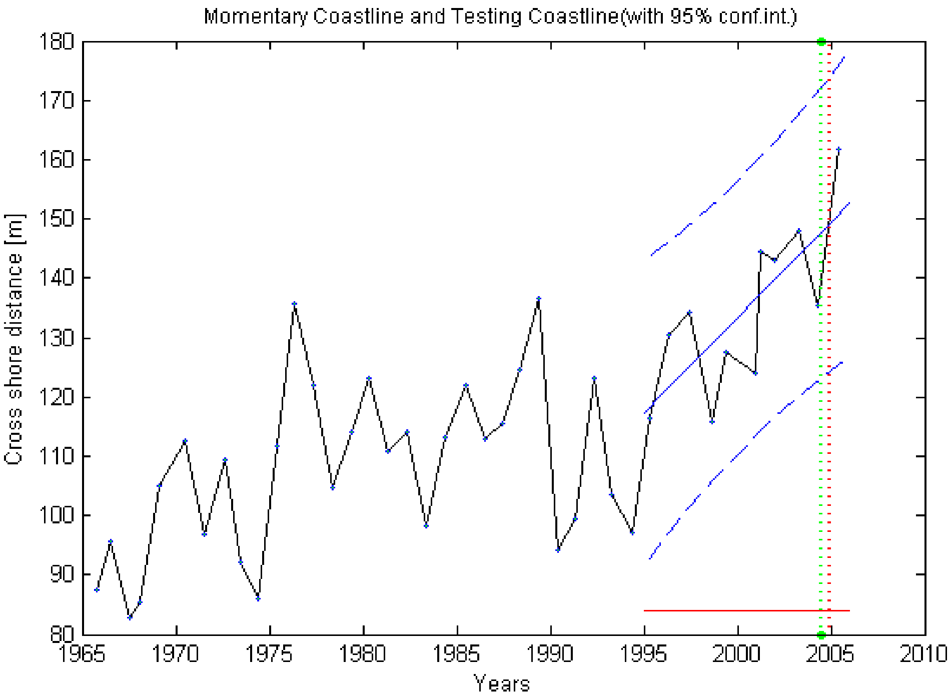


Figure 12 MCL and TCL in transect 3950

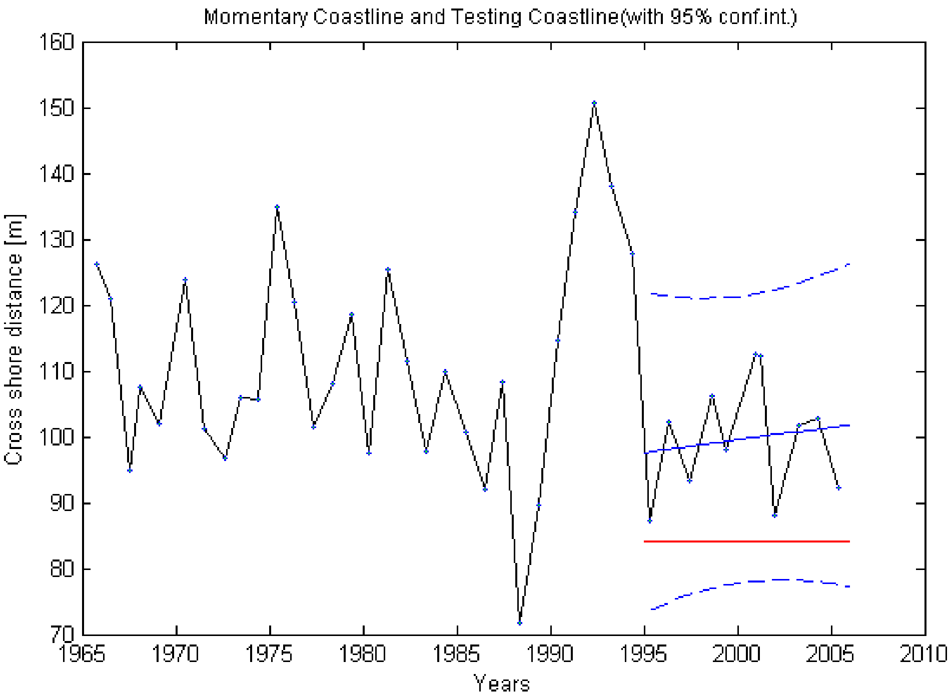


Figure 13 MCL and TCL in transect 4050

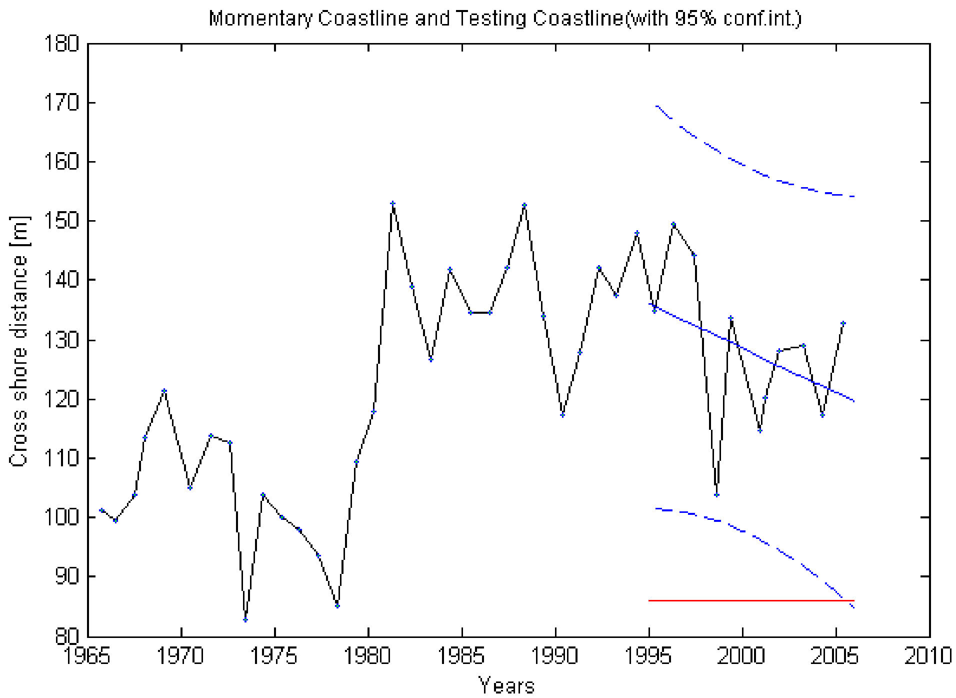


Figure 14 MCL and TCL in transect 4150

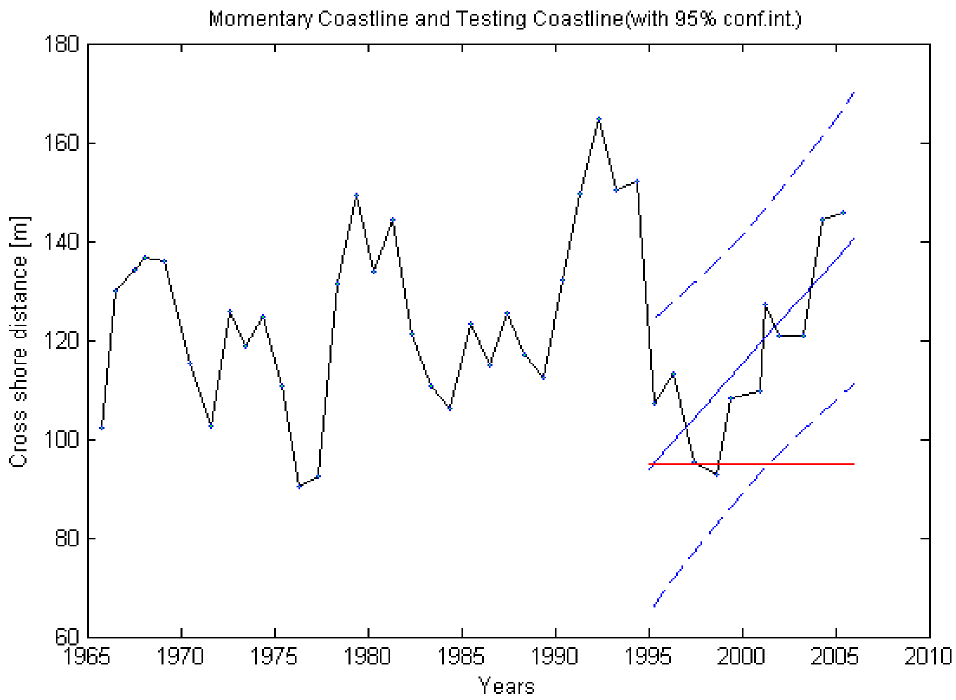


Figure 15 MCL and TCL in transect 4250

5 Research questions and Coastal State Indicators

5.1 Interviews

The objective of Phase 1 is to make a monitoring strategy to facilitate an objective evaluation of the PEM system. This is why several interviews have been carried out with coastal experts and people involved in the Ecobeach experiment in Egmond. The following persons where interviewed during Phase 1:

- Per Sorensen (Kystdirektoratet)
- Sander van Rooij/Kees van Ruiten (RIKZ)
- Klaas-Jan Visser/Ad van 't Zelfde (BAM)
- Aart Kroon (DTU)
- Henk Steetzel/Jan van de Graaff (ENW)
- Bas Arens (Arens Bureau voor Strand- en Duinonderzoek)

In this Paragraph, an overview is given of the expectations, recommendations and bottlenecks that exist with the interviewed persons.

5.1.1 Expectations

Expectations concerning the effects of the drainage pipes on the coastal system and the functioning of the pipes vary from no effect to an expected growth in beach volume of 100 m^3/m. Not much is known about the physical operation of the PEM drainage system. According to the interviewed coastal experts this makes it difficult to give a well grounded judgement and speak out on expectations. Due to lack of background information on the physical working of the PEM system and consequently the difficulty for experts to give their scientifically founded judgement we have decided to speak of *believers* and *disbelievers* in the working of the PEM system.

As regards the effect on the beach, expectations under the *believers* in the PEM system ranged from relatively small effects such as a quicker restoration of the beach profile after a storm than without the pipes, to more pronounced effects such as 100 m^3/m growth in beach volume. The *disbelievers* think that the PEM system will have no effect outside of the natural behaviour of the beach.

As regards the theory behind the drainage technique, the *believers* hypothesize that the system might have a pressure equalising effect on a tidal and/or shore wave timescale. Also, the pipes might stimulate 'washing out' of fine sediment, stabilizing the beach. The *disbelievers* see no physical reason why these passive drainage pipes would lower the water table. They argue that the effect, if any, will be very local and can never generate an overall growth of the beach on a larger scale than several meters in the horizontal. With an alongshore distance of 100 m between the pipes, this effect is nil.

5.1.2 Possible bottlenecks and recommendations

- The distinction between natural variation of the coastal behaviour and variations due to the drainage system has been seen to be difficult to make in the Danish case. This needs special attention in the definition of the research questions and the monitoring strategy.
- In the Danish case, sandwaves walking into the area of interest are brought up as possible cause of beach growth. The behaviour of sandwaves along the Egmond coast should be taken into acount in the monitoring strategy by choosing the area over which the mean behaviour is shown, large enough to incorporate possible sandwave movement. Aart Kroon advises a coastal stretch of 1.5 km minimum.
- In the Danish case, all analyses focus on the dry beach. It is recommended to include the subtidal area in the analyses of the Dutch case, and the interaction between the wet and dry beach, because cross-shore processes can be just as large as longshore processes, if not larger.
- Sand drift into the dunes can be substantial. If the drainage pipes have a lowering effect on the water table in the beach, the sand will be dryer and thus easier transported into the dunes by the wind.
- In the present set-up of the Egmond experiment, almost no spatial reference area is envisaged. It is recommended to do include a spatial reference area south of the southern test area, to compare the natural coastal behaviour and the coastal behaviour in an area with Ecobeach under the same conditions, instead of only comparing with historic data.
- Storm events can have a large (short-term) erosional effect on the beach. Because expectations exist about the behaviour of the beach with PEM modules after a storm, storm events should be taken into account in the monitoring strategy.
- For the operational management of the system through the first year, it would be convenient if monthly monitoring with a longshore spatial resolution of approximately 50 m will be operated. This way, it will be easy for BAM to get information about the local effect of the drainage pipes. If effects are negative, BAM can take measures (remove pipe, push pipe deeper into the sand, etc.).
- When looking at beach width it is important to take the barcycle in this area into account. Sandbars show a cyclic cross-shore behaviour with a lifetime cycle of approximately 15 years in Egmond. If a sandbar comes into existence from the beach, the beach width is temporarily larger, but the sandbar will detach from the beach, leading to a smaller beach width again. This effect should not be confused with a positive/negative effect of the PEM modules on the beach width.

5.2 Research questions on the effects of Ecobeach on the natural behaviour of the coast

From the present knowledge about the PEM system, the natural behaviour of the Egmond coast and the interviews with experts and people involved in the Ecobeach experiment, we can distil research questions which will serve as input for Phase 2. These research questions are given below (pointwise):

(1) Do the PEM modules have a substantial effect on the width and volume of the dry beach in the test area?
The definitions of beach width and volume are given in Paragraph 4.2.1. In the historic data of beach width and volume (Paragraph 4.2.4) trends, with uncertainty bands on the data, are given over the past 10 years. If the beach width and/or volume after one year with PEM modules lie outside these uncertainty bands, it can be concluded that a substantial effect of the PEM modules on the beach width and/or volume may exist. We need to focus on the southern test area because in this area the effects of the past nourishments are minimal. Also, a spatial comparison has to be made with a more southward undisturbed reference area, where no PEM modules are installed. The cyclic behaviour of the bars should be taken into account in this analysis (see Paragraph 5.1.2).

(2) Do the PEM modules have a substantial effect on the MCL position and volume in the test area?
The definitions of MCL position and volume are given in Paragraph 4.3.1. Also in this case, we have calculated the 10 year trend from historic data (Paragraph 4.3.2), together with its 95% confidence interval. From this data, the uncertainty bands on the data can be calculated (not shown in the figures). If the MCL position and/or volume after one year with PEM modules lie outside these uncertainty bands, the PEM modules may have a substantial effect on the MCL position and/or volume. Again, we need to focus on the southern test area, because of the reduction of nourishment effects in the data. A spatial comparison can again be made with a more southward located reference area without PEM modules.

(3) Do the PEM modules have a substantial effect on the slope/volume of the intertidal beach in the test area?
From the interviews we learn that it is expected by some people that the PEM modules will cause the intertidal beach to become concave, thus creating a buffer in case of storm events. During a storm, it is hypothesised that this buffer will be transported cross-shore. The presence of this buffer will then lead to a quicker restoration of the profile after a storm event. The slope and volume of the intertidal beach in the southern test area just before and just after a storm event should be compared with the slope and volume of the intertidal beach in a more southern reference area at the same points in time. Slope of the intertidal beach can be expressed in terms of beach width, because the z-levels of the intertidal beach are fixed. A wider intertidal beach will subsequently be a less steep beach.

(4) Do the PEM modules have a substantial effect on the aeolian transport from the dry beach into the dunes in the test area?
From the interviews it has to be realised that aeolian transport can play a significant role in cross-shore sediment transport processes. If the beach does become dryer due to the PEM modules, an increased aeolian transport into the dunes could and should be expected in the area with the modules.

5.3 Coastal State Indicators

To be able to answer the research questions described in Paragraph 5.2, we need to define clear indicators that tell us something about the state of the coast. The monitoring in Phase 2 can then be designed to give information about these indicators. In Table 2, the indicators to answer the research questions are given, together with the data needed to quantify the indicators and the measuring techniques available to collect these data. It can be seen from this table that several different measuring techniques are possible for one type of data. The available measuring techniques have different possible measuring frequencies. The choice for a certain measuring technique will depend on the frequency needed for the analysis of the indicator.

Table 2 Indicators defined for each research question with the data needed and the measuring techniques available.

Research question	Indicator	Data	Prefered frequency	Measuring techniques
1	Beach width	xyz +3.0 to -0.76 m NAP	once a month	dGPS, WESP, JARKUS
	Beach volume	xyz +3.0 to -0.76 m NAP	once a month	dGPS, WESP, JARKUS
	Bar location	xy bars	once a month	WESP, JARKUS, Argus
2	MCL position	xyz MCL area	once a month	WESP, JARKUS, Argus + dGPS
	MCL volume	xyz MCL area	once a month	WESP, JARKUS, Argus + dGPS
3	Intertidal beach volume	xyz +1.34 to -0.76 m NAP	event driven + once a month	Argus, dGPS, WESP, JARKUS
	Intertidal beach width	xyz +1.34 to -0.76 m NAP	event driven + once a month	Argus, dGPS, WESP, JARKUS
4	Dune volume	xyz first dune	once a month	dGPS, JARKUS, erosion pins

5.3.1 Prefered frequency of information

Beach width

Historic data for the analysis of beach width from JARKUS are measured once a year. Utrecht University has measured the dry beach (from dunefoot to low-water line) with dGPS each month for the period between May 2002 – June 2004 and March 2006 – present. To be able to extend the trends from these data and compare the beach width with this historic evolution, the prefered measuring frequency is once a month. In the comparison with historic JARKUS, all 2007 monthly data will be shown, but the regular 2007 JARKUS measurement will be marked, so that it can be treated as a normal JARKUS measurement in the analysis.

Beach volume

The same argumentation (as for beach width) applies to beach volume, so the prefered measuring frequency is once a month as well.

Bar location

In the analysis of beach width, it is stressed to take into account the location of the bars. Sandbars show a cyclic cross-shore behaviour with a lifetime cycle of approximately 15 years in Egmond. If a sandbar comes into existence from the beach, the beach width is temporarily larger, but the sandbar will detach from the beach, leading to a smaller beach width again. This temporary effect should not be confused with a positive/negative effect of the PEM modules on the beach width. The same measuring frequency as for beach width and volume should be chosen, to incorporate the results in the analysis. Thus, a monthly data collection for the analysis of bar location is prefered.

MCL position

Historic data for the analysis of the MCL position from JARKUS are measured once a year. The minimal prefered measuring frequency of the MCL area is thus once a year. It is though advised to measure the profile more often to track the MCL evolution through the year and to enable the link between the dry beach (which will be measured monthly) and the subtidal area. The prefered measuring frequency is thus once a month (comparable with dry beach measuring frequency).

MCL volume

The same argumentation (as for MCL position) applies to MCL volume, so the prefered measuring frequency is once a month as well.

Intertidal beach volume

The measuring frequency of the intertidal beach volume should be flexibel with respect to storm events. It is thus prefered to measure the intertidal beach volume once a month, as well as just before and just after a storm event. Because a storm can only be selected after occurance, the measuring frequency should be at least once a day, in order to enable selection of pre- and post-storm data.

Intertidal beach width

The same argumentation (as for intertidal beach volume) applies to the intertidal beach width, so the prefered measuring frequency is daily as well.

Sand transport into dunes

There has been no analysis yet of the volume changes in the dunes in the test areas, but JARKUS data, that includes a part of the dunes, is present. Aeolian transport from the first dune further landwards is negligible, so analysis of volume changes in the first dune will give a good idea of the sediment transport from the beach to the dunes. Analysis will be focussed on historic trends in JARKUS data in the first dune, which has a measuring frequency of once a year. The measuring frequency of the dune volume will thus be at least once a year, but it will be interesting to make a coupling with the volume changes in the dry beach and the dune. This will close the cross-shore sediment balance. The prefered measuring frequency will thus be once a month (comparable with dry beach measuring frequency).

6 Monitoring Phase 2

6.1 Measuring techniques

A reverse version of Table 2 is given in Table 3, where the current meauring programme for Egmond is given, together with the data that can be collected from the different measuring techniques. For the techniques that are already deployed in Egmond, the current measuring frequency is given. The indicators that can be derived from the collected data are given in the last column. Also, possible other techniques are shown, such as WESP measurements or erosion pins. Erosion pins are pins stuck into the dune with a regular spacing, that have a measure printed on the side. From this measure, the dune height can be read with the eye as often as needed.

Table 3 Possible measuring techniques in Egmond together with the data collected with these techniques, the current measuring frequency and indicators that can be derived from these data.

Measuring techniques	Data	Current frequency	Indicator
Argus	xyz +1.34 to -0.76 m NAP, xy bars	every hour	Beach width, intertidal beach volume, intertidal beach width, bar location
dGPS	xyz +3.0 to -0.76 m NAP	once a month	Beach width, beach volume, intertidal beach volume, intertidal beach width
WESP	xyz MCL area	none	Beach width, beach volume, intertidal beach volume, intertidal beach width, bar location, MCL position, MCL volume
JARKUS	xyz MCL area + first dune	once a year	Beach width, beach volume, intertidal beach volume, intertidal beach width, bar location, MCL position, MCL volume, dune volume
erosion pins	xyz first dune	none	Dune volume

6.2 Measuring frequency

The current measuring frequencies of the existing measuring programme in Egmond are given in Table 3. Of course, an adjustment to this programme is possible if monitoring needs ask for this. The indicators and measuring techniques are brought together in Table 4, where the match in data type is given with an 'x' and a match in frequency is indicated in gray. It can be seen that most indicators find a measuring technique that, with the current measuring frequency, satisfies the prefered frequency. The MCL position and volume and dune volume are exceptions to this, so for these indicators an adjustment needs to be made to the current measuring programme.

Table 4 Match between indicators and possible measuring techniques. A matching frequency is indicated in grey.

	Beach width	Beach volume	Bar location	MCL position	MCL volume	Intertidal beach volume	Intertidal beach width	Dune volume
Argus	x		x			x	x	
dGPS	x	x				x	x	
WESP	x	x	x	x	x	x	x	
JARKUS	x	x	x	x	x	x	x	x

It is thus needed to increase the measuring frequency of JARKUS and/or WESP to be able to satisfy the prefered frequency of the MCL position and volume. Also, for the dune volume, a denser frequency is needed. Because of logistic difficulties (costs/planning), it will not be possible to carry out more than two JARKUS and two WESP surveys a year. In total, four surveys of the MCL area will be feasable. For the dune volume, erosion pins can be applied, that will be surveyed (with the eye) once a month (possibly together with the dGPS survey). These data will be added to the JARKUS data of the first dune which will be measured twice a year.

6.3 Spatial range of monitoring

It is recommended (pers.comm. Aart Kroon) to focus the analyses on the southern test area and to move the planned (additional) monitoring efforts of the northern test area to a reference area to the south of the southern test area. It can be expected that objective conclusions about the effects of the PEM modules on the behaviour of the CSI's will be difficult to be made if no such spatial reference is monitored. The northern test area will then be monitored in the same way as is being done in the current monitoring programme, thus with Argus (every hour) and JARKUS (once a year). With these data, it will be possible to give an idea about the effects of the drainage system on an area which has been heavily nourished in the past years.

The advised spatial ranges and resolutions of the measuring techniques are given in Table 5, taking into account the addition of a reference area to the south of the southern test area. The length of the reference area will be 2 km (from RSP 4300 – 4500). In this area, no beach cabins are present, so no large shoving of sand is expected here.

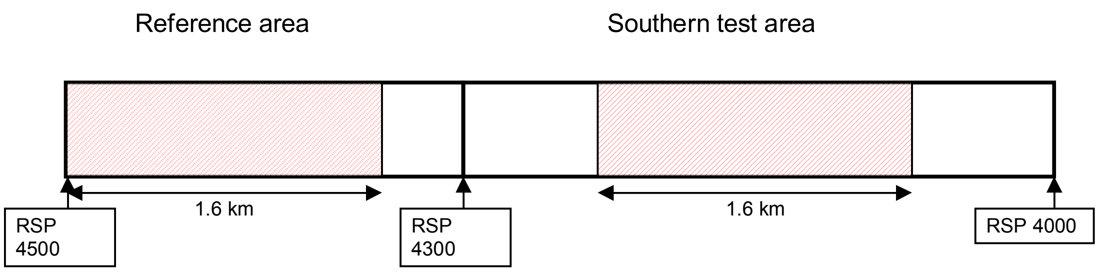
Table 5 Spatial range and resolution (cross-shore and longshore) for each measuring technique.

Measuring techniques	**Cross-shore range**	**Cross-shore resolution**	**Longshore range**	**Longshore resolution**
Argus (Coast3D)	+1.34 to -0.76 m NAP and xy bars	+/- 0.1 – 1 m	+/- RSP 3950 – RSP 4300	+/- 0.1 – 15 m
Argus (JvSpeijk)	+1.34 to -0.76 m NAP and xy bars	+/- 0.1 – 1 m (new cameras)	+/- RSP 3600 – RSP 3950	+/- 0.1 – 15 m (new cameras)
dGPS	+3.0 to -0.76 m NAP	+/- 20 m	RSP 4000 - 4500	100 m
WESP	MCL area	< 1 m	RSP 4000 - 4500	125 m
JARKUS	MCL area + first dune	< 1 m	RSP 3600 - 4500	125 m
erosion pins	+3.0 m NAP (dunefoot) to 50 m landwards (first dune)	5 m	RSP 4000 - 4500	125 m

6.4 Data transfer and analysis

The analysis of the data will be carried out on different longshore cubings in the test and reference areas. The cubings are shown in Figure 16. All indicators will be determined by averageing over the different cubings. To facilitate this analysis, it is needed that all data are provided in gridded format (20x20 m grid) as well as in the original measuring format (f.i. JARKUS transects). For the analysis of the dune area, data on a 5x5 m grid is needed.

The length of the largest cubing of 1.6 km is chosen based on recommendations made by Aart Kroon, considering the effect of longshore sandwaves. If we want to exclude the effect of these sandwaves, an averageing length of more than 1.5 km is advised (see Paragraph 4.2.3). The intermediate cubing is chosen to have a length of 200 m. This will ensure the inclusion of at least one cross-shore array of drainage pipes in the test area. Also, this length will capture all longshore measuring resolutions of all measuring techniques.



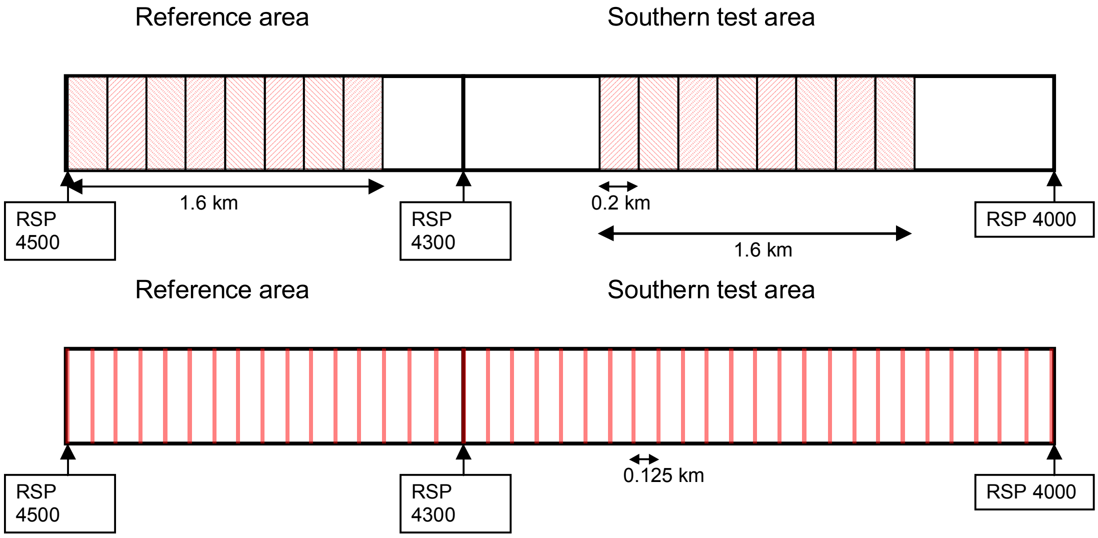


Figure 16 Cubings in southern test area and reference area. The upper panel shows the largest overall cubing with a longshore length of 1.6 km. The middle panel shows the intermediate cubings with a longshore length of 200 m each. The lower panel shows the individual JARKUS transects. These will be used in the analysis of the JARKUS and WESP data.

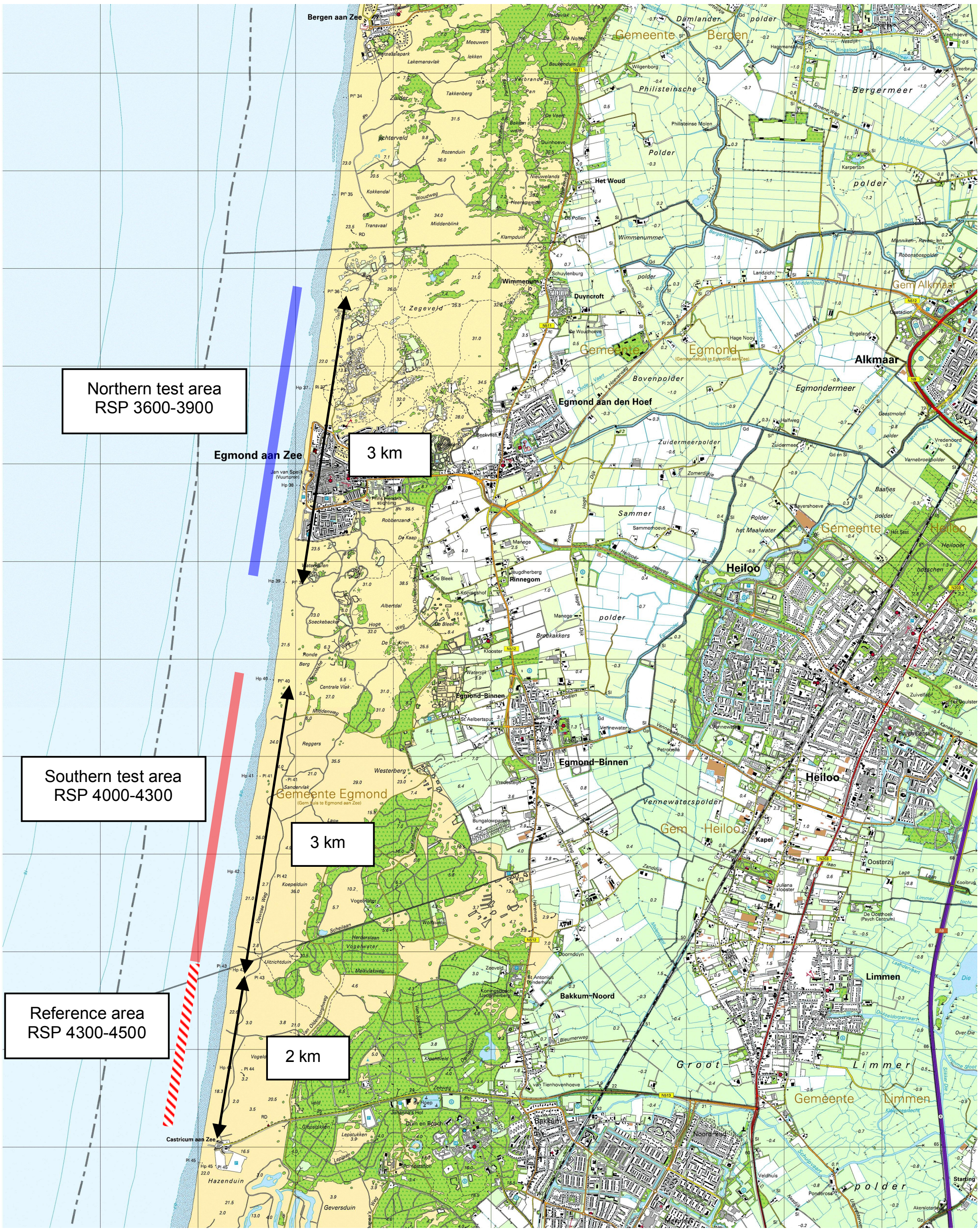


Figure 17 The two test areas and the reference area on a map of the Egmond coast. The southern test area and the reference area will be monitored intensively. The northern test area will only be monitored through JARKUS and Argus (JvSpeijk Lighthouse).

6.5 Summary table

Table 6 Summary table of advised monitoring and analysis during Ecobeach phase 2.

Measuring technique	Data (+ cross-shore range)	Monitoring frequency	Analysis frequency	Spatial range	Indicator
Argus	xyz +1.34 to -0.76 m NAP, xy bars	every hour	event driven + once a month	+/- RSP 3600 – RSP 4300	Beach width, intertidal beach volume, intertidal beach width, bar location
dGPS	xyz +3.0 to -0.76 m NAP	once a month	once a month	RSP 4000 - 4500	Beach width, beach volume, intertidal beach volume, intertidal beach width
WESP	xyz MCL area	twice a year (June/December)	twice a year (June/December)	RSP 4000 - 4500	Beach width, beach volume, intertidal beach volume, intertidal beach width, bar location, MCL position, MCL volume
JARKUS	xyz MCL area + first dune	twice a year (March/September)	twice a year (March/September)	RSP 3600 - 4500	Beach width, beach volume, intertidal beach volume, intertidal beach width, bar location, MCL position, MCL volume, dune volume
erosion pins	xyz first dune	once a month	once a month	RSP 4000 - 4500	Dune volume

A more detailed description of the analyses that will be carried out during Phase 2 will be given in a separate quotation by WL|Delft Hydraulics to RIKZ.

7 T0

To be able to distinguish the natural behaviour of the indicators from the behaviour due to the PEM modules it is valuable to define the T0 situation of the indicators as a historic trend of the indicators, rather than a static T0 situation. Examples of this type of trends are given in Paragraphs 4.2.4 and 4.3.2. In Phase 2, the historic trends will be determinded for all chosen indicators in all cubings. Together with experts on statistical analysis, a definition of a ‘substantial’ effect will be established (see research questions in Paragraph 5.2). Based on this definition and the T0 historic trend, the newly collected data will be analysed for each indicator.

To give an idea of the static situation of the beach in the test area(s), and to make sure a good measurement of the situation of the beach before installation of the modules is available, the static T0 from dGPS and Argus is given in the following paragraphs. These monitoring techniques will be used monthly in Phase 2 to show the intra-annual and event-driven behaviour of some indicators.

7.1 dGPS

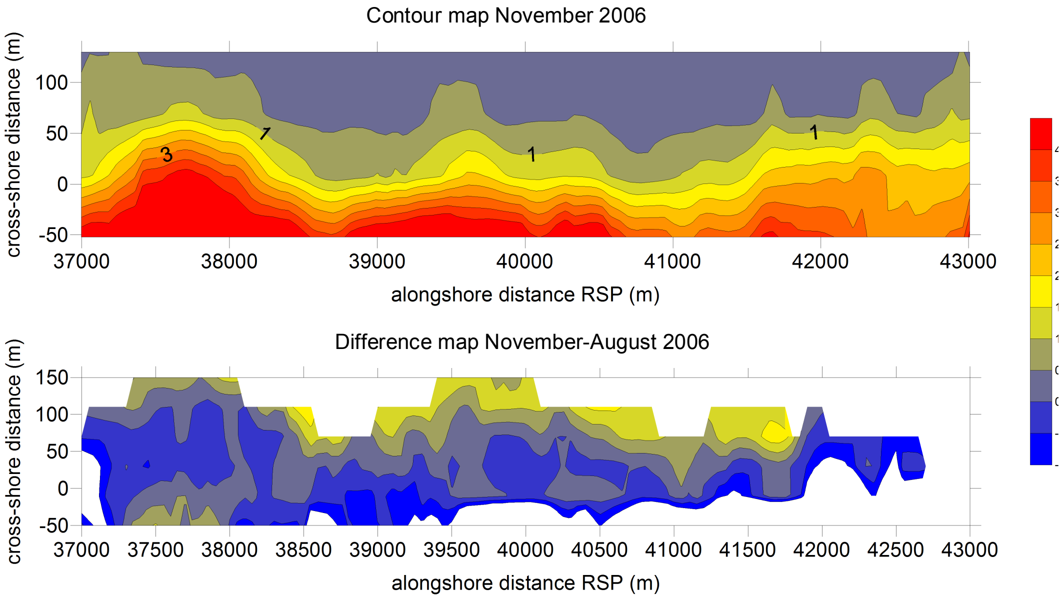


Figure 18 Contour map of the beach near Egmond aan Zee based on dGPS measurements done on 13 November 2006 (upper panel) and difference map showing the erosion and accretion between August and November 2006 (lower panel).

The upper panel in Figure 18 shows a contour map of the beach near Egmond aan Zee based on dGPS measurements done on 13 November 2007 (T0-survey). A sand wave feature can be observed with a wider beach (sand wave crest) near RSP 37.750 and a smaller beach (sand wave trough) around RSP 38.750. Compared to the survey on 9/10 August (see difference map in lower panel) the upper beach has eroded and the lower beach has accreted. This effect may have been caused by the storm that occurred in the first week of November, just before the T0 dGPS survey. Restoration of the beach to it's original state after the storm is expected. It may thus be recommended to also use the 9/10 August survey when analysing the original state of the beach before installation of the Ecobeach modules.

7.2 Argus

Just before the Ecobeach PEM modules where installed, a major storm hit the Dutch coast (first week of November 2006). It is very well possible that this storm has caused the beach to erode to the foreshore. After a while, this eroded material will then recover the beach to it's original position. To test this hypothesis, a first scan is made by looking at rectified Argus images of just before and just after the storm (see Figure 19 and Figure 20). From the figures we see that the beach just before and just after the storm look very much alike in the Argus images. The positions of the nearshore sandbars have slightly changed, but the beach width has not been affected very much due to the storm. At some locations the beach even appears to be wider after the storm than before, but this can be caused by the fact that the waterlevel in both images is not equal (difference of 6 cm).

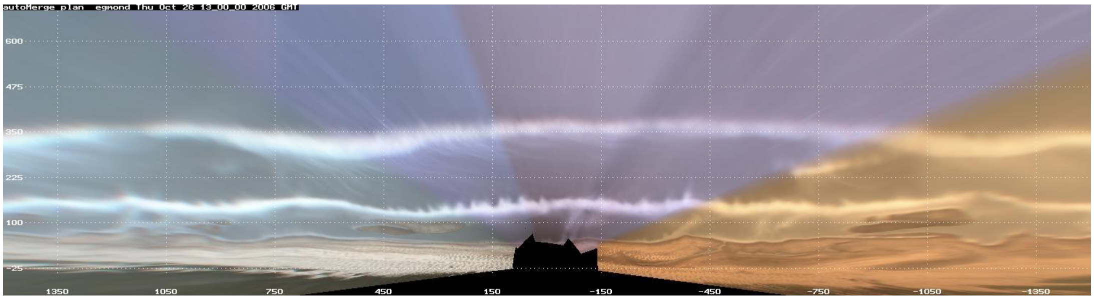


Figure 19 26 October 2006 (before storm) z-level = -0.60 m NAP

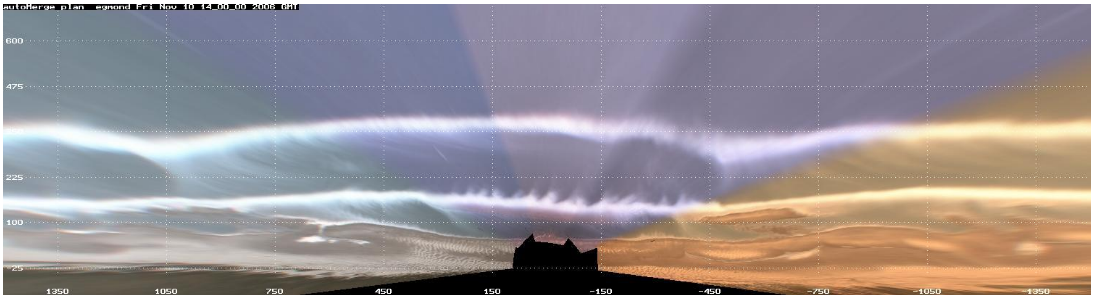


Figure 20 10 November 2006 (after storm) z-level = -0.66 m NAP

Concluding it can be said that at first sight, the storm appears to have had almost no effect on the beach width in the southern test area. The Argus image of 26 October 2006 will be chosen as the initial situation of the beach and foreshore from Argus. During the data analysis in Phase 2 of the Ecobeach project, this image will be used to derive initial values of all indicators that can be derived from Argus.

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A United States Patent 6547486

Patent information
Name: Method for Coastal Protection
Inventor: Poul Jakobsen
Assignee: SIC Skagen Innovationscenter
Patent no.: US 6,547,486 B1
Date of Patent: 15 April 2003

Abstract

In a method for coastal protection, where the coastal area has an underlying freshwater basin and below this a salt water tongue which extends obliquely down into the coastal area, the pressure is equalized in the groundwater basin at least along an area at the shore line completely or partly to the atmosphere through pressure equalization modules, preferably in the form of pipes with a filter at the bottom, which extend down into the groundwater basin. This causes sedimentation of material and thereby an increase in the width of the shore. The resulting sand drift may be utilized for additional building-up of the coastal area by further establishing fascines.

Claims

What is claimed is:

1. A method for protecting a coastal area which includes a beach area that meets salt water at a shoreline, and where a freshwater basin underlies the coastal area and a salt water tongue extends below the freshwater basin at an oblique angle, the method comprising extending at least one pipe downwardly in the beach area near the shoreline so as to reach the freshwater basin and communicate the freshwater basin with the atmosphere such that at least a partial equalization of a pressure in the freshwater basin with a pressure of the atmosphere is achieved in said beach area by means of said communication.

2. A method according to claim 1, wherein said at least one pipe includes a filter in a part thereof that extends into the freshwater basin.

3. A method according to claim 1, wherein a plurality of pipes are extended downwardly through the beach to the fresh water basin at a distance from the shoreline.

4. A method according to claim 3, wherein, said coastal area also defines a swash zone adjacent said shoreline, and including placing a plurality of additional said pipes in said swash zone to communicate with said freshwater basin.

5. A method according to claim 1 wherein fascines are provided on the coastal area.

6. A method according to claim 1, wherein said at least one pipe includes an anchoring element.

7. A method according to claim 6, wherein said at least one pipe has a pipe stub which protrudes upwardly from the coastal area and a downwardly bent extension attached to the stub which includes an aperture facing downwardly and which defines an upper free end of the pipe.

Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a method for coastal protection where the coastal area has an underlying freshwater basin and below this a salt water tongue which extends obliquely down into the coastal profile.

2. The Prior Art

For coastal protection, it is generally known to build breakwaters of huge stones or concrete blocks which extend from the beach to a distance into the water. Breakwaters are effective, but the costs of construction and maintenance are relatively great. Another coastal protection method is coastal feeding where large amounts of sand are transported to the stretch of coast which is to be protected. This method also involves great costs of construction and maintenance, since large amounts of sand have to be transported. These two methods are still the most widely used coastal protection methods.

In connection with the establishment of intakes for the pumping of sea water for use in salt water aquarias, it was discovered in the early 1980s that sedimentation took place around the intake, which became clogged because of the deposits on top of the intake. This was the incentive for experimenting with a new method for coastal protection, as described in DK 152 301 B. The idea of the method is to pump water from drains established along the shore line, resulting in sedimentation at the drains. However, this method never found extensive use, as it requires a great pumping capacity and consequently high costs of construction and high pump operating costs.

U.S. Pat. No. 5,294,213 discloses a similar system likewise based on drainage pipes established in parallel with the coastal both on the beach and in the water. The operation of the system, which is likewise based on pumping of water, is adapted to the weather, i.e., whether ordinary water level, low water, high water or storm conditions. The system includes a water reservoir into which the water may be pumped through the drainage pipes, and water may be pumped through these into the sea, e.g., to remove sand banks formed by a storm.

A corresponding method is known from U.S. Pat. No. 4,898,495 to keep an inlet, which debouches into the sea, open. This method is likewise based on pumps. The system comprises various diffuser arrangements to remove deposits from the mouth of the inlet by fluidizing these and transporting the material further downstream of the inlet mouth by generating a flow. Sedimentation is carried out downstream of the inlet mouth by pumping water from drains to the diffuser arrangements.

An object of the present invention is to provide a method for coastal protection which is not vitiated by the drawbacks of the known coastal protections.

SUMMARY OF THE INVENTION

This is achieved according to the invention by a method which is characterized in that the pressure of the groundwater basin at least along an area at the shore line is equalized completely or partly through pressure equalization modules, preferably in the form of pipes with a filter at the bottom, which extend down into the groundwater basin.

It has surprisingly been found by the invention that positioning of pressure equalization modules in the beach results in sedimentation of material at the area where the modules are placed.

A possible explanation as to why coastal accretion takes place is that the very fine sand which is fed to the profile partly by the sea and partly by the wind and which is packed with silt and other clay particles, reduces the hydraulic conductivity. Deeper layers in the coastal profile, which have exclusively been built by the waves of the sea, are primarily coarse in the form of gravel and pebbles which have a greater hydraulic conductivity. The difference in hydraulic conductivity will be seen clearly when digging into a coastal profile, it being possible to dig a hole in the profile, and the groundwater will then rise up into the profile once the water table is reached. The reason is the very different hydraulic conductivity and that the freshwater is under pressure from the hinterland. Thus, the coastal profile may be compared to a downwardly open tank where the tank is opened at the top with the pressure equalization modules which extend through the compact layers of the profile so that the water runs more easily and thereby more quickly out of the profile in the period from flood to ebb. This means that a pressure equalized profile is better emptied of freshwater and salt water in the fall period of the tide. When the tide then rises from ebb to flood, a greater fluctuation occurs in the foreshore, as the salt water in the swash zone is drained in the swash zone so that materials settle in the foreshore during this period of time. Conversely, coastal erosion takes place if the freshwater is under pressure in the foreshore, as the salt water will then run back into the sea on top of the freshwater and thereby erode the foreshore. In reality, the pressure equalization modules start a process which spreads from the pressure equalization modules, as the silt and clay particles are flushed out of the foreshore when the fluctuation is increased because of the draining action of the modules. Further, a clear connection has been found between the amount of sediment transport on the coast and the rate of the coastal accretion. It has been found that the pressure equalization modules create a natural equilibrium profile with a system of about 1:20, so that the waves run up on the beach and leave material, as water in motion can carry large amounts of material which settle when the velocity of the water decreases. The profile must therefore have a given width with respect to the tide and a maximum water level in the area. Coastal profiles with pressure equalization modules naturally become very wide, which results in a very great sand drift on the foreshore. This great sand drift is utilized by establishing longitudinal fascines high up in the beach and transverse fascines with an increasing height toward the foot of the dune, the fascines forming the upper part of the beach profile.

The invention will be described more fully below with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a cross-section through a coastal profile,
FIG. 2 shows a pressure equalization module intended to be positioned on the beach,
FIG. 3 shows a pressure equalization module intended to be positioned in the swash zone,
FIG. 4 shows a stretch of coast seen from above with pressure equalization modules and fascines, and
FIG. 5 shows a coastal profile in the stretch of coast in FIG. 4.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

As shown in FIG. 1, a freshwater basin is present below a coastal profile 1, and this freshwater basin is defined at the bottom in a downwardly inclined plane by a tongue of salt water 3 which has a greater density than freshwater.

The reason for coastal erosion is thus that when the freshwater below the beach profile is under pressure, the salt water seeping down into the profile runs back into the sea on top of the freshwater 2, as shown in FIG. 1. When the pressure of the freshwater decreases, the salt water seeps down through the material in the coastal profile and is mixed with the freshwater and thus does not erode the coastal profile, but, instead, material settles on the beach.

As shown in FIG. 2, the pressure equalization modules may consist of a rigid filter pipe 6 which is connected to a pipe 7 having a sleeve 7a. The filter and the pipe may thus be pressed, flushed or dug into the freshwater basin 2. Preferably, the pipe 7 has a length such that it protrudes slightly above the surface of the coastal profile 1 when the filter is in position in the freshwater basin. The pipes with filters, as shown in FIG. 2, are arranged in a row in a line which is perpendicular or approximately perpendicular to the shore line. The pipe 7 is open at the top so as to create good hydraulic contact down to the freshwater basin.

When the pressure in the freshwater basin has been equalized by means of the pressure equalization modules 12, the sedimentation of material on the stretch of coast may be accelerated according to the invention by establishing further pressure equalization modules 13 in the swash zone 4. An expedient arrangement of a module to be positioned in this zone is shown in FIG. 3 and comprises a rigid pipe 7' connected with a horizontal filter pipe 6'.

In both cases, the modules are provided with an anchoring element 8 intended to be dug into the sand to prevent unauthorized removal of the modules. The anchoring element is in the form of two angled plate elements secured to the rigid pipe. Furthermore, the pipe end, which protrudes from the sand, is provided with a curved termination 9 to prevent unauthorized filling of the pipe with sand, stone, etc. Optionally, the pressure equalization modules may be connected with dug pipes which are run to the foot of the dune where free communication with the atmosphere is created, thereby avoiding protruding pipe stubs.

The use of such pressure equalization modules on a stretch of coast has resulted in a land reclamation of a width of 4-6 metres and an increase in the coastal profile of 60-70 cm in 40 days.

Coastal profiles with pressure equalization modules naturally become very wide, as mentioned, which results in a great sand drift on the foreshore. As will appear from FIGS. 4 and 5, this great sand drift is utilized by establishing longitudinal fascines 10 high up in the beach and transverse fascines 11 of an increasing height toward the foot of the dune. The upper part of the beach profile may be given the desired shape by adapting the length, orientation and height of the fascines. The fascines may, e.g., be formed by brushwood of pine and spruce or the like dug into the coastal profile or stacked between buried piles, which makes it easy to give the fascines the desired shape.

The invention is unique by low costs of construction and operation, the cost of operation involving merely ordinary inspection and maintenance of the systems.

New research in the field has documented that the groundwater pressure on a coastal profile is very decisive for its appearance. It has been demonstrated that coastal profiles having a high freshwater pressure become narrow and concave (also called winter profile), while coastal profiles without noticeable freshwater pressure become wide and convex (also called summer profile). Narrow, concave coastal profiles having a high freshwater pressure are seen in Denmark typically at Vejby Strand on the north coast of Zealand and south of Lønstrup at Mårup Kirke.

Narrow, concave coastal profiles are greatly exposed to erosion, while wide, convex coastal profiles have beach accretion. With the invention, as described, it is possible to convert a narrow, concave coastal profile into a wide, convex coastal profile and thereby to protect the coast.

Schematic placing in coastal profile

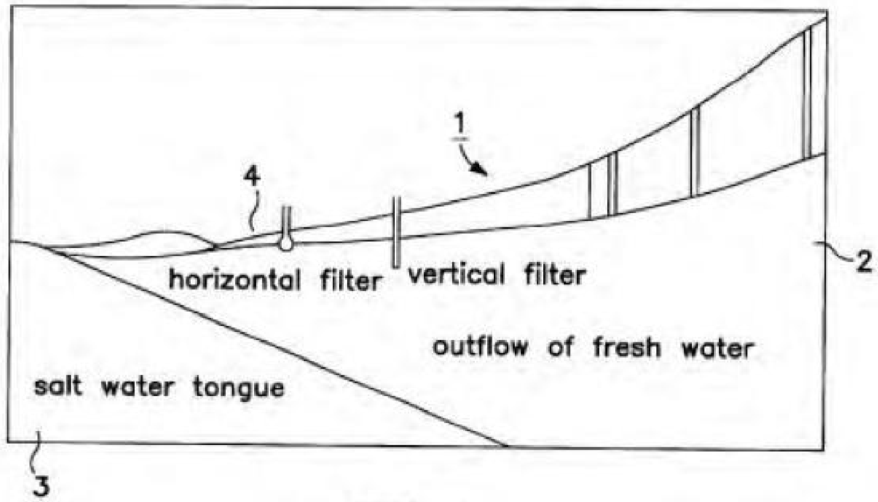

FIG. 1

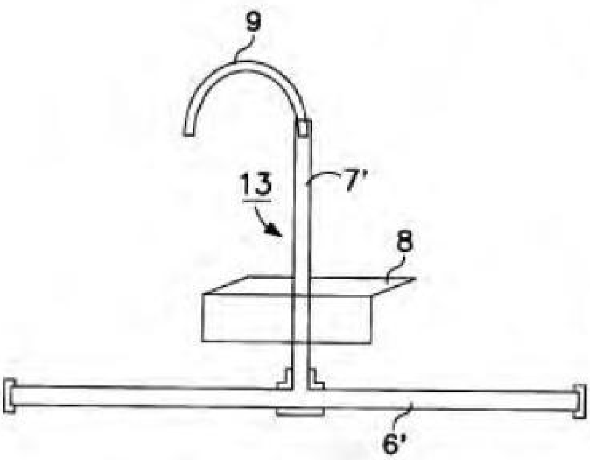

FIG. 3

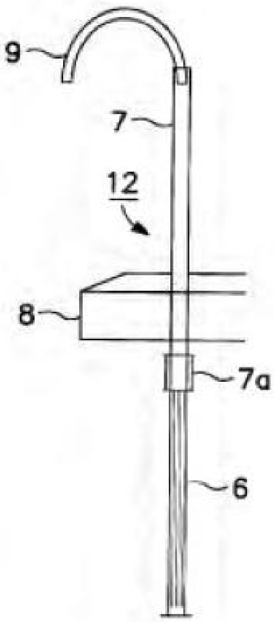

FIG. 2

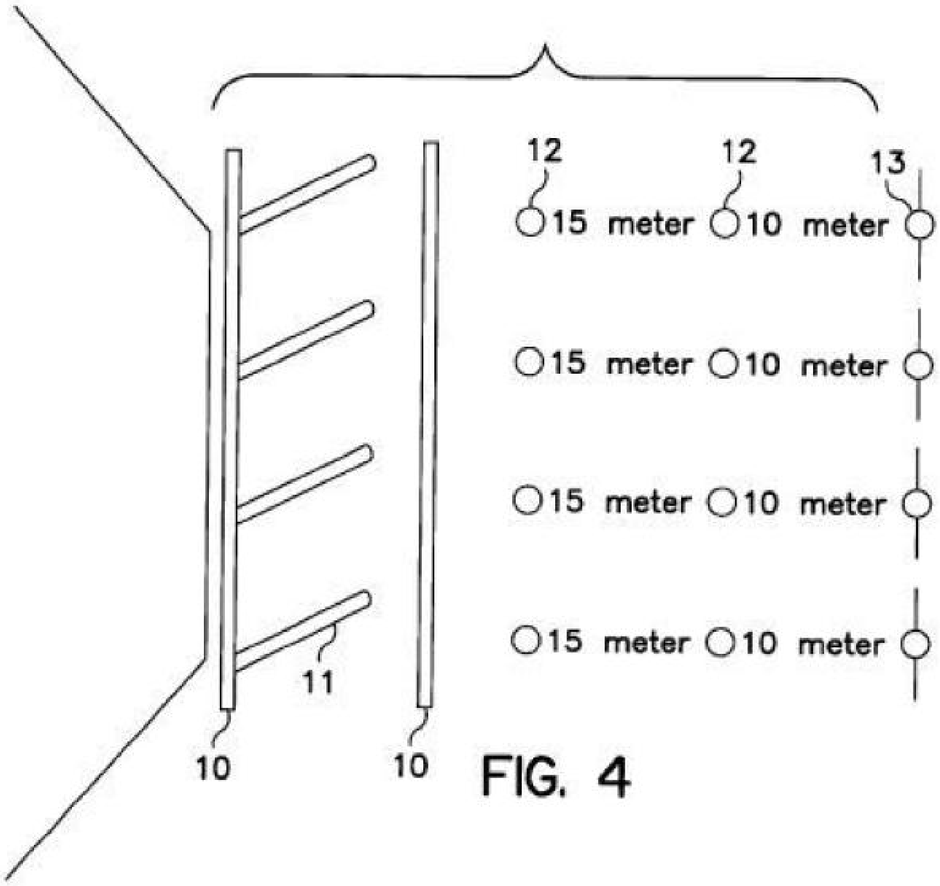
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FIG. 4

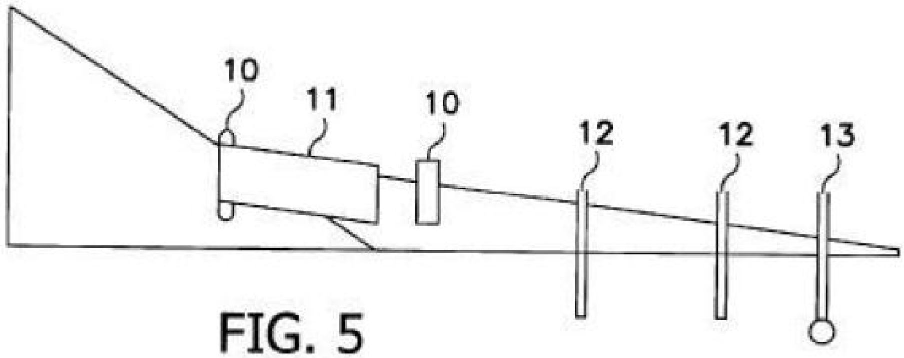
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FIG. 5

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