Morphological Impact of

Coastal Structures

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December, 2010

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Contents

Abstract

In many coastal engineering problems the application of coastal structures to resolve these problems seems to be a proper solution. In a lot of cases, however, the implementation of coastal structures does not lead to the expected situation.

Erosion management operations may have unwanted impacts on the ecology, geomorphology and appearance of a coastal system. Decisions on the most appropriate management approach at a given site should be driven in part by the desire to minimise these impacts so as to preserve the natural characteristics of the coast. It is important to bear in mind that erosion of beach and dune areas is a natural and dynamical process and normally should not be regarded as a problem. Problems only arise when erosion threatens human activities or assets, or when the erosion is the result of human interference with coastal processes along an adjacent frontage.

A profound study of the actual processes causing the problem should always precede the design of the structure itself; because history proofed that in many cases a wrong solution to the problem has been chosen. This report intends to provide some clear guidelines to facilitate the design process of coastal structures by discussing several cases and relevant design aspects that seem to be obvious but could easily be overlooked. Especially the recognition of the mechanisms that cause the occurring problem takes a central part in the design process of coastal engineering measures and thus the main emphasis of this report is to awaken consciousness of the mechanisms involved.

The cases as discussed in this report are all examples of actual problems, but the possible countermeasures that are sketched should not be implied as “the one and only solution to the problem”. Every solution has its impact on the morphological balance of the coastal zone; this report describes these impacts. It becomes clear after studying all cases that measures to resolve coastal engineering problems are very complicated and adverse effects can be expected in many cases. The main purpose of this report is to make decision-makers in coastal engineering matters aware of the complications that are involved.

This report is basically a tool for decision-makers with none or little (coastal) engineering background e.g. politicians. After reviewing the cases and taking notice of the conclusions and recommendations provided in this report the decision-maker should be a serious party in a discussion on coastal zone management topics.

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1. Introduction

1.1. Introduction to this report

Many coastal areas suffer from (severe) erosion of the beach and dune area. A study carried out in 2004 by the European Commission indicates that about 20,000 km of European coasts are affected by coastal erosion; most of the impacted zones (15,100 km) are actively retreating, some of them in spite of coastal protection works (2,900 km). In addition, another 4,700 km have become artificially stabilized (EUROSION, 2004 [3]).

Erosion does not only occur on the European coasts but is a worldwide phenomenon. Actually erosion (and accretion) of coastal zones is a natural and dynamical process driven by various factors such as:

- waves
- currents
- tides
- wind
- geological circumstances
- sealevel fluctuations

Erosion is a natural process and only becomes a problem when other functions of the beach and dune area are threatened. For example tourist beaches or commercial buildings in the dune area are threatened by a retreating coastline. When erosion becomes a problem it is often considered to interfere within the coastal zone by implementing engineering measures. Past experience however has learned that sometimes these implementations have not always led to the expected effects on the long term coastline development.

Many coastal engineering failures can be traced back to inadequate site characterization analyses. Site characterization involves identifying distinguishing qualities and features of a region that have a direct and indirect impact on the conception, design, economics, aesthetics, construction, and maintenance of a coastal project (ASCE, 2001 [1]). The coastal environment varies spatially and temporally and therefore a design that is functionally, economically, and environmentally appropriate at one location may be inappropriate at another. Physical, biological, and cultural attributes need to be delineated so that an acceptable project is adopted and potential effects of the project are determined.

The risk of coastal erosion is defined as the result of the probability (frequency) of coastal erosion events and of the impacts (capital investment or population in the risk zone) (EUROSION, 2004 [3]). To reduce the risk of erosion and flooding at a particular location there basically are two approaches:

- ***Interfere within the natural processes by implementing coastal engineering tools (reduction of the "probability").***
- ***Abandon the area at risk and let nature develop a new equilibrium beach profile – this will often lead to loss of land (reduction of the "impact"),***

This report mainly discusses the implementation of coastal structures and therefore the option of abandoning the coastal area and let nature take it's cause is not further discussed here. In practical problem cases the most profitable approach in economical, environmental or social interests has to be determined preliminary.

Interfering within the natural processes by implementing coastal engineering tools
Coastal engineering tools can consist of "hard" measures or "soft" measures or a combination of these two. With 'hard' measures the implementation of structures such as groynes, breakwaters or seawalls is meant. 'Soft' measures are e.g. beach or dune renourishments or implementation of vegetation to prevent erosive forces to reach the backshore.

Past experience on the use of ‘hard’ protection schemes in coastal engineering practice learned that often the application of these structures has failed to resolve the problem under consideration for the long term. Many hard structural measures have had positive effects only in a short time and space perspective. The implementation of ‘hard’ structures in the coastal zone interferes within the morphological processes and can introduce new erosion problems (at adjacent coasts).

Past experience on the use of ‘soft’ protection techniques learned that renourishing the beach and dune or foreshore area contributes positively to safety as well as to other functions such as recreational and ecological values. Renourishments will have to be repeated at a regular basis because the processes causing the erosion problems are still active. The success of renourishment schemes depends for a great extent on the (easy) availibility of appropriate sediments to be used (mainly because of the costs involved to dredging operations or the environmental impact of dredging and renourishing operations).

The limited knowledge of coastal sediment transport processes at the (local) authority level has often resulted in inappropriate measures of coastal erosion mitigation (EUROSION, 2004 [3]). In many cases, measures may have solved coastal erosion locally but have introduced or severed erosion problems at other locations or have generated other environmental problems.

The Coastal Engineering Manual (ASCE, 2001 [1]) summarizes the site characterization as follows:
It is important when characterizing a site to:
- Include **all components** of the system.
- Recognize the extreme **temporal variability** in most physical and biological processes.
- Be cognizant of the **spatial variability** of processes, climate, land forms, underlying geology, biological habitat, and cultural resources. Process measurements made at one site may not be valid at another site only a short distance away.

The Coastal Engineering Manual (ASCE, 2001 [1]) concludes on site characterization:

‘the designer must think globally and engineer locally.’

1.2. Objectives of the report

This report mainly intends to:
- Provide awareness and understanding of the ***processes taking place at an eroding coast***. Especially for those without a coastal engineering background that are involved in coastal zone management (such as (local) authorities or politicians).
- Provide acknowledgement of the ***parameters determining the occurring processes*** at a particular problem site and the consequences of variations of these parameters.

In this report the application and implementation of coastal structures is discussed. The study will not describe specific practical problems but intends to give an overview of the possibilities on using coastal structures in various ‘problem areas’. Main emphasis is given on the description of processes rather than on the mathematical formulation of these processes.

Behaviour of possible beach or dune protection schemes during day-to-day conditions or storm surge conditions will be indicated in each case to create awareness of possible adverse effects or unforeseen behaviour during the life cycle of a protection scheme. Sometimes protection schemes are designed primarily for one particular (extreme) situation, but during the life-cycle of a protection scheme various conditions will occur and this also will have effect on the (morphological) impact of protection schemes.

The main aim of the present report is:
- ***To define a number of “standard” cases (problems) where structures might be used.***

The cases start with a brief description of the (assumed) physical background and a sketch to clarify the case. In each case the possibility of implementing various coastal structures will be discussed and possible adverse effects will be indicated. These sort of standardised cases can be reviewed by decision-makers ("the readers") as a comparison to their actual erosion problem to point out the various underlying processes that may be the cause of their problem.

- ***To provide clear guidelines to facilitate the design process.***
  Review of all cases and possible structural measures to point the wide variety in possible underlying problems and possible countermeasures.

Another intention of this study is to make decision-takers aware of the ***possible use of computer models*** to make a preliminary design or a feasibility study and also point out the shortcomings of computer models and the results (output) produced by computer models. It is not intended that the reader completely understands the mathematical schematisations used in a computer model but will become aware of the possibilities and can judge results critically.

Last aim is to ***present some practical examples*** in coastal engineering practice and discuss the effects of implemented coastal structures in example cases.

1.3. Outline of the report

This report's main emphasis is on:

- sandy coasts
- far field morphological impacts
- consequences on the seaside of the coastline

Sandy coasts
A large part of the worldwide coasts consists of sandy coasts and because of its unconsolidated character sandy beaches easily suffer from erosive forces. Unlike muddy coasts, sandy coasts are commonly in use for various purposes, such as recreation and protecting the hinterland from flooding. Because of the various uses of the sandy coast it is frequently desired to adjust the coast by engineering measures.

Far field morphological effects
This report mainly discusses the far field (or large scale) effects of implementation of structures; thus local scour around structures or instability of the structures are no subject in this report. Of course these aspects have to be taken into account later in the design process.

Consequences on the seaside of the coastline
This report only discusses the effects of measures at the seaward side of the coastline; thus the complex behaviour of shoals and gully's in a tidal estuary or lagoon is not discussed in this report. An overview of various coastal formations of sandy coasts is presented in Figure 1.1.

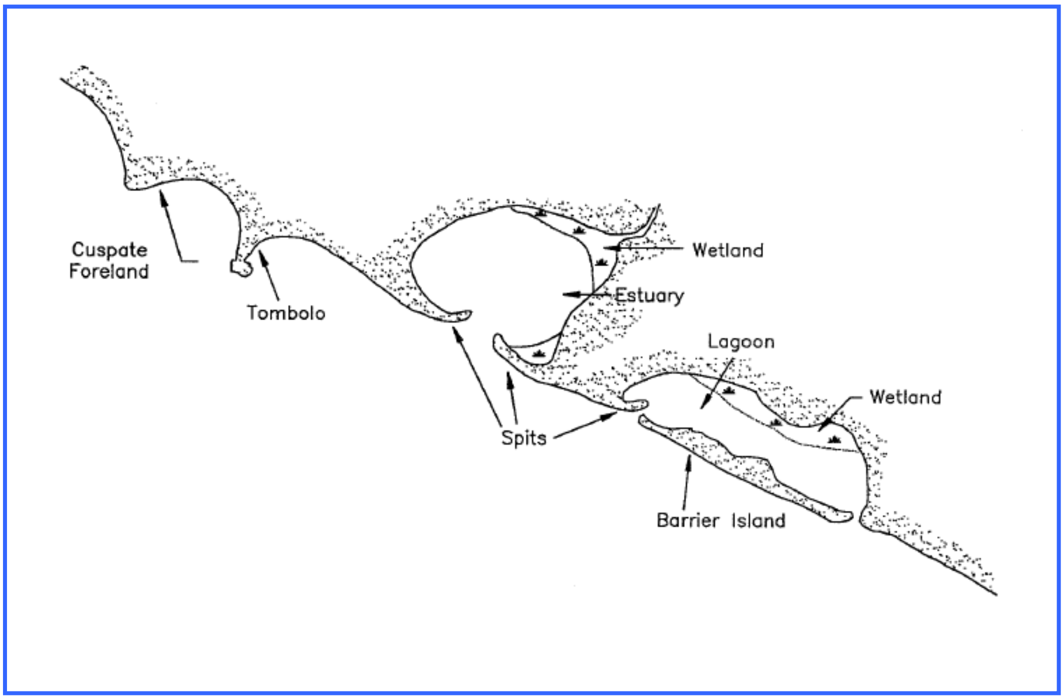

Figure 1.1: Various coastal formations at sandy coasts (from ASCE, 2001 [1])

In this report various erosion problems are presented as a "case" in a separate chapter. Each chapter describes a case and it's relevance to coastal engineering practice. The cases are fictitious but are derived from actual coastal engineering problems.

Chapter 2 points out the main distinctions between structural erosion and temporary erosion due to storm surge events. The theoretical knowledge is presented to clarify the main principles to the reader but is not intended to be used as a textbook on coastal engineering theories.

An overview of all cases with a short description of each case and an explanation of the relevance of each case is provided in Chapter 3. Besides this overview of all treated cases Chapter 3 also describes the used schematisations and symbols in the various case-studies.

Chapters 4 to 16 present the fictitious problem cases. In the problem definition in every chapter it will be pointed out if the problem is (mainly) caused by structural erosion or erosion during (severe) storm surge.

Chapter 17 discusses the conclusions and recommendations of the cases and presents an overview of possible engineering tools as discussed in the several case-studies. The objectives of the report are reviewed and recommendations for further research studies are indicated.

Appendix A provides a brief description and overview of the main structures used in coastal engineering practice to defend coasts against erosion. The main properties and parameters of importance are discussed for each type of structure. In the cases cross-references will be made to the theory as presented in Appendix A. An overview of advantages and disadvantages of several coastal structures is provided. The contents of Appendix A are not intended to be a textbook on coastal structures.

In Appendix B some examples of the use of structures in coastal engineering practice are briefly described and the expected behaviour is reviewed

Appendix C provides an example of the use of the computational model UNIBEST on the situation as sketched in Case 1 while using groynes to protect the coast against (further) erosion.

2. Background of erosion problems

2.1. Introduction

The basic cause of any erosion problem is a situation where the losses of sediment from a particular area exceed the gains of sediment. Various mechanisms that will lead to either supply of sediment or losses of sediment are sketched in Figure 2.1.

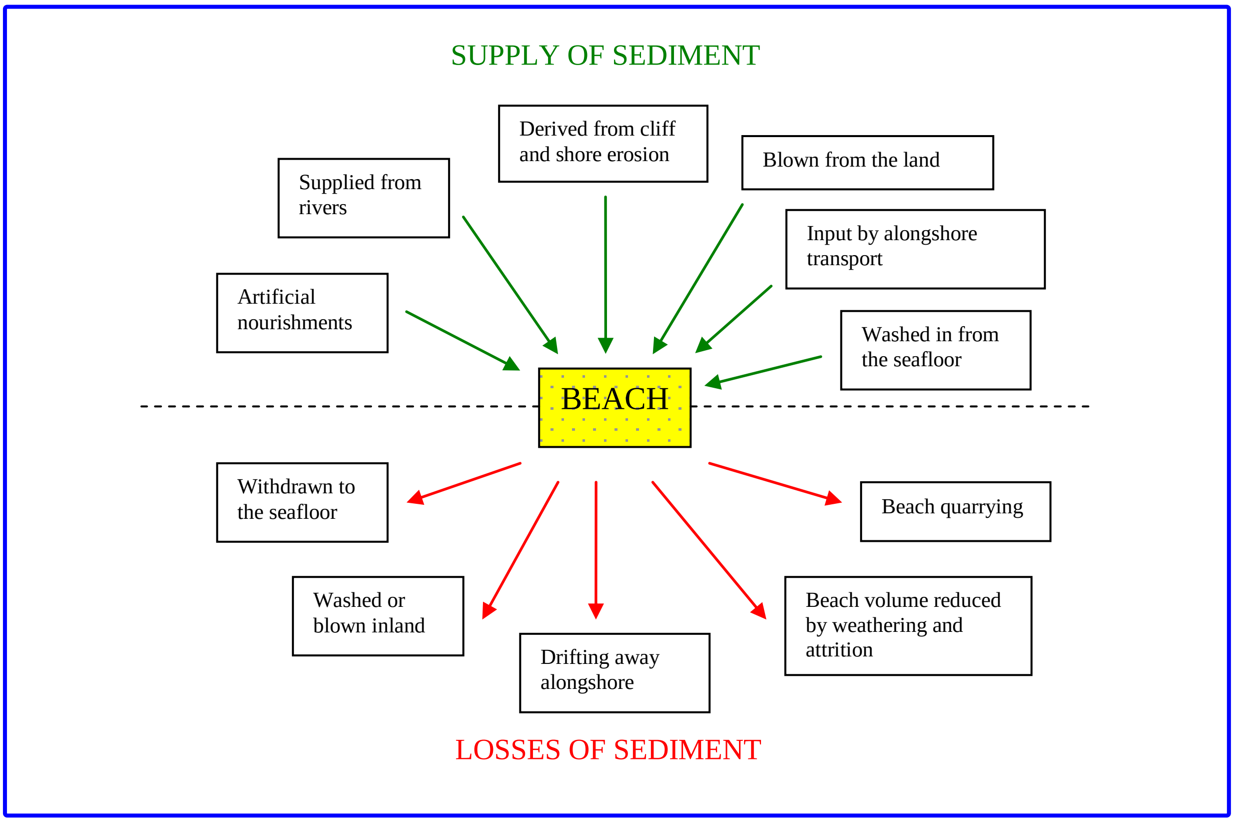

Figure 2.1: Causes of supply and losses of sediment (after Bird, 1996 [2])

The sediment budget in a coastal volume can be defined as:

$$\sum_i Q_i = \frac{\partial V}{\partial t}$$

with:
Q_i = total volume of sediment transported through the boundaries of a particular section of coast during a period t by various sediment transport processes as presented in Figure 2.1.
V = total volume of sediment on a particular stretch of coast.
t = period of time

Erosion can occur because of two fundamentally different phenomena:
- Structural erosion
- Erosion during a severe storm surge

In this report a clear distinction between both possible causes is made. Cases of both structural erosion and erosion during severe storm surge are defined. In the design of coastal structures it is however important to take the behaviour into account under conditions the measure is not primarily designed for. E.g. one has to examine the behaviour under storm surge conditions of a structure that is meant to prevent structural erosion and vice versa.

2.2. Structural erosion

In general the longshore sediment transports are responsible for the long-term changes in the coastline. A gradient in the longshore sediment transport generally is the cause of the structural erosion phenomenon. This gradient in the longshore sediment transport causes more sediment to be transported out of a particular section of coast than is transported into this section. Unless the eroded amounts of sediment on a stretch of coast due to littoral sediment transport are compensated by other sources of sediment (e.g. artificial nourishments or sediments supplied by a river outflow) entering this stretch of coast, a retreat of the shoreline is inevitable. In a matter of time this process will lead to loss of beach and dune area that may be of value to society. Variation of the longshore sediment transport typically is a result of:

- ***Variation of wave and tide conditions along a coast.***
- ***Variation of wave and tide conditions in time.***

The timescale on which erosion events become a problem is strongly depending on the total volumes of sediment that are being transported on a stretch of coast. The net yearly littoral sediment transport is the total sediment transport over a year integrated over a cross-section; a gradient in the net littoral sediment transport causes erosion. The day-to-day erosion rate might of course be different from the average erosion rate over a year. A distinction can be made in net yearly littoral sediment transport and gross yearly littoral sediment transport through a ray A defined as:

$$S_{A;net} = \sum_i S_{i;} + \sum_j S_j$$

$$S_{A;gross} = \sum_i S_{i;} + \left| \sum_j S_j \right|$$

with:

S_i = *Sediment transport integrated over the cross section in positive direction (crossing ray A from left to right)*
S_j = *Sediment transport integrated over the cross section in negative direction (crossing ray A from right to left)*

In most cases the magnitude of the gross sediment transport is (much) larger than the magnitude of the net sediment transport. In exceptional cases where all the sediment transport occurs in one direction the net transport and the gross transport are equal.

Finally it is emphasized that the spatial and time variation of the longshore sediment transport is a continuous and dynamical process. With every change in wind (wave) and tidal condition, the longshore sediment transport varies in magnitude and direction. Due to the dynamical character of the sediment transport process it is necessary to use integrated parameters (over a certain period of time or space) to be able to use these parameters in mathematical or numerical modelling. One has to bear in mind that integration is a smoothing process which reduces the variance in data.

2.3. Erosion during (severe) storm surges

The cross-shore transport, and thus the variation in the coastal profile, is mainly responsible for the short-term fluctuations in the upper part of the cross-shore profile. The short-term effects of cross-shore transport can also be easily discerned, for instance from the changes in magnitude and position of breaker bars and erosion of the dunes during storm surges.

In the case of erosion during a severe storm surge the erosion takes place during a less frequent extreme event compared to the long term (or structural) erosion. The sediment that is eroded from the beach and dunes is transported to deeper water during the storm surge, but in general this kind of erosion does not change the total amount of sediment within a cross-section. The sediment is redistributed over the cross-shore profile and during calmer periods (day-to-day situations) the sediment will return to the position it was before the storm surge by natural accretion processes and wind effects.

Two situations can occur in which measures can be implemented:
- The loss of beach and dune area during an extreme storm surge (design conditions) is so large that valuable parts of the dune area are physically threatened.
- The frequency of extreme events is so high that the beach and dune area does not have the time to resettle naturally after a storm surge event. The design conditions for coastline defence works will have to be increased, which may result in (extra) protection works.

The coast only has to be defended when the risk of the erosion is considered too large.

3. Introduction to the cases

3.1. Overview of the used symbols in the cases

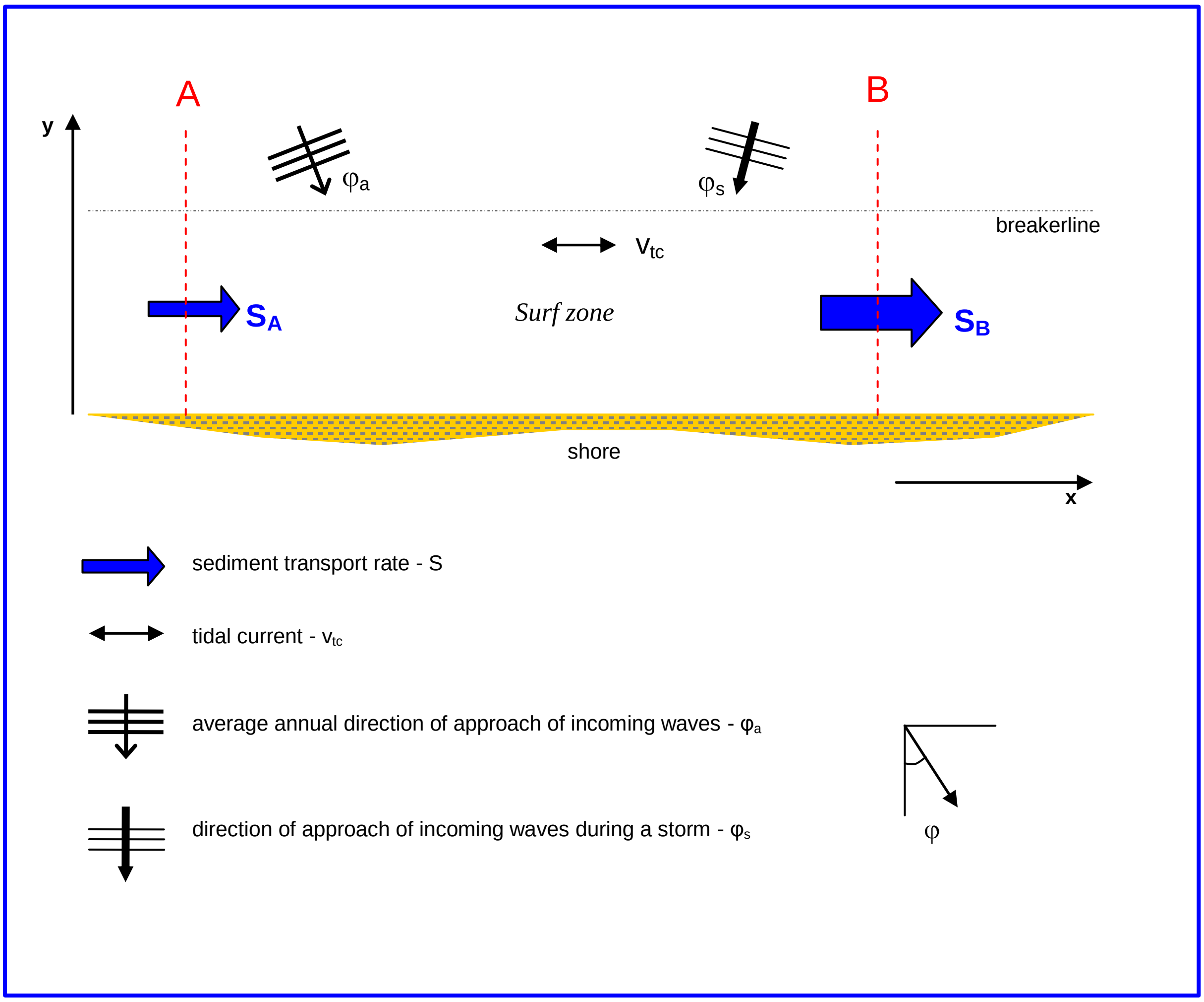

Figure 3.1: Legend

A schematical sketch of the problem area accompanies every case discussed in this report. In Figure 3.1 is indicated what kinds of symbols and quantities are used in these figures.

3.2. Schematisations

Schematisations used (see also Figure 3.1 and Figure 3.2):

- In the figures throughout the report a straight stretch of coast is sketched. Even in the case of structural erosion caused by a curved shape of the coastline, the coastline is represented as straight in the figure. The gradient in sediment transport is presented by the increasing size of the arrows used.
- In each case a section of coast is considered between two rays. The problem as sketched has to be solved primarily for this stretch of coast; the effects of a measure on the adjacent sections will only be indicated.
- The sediment transport in the figure is the total transport integrated over a cross-section.
- The sediment transport is considered to take place mainly in the surf zone, unless it is specifically mentioned differently in a case.

- The positions of the breaker line and the shoreline are drawn although in practice these change with the tide and with the occurring wave heights.
- The average annual conditions are the conditions used for day-to-day situations in the design process. The conditions during a storm are used to determine the behaviour under storm surge conditions.
- In Figure 3.2 a representative cross-section of a sandy beach is shown.
- Quantities and values indicated in the various cases are fictitious but realistic. Quantities are mentioned to illustrate the impact of variation in quantities on applicable measures.

Background information, examples or side information on the contents of a chapter is presented throughout the report occasionally in a frame like this one.

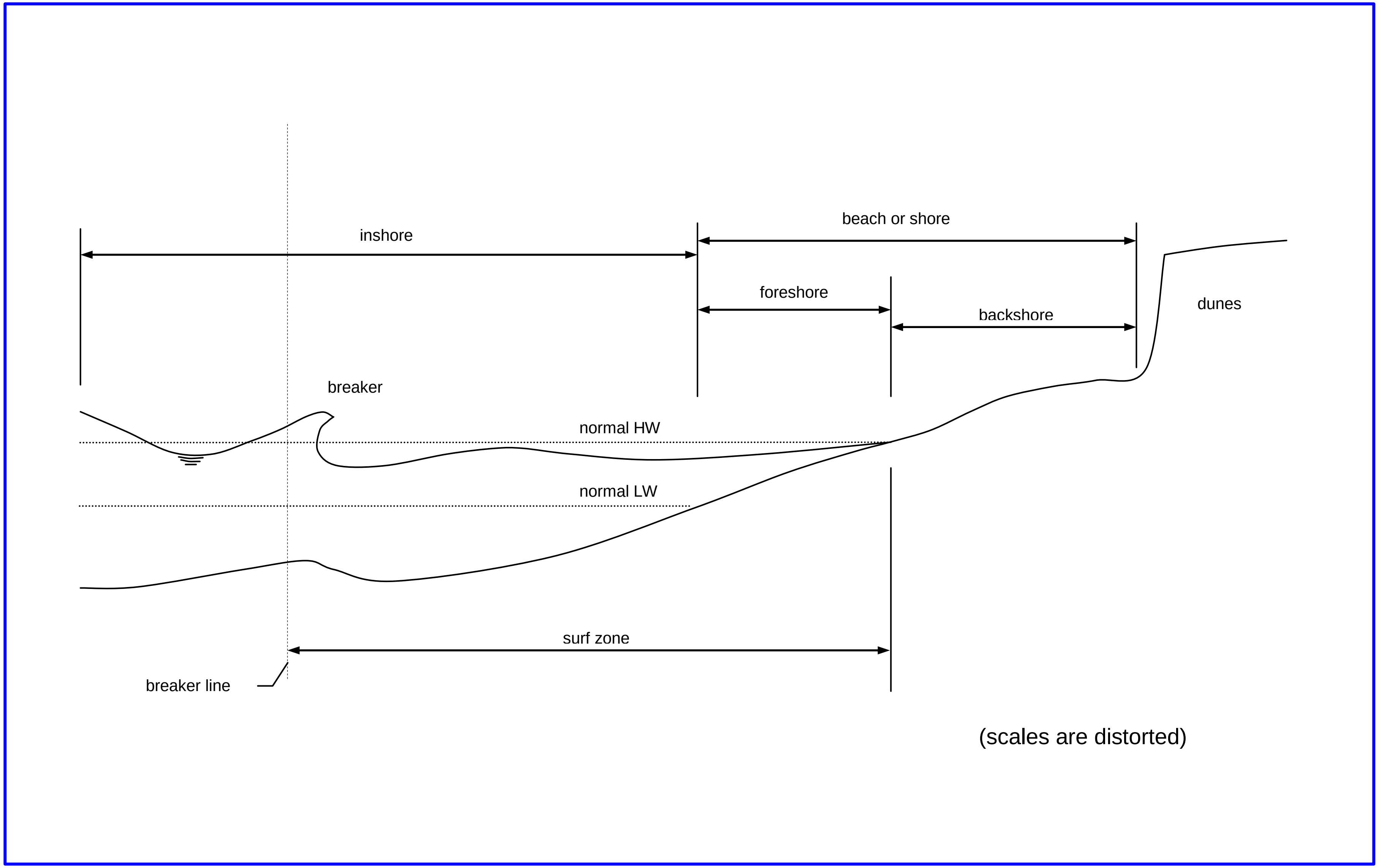

Figure 3.2: Cross-section of a sandy beach profile

3.3. Determination of the cases

The cases of erosion problems in this report can be divided in four basically different types of problems.

The first type of problems is discussed in cases 1 to 7, these cases concern problems of a deficit in sediment supply caused by natural processes.

The problem usually has natural causes such as e.g. a curved shape of the coastline, which causes an increasing angle of incidence of incoming waves along a stretch of coast. Structural erosion occurs when the losses of sediment exceed the gains permanently over a specific period of time, this means the erosion will go on until some kind of natural and stable equilibrium situation would develop.

- ***Case 1:***
  The first case can be considered as a sort of standard case; a sediment deficit of 100,000 m^3/y over a stretch of coast of 5 km is thought to be caused by a curved shape of the coastline. In this case the main effects of the various types of structures (which might be used to resolve the erosion problem) are discussed with cross-references to Appendix A. Appendix A sets out the main properties and parameters of the various types of structures that can be applied. In cases 2 to 7 cross-references to both Case 1 and Appendix A are made.
- ***Case 2:***
  Case 2 describes basically the same problem as Case 1, the net deficit is still 100,000 m^3/y over a stretch of coast of 5 km. The incoming and outgoing transports are considerably larger in this case however. In Case 2 the effects of a considerably larger sediment transport on the solutions as sketched in Case 1 will be outlined.
- ***Case 3:***
  Case 3 describes a problem where the input of sediment is zero and the output of sediment transport still is 100,000 m^3/y.
- ***Case 4:***
  Case 4 describes exactly the same problem as Case 1 on first sight. A stretch of coast of 5 km with an input of sediment of 200,000 m^3/y and an output of 300,000 m^3/y. The cause of the problem is different however in this case. An increasing wave height instead of an increasing angle of approach of the incoming waves is thought to be responsible for the deficit in sediment supply. The effects of these different conditions on the various solutions with structures will be discussed.
- ***Case 5:***
  Case 5 describes a problem where a net deficit of 100,000 m^3/y still is the main problem; this deficit is a resultant of sediment transports that are considerably larger in both longshore directions.
- ***Case 6:***
  Case 6 describes a problem of a very wide surf zone where the largest part of the sediment transport takes place a considerable distance out of the coast. The basic problem still is a deficit of 100,000 m^3/y.
- ***Case 7:***
  Case 7 concerns a structural erosion problem with both wave driven as tide driven transport, the effects of a tidal current on the various structural solutions will be outlined in this case

The second type of problems concerns a stable section of coast where the beach is of insufficient width to the users of the beach area.
This is not a structural erosion problem on itself but the solutions to the problems as sketched in Cases 8 and 9 will lead to structural erosion problems that may lead to the application of ‘hard’ structures.

- ***Case 8:***
  Case 8 concerns a stretch of coast with perpendicularly approaching waves and thus no sediment transport along the coastline.

- ***Case 9:***
  Case 9 describes basically the same problem, the waves are approaching obliquely however in this case and thus there is a longshore sediment transport along this stretch of coast.

The third main type of problems are problems that are caused by an intervention in the natural system, either by human activity such as structures in the surf zone or by natural interventions such as the outflow of a river.

- ***Case 10:***
  Case 10 describes the problems that occur after the construction of port jetties and possible countermeasures that can be taken.
- ***Case 11:***
  Case 11 concerns the same problem as sketched in Case 10, however this time in combination with a tidal current.
- ***Case 12:***
  Case 12 describes the problems that occur when a river flows into sea.

The fourth type of erosion problems are problems of severe dune or beach erosion due to storm surge events.

- ***Case 13:***
  This case describes a stable coastline that suffers from (severe) erosion due to storm surge events.
- ***Case 14:***
  Case 14 describes a similar case of storm surge erosion but this time combinated with (large) longshore sediment transport or permanent loss of sediments. Resulting in a situation without full restore of the beach and dune profile.

In this report the application of the use of structures is paramount but that does not alter the fact that artificial beach and/or shoreface nourishments can be applied too in most cases (or can even be preferred over the use of structures).

4. Case 1: Structural erosion: 200,000 m^3/y IN – 300,000 m^3/y OUT

4.1. Description of the problem

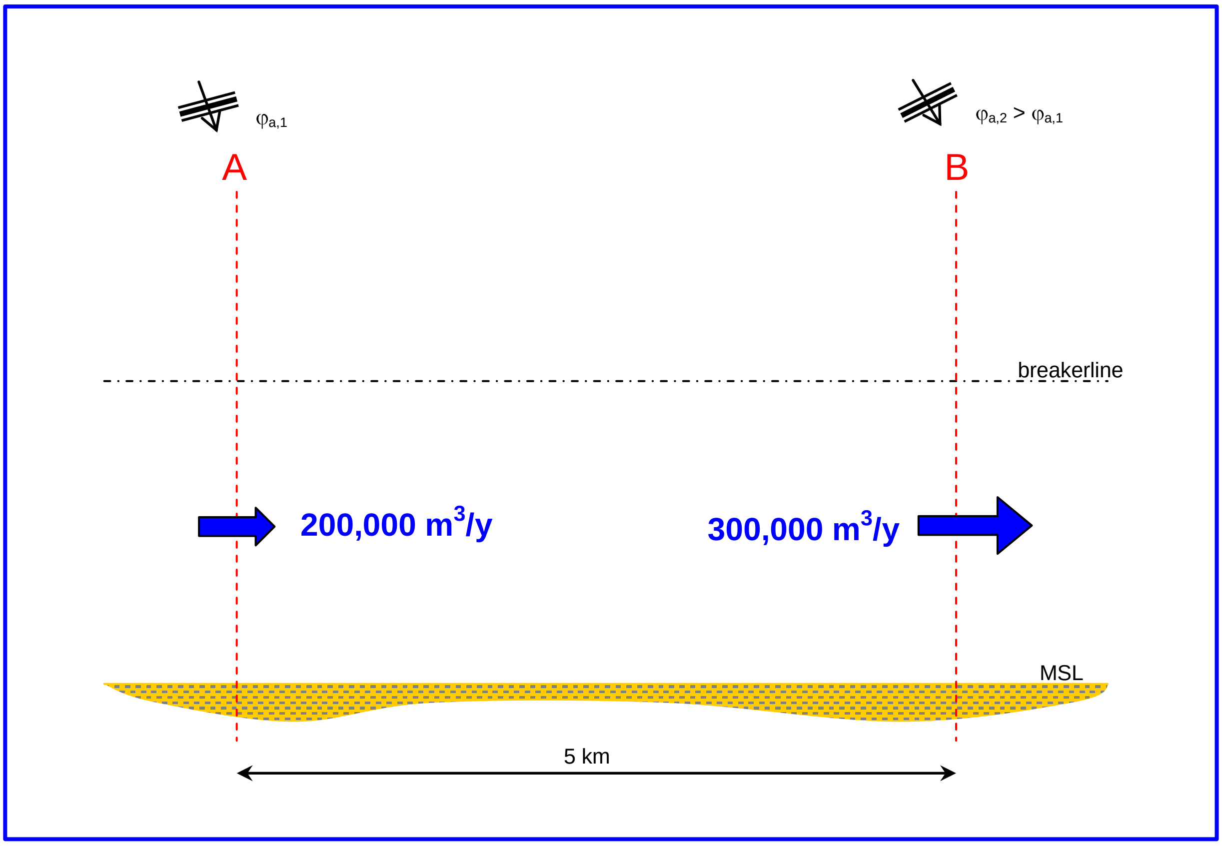

Figure 4.1: Situation case 1

The problem of a structural eroding coast occurs often in coastal engineering practice.
In this case a stretch of coast suffers from structural erosion due to an increasing angle of incidence of incoming waves of the dominant annual wave direction. It is assumed that the average yearly sediment transport into this stretch of coast is 200,000 m^3 and out of this stretch it is 300,000 m^3. The transport mainly takes place in the surf zone and is directed in one main direction (in this case from the left to the right).

The use of coastal structures usually changes the morphological conditions, because it is intended to take away the cause of the erosion while beach nourishment only deals to redress the effects of the problem. The points for attention related to the design of coastal structures for solving structural erosion problems are discussed in this chapter. The case is sketched in Figure 4.1.

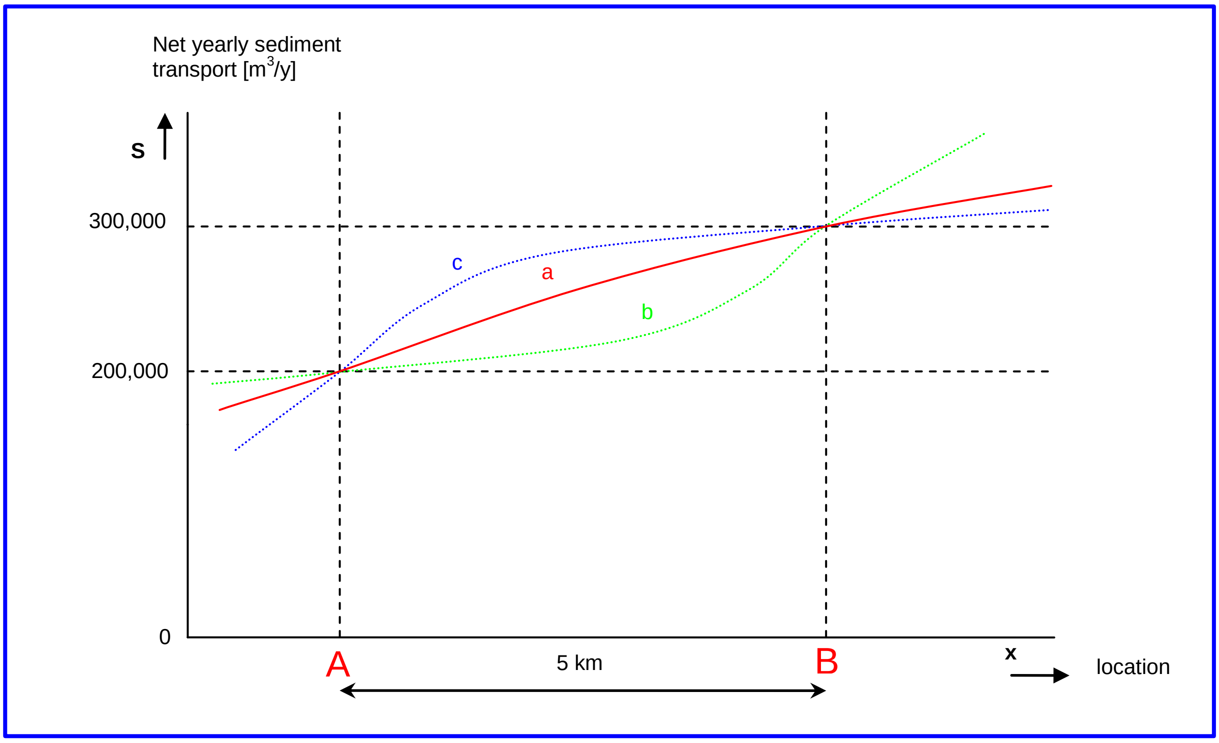

Figure 4.2: Sediment transport rate

4.2. Cause of this problem

This problem occurs because a positive gradient occurs in the sediment transport rate; $\left(\frac{\partial S}{\partial x} > 0\right)$ as is shown in Figure 4.2. In principle different S distributions as a function of x are possible. In Figure 4.2 a few possibilities are sketched.

The local physical conditions determine the actual shape of the (S,x)-diagram, but for this example the situation described by line a is supposed to occur, which causes a more or less constant rate of erosion along stretch AB (nearly constant gradient).

4.3. Solution to the erosion problem

To resolve this problem with the help of structures a situation has to be achieved in which the gradient in the sediment transport rate becomes zero, or in some cases a reduction in the gradient and thus in the erosion rate may meet the requirements. If accretion of this stretch of coast is the goal of the

Loss of 300,000 – 200,000 = 100,000 m^3/year over 5 km of coast

100,000 m^3/year per 5000 m results in an erosion of 20 m^3/m per year.

Active part of the beach profile approximately say from Datum –7 m – Datum +8 m

so the beach retreat is 1,3 m/year, which is a common situation at eroding coasts.

The basic problem is a loss of 100,000 m^3/year out of the stretch of coast of 5 km.

measures then a negative gradient has to be achieved. These situations are presented in Figure 4.3.

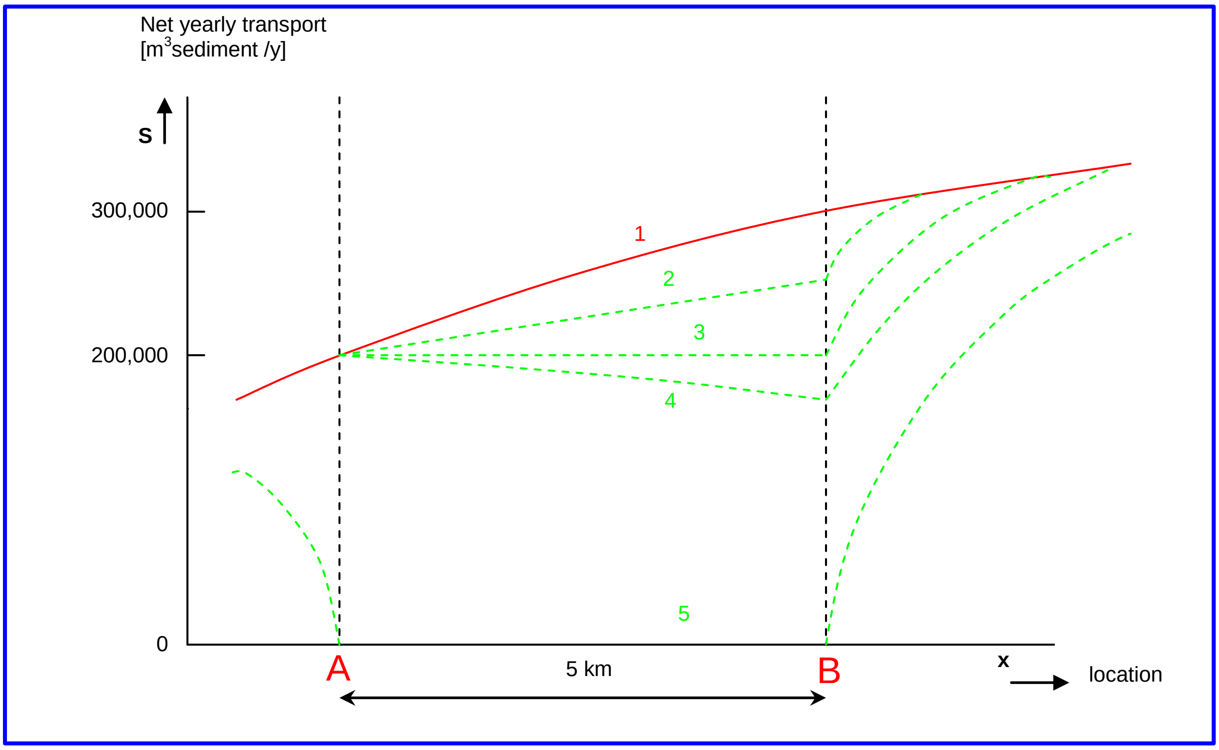

Figure 4.3: Effect of coastal engineering measures

Figure 4.3

line 1: *original situation*

$$\frac{\partial S}{\partial x} > 0$$ *so erosion occurs on stretch A-B*

left from A and right from B also gradients occur

line 2: *reduction of the erosion rate on stretch A-B*

$$\frac{\partial S}{\partial x} > 0$$ *but gradient smaller than according to line 1, so the erosion rate will decrease*

right from B the erosion will increase due to larger gradients (lee side erosion)

line 3: *zero erosion on stretch A-B*

$$\frac{\partial S}{\partial x} = 0$$ *so no erosion takes place*

right from B the erosion will increase (lee side erosion)

line 4: *accretion will take place on stretch A-B*

$$\frac{\partial S}{\partial x} < 0$$ *so accretion will occur*

right from B the erosion problem will increase compared to the other solutions

line 5: *no sediment transport in stretch A-B*

left from A accretion will occur and right from B a large amount of sand will be eroded (severe lee side erosion)

Figure 4.3 shows that the measures taken to protect the stretch of coast between A and B will have a great effect on the downdrift side of B, because here increased erosion will take place on the undefended coast. This erosion may not be a problem if the beach and dunes are wide enough and no further harm is done to the users of this coastal area. Otherwise it might be unacceptable to create such a problem while solving the erosion problem in stretch A-B.
If stretch A-B is worth the protection and the adjacent coast is of no further use, several structures could be applied, such as groynes and offshore breakwaters. The application of these structures is discussed in Paragraphs 4.4 and 4.5 for the case belonging to line 3 in Figure 4.3 ("wanted situation").

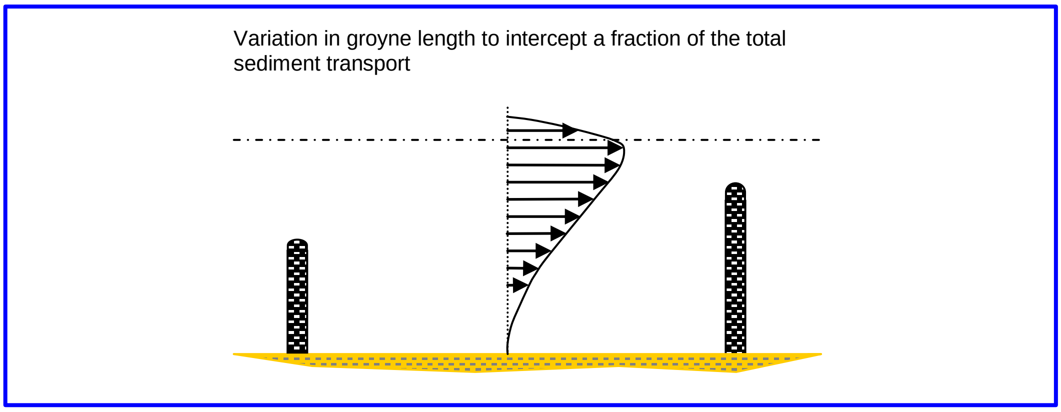

Figure 4.4: Sediment transport distribution

In many practical cases the situation as sketched by line 5 is probably the easiest to achieve while using coastal structures. The adverse effects on the downdrift side of ray B, enormous erosion rates, are however significantly for these amounts of sediment transport. That is the reason that the solution sketched by line 3 is preferred over the situation sketched by line 5. Near cross-section B the sediment transport has to be reduced from 300,000 m^3/year to 200,000 m^3/year; a reduction with 1/3 of the original transport rate. The ratio 1/3 is also to be considered as a measure for the required effect of the protection operation. Figure 4.4 schematically indicates the relation between the length of a groyne (field) and the ratio of sediment transport blocked by these groynes.

4.4. The use of groynes

By using groynes the sediment transport in the surf zone is intercepted partially. In each cross-section the amount of sediment passing the groyne has to be 200,000 m^3/year so the gradient becomes zero along the coast.The distribution of the sediment transport over the surf zone differs for each cross-section along stretch A-B, but the shape is assumed to be alike. The amount of sediment that has to be

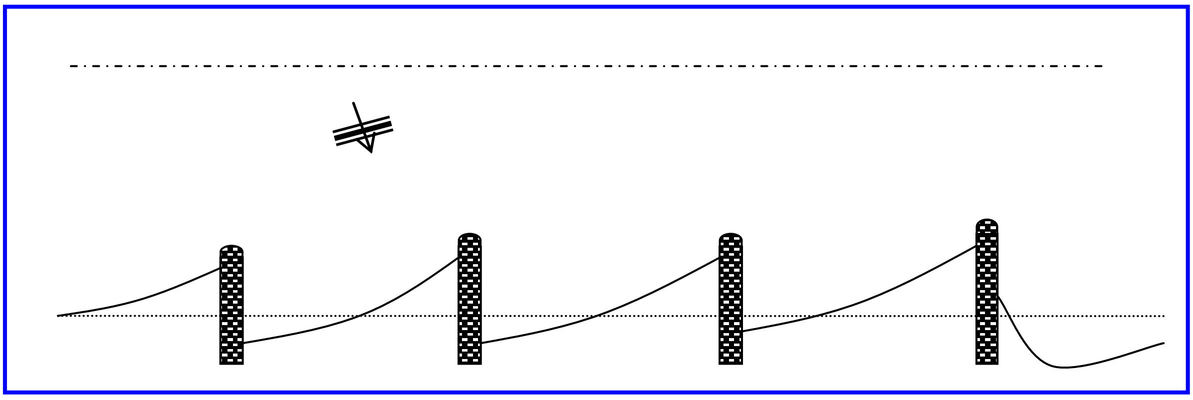

Figure 4.5: Sketched shape of the coastline after construction of groynes

stopped by the groynes increases from 0 m^3/year at point A to 100,000 m^3/year at point B. In the intermediate cross-sections a part of the total sediment transport has to be intercepted just so that 200,000 m^3/year will pass. The length of the groynes can be estimated from the cumulative sediment distribution as is explained in Appendix A, see also Figure 4.4.

The shape of the coastline will be affected by the application of groynes as is sketched in Figure 4.5. It will take a certain period of time and an amount of sediment to develop the new equilibrium shape of the coastline. During the formation of the new shape, the lee side erosion may be larger than expected, because extra volumes of sediment will accrete between the groynes; these amounts of sediment will be withdrawn from the morphological system. Such adverse effects can be reduced by applying artificial nourishments either between the groynes or downstream of the protection scheme.

It is recommended to start the construction of the protection scheme with the most downdrift groyne (nearest to cross-section B) so that during the construction phase of each groyne a certain amount of sediment can accrete on the updrift side of the groyne. By doing so the new equilibrium situation will be reached sooner after completion of the protection scheme.

Application of groynes always leads to erosion on the downdrift side of the defended coast. The application of groynes in such a case as sketched in this chapter will be discussed in further detail in Appendix C with the help of the morphological computer models Unibest LT and Unibest CL.

Under storm surge conditions groynes have little to no effect, so this solution is only applicable when structural erosion is the only problem.

4.5. The use of offshore breakwaters

By using offshore breakwaters the objective is to create a situation without erosion, so the gradient in sediment transport rate along the 5 km long stretch of coast between rays A and B has to be zero. In every cross-section a transport of 200.000 m^3/year has to take place (situation as sketched by line 3 in Figure 4.3). The construction of offshore, detached breakwaters will lead to accretion in the shallow zone landward of the breakwater, so the remaining cross-section will become narrower.

To achieve a situation as sketched by line 3 in Figure 4.3 (transport of 200,000 m^3/year in each cross-section), three basically different types of application of offshore breakwaters are possible, as is sketched in Figure 4.6.

Type a:
The breakwater is constructed inside the surf zone; the sediment transport at the shoreside of the breakwater is interrupted by the formation of a tombolo. Along the seaside of the breakwater a sediment transport of 200,000 m^3/year has to be maintained in each cross-section.

Type b:
The breakwater is constructed inside the surf zone, but no tombolo is formed. A salient is formed, which results in sediment transport on both the shoreside and the seaside of the breakwater. The total sediment transport over a year has to be 200,000 m^3 in each cross-section.

Type c:
The breakwater is constructed outside of the surf zone and the formation of a salient takes place. The sediment transport at the seaside of the breakwater is assumed to be zero, so the total transport of 200,000 m^3/year has to take place at the shoreside of the breakwater.

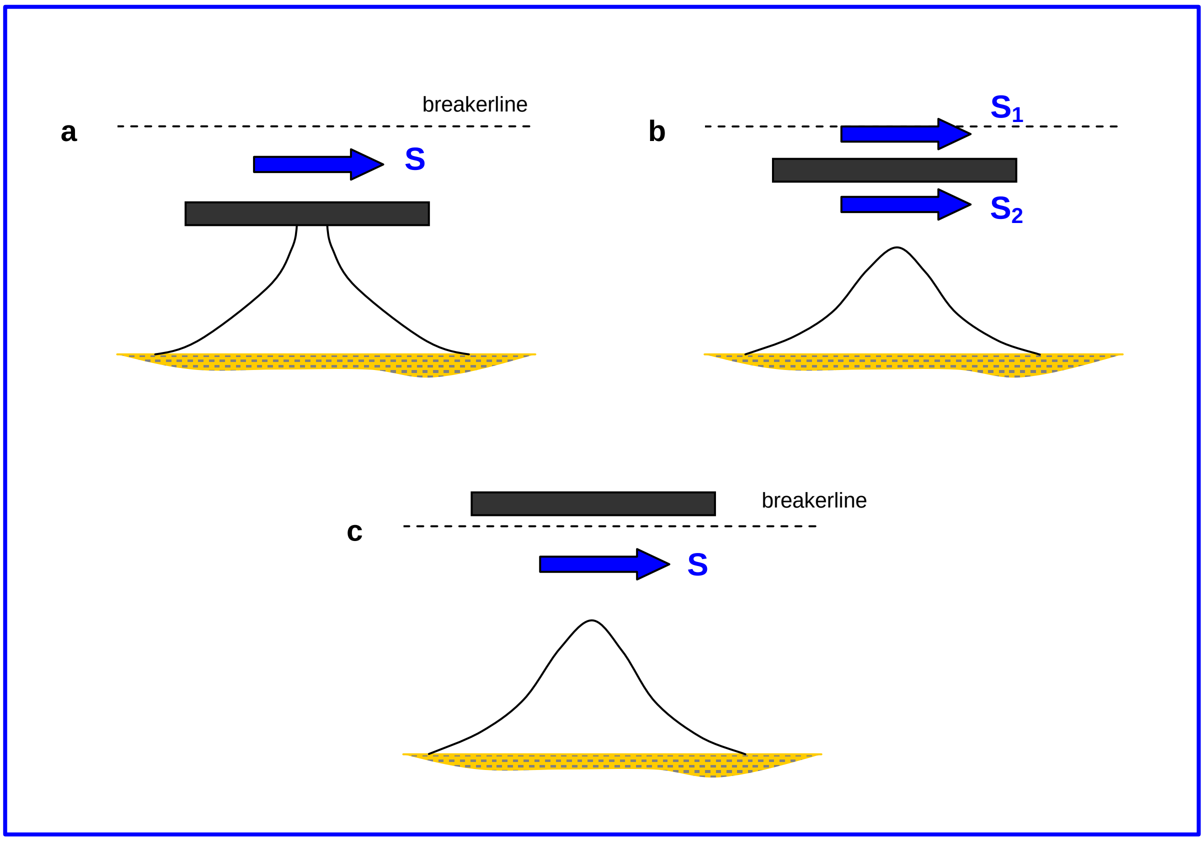

Figure 4.6: Different types of situations using offshore breakwaters

For each case a fine-tuning is necessary, so the sediment transport will adjust in the way it was intended. A distinction between the conditions in the initial phase and the fully developed phase has to be made as well as in the phase of development of a salient or tombolo. There is however little experience in applying offshore breakwaters for these kinds of problems. Especially the situations where a salient is formed (type b and c) are very hard to design.

Offshore breakwaters can have an effect under storm surge conditions, because incoming storm surge waves will (e.g. partially) break on the crest of the breakwater, which results in less wave energy reaching the beach and dunes. And besides that the offshore breakwater can trap the sand, which is eroded from the beach and dunes. Under the initial conditions without offshore breakwaters this sand can be redistributed over the beach profile.
The offshore breakwater itself has to resist the heavy loads of wave attacks during severe storm surges so the design of the breakwater has to be sufficiently solid and stable.

4.6. The use of seawalls or dune revetments

The cause of the structural erosion problem discussed as Case 1 is a gradient in the longshore sediment transport rate, the use of seawalls or dune revetments does not interfere with the longshore transport right after the construction and thus these structures are not applicable for this type of problems.

4.7. Remarks on this case

In many structural erosion problems the easiest way to resolve the problem is to restore the eroded amount of sediment every once in a while. By renourishing the beach or shoreface the natural processes are essentially not disturbed and thus no adverse effects have to be expected on adjacent beaches. The application of structures will cause adverse effects on adjacent beaches in most cases.

Structures can be applied when the problem on the considered stretch of coast has to be resolved permanently and the adverse effects are acceptable on the adjacent sections of coast or other measures will be taken on the adjacent beaches.

The experience on using structures to defend beaches against structural erosion is not sufficient to properly design protection schemes for every situation. Detailed studies have to be carried out before designing a protection scheme. Many protection schemes that have been built in the past do not work as they were expected to, or have led to unforeseen adverse effects.

5. Case 2: Structural erosion: 500,000 m^3/y IN – 600,000 m^3/y OUT

5.1. Description of the problem

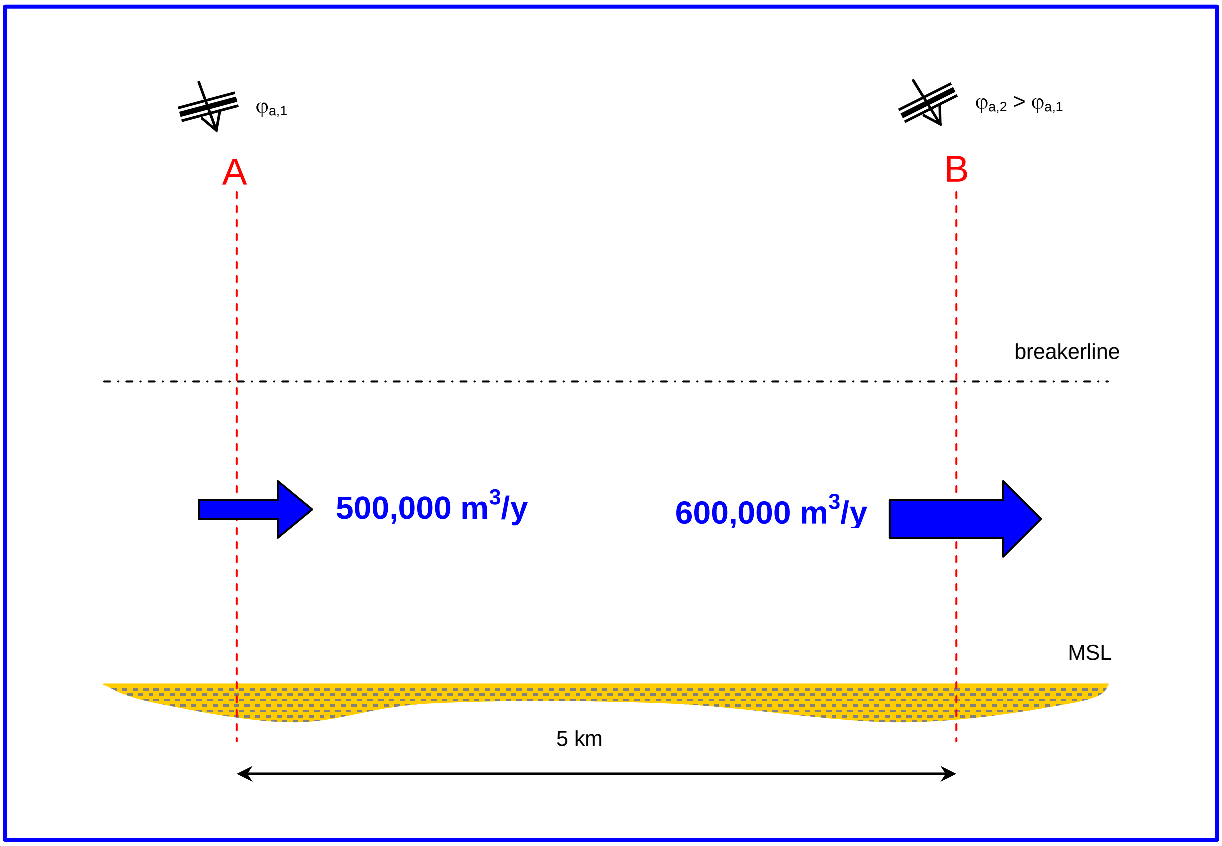

Figure 5.1: Situation case 2

In this case the problem appears to be similar to the problem sketched in Case 1, a loss of 100,000 m^3/y out of section A-B because of an increasing angle of incidence of the approaching waves. The amounts of sediment that are being transported through ray A and ray B are however thought to be significantly larger as in Case 1, which may be of influence on the applicability of coastal structures. The causes of this significantly larger transport can be several, such as:

- higher waves approach the coast as in Case 1
- the angle of approach is larger than in Case 1
- the surf zone is wider than in Case 1 (the slope of the beach profile is milder)
- the beach material is transported easier as in Case 1 (e.g. by a smaller particle size)

The causes of the differences between Case 1 and Case 2 are of course relevant to the solution of the problem, but in the further discussion the main emphasis is on the larger sediment transport rates although the difference in transport rates between ray A and B is the same as in Case 1.

5.2. Cause of the problem

The cause of the problem is generally the same as it was in Case 1, a positive gradient in the sediment transport rate S: $\frac{\partial S}{\partial x} > 0$. See also Figure 5.2.

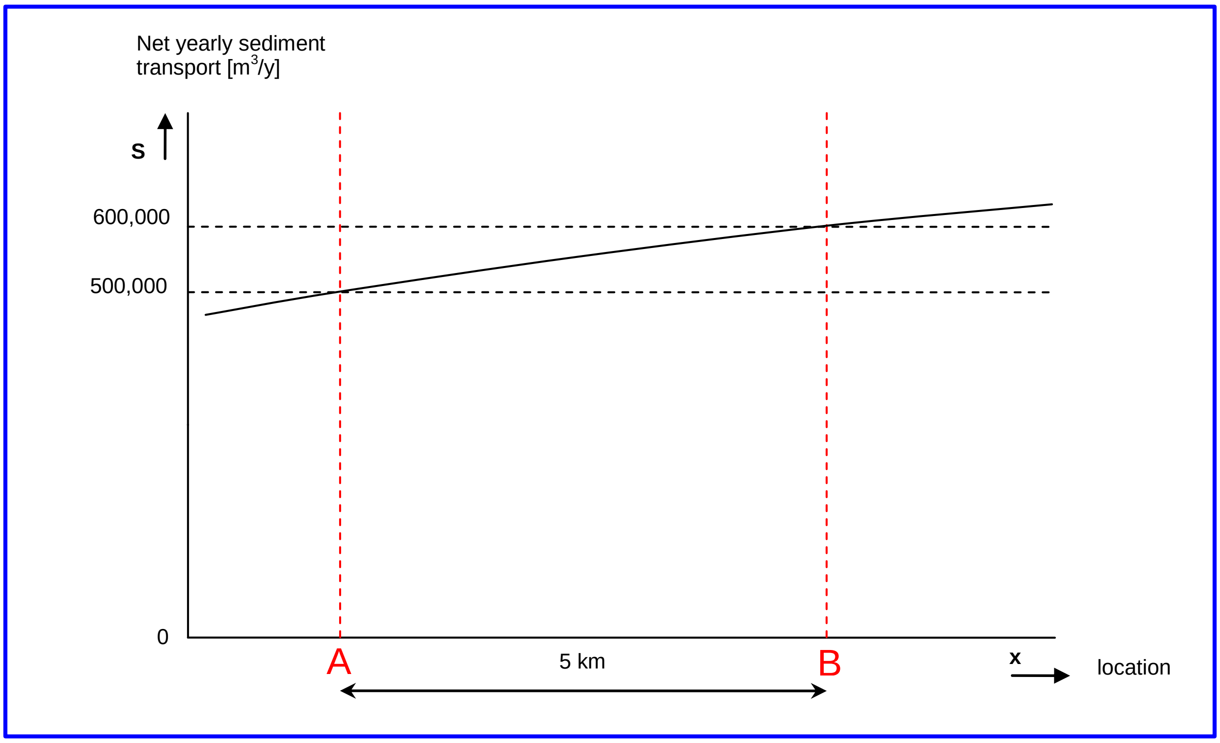

Figure 5.2: Positive gradient in sediment transport rate

5.3. Solution to the erosion problem

Solutions to this case are basically the same as the solutions to Case 1 as is shown in Figure 4.3. The only difference is the amount of sediment transport that occurs. In this case the transport rates are considerably larger, but to achieve a stable situation without erosion the gradient in sediment transport rate has to be made zero. In this case that implies that a sediment transport of 500,000 m^3/y has to take place in every cross-section between rays A and B. Downdrift of B increased erosion will occur because of the increased gradient in sediment transport.

Realisation of a constant sediment transport by using 'hard' coastal structures requires fine-tuning and will be very hard to accomplish in practice. In the following paragraphs the use of various structures to achieve a stable situation without erosion for stretch A-B will be discussed, the basic differences with Case 1 will be indicated. Near cross-section B the sediment transport rate has to be reduced from 600,000 m^3/year to 500,000 m^3/year; a reduction of 1/6 of the original sediment transport. This ratio is considerably smaller than in the previous case (where it was a reduction of 1/3).

5.4. The use of groynes

By applying groynes it is possible to achieve a situation without erosion in this case. Similar to the use of groynes in Case 1, one has to design the groyne field just so that in every cross-section a transport of 500,000 m^3/y will occur.

The smaller ratio of the total sediment transport that has to be captured by the groyne protection scheme will result in considerably shorter groynes as in Case 1, see also Figure 5.3.

The significantly larger sediment transport will also result in a quicker adjustment of the shape of the coastline to its new equilibrium shape; because of the relatively shorter groynes a relatively smaller volume of sediment has to be captured from the system by the groyne field and thus the lee-side erosion is relatively smaller than it was in Case 1. Possible adverse effects on a short term after construction can be prevented by artificial nourishments updrift of the groynes or downdrift of ray B.

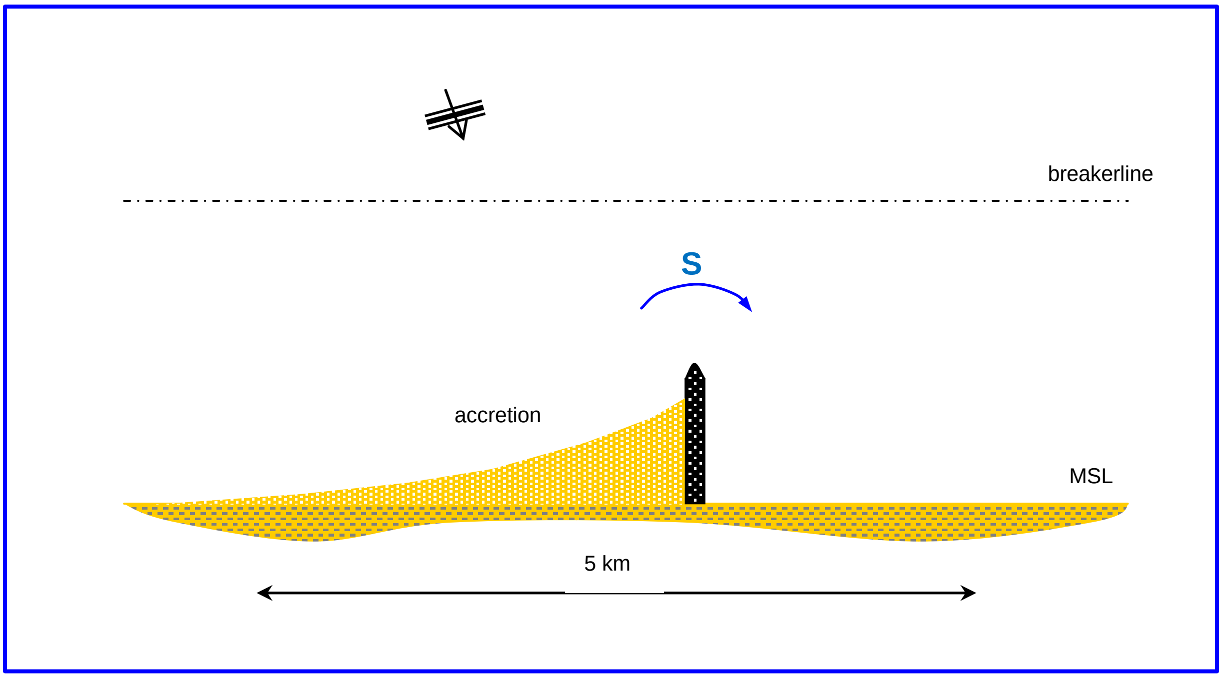

Figure 5.3: Sand bypassing along the head of a groyne

5.5. The use of offshore breakwaters

Similar to the application of offshore breakwaters in Case 1, offshore breakwaters are applicable in this case. Principally the same three types of solution as were shown in Figure 4.5 can be used in this case.

A transport of 500,000 m^3/y in every cross-section has to be achieved, which is a difficult situation to design, because after constructing the breakwater a tombolo or salient will be formed. There is still little experience on application of offshore breakwaters for these kinds of problems; especially the differences between Cases 1 and 2 are still not well understood.

5.6. The use of seawalls or dune revetments

The basic problem in this case, similar to the previous case, is a gradient in the longshore sediment transport rate, which ultimately leads to erosion of the beach and/or dunes. The application of seawalls or dune revetments does not interfere with the longshore transports. These structures are not applicable for these kinds of problems.

5.7. Remarks on this case

Similar as in the previous case in this case an artificial beach and/or shoreface nourishment is probably the easiest (and cheapest) solution. When the use of structures is preferred over the application of nourishments the use of groynes is probably the best solution in this case. The adverse effects of a groyne scheme are less severe as in Case 1 because of the shorter groyne length and the quicker adjustment of the coastline to its new equilibrium shape.

The use of offshore breakwaters still is very risky because the formation of a tombolo or salient cannot be predicted in great detail, so unforeseen adverse effects can be expected while applying offshore breakwaters.

6. Case 3: Structural erosion: 0 m^3/y IN – 100,000 m^3/y OUT

6.1. Description of the problem

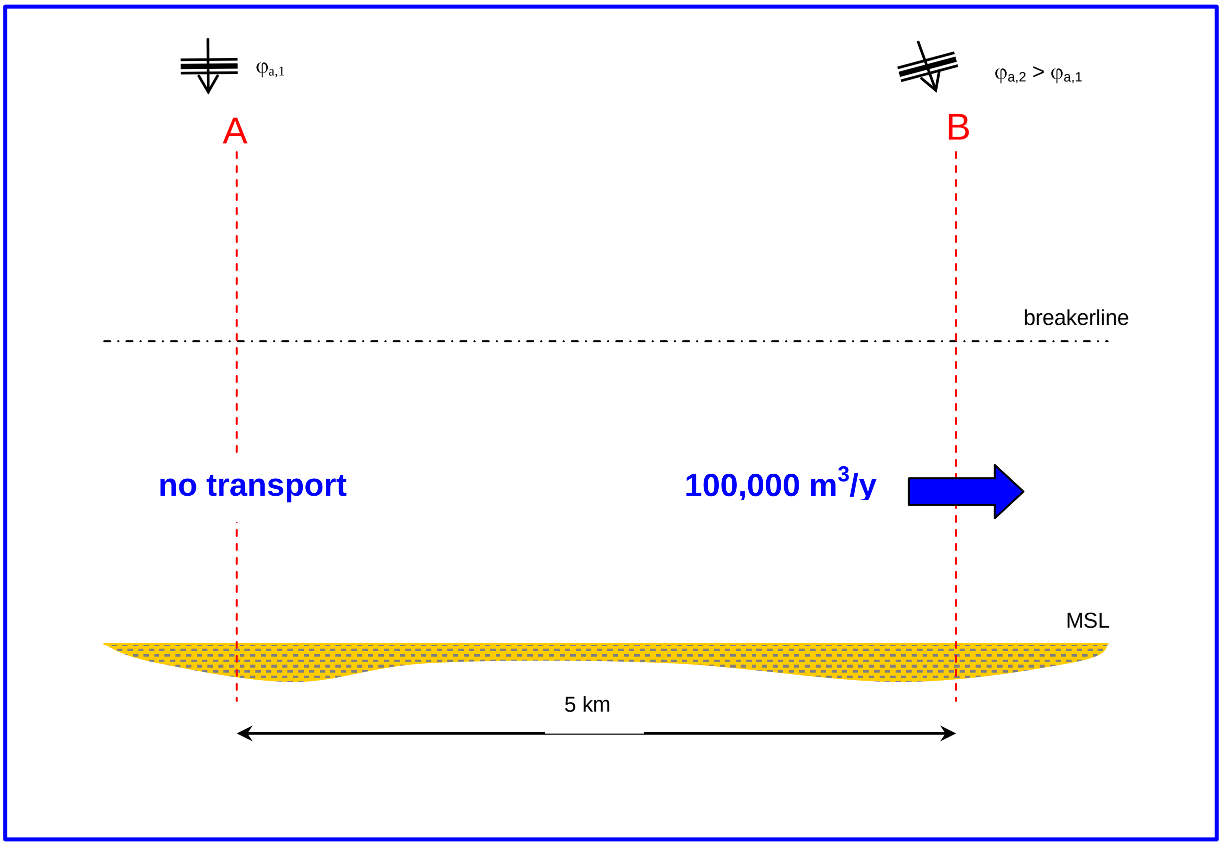

Figure 6.1: Situation case 3

This case again has a basic erosion problem of 100,000 m^3/y. The fundamental difference with the previous two cases is the absence of sediment transport through ray A and the relatively small transport in stretch A-B. The cause of the absence of sediment supply through ray A is not relevant to the erosion problem in stretch A-B in this particular case. It is assumed that the waves approach the coast perpendicularly at ray A, as can be seen in Figure 6.1.

6.2. Cause of this problem

The cause of the erosion problem in this section of coast is assumed to be the same as in the previous two cases, namely a gradient in the sediment transport rate, as is sketched in Figure 6.2. The zero transport through ray A is relevant for cases where the sediment is blocked by e.g. port jetties or a large breakwater. A situation of perpendicularly approaching waves will also lead to the same initial situation, these conditions are however less likely to occur in a practical situation. The gradient along stretch A-B is initiated by a change in the orientation of the coastline compared to the incoming wave direction.

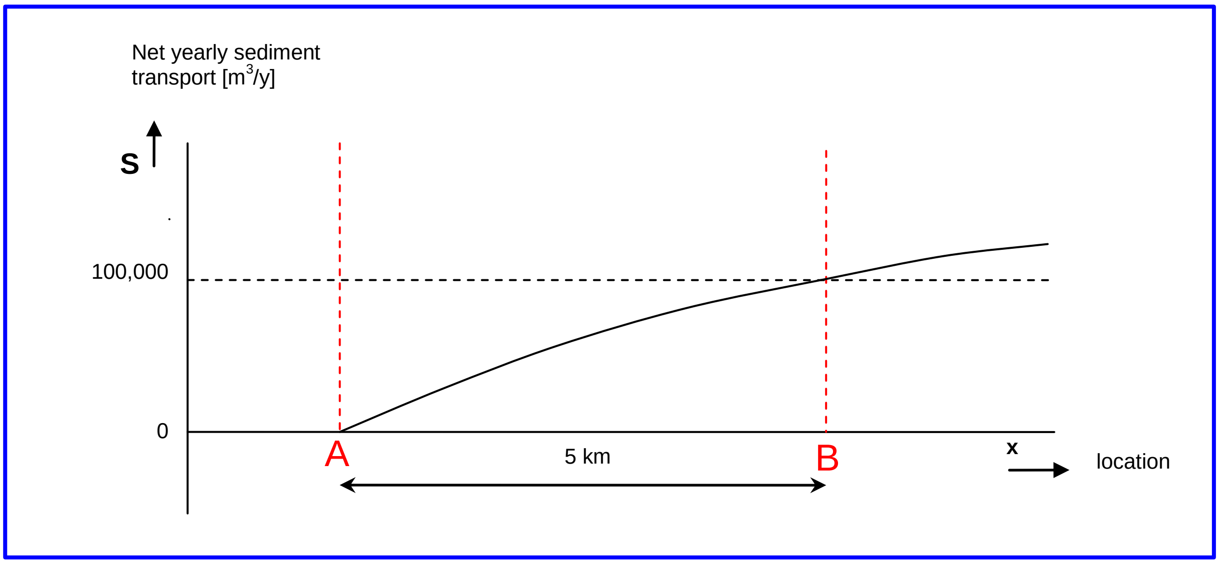

Figure 6.2: Cause of the erosion problem

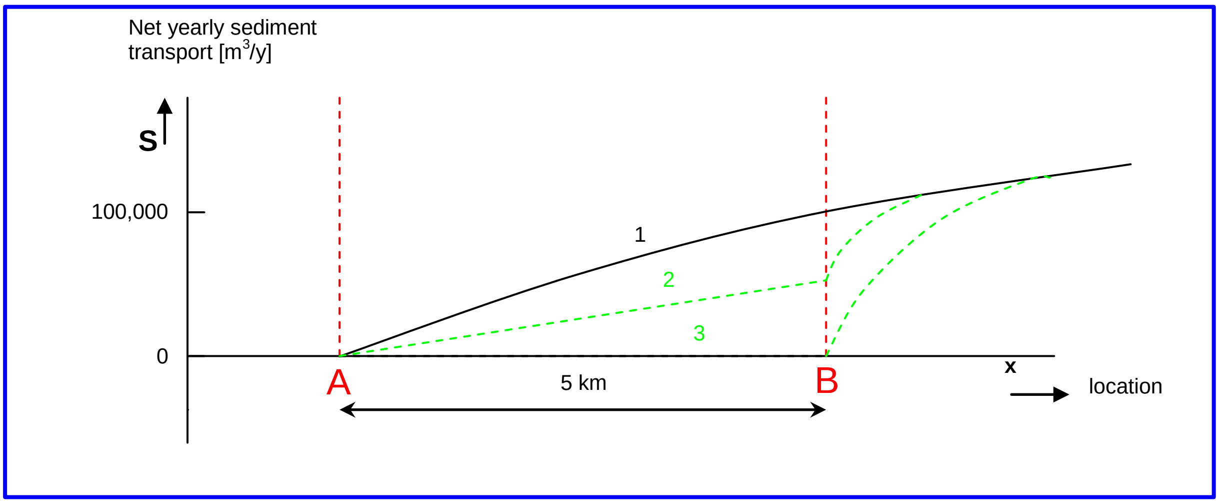

Figure 6.3: Solutions to the erosion problem

<u>line 1:</u> *original situation*

$\frac{\partial S}{\partial x} > 0$ *so erosion occurs on stretch A-B*

right from B also gradients occur

<u>line 2:</u> *reduction of the erosion rate on stretch A-B*

$\frac{\partial S}{\partial x} > 0$ *but gradient smaller than with line 1, so the erosion rate will decrease*

right from B the erosion will increase due to larger gradients

<u>line 3:</u> *zero erosion on stretch A-B*

$\frac{\partial S}{\partial x} = 0$ *so no erosion takes place*

right from B the erosion will increase

6.3. Solution to the erosion problem

While defending the coastline on stretch A-B with structures one shifts the problem to a more downdrift location. If the effects are less harmful or countermeasures are easier or cheaper to apply this might be a solution. This solution is sketched by line 3 in Figure 6.3. Another possible measure is to reduce the erosion by applying measures as sketched by line 2; in this case the erosion problem reduces, but still exists.

Achieving line 3 in Figure 6.3 is a rather easy problem compared to the problems in the previous cases in which a fine tuning was necessary. A zero sediment transport has to be achieved on stretch A-B, which means that a situation without sediment transport taking place has to be achieved. A way to do so is to adjust the orientation of the coastline by using structures just so that the waves approach the coastline perpendicularly and thus no transport is initiated. Updrift from cross-section A it was supposed that the sediment transport was zero, so the transport will stay zero along stretch A-B.

6.4. The use of groynes

As is shown in Figure 6.3 by line 3 the transport in stretch A-B has to become zero, this can be achieved by the application of groynes. A stable equilibrium situation has to be reached in which no wave induced transport occurs, this means the waves have to approach the coastline perpendicularly. Such a situation is sketched in Figure 6.4.

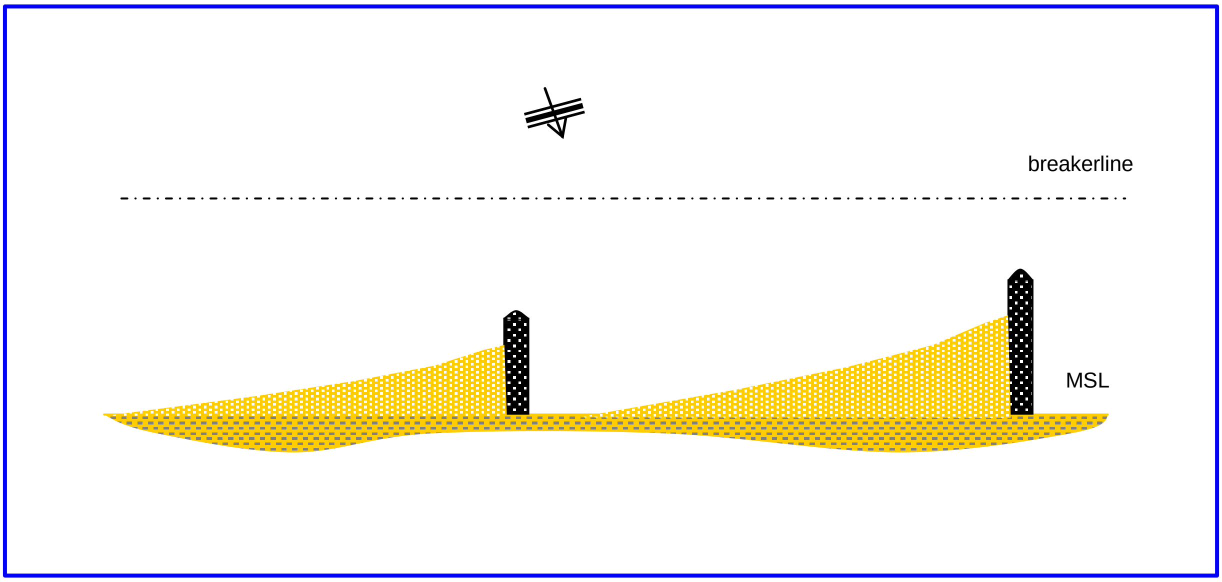

Figure 6.4: Stable situation without wave induced transport

Different approaches are possible concerning groyne length and spacing between groynes to achieve a stable situation. First of all one has to realise that stretch A-B will be divided in smaller sections by the groynes and within these smaller sections the coastline orientation will change so that the waves approach the coastline perpendicularly. To adjust the orientation of the coastline, sediment transport has to occur. The total volume of sediment in a stretch between two groynes will stay the same (assumed that no sediment transport along the head of a groyne occurs), but a redistribution along the coastline will occur. In Figure 6.5 an overview of different groyne lengths and spacing between groynes is provided.

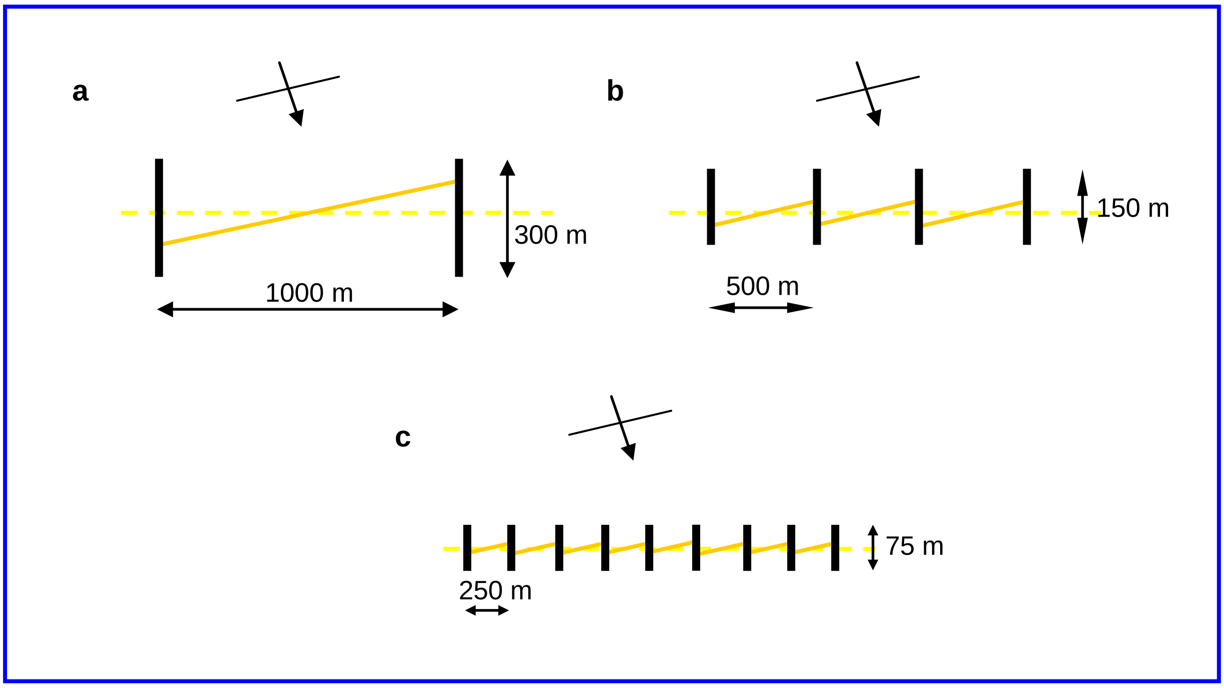

Figure 6.5: Different approaches to groyne length and spacing

- Situation "a" consists of rather long groynes and a large distance between the groynes. On a stretch of coast of 5 km approximately 5 groynes with a length of approximately 300 m are applied. A change of the coastline orientation and some sediment transport between the groynes are to be expected in order to reach an equilibrium situation.
- Situation "b" consists of groynes that are considerably smaller, about 150 m length at an interval of about 500 m. The coastline positions change less than in situation "a" but still a considerable redistribution of sediment along the coastline will occur.
- Situation "c" consists of many short groynes with small intervals between them. The length will be about 75 m at an interval of 250 m. The coastline position stays very much the same as in the initial situation but many structures are necessary.

It can be seen from Figure 6.5 that the initial position of the coastline is maintained the best when the spacing between the groynes is rather small. The larger the intervals between the groynes and thus the longer the groynes, the more change in coastline position compared to the initial situation will occur. One has to decide what amount of sediment redistribution is allowed before designing a groyne scheme. If any retreat of the coastline is not allowed, the construction of groynes might be accompanied with some nourishment.

6.5. The use of offshore breakwaters

By using offshore breakwaters a situation without longshore transport can be achieved when a tombolo is formed and the transport at the seaside of the breakwater is zero. Application of offshore breakwaters in this case may be easier as in the previous two cases, because no longshore transport has to be maintained.

6.6. The use of seawalls or dune revetments

In this case seawalls or dune revetments are not applicable because they do not interfere with the longshore sediment transport processes that cause the erosion problem.

6.7. Remarks on this case

In this case it is of course possible to use artificial nourishments instead of structures to resolve the erosion problem, but also the use of structures is possible to achieve a situation without transport on stretch A-B. Using structures will shift the problem to adjacent beaches downdrift of stretch A-B. To achieve a situation with no transport taking place is relatively simple compared to other cases where fine tuning is necessary.

7. Case 4: Structural erosion: 200,000 m^3/y IN – 300,000 m^3/y OUT (increased wave height)

7.1. Description of the problem

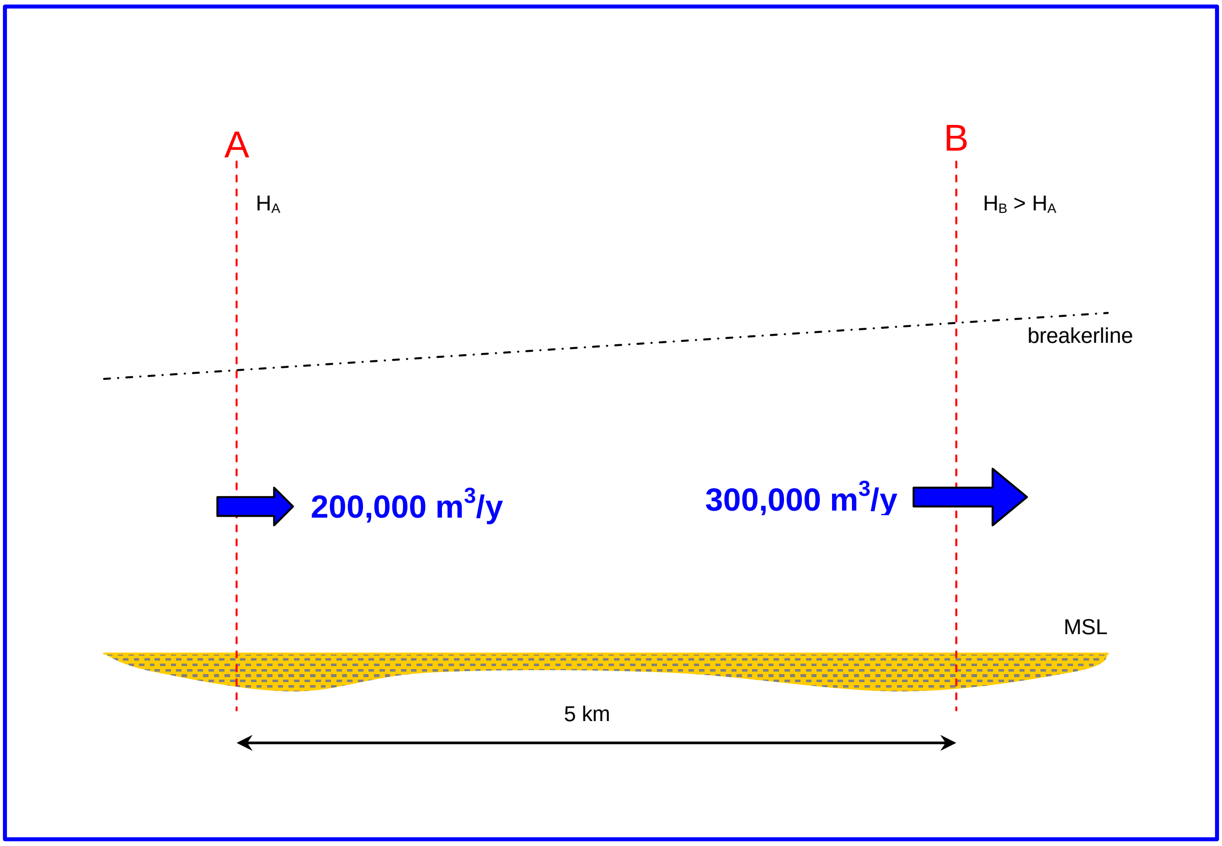

Figure 7.1: Situation case 4

In this case the transport rates through the boundaries of the problem area are assumed to be the same as in Case 1, the cause of the gradient however is assumed to be different in this case. An increasing wave height instead of an increasing angle of incidence is thought to be responsible for the increasing sediment transport along this stretch of coast. The increasing wave height also results in an increasing width of the surf zone, because the waves will start breaking at deeper water if the wave heights are larger. An illustration of the situation in this case can be seen in Figure 7.1.

7.2. Cause of the problem

The basic cause of the erosion problem sketched in this case is basically the same as in Case 1: a gradient in the longshore sediment transport. The physical conditions in this case are different however, because of a widening of the surf zone due to waves breaking at deeper water when the wave height increases along the coast.

7.3. Solution to the erosion problem

In this case again the solution is to create a situation without erosion by trying to redress the gradient in the longshore sediment transport. This means that in every cross-section within stretch A-B a sediment transport of 200,000 m^3/y has to take place.

7.4. The use of groynes

Groynes can be applied to resolve the problem in this case, the length and spacing of the groynes has to be designed so that a transport of 200,000 m^3/y will take place in every cross-section. The shape of the sediment transport distribution over a cross-section changes because of the widening of the surf zone. The length of the groynes has to be adapted to the sediment transport distribution, just so that a transport of 200,000 m^3/y remains in each cross-section. Compared to Case 1 this will lead to the use of longer groynes, because the surf zone becomes wider.

7.5. The use of offshore breakwaters

Similar to the application of offshore breakwaters in Case 1, in this case application of offshore breakwaters is possible too. The 'tuning' of the sediment transport will even be more difficult than it was in Case 1 because of the increasing width of the surf zone. Because the lack of experience and complexity of the problem the application of offshore breakwaters has to be studied thoroughly. Unforeseen and adverse effects may occur when the design is not adequately.

7.6. The use of seawalls or dune revetments

Also in this case the application of seawalls or dune revetments will not result in a long-term solution to the problem because these measures do not interfere with the longshore sediment transport and thus do not redress the gradient in this transport.

7.7. Remarks on this case

Structural solutions in this case can be applied similarly to the applications as sketched in Case 1, the problem is a bit more complex because of the variation in surf zone width. Thorough study has to be carried out before applying any kind of structures, especially because the application of structures will influence the wave heights in the considered stretch of coast and therefore the conditions in the initial phase will differ from the conditions during construction or after construction.

Application of artificial beach nourishments also is a (recommended) solution in this case and this will be less risky compared to the application of structures. Nourishments will have to be repeated on a periodically basis however.

8. Case 5: Structural erosion: Seasonal differences

8.1. Description of the problem

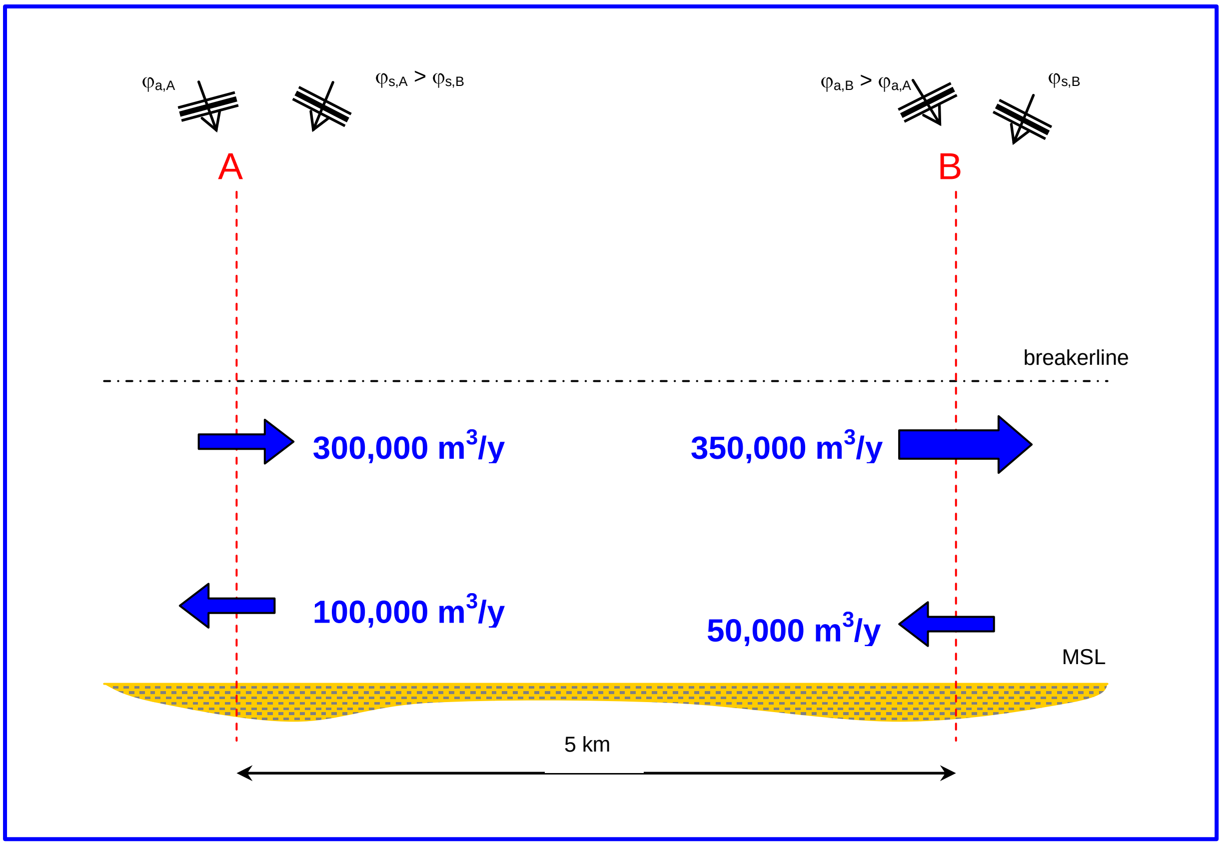

Figure 8.1: Situation case 5

So far all the problems discussed in this report were problems of structural erosion with a gradient in the longshore sediment transport in one direction only. Of course this is unlikely to occur in practice. However the average situation over a year could very well be described by such a schematisation. In the following case the gradient in longshore sediment transport is not just in one direction only, but during a year a distinction can be made between gradients in both longshore directions. These transports do not occur at the same time, but averaged over a year a gradient in both longshore directions can be perceived.

In this case also it is assumed that a net loss of 100,000 m^3/year out of section A-B occurs similar to the problems discussed in the previous cases. The actual causes of the two gradients that occur can be several. In this case it is assumed that a seasonal variation in the angle of incidence of the incoming waves is the reason, but various other causes may lead to the same problem as sketched in this case and illustrated in Figure 8.1.

The net yearly transports through rays A and B are similar to those as discussed in Case 1 (Chapter 4), in this case the main differences compared to Case 1 are discussed and the points of attention when designing a proper solution for this problem are mentioned.

8.2. Cause of the problem

It is clear that during a year there are periods of transport in one direction and periods of transport in the opposite direction. The net yearly transport is the same as it was in Case 1, a net yearly transport through ray A of 200,000 m^3 into stretch A-B and a net yearly transport through ray B of 300,000 m^3 out of stretch A-B. The gross transport into stretch A-B during a year however is 350,000 m^3 and out of stretch A-B it is 450,000 m^3/year.

The net erosion is the main problem but in the design one has to deal with transports in two longshore directions.

8.3. Solution to the erosion problem

In this case especially it is important to take into account the two different directions of the longshore sediment transport taking place on the same stretch of coast.

A possible solution to such a problem is to adjust the sediment transports in and out of stretch A-B just so that the volume of sediment that is transported through rays A and B during one part of the year is the same (assume: 50,000 m^3/y in and out of section A-B) and the volume of sediment that is transported in opposite direction through rays A and B during the other part of the year is the same too (assume: 300,000 m^3/y in and out of section A-B). In this situation the transport processes can still go on and there is no net erosion taking place along the coast. To achieve such a situation a protection scheme has to be designed that influences the sediment transport during a certain angle of incidence of the incoming waves and does not interfere the processes when waves approach from a different direction. Solutions to create such a situation are discussed in the following paragraphs.

8.4. The use of groynes

With the use of groynes it seems very hard to achieve a situation without erosion on stretch A-B. Application of groynes will affect the large transports during one part of the year as well as the small transports during another part of the year in relatively the same extent. For example a groyne near cross-section B which is able to reduce the (large) sediment transport in the right-hand direction will also reduce the (small) sediment transport near B in the left-hand direction. Taking into account that downdrift from B (in the area right from B) lee-side erosion will take place, it might be assumed that the left-hand directed transport near B (50,000 m^3/year) will totally settle in the area right from B. In order to achieve a proper solution the right-hand directed transport near B has to be reduced from 350,000 m^3/year to 200,000 m^3/year in that case under the given assumptions.

8.5. The use of offshore breakwaters

The use of offshore breakwaters might lead to a situation of no erosion on stretch A-B. By changing the orientation of the offshore breakwaters compared to the orientation of the incoming waves it would probably be possible to affect the transport in one direction to a greater extent than the transport in the opposite direction. Fine tuning is necessary, however, and the dynamic processes of the change of the coastline position due to the formation of a salient behind the offshore breakwaters are hard to predict in great detail. It seems to be possible to tackle the erosion problem with offshore breakwaters but it must be clearly understood that there is a risk of unforeseen adverse effects.

With using offshore breakwaters it could also be possible to design two separate protection schemes with different orientations on the same stretch of coast. One scheme influences the sediment transport during one part of the year and does not interfere in the sediment transport processes during the other part of the year. The other scheme does the other way around. In theory this could be designed when the variation in angle of incidence if the incoming waves is very constant during the different parts of the year; in practice however this is not to be expected and thus unforeseen adverse effects can be expected. Thorough study should take place prior to interfering in such a complex situation.

8.6. The use of seawalls or dune revetments

Seawalls or dune revetments seem to be useless in this case because they do not interfere in the longshore sediment transports in the way that is needed in this case.

8.7. Remarks on this case

In this case because of the complexity of the situation a solution with structures seems much more risky as a “simple” beach replenishment. Offshore breakwaters might be used to affect both transports in a different extent but research and the use of complex hydraulic computer models will be inevitable to achieve a desired situation. When even more variations in the transport processes can be distinguished during a year the case will become even more complicated, but in practice this might occur very well.

9. Case 6: Structural erosion: Wide surf zone, transport seawards side

9.1. Description of the problem

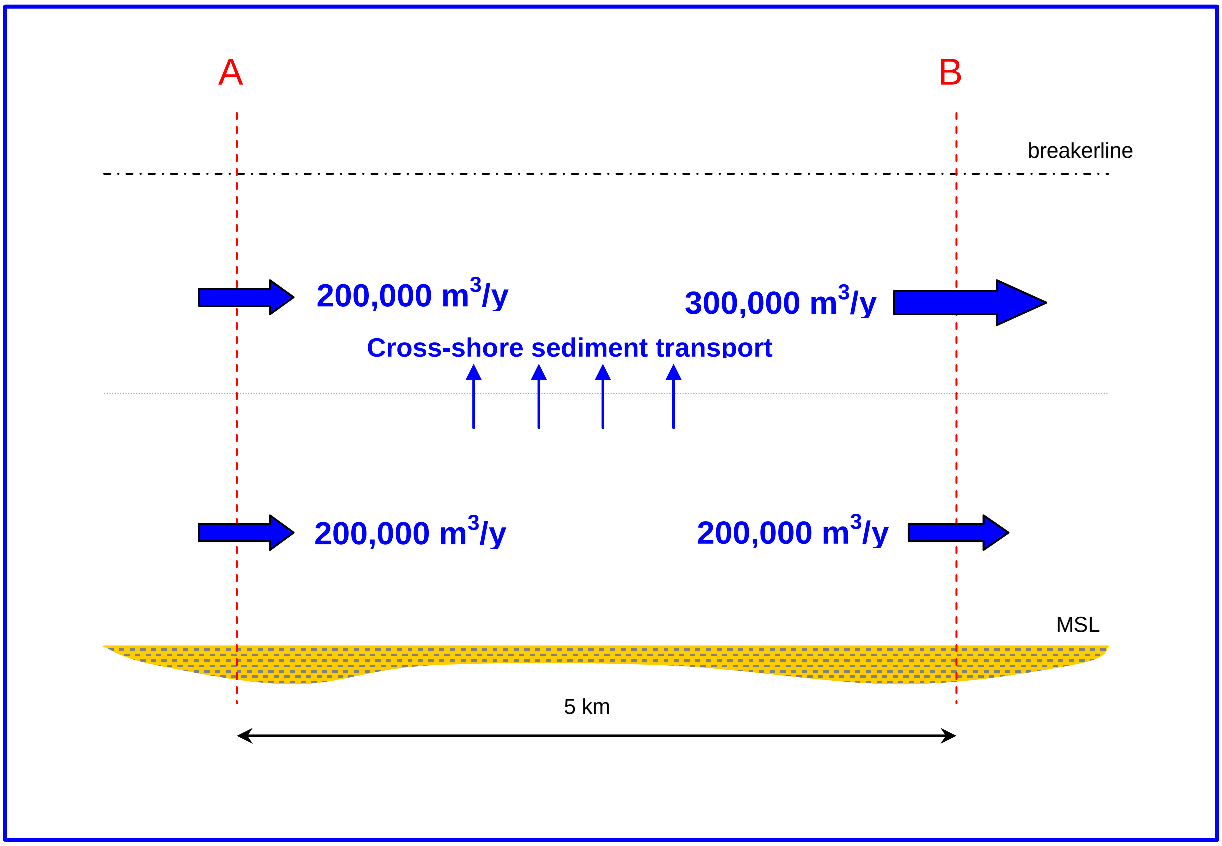

Figure 9.1: Situation case 6

The sediment transports vary over the width of the surf zone. In the present case the erosion processes are thought to be concentrated at relatively deeper water within the surf zone; the sediment transport is assumed to be divided roughly into two areas, a nearshore area with an assumed constant sediment transport rate and thus no erosion problems and a further offshore area with a gradient in the longshore sediment transport rate causing erosion. The erosion does not directly lead to a retreat of the coastline but similar to the processes sketched in case 1 during severe storm surges, the erosion on the seawards side of the transport zone will lead to a deepening of this area. This will result in a change of the equilibrium beach profile. The erosion at deeper water triggers a cross-shore transport causing ultimately the coastline to shift to the landward side. Eventually this process can lead to retreat of the dry beach and dune area.

Various causes can lead to the occurrence of this problem, e.g. an increasing tidal current or significant changes in waterdepth. A sketch of the situation is presented in Figure 9.1.

9.2. Cause of the problem

The erosion processes are assumed to be concentrated at deeper water and will lead to a steepening of the beach. This steepening can eventually lead to a retreat of the dry beach and dune area which is of use to society. Thus although the problems are located further offshore still a retreat of valuable

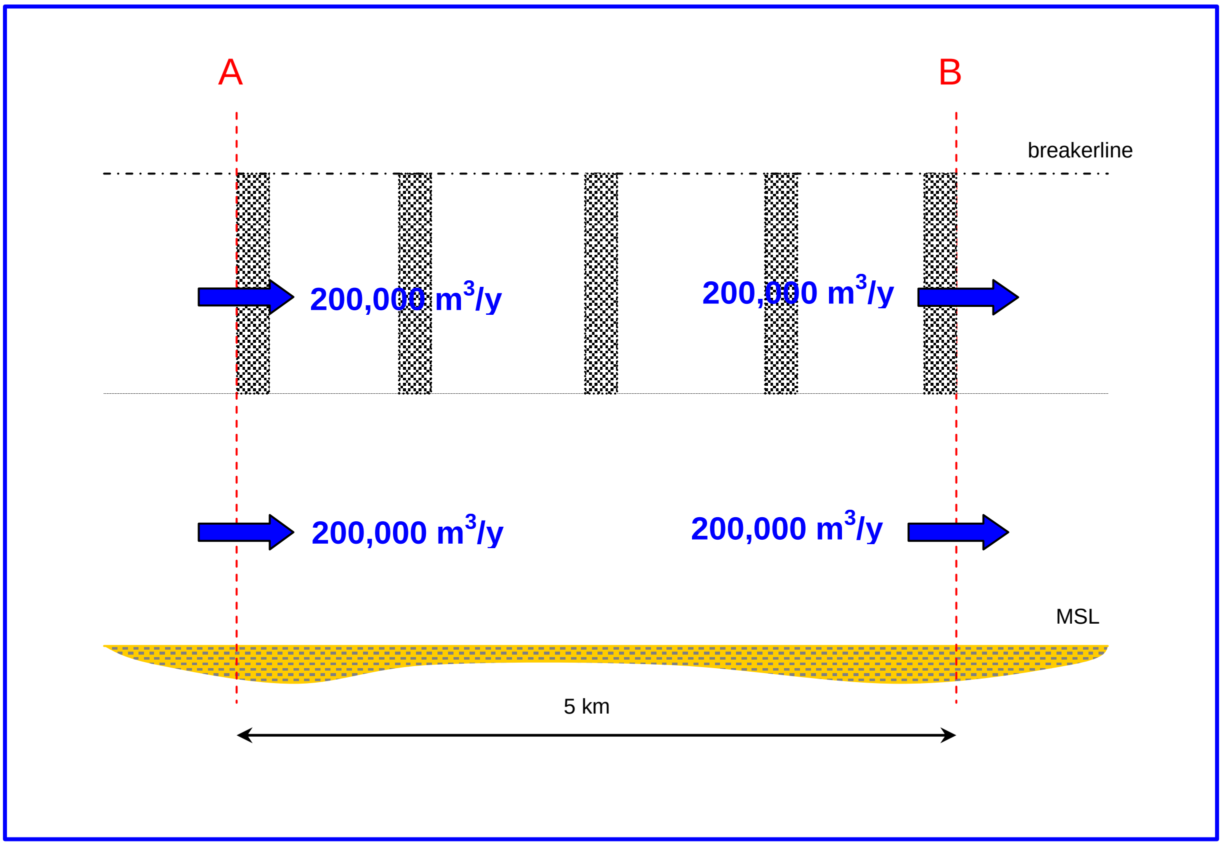

Figure 9.2: Use of underwater dams to reduce the tidal current velocity

coastal area can occur as a consequence.

9.3. Solution to the problem

Two principally different ways to resolve the problem as sketched in this case can be distinguished. The first possibility to achieve a situation without erosion is to interfere in the 'problem area'. This means that one has to design some protection scheme in deeper water farther offshore which is very difficult, and because of the harder conditions, also more expensive. The second possible way of interfering is to design some sort of protection in the near shore zone just so that the eroded amount of sediment to deeper water will be provided by trapped sediment behind the protection scheme in the nearshore zone.

Interference further offshore on deeper water

In deep water it is hard to work with structures that are orientated perpendicularly to the coast. A protection scheme of underwater dams that reduce the velocity of the tidal currents might be effective if the erosion is caused by an increasing tidal current velocity, see also Figure 9.2. If the current flows around the protection scheme this may lead to increasing erosion problems in the areas around the protection scheme both on the farther offshore zone as in the nearshore zone. Local erosion processes near the heads of the underwater dams are not discussed in this report but will have to be considered when designing a protection scheme. It is important to design the protection scheme so that the velocities of the tidal current are reduced in stretch A-B in the area where the underwater dams are situated, but so that the current will not increase dramatically in the adjacent sections on stretch A-B.

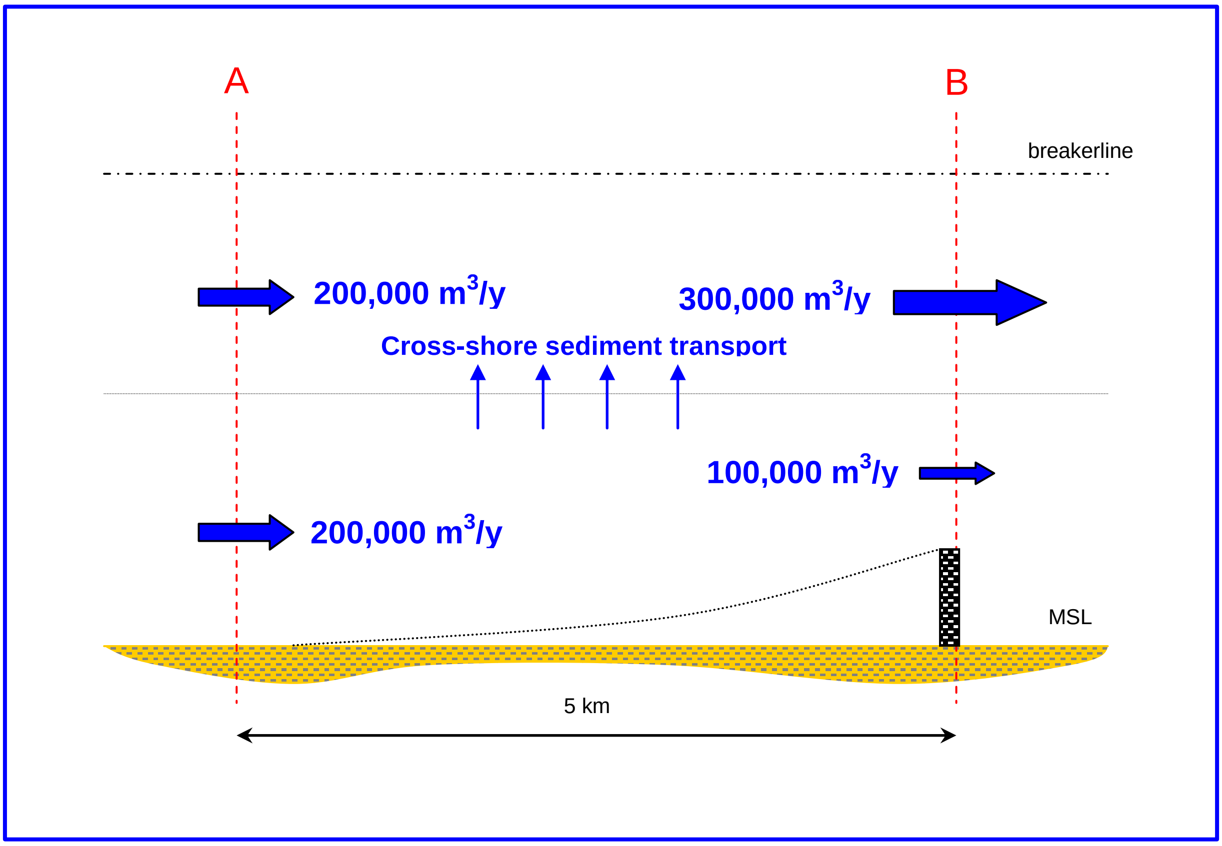

Figure 9.3: The use of groynes in the near shore zone

On deeper water it is also possible to use offshore breakwaters to interfere within the morphological system. It is inevitable, however, that the offshore breakwaters will also influence the processes in the nearshore area. Because of this complicated interaction in the entire coastal zone behind the offshore breakwaters a profound study has to be carried out before constructing such a protection scheme. The use of either physical or computational morphological models might determine whether offshore breakwaters are applicable in a practical situation.

Interference in the nearshore zone

It is also possible to interfere in the nearshore zone, although the gradient in the longshore sediment transport is assumed to occur further offshore. The intention of interference in the nearshore is to catch additional volumes of sediment that after being transported towards deeper water will be eroded, as is sketched in Figure 9.3. The amount of accretion that has to take place in the nearshore zone must equal the amount of erosion caused by the gradient on deeper water. Cross-shore transports will redistribute the extra amounts of sediment over the entire cross-shore profile and a new equilibrium situation will develop without retreat of the coastline. To accrete sediment in the near shore area groynes can be used. One has to design the groyne field just so that the amount of accretion equals the amount of erosion to deeper water in every cross-section. An inevitable adverse effect of the application of groynes is that they will lead to lee-side erosion and thus a problem on adjacent sections of coast may be developed by protecting the stretch A-B.

In principle offshore breakwaters can also be applied to accrete the amount of sediment required to balance the morphological system, but because of the interference in the cross-shore sediment transport they are not applicable in this situation, because the redistribution of sediment over the cross-section by cross-shore transports is necessary to achieve the desired situation.

9.4. Remarks on this case

In a situation as sketched in this case it is possible to interfere in the system by applying structures, the application of groynes in the nearshore area seems to be the most effective way of protecting stretch A-B, this measure will lead to lee-side erosion however. If that is not allowed the use of flow reducing underwater dams might be an option, but model studies should be carried out to investigate the (unforeseen) effects. Probably the easiest way of prevent the coastline to retreat is to apply artificial nourishments. These nourishments can be applied in the nearshore zone or on the beach to supply additional volumes of sediment that can erode to deeper water and have to be repeated on a regular basis.

10. Case 7: Structural erosion in combination with a tidal current

10.1. Description of the problem

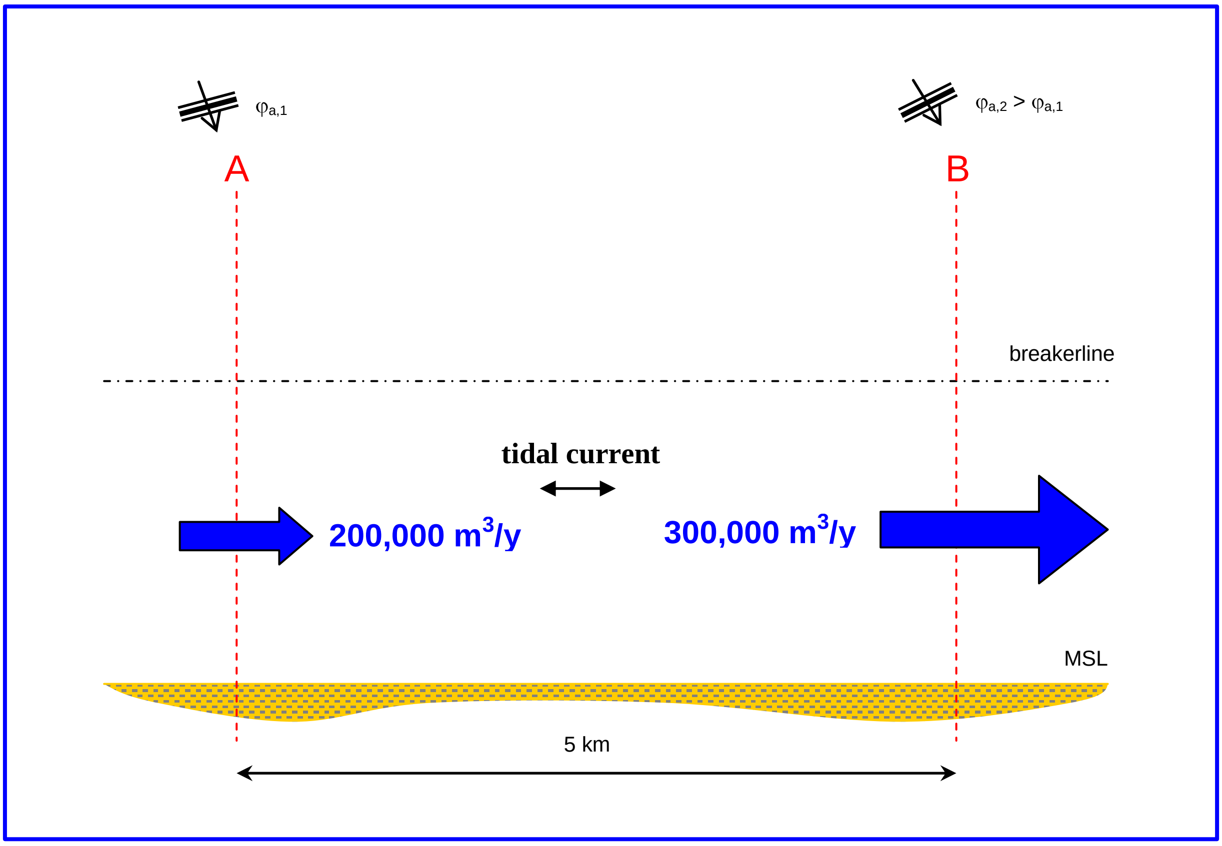

Figure 10.1: Situation case 7

The problem sketched in this case is caused by wave driven sediment transport in combination with tidal current driven sediment transport. The tidal current is assumed to be not strong enough to transport large volumes of sediment by the current itself, but the tidal current will transport the sediment that is lifted from the bottom by the orbital motions of the waves.

10.2. Cause of the problem

As mentioned in the description of the problem the causes of the problem are both waves and a tidal current. The waves do not necessarily have to create a gradient in longshore transport as is sketched in Figure 10.1, it is well possible that the waves only cause the stirring up of the sediment and the tidal current is responsible for the transport taking place. A gradient in the transport rates might be caused by variations in the tidal current velocity.

10.3. Solution to the erosion problem

In general the gradient in the longshore transport rates has to be made zero in this case. When hard structures are used one has to consider the influence of these structures on the tidal current velocity. Flow contraction for example may lead to increasing current velocities or generation of rip currents.

10.4. The use of groynes

Application of groynes is very well possible. By varying the length of the groynes one can adapt the groyne field just so that a constant sediment transport rate will occur, the tidal current will contract around the heads of the groynes, where high velocities and local scour can be expected. Circulating currents between the groynes can cause rip currents, which might be dangerous for swimmers or other recreational users of the beach area. In Figure 10.2 the use of groynes to resolve such a problem in Scheveningen, The Netherlands is shown. Figure 10.3 shows a schematical indication of the flow directions.

In this case the application of groynes will lead to lee-side erosion as well.

Figure 10.2: Application of groynes at Scheveningen, The Netherlands

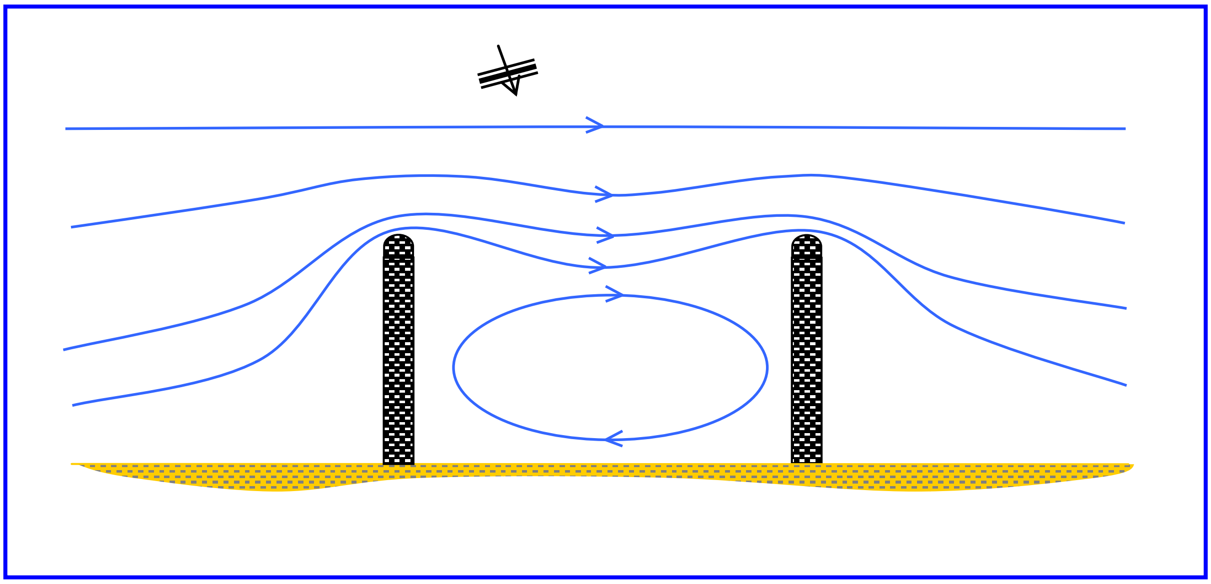

Figure 10.3: Flow patterns around the groynes

10.5. The use of offshore breakwaters

Offshore breakwaters can be used in principle to prevent erosion from taking place on this stretch of coast. The formation of a tombolo or salient will be affected by the tidal current and therefore it will be very difficult to design a proper protection scheme. Unforeseen effects are likely to occur and therefore a profound study has to be carried out, while using physical or mathematical morphological models.

10.6. The use of seawalls or dune revetments

The application of a seawall or dune revetment is not feasible in this case because such structures do not interfere in the longshore sediment transport as is discussed in Case 1.

10.7. Remarks on this case

The presence of a tidal current complicates the design of a protection scheme. The easiest way to resolve most of such problems is by artificially renourish eroded amounts of sediment. If a structural solution is preferred then the use of groynes is possible. The groynes will lead to flow contraction and local scour, rip currents and of course lee-side erosion, but by tuning the groyne field one should be able to design a stable situation with lee-side erosion. The use of offshore breakwaters seems less easy because of the interaction between the structures and the waves and flow patterns. By using morphological models it should be possible to design a proper system with offshore breakwaters as well.

11. Case 8: Beach of insufficient width

11.1. Description of the problem

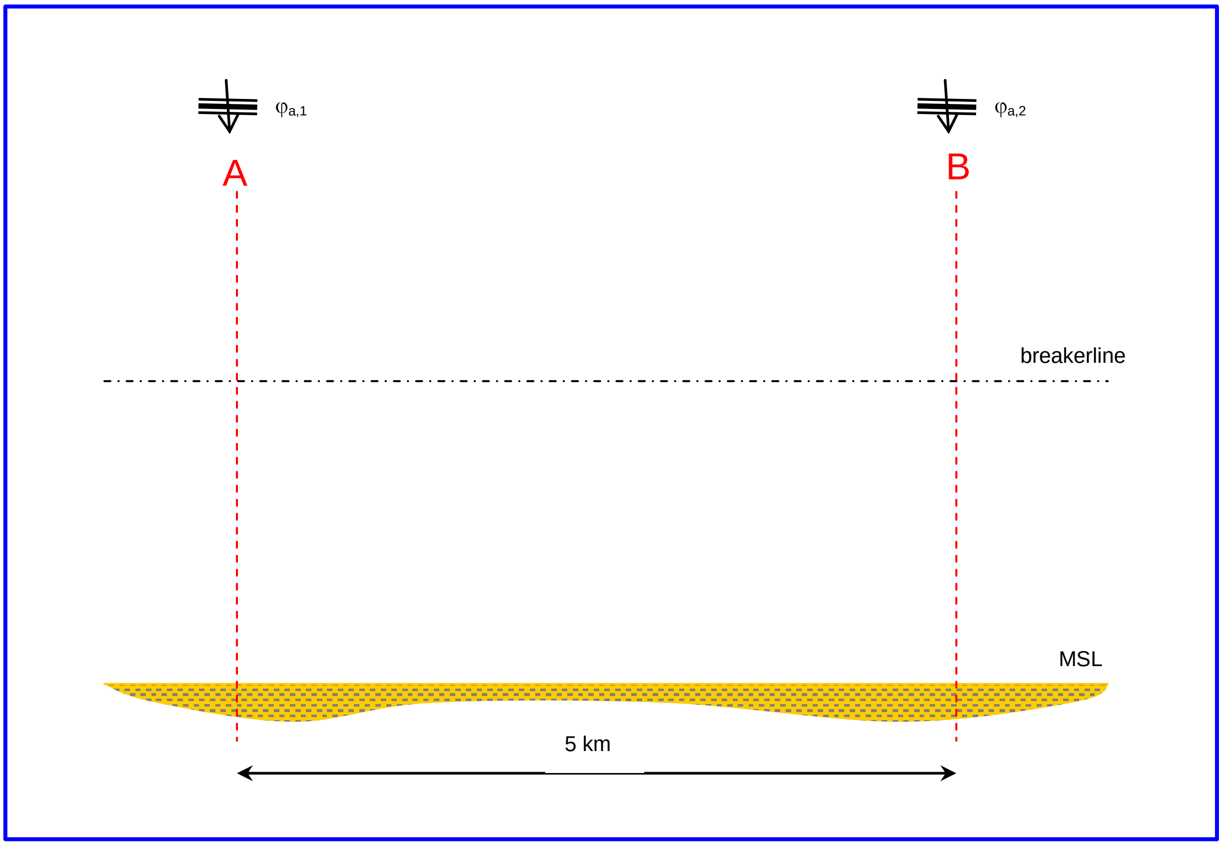

Figure 11.1: Situation case 8

Many beaches are used for recreational purposes and therefore it is highly desirable that a sufficient stretch of dry beach even during normal high tides is present. In this case a stable beach is considered, the waves are approaching perpendicularly and thus they do not initiate a longshore sediment transport. In fact it is assumed that there is no transport at all through rays A and B, as can be seen in Figure 11.1.

11.2. Solution to the problem

The solution to the problem can be a simple beach nourishment because there is little transport. This could be sufficient for quite a long period of time. Structures can be used to protect the nourishment from being eroded. It might also be possible to use structures to let the beach accrete by natural sedimentation processes. Various ways to achieve a situation with a sufficient beach area are discussed in the following paragraph.

11.3. The use of various engineering tools

The easiest way to increase the width of a beach is to artificially nourish a large volume of sediment on the shore that will be redistributed along the coast by natural processes in a matter of time. An example of such a beach widening is shown in Figure 11.2.

Figure 11.2: Artificial beach nourishment, Castilla (Spain)

In Figure 11.3 is sketched how the sediment is redistributed along the coast. A nourishment will lead to a widening of the beach along a long stretch of coast. If a considerable widening along a short stretch of coast is the objective, structures can be applied to 'protect' the beach nourishment.

Groynes can be applied to avoid erosion of an artificial nourishment. The nourishment has to be carried out between two groynes. The beach between the groynes will become considerably wider, which is especially interesting when this stretch of beach is in use for recreational purposes. The application of groynes to protect a nourishment is sketched in Figure 11.4. Because of the absence of

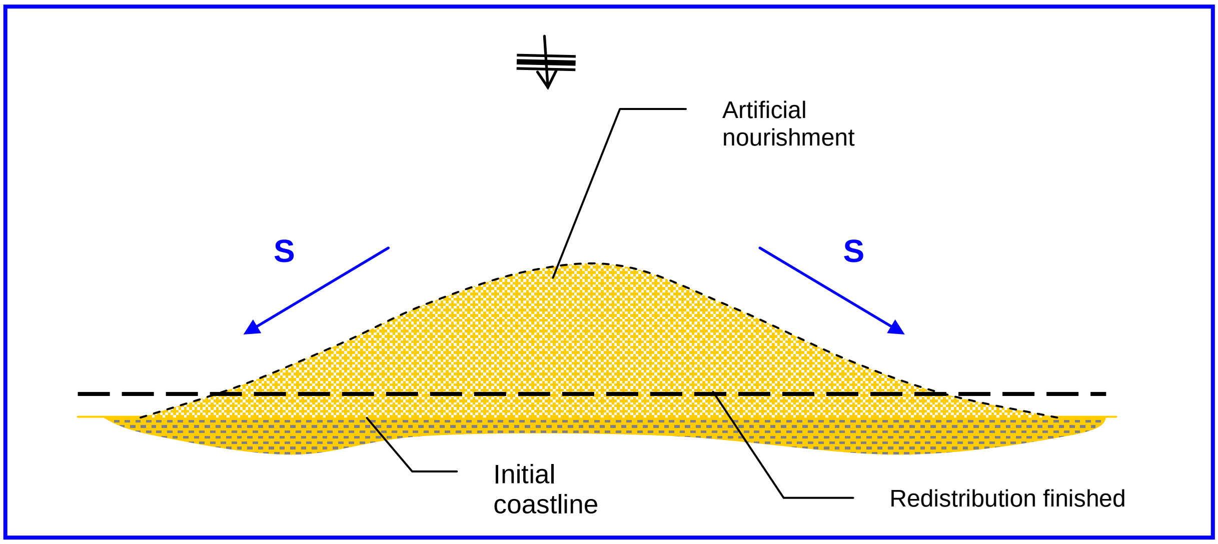

Figure 11.3: Sediment redistribution along the coastline

longshore sediment transport in this case it is assumed that no adverse lee-side effects have to be

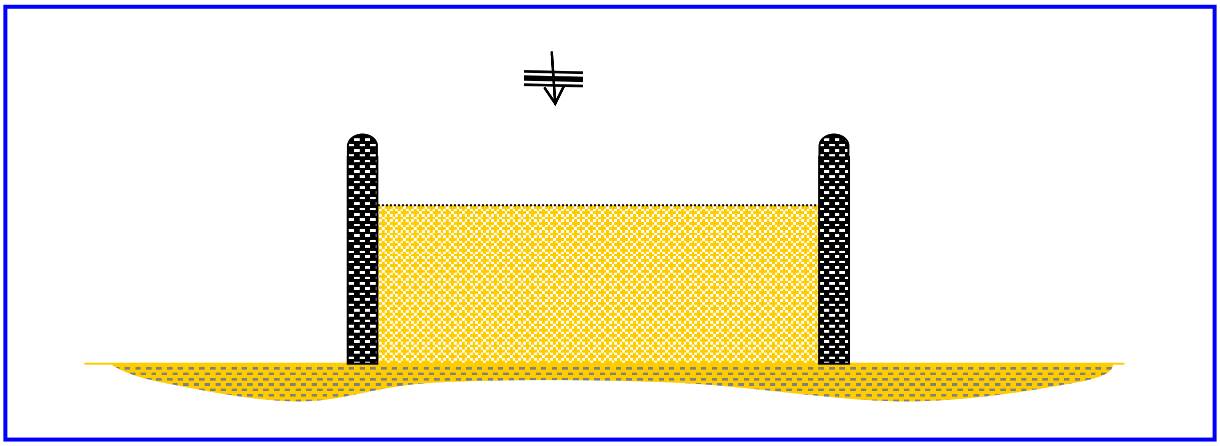

Figure 11.4: The use of groynes to defend an artificial beach nourishment

expected after construction of the groynes and filling the area between the groynes.

Offshore breakwaters can also be applied to protect an artificial beach nourishment from being eroded and redistributed over the entire coastline. Wave diffraction in the shadow zone can lead to some redistribution and thus groynes seem to be preferred over offshore breakwaters to protect a nourishment from being eroded.

Offshore breakwaters can be applied however to let the beach grow by natural processes. In the shadow zone that is created behind the breakwater the wave climate is much milder and therefore the driving force of the littoral transport process has decreased and also less bottom material is stirred up. The littoral sediment transport is distorted by the offshore breakwater and sediment will be deposited behind the breakwater. The advantage of using offshore breakwaters over groynes is the possibility to modify the littoral transport process in a smoother manner. The wave set-up behind the breakwater also decrease. This causes a current that can transport sediment into the shadow zone behind the breakwater, as is sketched in Figure 11.5. In Figure 11.5 an ultimate situation with a tombolo has been schetched. One has to take into account that the sediments accreted while forming the tombolo are at the spent of the adjacent beach areas. If one likes to ultimately prevent such a situation, it is recommended to artificially nourish sediment in the shadow zone.

Application of a submerged breakwater will have just the opposite effect because of the wave-overtopping as is explained in Appendix A.

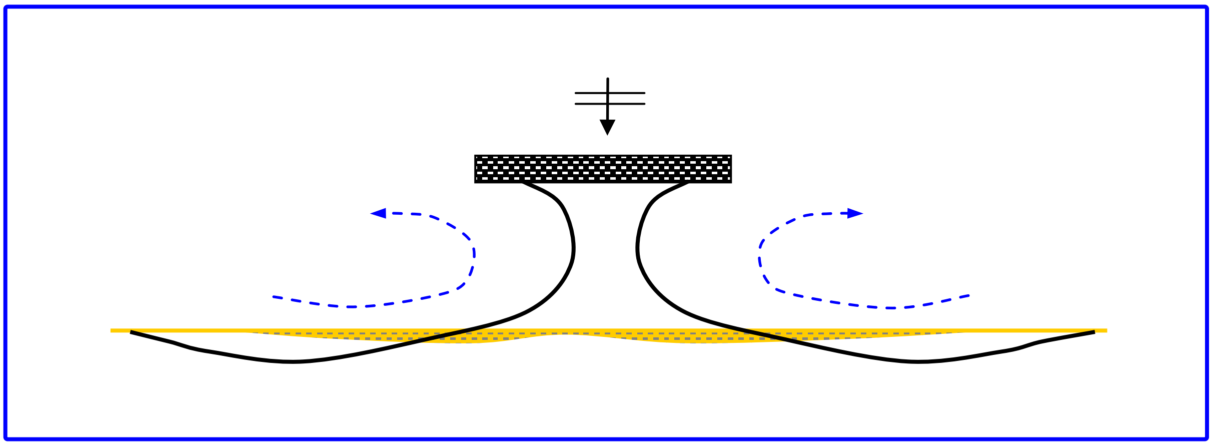

Figure 11.5: Application of offshore breakwaters

11.4. Remarks on this case

The use of offshore breakwaters to let the beach ‘grow’ by natural processes probably does not lead to a situation with sufficient beach area in this stretch and erosion on adjacent beaches will even lead to a reduction of the beach area in those sections of coast. So probably the use of nourishments is inevitable to create sufficient beach area. Whether the nourishment should be protected by structures (in this case groynes seem to be most effective) depends on economical conditions. The costs of repeating an unprotected nourishment every few years have to be compared with the costs of constructing groynes to protect the beach. Also environmental and aesthetical arguments have to be taken into account in the final decision which solution is favourable. Unprotected nourishments also have an accreting effect on adjacent beaches.

12. Case 9: Beach of insufficient width with longshore transport

12.1. Description of the problem

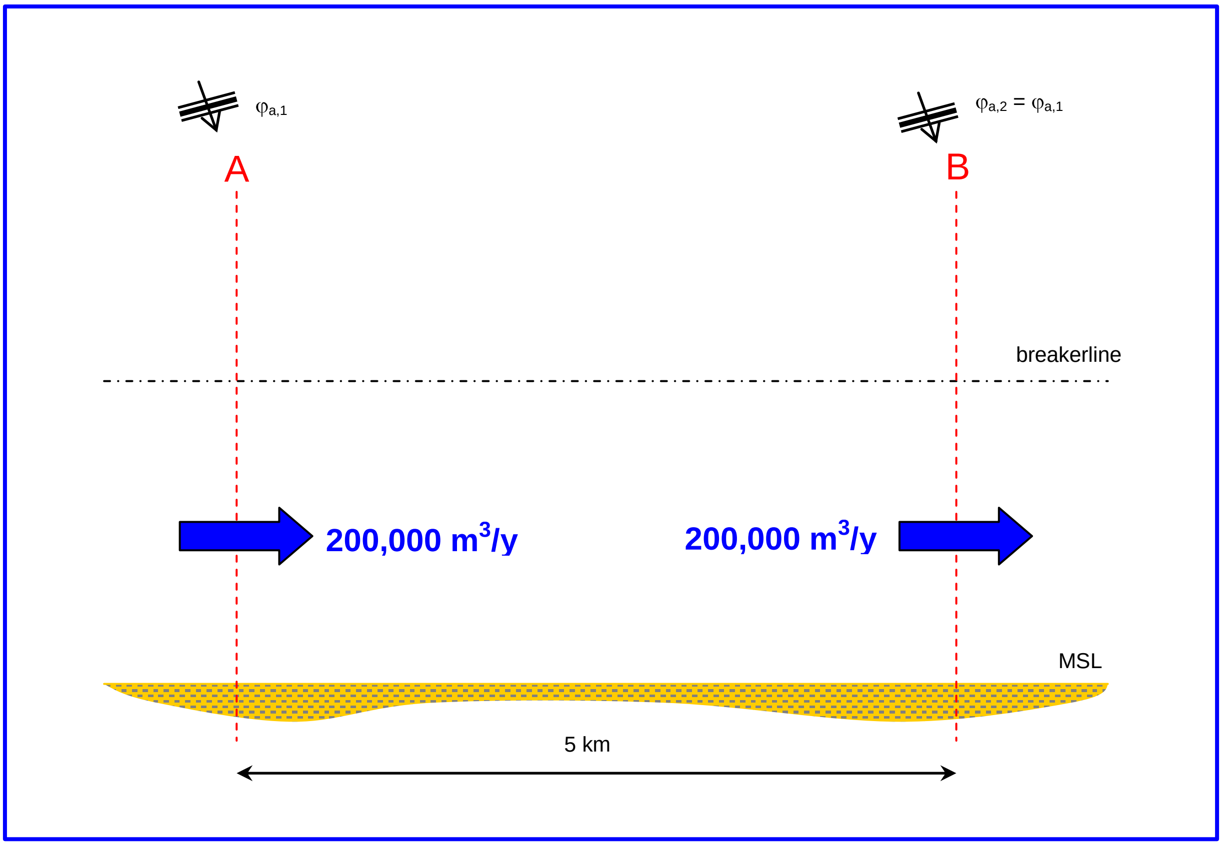

Figure 12.1: Situation case 9

The problem discussed in this case is similar to the problem discussed in the previous case with one clear difference; in this case a longshore sediment transport is present in stretch A-B. The beach is stable because the amount of sediment transport through ray A into this section is equal to the sediment transport out through ray B. The beach is assumed to have an insufficient width to satisfy the needs of the recreational users. The transport that occurs in this case is assumed to be wave driven, caused by an angle of incidence of the incoming waves.

12.2. Solution to the problem

The solution to this problem can be an artificial nourishment as is shown in the previous case, but it is also possible to make use of coastal structures to use the longshore sediment transport to naturally widen the beach. Both the application of groynes and offshore breakwaters might meet this requirement.

12.3. The use of various engineering tools

Groynes can be applied to trap the sediment that is being transported along the shore. Accretion on the updrift side of every groyne will increase the width of the beach. An adverse effect of this measure is

Figure 12.2: The use of groynes; location unknown (from: TAW, 1995 [4])

however an erosion problem at the downdrift side of the groyne (field). In the initial situation there was no erosion problem, but when the downdrift area is less important and no harm is done to the safety of the hinterland in that area erosion may be accepted. Figure 12.2 shows how groynes are being applied to enlarge the dry beach area.

Similar to the use of groynes offshore breakwaters can be applied too. Figure 12.3 shows the use of offshore breakwaters with a salient formed behind. It is however also possible to apply offshore breakwaters with a tombolo formed behind them.

In this case it is also possible to make use of artificial nourishment. The nourishment will also be redistributed over the entire coastline similar to Case 8. An artificial nourishment will also have an effect on the longshore sediment transport however.

Figure 12.3: Application of offshore breakwaters, Murcia (Spain)

12.4. Remarks on this case

In this case it might be possible to make use of the present longshore sediment transport to supply the needed amounts of sediment, this can be done by applying either groynes or offshore breakwaters. To achieve sufficient beach area on a short term after construction artificial nourishments can be used as well. If only structures are applied severe lee-side erosion has to be taken into account. Applying beach nourishments only, leads to a similar redistribution as discussed in Case 8. Due to the longshore transports it is not good feasible to confine the artificially nourished sediments between two end-groynes like in Case 8.

13. Case 10: Interruption of longshore transport by port jetties

13.1. Description of the problem

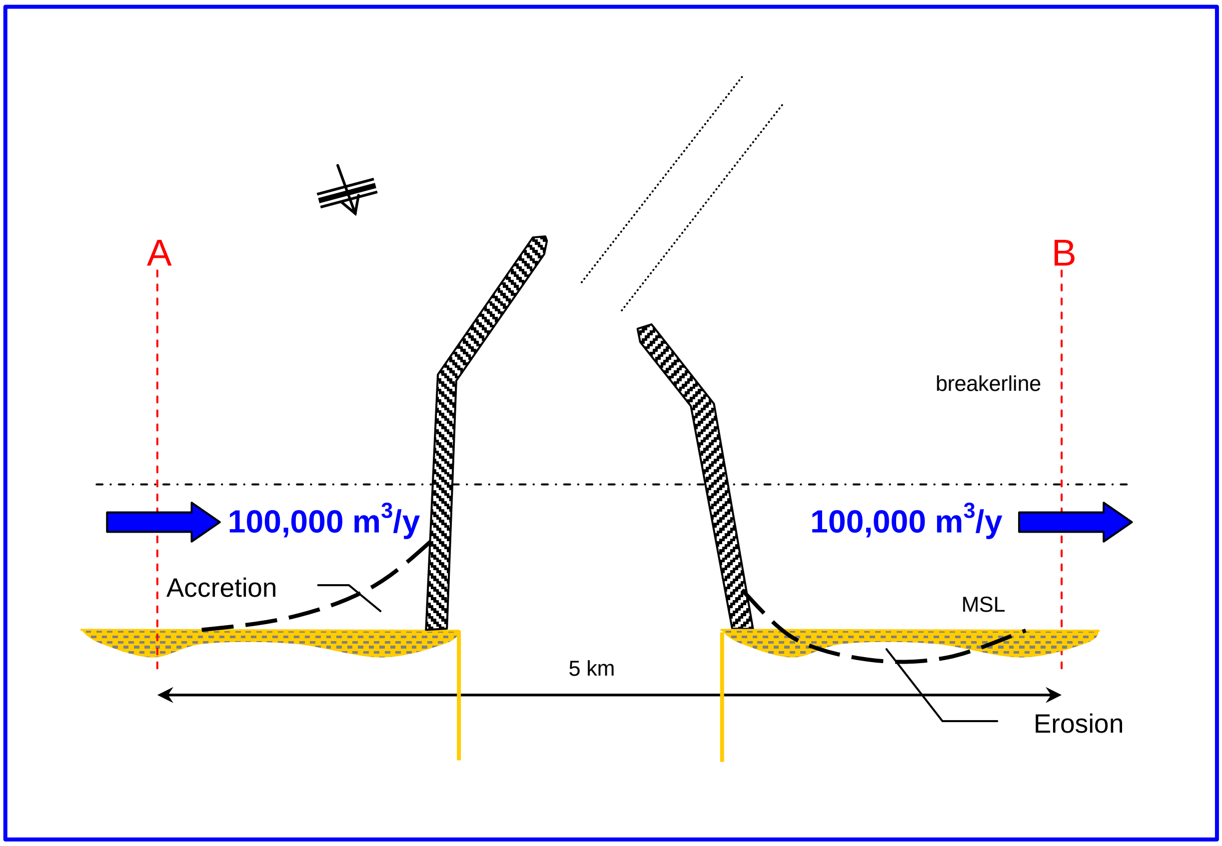

Figure 13.1: Situation case 10

In order to protect a port or port entrance against wave attack and to prevent an approach channel to be silted up by the longshore sediment transport, often port jetties are being applied. Port jetties stretch far out the surf zone and thus totally block the longshore sediment transport. Evidently this will lead to accretion and erosion problems on the updrift and downdrift side of the port entrance, as is shown in Figure 13.1.

13.2. Cause of the problem

The cause of the problem is very clear in this case because the port jetties form a physical interruption to the longshore sediment transport. The longshore sediment transport is driven by obliquely approaching waves. As is sketched in Figure 13.2, the accretion on the updrift side will accumulate until the head of the port jetty is reached; at that point the sediment passes (partly) the head of the jetty and will be deposited in the approach channel. The erosion will continue similarly, because no sediment is supplied on the downdrift side.

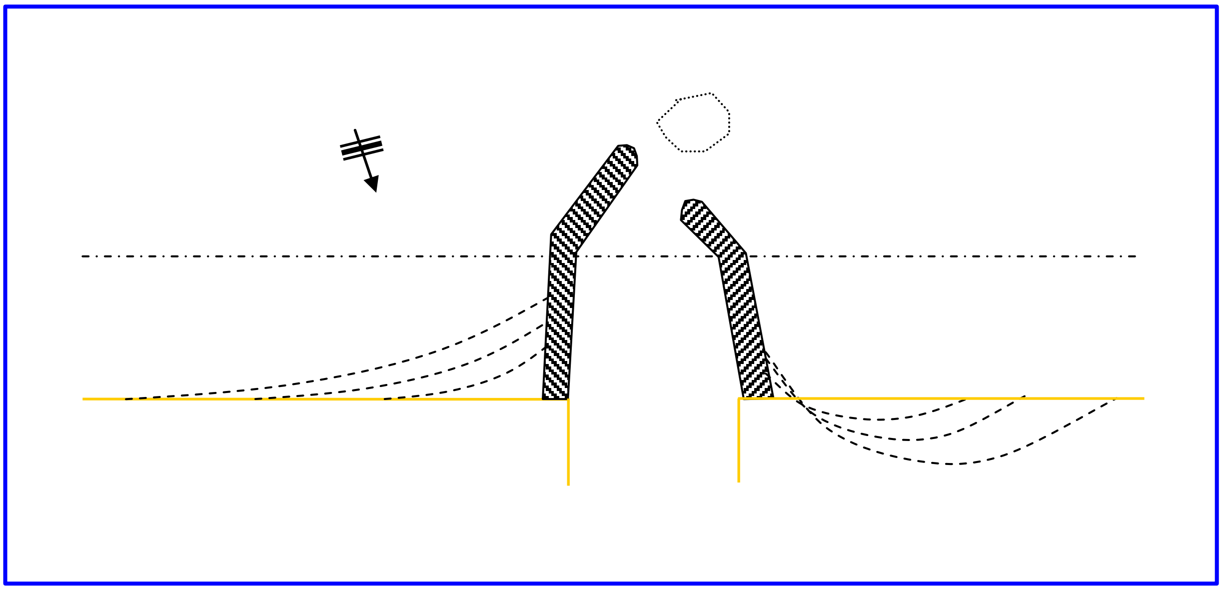

Figure 13.2: Accretion and erosion according to Pelnard-Considère

13.3. Solution to the problem

A solution to the problem sketched in this case is not very easy to design. One has to find a way to reduce the adverse effects of the port jetties to a minimum. Assuming that the location of the port is not variable, the local conditions have to be considered. The adverse effects of the port jetties are both accretion at the updrift side and erosion at the downdrift side. The easiest way to resolve the problem would be to redistribute the accreted amount of sand on the downdrift side by an artificial sand bypass system or by simply dredging and replenishing. Whether an artificial sand bypass system is economically acceptable depends on the amounts of sediment that are being accreted near the updrift jetty. The costs of dredging on a periodically basis have to be compared to the construction and operation costs of an artificial sand bypass system.

If accretion on the updrift side and sand bypassing around the head of the jetty is the main problem one could decide to apply structures on the updrift side or to extend the port jetty itself. Both solutions will result in an increased “storage area” for the transported sediment. Erosion on the downdrift side will continue undiminished because the supply of sediment on the downdrift side is still zero.

If erosion on the downdrift side is the main problem one could apply structures on the downdrift side to create a situation without gradients in the sediment transport along (a part of) the downdrift coast. In practice this means that a situation without sediment transport has to be designed. The use of structures can be accompanied by an artificial nourishment. Solving the problem for the stretch of coast directly downdrift of the port jetty will shift the erosion to a more downdrift section of coast. This might be an acceptable solution when that stretch of coast is of less interest to society and the erosion will not lead to unwanted consequences.

13.4. Engineering measures on the updrift side

On the updrift side groynes can be applied to enlarge the area where sediments can be accreted. By doing this one possibly increases the period of time between two dredging operations (it will take longer until the accretion will form a problem to other coastal activities or sediment will pass along the head of the port jetty). The use of groynes for this purpose is sketched in Figure 13.3.

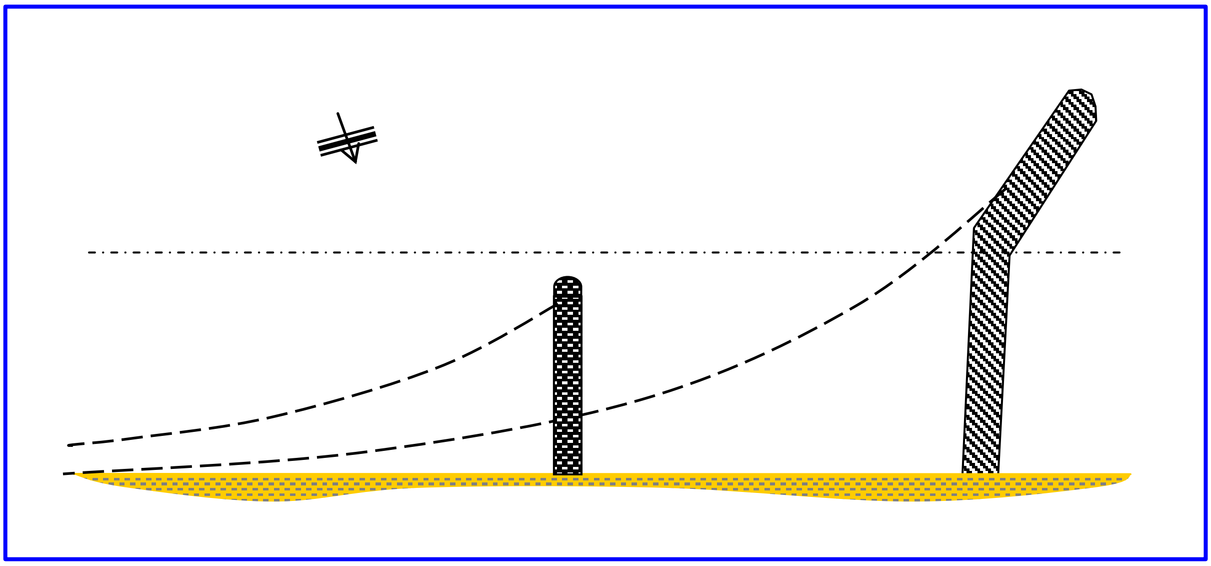

Figure 13.3: Application of groynes on the updrift side

Instead of applying a groyne to enlarge the 'storage area' for sediment, one could also decide to enlarge the port jetty itself. Another possible measure to enlarge the volume of accreted sediment is the application of an offshore breakwater, see also Figure 13.4, or even several offshore breakwaters as shown in Figure 13.5 (Figure 13.5 is only used as an illustration of this possible approach).

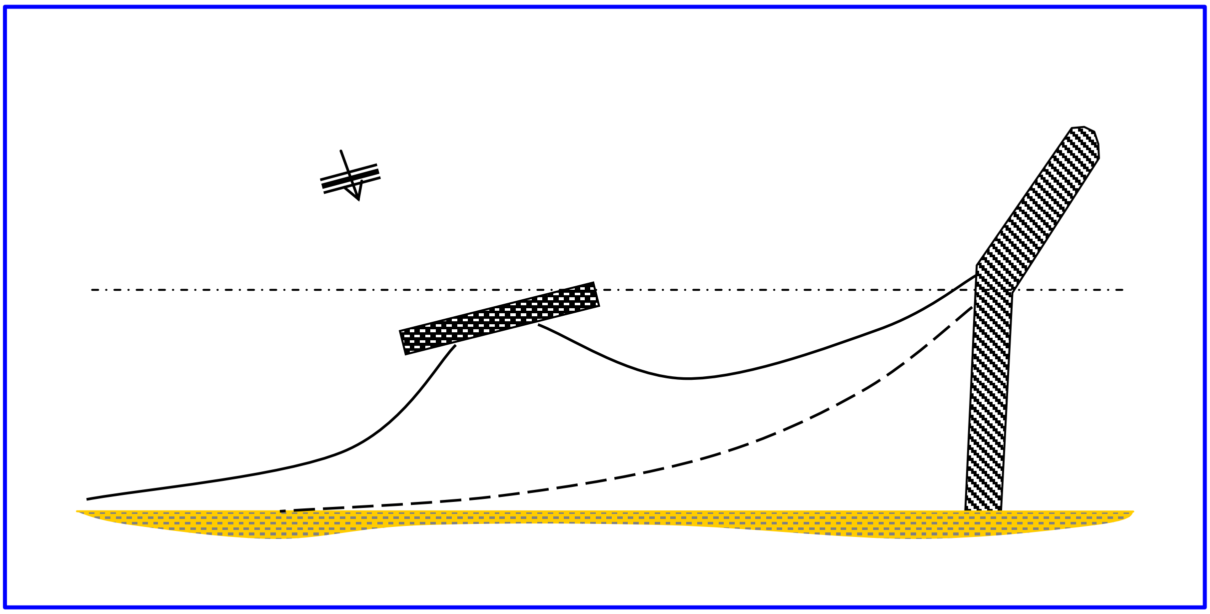

Figure 13.4: Application of offshore breakwaters on the updrift side

Figure 13.5: The use of offshore breakwaters at the updrift side of a port entrance, Fiumicino (Italy)

13.5. Engineering measures on the downdrift side

On the downdrift side it might also be possible to use groynes to reduce the adverse erosion effects. Application of groynes may lengthen the period between two artificial renourishments, because the sediment is eroded less easy on the downdrift side since it is trapped between groynes. If properly designed the longshore sediment transport is stopped by the application of the groynes; farther downdrift erosion will occur, because of lee-side effects. The use of groynes on the downdrift side is sketched in Figure 13.6. It is questionable if the use of groynes in this case will be economically acceptable.

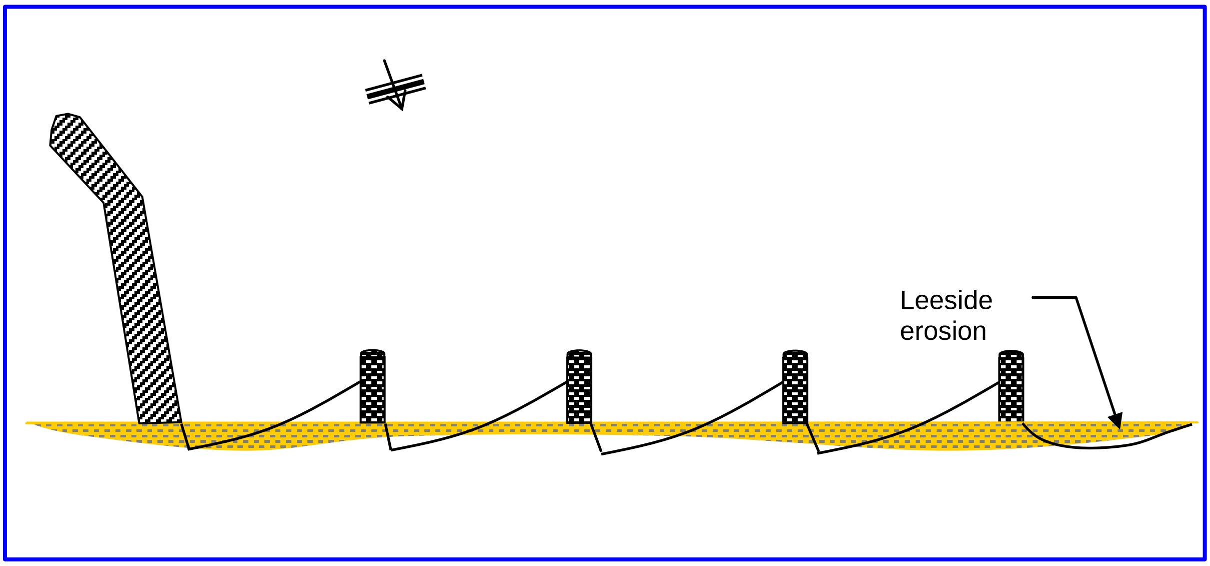

Figure 13.6: Application of groynes on the downdrift side

Offshore breakwaters can also be used to create a situation without transport and thus without erosion immediately downdrift of the port jetty. In Figure 13.7 a situation after redistribution of the available sediments has been sketched. So some local retreat of the coastline will occur. If that does not fit the requirements the sand trapped by the offshore breakwaters has to be artificially nourished.

This solution will also lead to lee-side erosion downdrift of the protected area.
In practice only in very special occasions measures will be taken on the downdrift side because of the great costs of these structures that only shift the location where the erosion takes place farther downdrift.

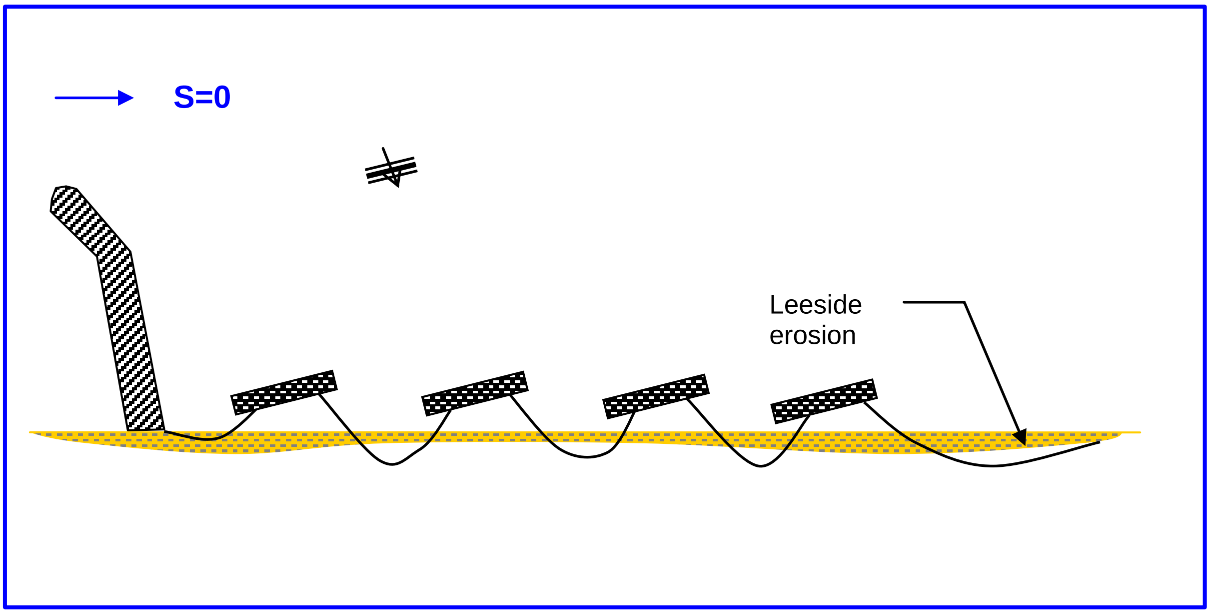

Figure 13.7: Application of offshore breakwaters on the downdrift side

13.6. The use of seawalls or dune revetments

In this case there is no use for seawalls or dune revetments, because they do not interfere with the longshore sediment transport.

13.7. The use of an artificial sand bypass system

The only solution to the basic problem of this case is to remove the accreted volumes of sediment and to restore the eroded volumes of sediment. Of course it is recommended to use the sediment accreted on the updrift side to restore the eroded amount on the downdrift side. Redistribution of these amounts of sediment can be realized in several ways; in principle there are two possibilities:

- A permanent bypass system
- A temporary bypass system

The frequency of the required bypass operations and the possibility to block the port entrance with dredging equipment determine which system should be applied.

13.8. Remarks on this case

In most cases the use of port jetties will lead to accretion at the updrift side and erosion at the downdrift side. It is recommended to use the accreted volumes of sediment updrift to replenish the eroded volumes of sediment on the downdrift side. This can be done either by regularly dredging operations or by a permanent sand bypass system. The ultimately chosen method depends on the use of the port and the economical situation. The use of structures updrift of the port jetty to enlarge the interval between two dredging operations is possible and may serve other purposes as well (e.g. recreation or environment). Application of structures on the downdrift side only shifts the erosion area farther downdrift and is therefore unlikely to be applied. Only if there are serious reasons to prevent erosion directly downdrift of the port jetty this might be applied.

14. Case 11: Port jetties in combination with tidal currents

14.1. Description of the problem

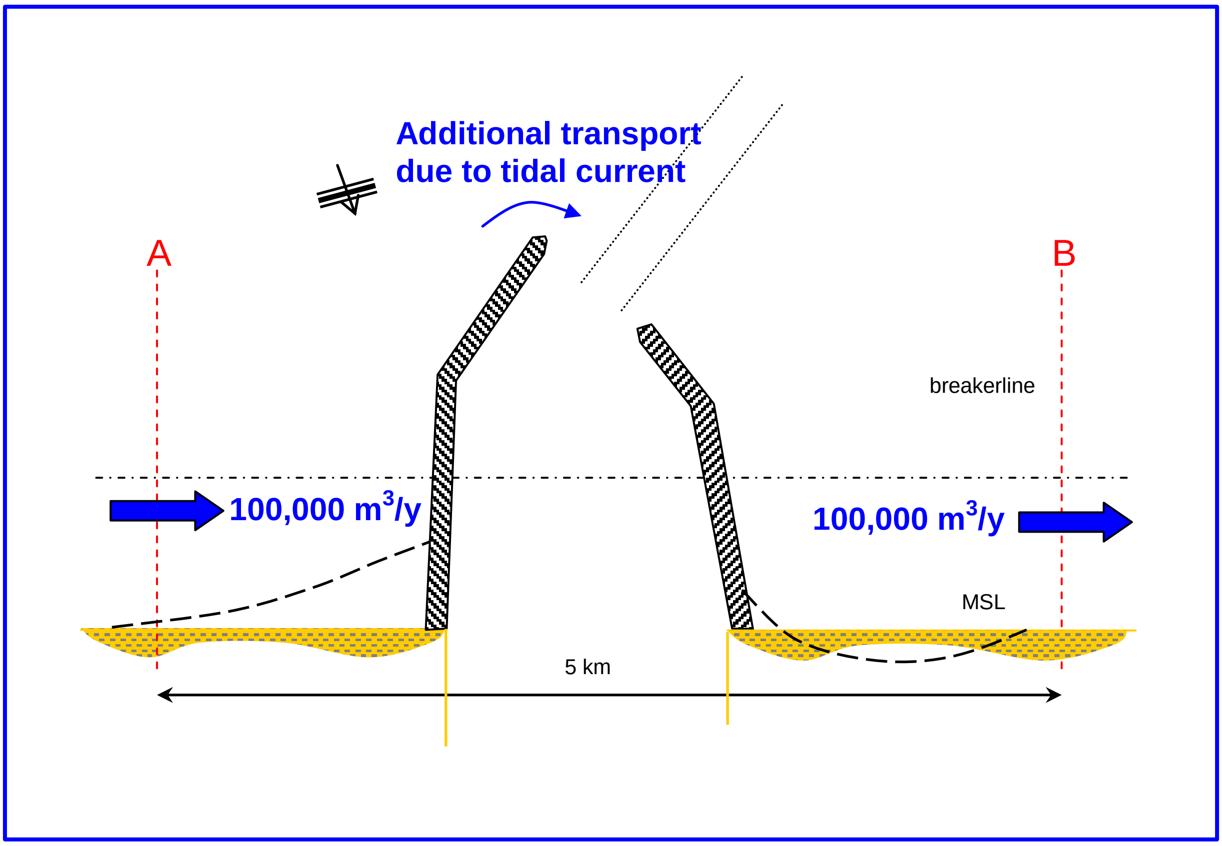

Figure 14.1: Situation case 11

The problem discussed in this case is basically the same as the problem in the previous case with one important difference: in this case a combination of wave driven transport and tide driven transport occurs as illustrated in Figure 14.1 whereas the previous case only dealt with wave driven transport. The presence of a tidal current affects the local physical conditions and thus it is likely that it also affects the design to resolve this problem. It is assumed in this case that the presence of a tidal current causes an additional sediment transport compared to the previous case. The net yearly sediment transport rate is not influenced by the tidal currents because the effect of the tide consists of a flood current in one direction and an ebb current in the other direction. One of the main effects of the tidal currents is the possibility of sand bypassing the heads of the port jetties and sedimentation taking place in the approach channel of the port (which is often artificially created by dredging). This sedimentation can lead to regular dredging operations .

Even when the tidal current will not lead to greater sediment transports it is still important to realise that different initial conditions (compared to the previous case) may affect the structural solutions that can be applied, even when the rates of longshore sediment transport are equal.

14.2. Cause of the problem

Similar as in the previous case initially the longshore sediment transport is blocked totally by the port jetties which stretches out far beyond the breakerline. It is assumed that the sediment transport that is caused by the tidal current will also take place mainly within the surf zone, because the tidal current mainly transports sediment that is stirred up by the turbulence of the breaking waves in the surf zone. The tidal current will flow around the port jetties and it can be expected that the current velocities increase around the heads of the jetties due to contraction of the streamlines. Additional erosion due to the increased flow velocities can be expected in the vicinity of the heads of the port jetties. The tidal current is thought to initiate erosion in this zone. Eddies will occur in the accretion zone updrift of the port jetties and in the erosion zone downdrift of the port jetties, as is sketched in Figure 14.2. These flow conditions will have the following effects on the accretion and erosion problem as described in case 10 (Chapter 13): accretion close to the breakwater on the updrift side will decrease because of the large eddy on the upstream side, sediment will accrete over a larger stretch of coast and further upstream of the port jetty. Erosion right on the downdrift side of the port jetties is also thought to be less than in the previous case, because of the eddy on the downdrift side. Both eddies affect the conditions in such a way that the adverse effects close to the breakwaters are less harmful. An additional problem that the tidal current causes is the erosion around the head of the breakwater which may lead to local instability of the structure.

14.3. Solution to the problem

To prevent accretion taking place in the approach channel the port jetties will have to be longer than in the previous case. The length depends on the area in which the tidal current effects the sediment transport processes. When the port jetty is so long that no sediment transport is assumed to pass the head of the port jetty the case will become very similar to the previous except for the additional problems of local scour at the heads of the port jetties (these problems will not be discussed further in this report).

The solutions to the problem as sketched in this case are very much similar to the solutions as sketched in the previous case. In the design of any structural solution one has to take into account the effect of the tidal current on the structural solution. Flow contraction and local scour are likely to occur in situations where structures are being applied. The far field problems of this case are however very similar as in the previous case: accretion on the updrift side of the port and erosion on the downdrift side. Sand bypassing seems to be necessary in this case too. The use of sand bypassing systems will be similar to that as discussed in the previous case.

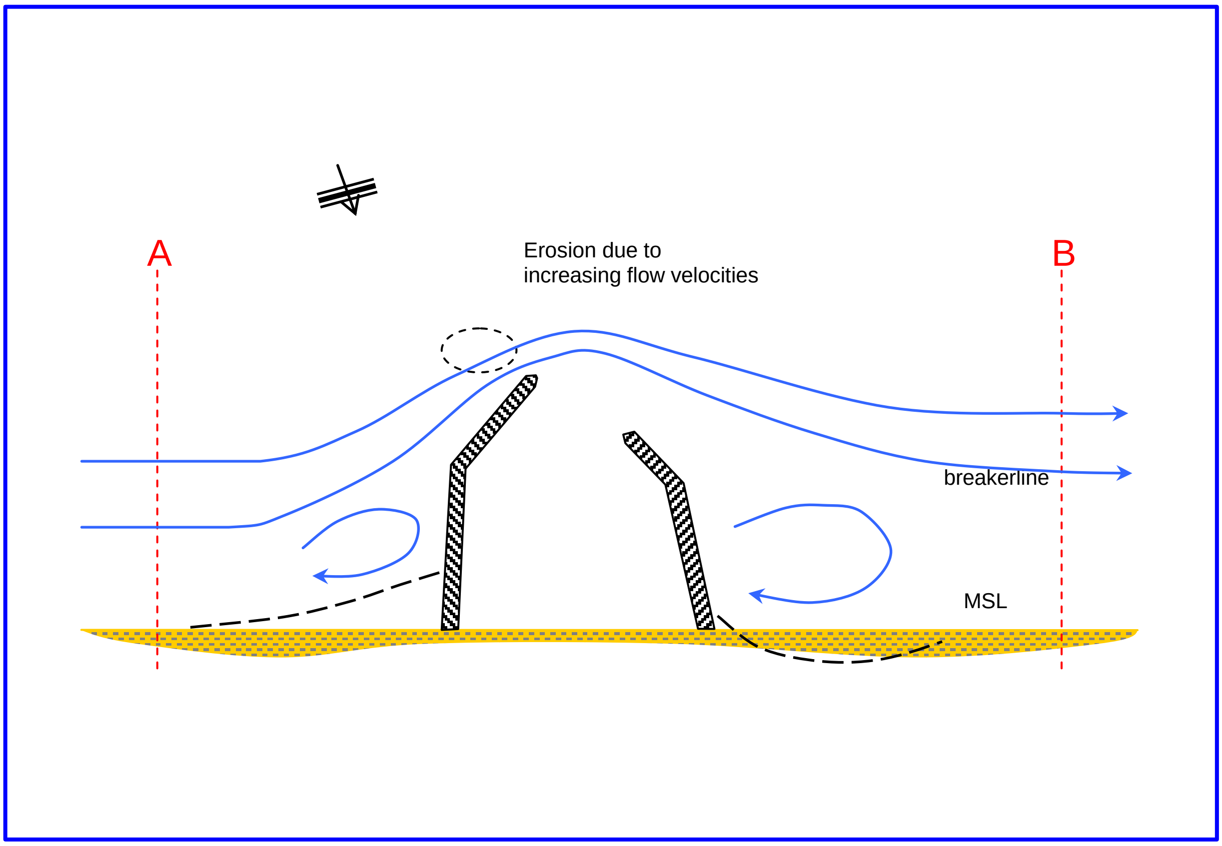

Figure 14.2: Streamlines around the port jetties

14.4. Engineering measures on the updrift side

Accretion on the updrift side is thought to be taken place on a larger stretch of coast caused by the eddy that is induced by the tidal current. However there will still be accretion and the more sediment is deposited updrift of the jetty, the less the influence of the eddy will be. The accretion will eventually lead to a situation in which the coastline adjusts to the shape of the streamlines and thus the eddy will disappear. Sediment will be transported by the tidal current around the port and will accrete further downstream where the flow velocities decrease. If the accretion becomes a problem because large volumes of sediment are transported around the port jetty and accretion of the approach channel occurs, the same measures as in the previous case can be taken. One has to take into account that the application of additional structures will lead to local scour and the formation of eddies because the tidal current will flow around them.

14.5. Engineering measures on the downdrift side

On the downdrift side it is less likely to use any structural solution in this case. Compared to the situation in the previous case, a large eddy on the downdrift side complicates the morphological developments. Sediment passing around the port because it is transported by the tidal current, complicates the problem even further. If erosion becomes a problem an artificial nourishment seems the best solution. It is recommended to use sediment that is accreted on the updrift side to renourish the beach area on the downdrift side.

14.6. Remarks on this case

The presence of a tidal current enlarges the adverse effects of the port jetties and thus it is likely to use structures in such a situation. An artificial sand bypassing system is recommended to redistribute sediment when accretion or erosion will become a problem. Local scour might become a problem in the vicinity of the head of the jetties, but this aspect will not be further discussed in this report. Only the far field morphological effects are discussed in this report. Because of the complexity of the problem it is very hard to design a proper protection scheme on the updrift or downdrift side of the port. Problems that can occur because of these structures are not only of a 'far field' nature but also of a local nature. Artificial nourishments seem to be the best solution with the least adverse effects.

Another phenomenon that may occur in the situation of a port entrance with jetties is the development of "shadow zones" in the vicinity of the jetties (near the shore). In these shadow zones sediments can deposit which leads to withdrawal of sediment from the coastal system. This may lead to erosion (locally) on adjacent beaches because less sediment is transported alongshore. This phenomenon occurs near the port jetties of IJmuiden (in The Netherlands) for instance.

15. Case 12: Outflow of a river

15.1. Description of the problem

An interruption of the coastline due to the outflow of a river can lead to sedimentation problems caused by sediment that is transported by the river. The sediment will be deposited in the area where the flow velocities are too small to transport the sediments which are supplied by the river . If the river is used by ships to enter or leave a port this could become a problem. To extend the river and thus to achieve a situation with accretion of sediments in deeper water in some cases breakwaters are built. The breakwaters also have the additional advantages of port breakwaters as discussed in Case 10 and 11. They provide a sheltered area so sailing ships are protected against waves and tidal currents. The main disadvantage of constructing breakwaters will be the interference in the longshore sediment transport similar to the situation with port jetties as discussed in the previous cases.

The application of such breakwaters will interfere the longshore sediment transport which may lead to accretion and erosion problem on the updrift and downdrift side of the river outflow.

In Figure 15.1 two situations are sketched. The first is a situation with some sediment transport by the river and thus volumes of sediment that are being deposited in the coastal zone. In this situation the beach area grows with time because of the fluvial sediments. The second situation sketched is that of a river without a considerable sediment transport. In this situation the river mouth will be unstable and this could be an unacceptable situation for shipping or tourism. .

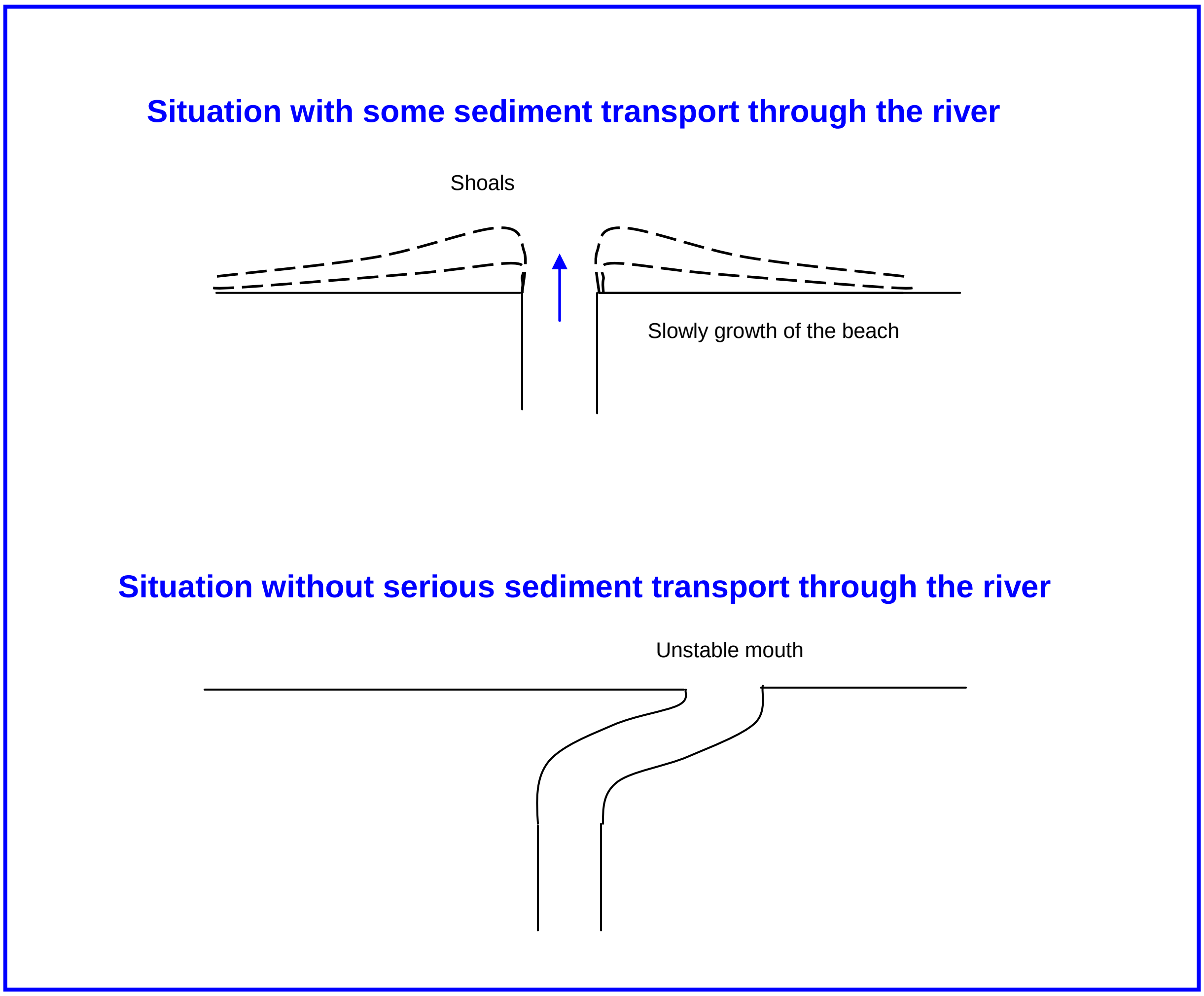

Figure 15.1: Possible situations at a river outflow

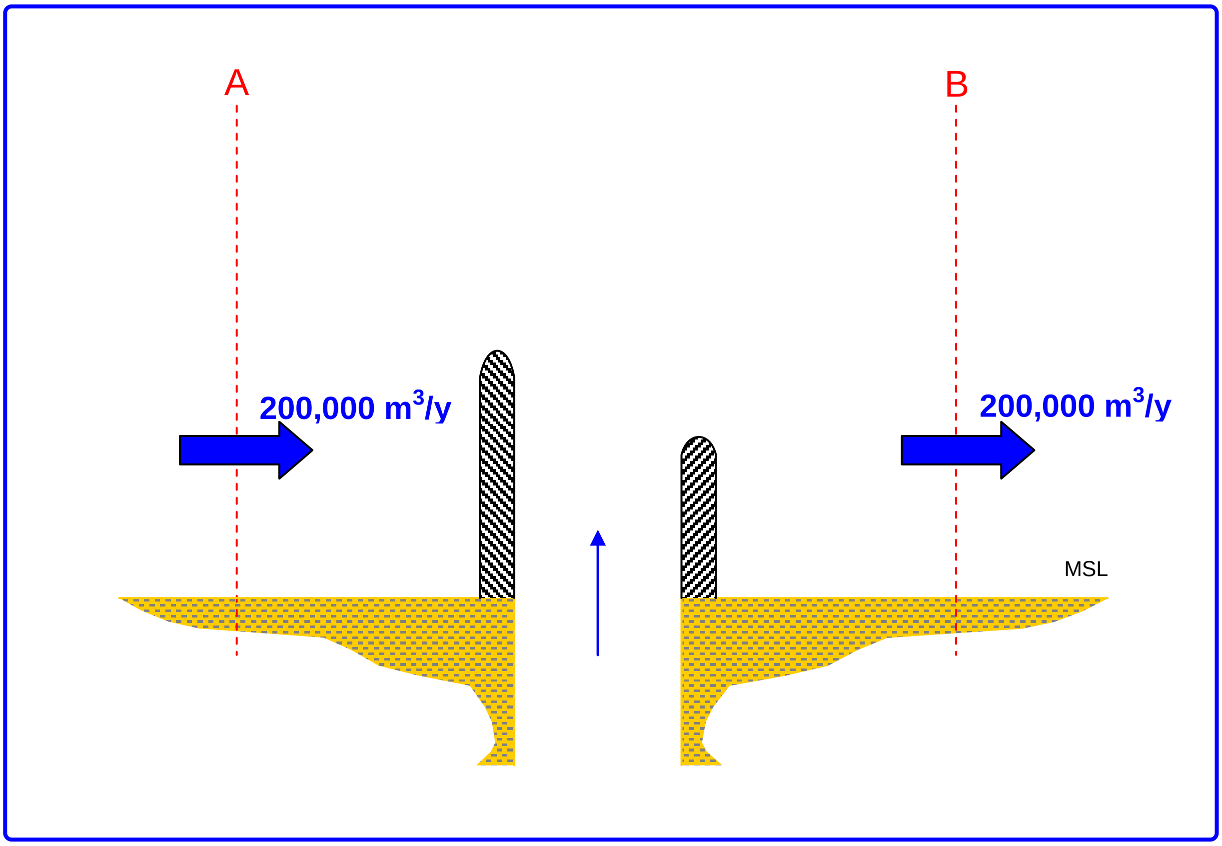

Figure 15.2: Situation case 12

15.2. Cause of the problem

The longshore sediment transport is blocked (partially) by the breakwaters that are built to stabilize a river outflow. On the updrift side this will lead to accretion and on the downdrift side to erosion. Besides the blocking of the longshore sediment transport also the sediment transported by the river will be deposited further offshore.

15.3. Solution to the problem

An artificial sand bypassing system seems to be the best solution; accreted sediment at the updrift side will be used to renourish the erosion area at the downdrift side. By protecting a river entrance or a port it is inevitable to interfere with the longshore sediment transports and one just has to deal with the effects. If the accretion at the updrift side will proceed until the head of the breakwater is reached a new equilibrium situation will develop. If this new equilibrium causes problems, e.g. because of accretion in the approach channel, measures have to be taken, such as artificial sand bypass.

15.4. Remarks on this case

In the case of port jetties it is sometimes possible to choose a location of a new port and one can choose the ideal location (with the best conditions). But in most cases the location of a port or a river are given and one has to deal with the present conditions. If these conditions will cause accretion or erosion problems it is recommended to artificially bypass sediment around the river outflow.

16. Case 13: Dune and beach erosion during a severe storm surge

16.1. Description of the problem

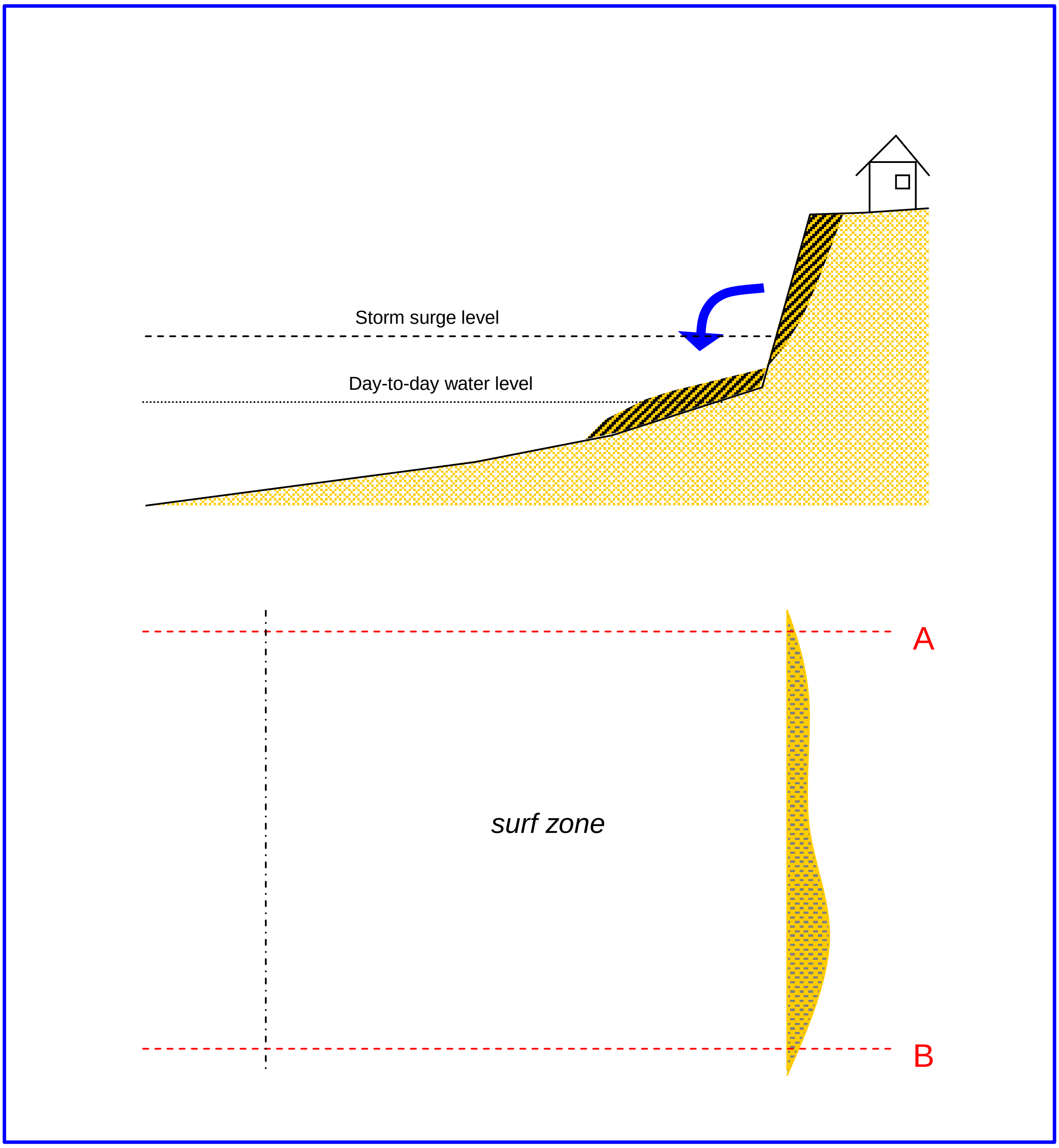

Figure 16.1: Situation case 13

In most cases storm events are accompanied with high water levels. During a severe storm surge event the water level might rise up to the toe of the dune area or even higher. The high waves caused by the strong wind severely attack the unprotected dunes which lead to a large erosion of the dunes. A retreat of 10 m of the brink of the dunes during a severe storm surge is well possible. Figure 16.1 schematically illustrates the dune erosion during severe storm surge events. In most cases the width of the dune area is large enough to accommodate such a loss.

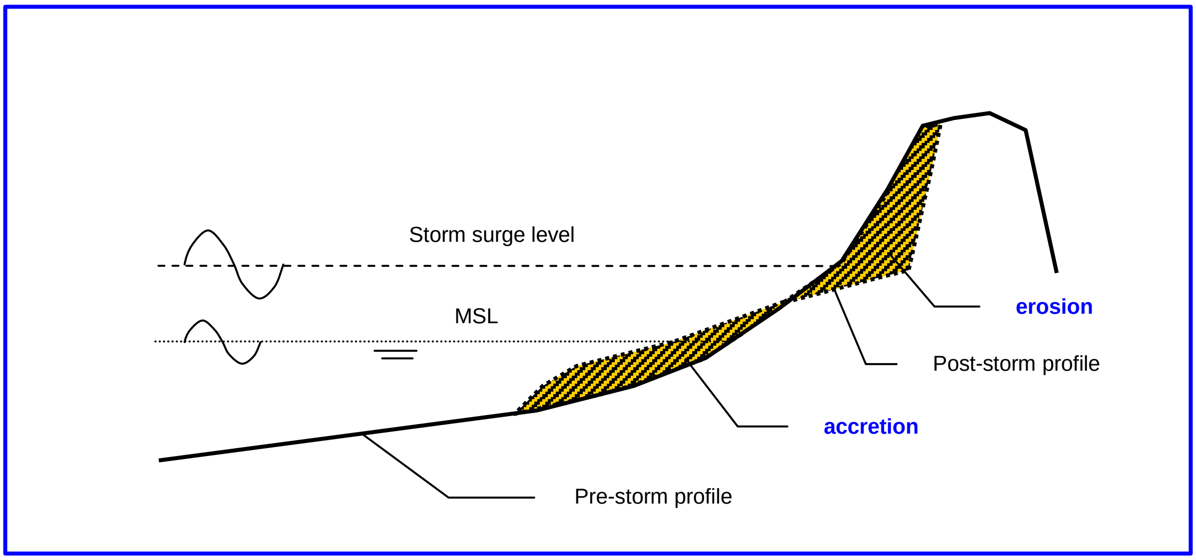

Figure 16.2: Stable beach profile

In Figure 16.2 a stable situation is sketched; a situation without structural erosion.

In a stable situation every once in a while a storm surge occurs which will lead to erosion of the beach and dune area; depending on the severity large amounts of sediment can be eroded during a storm surge event. The eroded volume of sediment is completely deposited on the shoreface, the sediment is redistributed over the beach profile, but the total amount of sediment is still the same in a stretch of coast. During milder weather conditions (day-to-day conditions) the sediment deposited on the shoreface will be completely transported back to the beach and dunes by natural processes (water motion and wind). Recovery of the beach and dunes will occur and the coastal zone is 'ready' for a new storm surge event.

Erosion during storm surge events will only become a problem when buildings or infrastructural structures are situated in the part of the dunes that suffers from erosion or when the dune area is too narrow to accommodate erosion.

16.2. Some remarks to decision-making

Decision-making in cases dealing with (severe) beach and dune erosion during storm surges is very complex because of the conflicting interests involved. On the one hand the dune area is the primary defence against the sea and on the other hand the dune area is a popular location for tourism and housing. In order to make a judgement whether commercial use of the dune area is admissible some insight in the risks is inevitable.

The risks can be formulated in terms of the chance of occurrence of a certain storm surge (or sea level) and the damage (loss of capital) caused by this storm surge (or sea-level). The chance of occurrence is a statistical number derived from long-term analysis of storms and sea-levels. The damage is an amount of money reflecting the loss suffered from the storm-surge. In practice the damage is hard to define especially when losses of human lives can be expected; in most cases however the losses concern mainly real-estate or properties.

In order to make decisions there should be agreements on which hazards are acceptable and which are not. These agreements are based upon an analysis of costs (the costs consist of a sum of investments and risks) and profits in various cases and have to be made by political decision-makers. The results of these agreements should be laid down in a treaty or a law so judgement of future cases becomes objective.

In cases where the risks are considered too large to admit commercial use of the beach and dune area there are two possible decisions. The first possibility is to forbid the use of the beach and dune area as proposed and search for another location. The second possibility is to consolidate the coastal defence system in an artificial way so the risks are reduced to an acceptable level for commercial use as proposed. The application of structural solutions is discussed further in this chapter.

16.3. Structural solutions to this problem

Both seawalls and dune revetments and offshore breakwaters might reduce the force of the waves that threaten the dunes. So these solutions might be applied if the erosion of the dunes will form a threat to people or real estate. Adverse effects of these hard structures might be the effect on the longshore transport during the severe wave attack during storm surge. During normal day-to-day conditions the seawall or revetment does not interfere within the sediment transport processes. Because of the reflection of waves from the hard structures during storm surge conditions, erosion occurs in front of the seawall or dune revetment (threatening the stability of the structure).

If there is no particular use of the beach or dune area it is advised to accept the beach and dunes to erode from time to time. The natural processes will redistribute the eroded sediments so the beach and dune area might entirely restore. It is probably the best solution to accept the erosion that can occur during storm surges and provide enough dune area to be eroded (allow the sea to have some playground). It is therefore recommended to avoid the erection of houses and hotels and important infrastructural structures like roads and railways in the dune area at risk. On the other hand the risk of flooding can be subordinate to the commercial use of the dune and beach area. One has to accept the possibility of loss of buildings like restaurants, but lots of money can be made exploiting these buildings on sites tourists are fond of.

The use of artificial protection schemes is possible but the risk of collapse or undermining during the severe storm surges has to be taken into account.

16.4. Remarks on this case

The most preferable situation would be to let the natural restoration of the beach take place. In many cases however this is not possible because the erosion of beach and dunes forms a threat to either the recreational use of the beach and dune area or the safety of the hinterland. In some cases it is possible to protect the dunes from being eroded by applying dune revetments or a seawall, but in cases where structural erosion is taking place too, these solutions will not meet the requirements on the long term and must be accompanied by artificial nourishments to restore sediment volumes.

17. Case 14: Dune and beach erosion during severe storm surge without a full restore

17.1. Description of the case

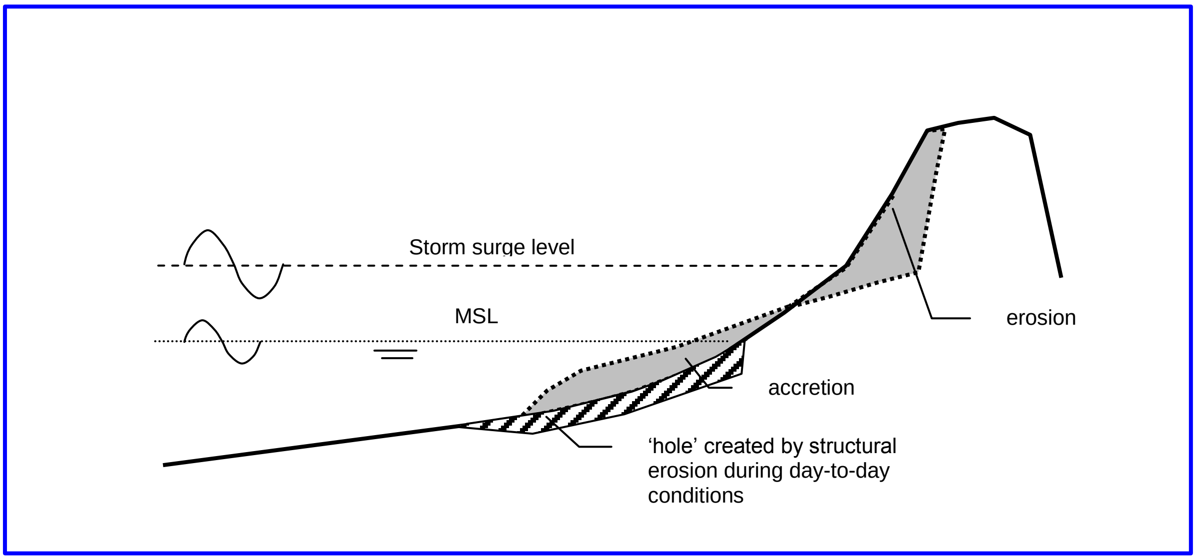

Figure 17.1: Situation of Case 14

Compared to the previous case the main difference in this case is the combination of both longshore and cross-shore erosion. In a situation with structural erosion the sediment eroded from the beach and dunes during a storm surge (even a modest one) will partially replace the sediment which is eroded during day-to-day conditions by structural erosion, as is shown schematically in Figure 17.1. It is very well possible that the eroded amount of sediment from the dune and beach area is deposited in some sort of 'hole'. This hole can be a scour depth caused by structural erosion processes or it could be a natural depth. In either case the natural restoration of the beach area cannot take place, this implicates that the losses to the beach and dune area are permanent.

After a storm surge the beach and dunes will only partially recover because the available amount of sediment is less than is required for full recovery. The total amount of sediment in a stretch of coast decreases because of the structural erosion process. Over a long period (e.g. a number of years) the equilibrium beach profile (the shape of the profile) will shift towards the landside as is shown in Figure 17.2.

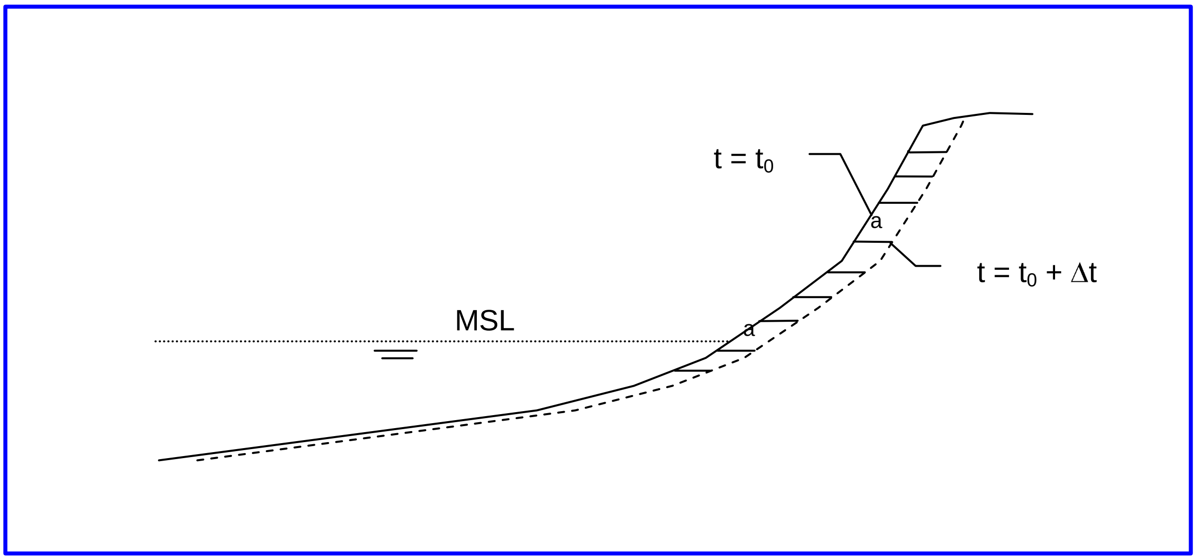

Figure 17.2: Retreatment of the coastline

The retreat of the coast and the dunes seems to be caused by the erosion during storm surges, but the real cause of the problem is the structural erosion on the shoreface.

17.2. Structural solutions to the problem

Application of seawalls or dune revetments will defend a coast only temporary by physically protecting the dune area against erosion during storm surges. The structural erosion problem however will go on (and natural replenishments from the upper part of the cross-shore profile will no longer occur) and in a matter of time the beach in front of the seawall or revetment will become deeper and steeper which eventually will lead to the loss of the seawall or revetment and severe erosion of the dune area behind the structure.

The application of structures like dune revetments or seawalls will prevent the coast from eroding on the short term, but these measures are being undermined by erosion processes, especially if structural erosion also is a problem on that beach. The best solution to these kinds of problems would be an artificial beach or dune nourishment after a storm surge event or after a number of storm surge events, which depends on the eroded volumes and the safety hazards to people or real estate. The nourishments have to restore the amount of sediment which is deposited from the coastal system due to scour holes or natural depths at deeper water near the coast.

17.3. Remarks on this case

Probably the safest and cheapest way to protect a beach and dune area that does not restore itself properly is to apply artificial beach or dune nourishments or foreshore nourishments. These measures will have to be repeated whenever new losses of sediment occur. Nourishments can be combined with structural measures such as seawalls. The seawall may prevent sediment erosion from the dunes and thus less sediment will be deposited from the coastal system. Disadvantage of a seawall is local scour at the foot of the seawall due to standing waves and reflection of waves from the wall.

18. General conclusions and recommendations

18.1. Conclusions of the reviewed cases

After reviewing a number of cases involving imaginable coastal engineering problems several things become clear.

Probably the most important lesson that is to be learned from this review is that there are no standard solutions to the problems that have to be resolved. The complexity of the problems and the underlying mechanisms involved are what makes coastal engineering challenging (and sometimes even somewhat frustrating). The various conflicting interests in the coastal zone area and the great impact of coastal engineering measures are what makes the problem extra complex. Political and commercial interests are of great influence on engineering measures. In many practical cases political or commercial interests have led to the implementation of engineering tools that did not resolve the problem as intended but led to new problems on the considered or adjacent beaches.

Another important lesson for designing coastal engineering measures is to determine a clear programme of requirements before the start of the design proces. In other words clearly define the objectives of a protection measure. For example it makes a great difference if the objective of a protection measure is to maintain a coastline (and dry beach area) during a whole year under all weather conditions or if the objective is to preserve a dry beach area during the summer season with commonly less severe erosion conditions and erosion under more heavily conditions is acceptable. In many cases these objectives or requirements are not clearly determined prior to the design process and thus unwanted solutions might be designed or realised.

18.2. Recommendations for coastal engineering decision makers

One should always take time to consider and study a case thoroughly. Rushing into solutions to problems that are not well understood is bound to lead to problems or adverse effects. Same can be stated for rushing into solutions without clearly determining the programme of requirements. In many cases the pressure of commercial or political interests involved initiates the implementation of certain engineering measures without proper understanding of the problems and mechanisms involved. Most times a solution that has been successfully implemented in another (apparently similar) situation is copied to the problem involved. The effect can be that the solution does not act as expected and new, maybe even bigger, problems will occur.

Society and politicians will not accept such bad investments and thus the original idea of serving the commercial or political interests will have the opposite effect; the decision-maker will be held responsible for the waste of (tax-payers) money. The problem however is still to be resolved so new investments will have to be made in the (near) future hopefully based on profound study of the mechanisms involved.

Especially the application of ‘hard’ measures can only be successful when one understands the problems and occurring processes precisely. With ‘soft’ measures it is also desirable to completely understand the problems and occurring processes, but the consequences of misjudgement are less severe.

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Appendix A: Engineering tools

1. Introduction

To protect a coast against erosion, caused by natural processes or human activities, two main strategies are possible: so called ‘soft’ and ‘hard’ measures. ‘Soft’ measures do not basically interfere with the coastal morphological processes. They just restore the original situation by renourishing the eroded amount of sediments on a particular stretch of coast. ‘Hard’ measures are intended to take away the cause of the erosion problems by applying structures that interfere with the morphological processes in the coastal zone. In this chapter an overview of this kind of structures is sketched.

In general a distinction can be made in two main types of ‘hard’ structures:
- structures perpendicular to the coast
- structures parallel to the coast

Structures perpendicular to the coast interrupt the longshore sediment transport either partially or totally. In general they do not directly affect the onshore-offshore transport. Examples of structures perpendicular to the coast are:
- groynes or pile rows
- breakwaters or jetties (e.g. at harbour entrances or river outlets)

Structures parallel to the shore can be built at different positions with regards to the waterline. The first type is constructed to defend the dry beach or the dunes against erosion. They interfere with the onshore-offshore transport taking place during severe storms or high tides. Examples of these structures are:
- beach or dune revetments
- seawalls

The second types of structures are detached shore parallel structures. They interfere with both the cross-shore and longshore sediment transport processes, examples of these structures are:
- offshore breakwaters (either submerged or emerging)

In the following paragraphs the main properties of the most important ‘hard’coastal engineering tools are discussed. The contents of the following paragraphs are partly abstracts of the reference literature, such as Basic Report Sandy Coasts and the Shore Protection Manual/Coastal Engineering Manual.

2. Groynes and pile rows

Groynes are able to interfere with the longshore sediment transport. The transport perpendicular to the coast (cross-shore transport) is generally not affected by the application of groynes. Groynes stretch from the upper part of the beach (preventing outflanking which can lead as far as the toe of the dunes) to the necessary depth, which depends on the occuring sediment transport and the width of the beach that is wanted.

A pile row is in fact a special kind of groyne, most properties are alike, the main difference is the permeability of a system of pile rows, allowing the longshore currents and thus the longshore sediment transport to take place in a reduced strength. Most of the properties explained in this paragraph can be applied on both groynes and pile row systems.

In general groynes should not be made too high, in order to prevent unnecessary blocking of currents (which leads to scour) and wave attack. To give an idea: 0.5 to 1 m above the wanted beach level is sufficient in most cases. In that case the zone of wave-attack varies with the water level (see Figure 1).

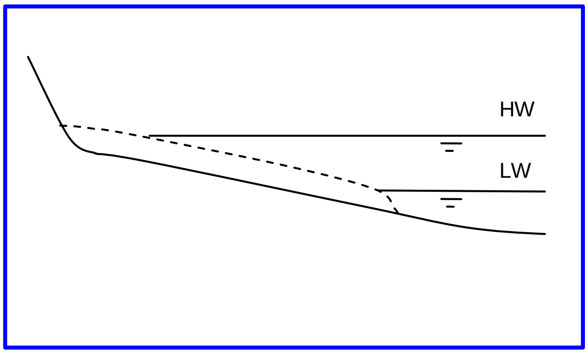

Figure 1: height of groyne above beach roughly constant

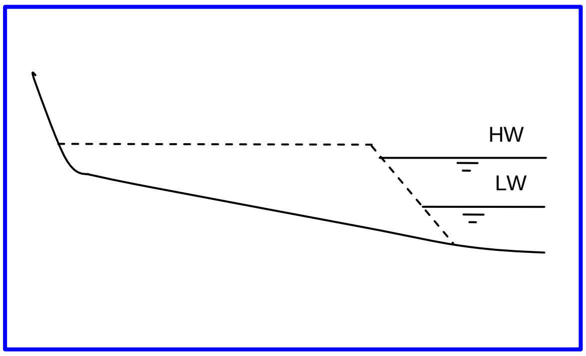

Figure 2: crest-level of groyne roughly constant

If the groynes are necessary to push the current from the shore at high water levels, the crest has to be about horizontal (see Figure 2). In that case the attack is concentrated at the head and measures against scour of the bed near the head should be taken.

In general it is assumed that groynes do not affect the onshore-offshore sediment transport. In some cases however this is not completely what happens. The following two phenomena can contribute to the cross-shore transport:

- The construction of groynes might affect the shape of the dynamic equilibrium beach profile. The shape of the profile of a beach with a significant longshore sediment transport may deviate to some extent from the shape of the profile without longshore transport. The originally present amount of sand will be redistributed over the beach profile. If this will lead to a steeper slope of the beach, then some accretion of the dry beach occurs.

- Rip currents can be tied up by groynes, which together with wave-driven longshore currents can lead to horizontal circulation cells. The strength of these circulation currents and the influence of the circulations on the cross-shore transport depends on the length and height of the groynes, the distance between the groynes, the tidal range and the local wave climate.

The influence of these phenomena has to be investigated more thoroughly to take it into account in the design process of new groyne schemes.

Design aspects:

The following aspects play a part in the design process of groynes:
1. the length perpendicular to the coast
2. the height and slope of the groyne
3. the width
4. the distance between the groynes
5. the applied material
6. the porosity

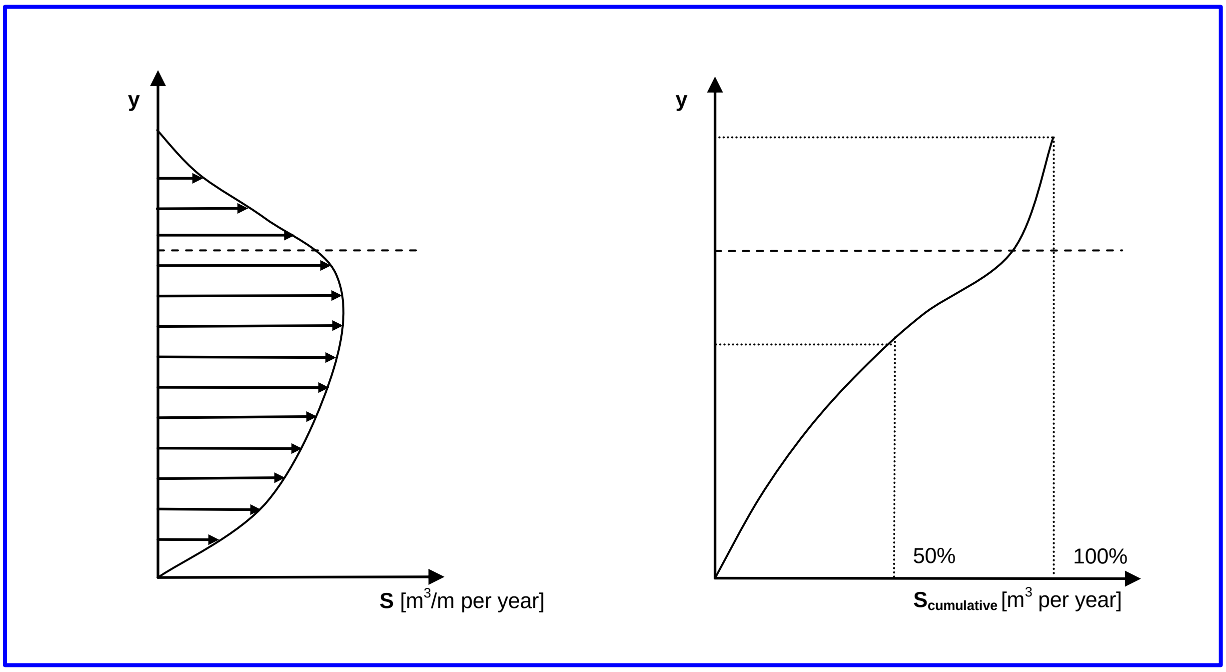

Figure 3: Approximation of the length of groynes

7. the orientation
8. the sequence of construction

ad 1. the length
The desirable length of a groyne depends on the intended reduction of longshore sediment transport. There are no generally applicable rules available to determine the length of a groyne or pile row. Every situation has to be considered separately. It is not necessary to make each groyne out of a series the same length.

An approximation to determine the length of the groyne in case of a typical wave driven sediment transport distribution can be made by using the cumulative sediment distribution, as is shown in Figure 3. The intended amount of sediment that still has to be transported in the groyne section has to be determined in each cross-section as a percentage of the total sediment transport.

The length can roughly be estimated by determining the amount of sediment that has to be blocked by the groyne. If this amount is e.g. 50% of the total sediment transport in that particular ray one can read the required length on the y-axis in the cumulative sediment distribution curve. If the percentage of blocked sediment is larger it can be seen that longer groynes have to be applied.

ad 2. the height and slope
The height and slope of a groyne is of great importance for a well performance of the groyne (the slope has to be compared to the slopes of the beach and foreshore profile). The reduction of current velocities increases as the groyne height increases above the bottom. With regard to the slope of the crest of a groyne two procedures might be considered.

The crest of the groyne follows more or less the existing shape of the beach profile (e.g. 0.5 – 1.0 m above) or the crest of the groyne is adapted to expected changes in the shape of the beach profile.

The height of the crest can be chosen freely. However, when the crest is too high with respect to the surrounding bottom, adverse effects, such as wave reflection, turbulence and rip currents, occur. These effects may cause damage or cause stability problems of the groyne.

Just as with the length there are no general rules for designing the height of a groyne. In some cases the height of the groyne has to be adjusted several years after the construction because the bottom and the beach profile has changed due to the construction of the groyne.

ad 3. the width (of the crest)
The resistance a groyne causes to the flow depends on the width of the groyne and the used construction material. Formally the width is a design parameter, but in engineering practice the width is determined by practical conditions, such as the accessibility for heavy equipment.

ad 4. the distance between the groynes
The distance between the groynes is sometimes related to the length of the groynes. In practice the distance between the groynes is often taken about 1 to 3 times the length.

ad 5. the material
The following aspects should be considered when the material is chosen:

- resistance against wave and current forces
- resistance against salt water intrusion and marine vegetation
- accessibility during construction and maintenance
- settlement to effects due to local scour
- minimal impediment to beach recreation
- ease of adjusting the length or height

Groynes

Advantages	*Disadvantages*
• *Groynes are effective against erosion caused by sand losses due to gradients in longshore transport.* • *Much data is available on the performance of groynes in various physical environments.* • *Groynes can be built using shore based equipment and are therefore often less expensive to construct.* • *Groynes do not essentially change the character of the surf zone. Wave heights along a beach after groyne construction are virtually unchanged.* • *Groynes can be constructed of various types of materials (e.g., rubble-mound, steel, and concrete sheet piling, timber, etc.)* • *By adjusting their dimensions and permeability, groynes can be designed to either completely block longshore transport along the beach face or to allow sand bypassing.*	• *Groynes are not effective in preventing offshore sand losses.* • *Groynes can cause rip currents to develop along their flanks and, thus, might enhance offshore sand loss.* • *Since groynes (partly) interrupt the longshore sediment transport downdrift beaches may suffer from erosion problems.* • *There is a range of conflicting design philosophies: permeable versus sand tight; high versus low; long versus short, etc.*

(adapted from ASCE, 1994 [1])

ad. 6 the porosity
This aspect is mainly important for the design of pile rows. The performance of a pile row depends on the resistance that is created. Local scour due to rip currents and flow contraction in between the piles is another important aspect.

ad 7. the orientation
In general groynes are constructed perpendicular to the coastline. From a coastal engineering point of view there is no clear reason to construct them in any other direction.

ad 8. the sequence of construction
The determination of the sequence of construction has to be done judging from the local sediment transport distribution. Knowledge of the local behaviour of the coast is of great importance.

3. Offshore breakwaters

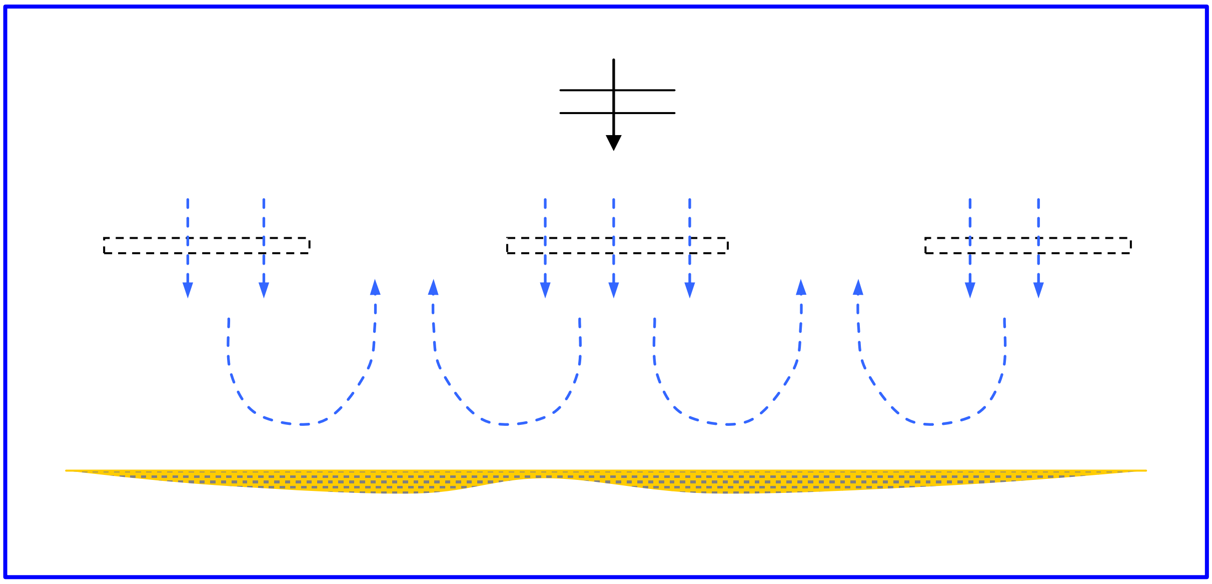

Figure 4: Circulation cells behind a submerged breakwater

The purpose of offshore breakwaters can be reduction of both structural erosion and erosion due to severe storms. In general a distinction between three types of offshore breakwater structures can be made:
<u>Emerging offshore breakwaters:</u> Emerging detached breakwaters can be built singly or in series. Their crest height is above the level of MHW.
<u>Submerged breakwaters:</u> A series of detached breakwaters with a crest level under the MLW level.
<u>Submerged dam:</u> A continuous dam with a crest under the level of MLW.

A well-designed offshore breakwater will decrease the wave height in the area between the coast and the offshore breakwater. The decrease in wave height will influence the longshore sediment transport processes in this zone. A submerged breakwater will have different effects as an emerging detached breakwater.

In case of a submerged breakwater (with a crest height beneath the mean low water level (MLW)) the reduction of the wave height will be less than in case of an emerging breakwater (with a crest height on a higher level). In general a part of the incoming waves will pass the breakwater, only the higher waves will break on it. Of course the tidal range is of great influence on this process. Nevertheless an average reduction of wave height will be achieved by constructing a submerged breakwater. Because of the mass transport over the breakwater a concentrated outflow of water through the gaps will take place, as is shown in Figure 4.

Besides this reduction of wave heights the submerged breakwater will interrupt the cross-shore sediment transport by trapping the sediment. Behind the submerged breakwater a new equilibrium beach profile will develop with a higher elevation than the adjacent beaches.

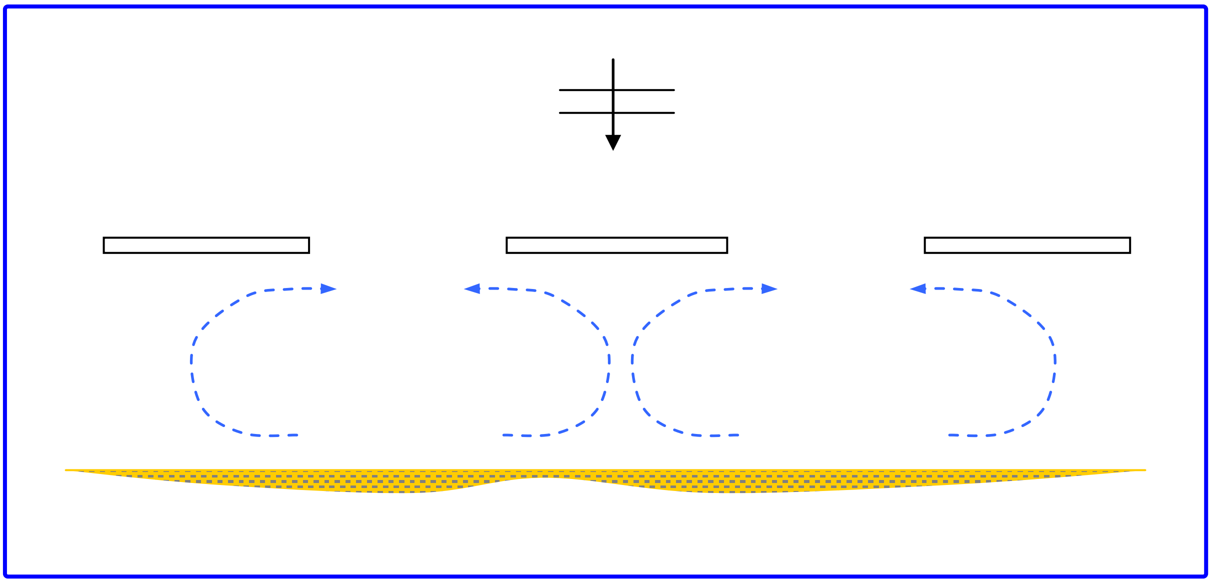

Figure 5: Circulation cells behind an emerged breakwater

By constructing a detached breakwater with a crest level above MLW a 'shadow zone' will develop behind the breakwater resulting directly in a reduction of wave height in the zone between the breakwater and the coastline. Still some wave action will remain in this zone due to diffraction of waves around the heads of the breakwater. Because of a difference in wave set-up between the shadow zone and the zone behind the gaps, water will flow in the opposite direction as is shown with submerged breakwaters. The circulation cells that occur with emerged breakwaters are shown in Figure 5.

When the offshore breakwaters are used to prevent structural erosion and properly designed, erosion on the downdrift side of the protected area will occur. This erosion is caused by the increasing gradients in longshore transport directly downdrift of the protected coast. The waves approach an undefended beach at this point. The application of offshore breakwaters, with the goal to prevent structural erosion, demands a precise tuning.

Due to the overall reduction of wave height it may be expected that an offshore breakwater will decrease the amount of dune erosion during storm surge conditions. This is not always the case however; every situation has to be considered separately. During storm periods overtopping of the breakwaters may occur which can result in strong rip currents through the gaps between the breakwaters. These strong currents can erode sediment from the nearshore area and deposit it further offshore. The normal redistribution of sediment during calmer periods can be disturbed by the breakwater construction, so this process may result in a permanent loss of sediment from this specific stretch of coast and thus a change in the equilibrium beach profile.

The most important design parameters of offshore breakwaters:

- clear description of the intended goal of the breakwater (reduction of structural erosion or reduction of dune erosion)
- type of breakwater
- height of the crest
- width of the crest
- length of the breakwater compared to the size of the gaps in between them
- depth or distance out of the coast
- slope of the breakwater or dam
- used construction material (stability during both day-to-day and storm surge conditions)
- secondary effects such as rip currents, wave reflection, turbulence and local scour

Submerged breakwaters

Advantages	Disadvantages
• *Submerged breakwaters (perched beaches) may be more aesthetically acceptable than groynes or emerging breakwaters because they are usually submerged and not visible from the shore.* • *Submerged breakwaters reduce the level of wave action on a beach.*	• *The low crest of the structure may not be high enough to significantly reduce wave action and may not retard offshore losses.* • *The submerged breakwater may prevent beach recovery during beach-building wave conditions.* • *Submerged perched beach structures may pose a hazard to navigation.* • *There has not been much experience with submerged breakwaters/perched beaches; therefore, there are not much data upon which to base a design.* • *It may be difficult and expensive to build the breakwater structure because it is both offshore and submerged. Construction may require floating equipment and thus may be expensive.* • *The submerged breakwater may be difficult to inspect since it is underwater.*

(adapted from ASCE,1994 [1])

Detached emerging breakwaters

Advantages	Disadvantages
• *Detached breakwaters might be effective against erosion caused by both alongshore and offshore sand losses.* • *Detached breakwaters have been proven to stabilize shorelines.* • *Detached breakwaters are often aesthetically acceptable when other shore stabilization structures are not. (They can be designed to be submerged over most of a tidal cycle.)* • *They can be built of inexpensive, readily available material, (e.g., rubble mound, dumped stone, etc.)* • *They can be built to allow sand bypassing and control the rate of bypassing.* • *They can be designed to permit overtopping to improve water quality in the breakwater's lee.* • *Nearshore breakwaters can significantly reduce wave heights along a reach of shoreline.*	• *Detached breakwaters may be expensive to construct because they are not connected to shore and may require either temporary structures or floating equipment to support construction equipment.* • *Breakwaters significantly alter the character of the surf zone and may restrict certain beach activities (e.g., bathing in the vicinity of the structures, surfing, etc.)* • *They may pose a navigation hazard and may require the installation and continued maintenance of navigation aids.* • *They may pose a hazard to swimmers.* • *If improperly designed, they could cause water quality problems due to poor circulation behind them.* • *Even if properly designed they cause downdrift erosion.* • *Detached breakwaters may connect with the shore by forming a tombolo. This could seriously interrupt longshore transport and downdrift erosion will be further enhanced.*

(adapted from ASCE, 1994 [1])

4. Seawalls and dune revetments

Seawalls are intended to protect the land from the sea. It has to be clearly understood that only the land behind the wall is protected by the seawall. Seawalls with a normal beach in front of them will hardly affect the normal coastal processes. Only during severe storm surges the water level rises and the seawall will protect the dune-area from being eroded. During storm surges seawalls may have a substantial impact on the coastal processes, because the seawall can lead to denial of littoral material from the sediment transport system and waves reflect against the seawall. Both these effects can lead to erosion problems. That is why the construction of a seawall is often combined with other measures like artificial beach nourishments or groyne fields to rstore the beaches in front of the seawall and prevent erosion in the vicinity of the seawall during day-to-day conditions. In the design process of a seawall full account has to be taken not only to the required height to prevent flooding but also to the effects on the relevant coastal processes. The designer should always be aware of the complexities of coastal processes and the fact that a natural coast is almost always in a state of change.

The primary functions of a seawall structures are:
- To protect land and property from damage by wave attacks
- To prevent or alleviate flooding of low-lying land

On a naturally eroding coastline the application of a seawall to prevent further landward regression will not stop the overall erosion processes.

5. Alternative coastal structures

In the engineering practice many inventors have developed various beach stabilization concepts. In many cases these new solutions are derivatives of a groyne or breakwater type of solution. The difference, with the traditional coastal structures like groynes and breakwaters, is often a cheaper or easier way of constructing (e.g. by using prefabricated concrete elements or sand-filled bags). The

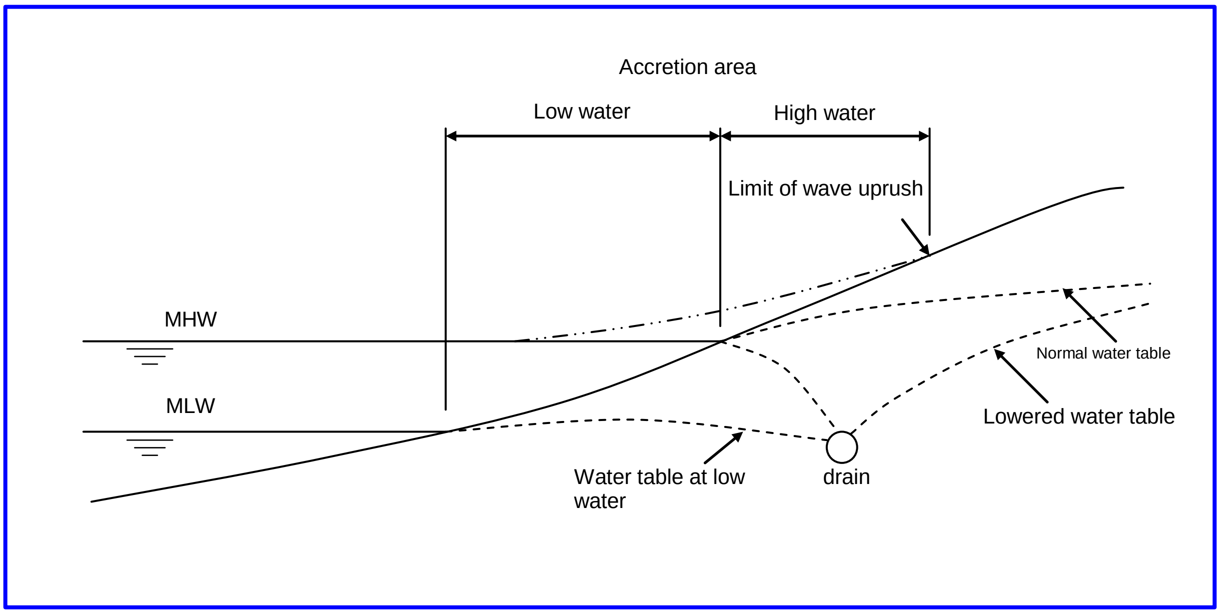

Figure 6: Beach dewatering system

morphological effects of these smart solutions, however, are similarly to those of the traditional structures.

Alternative shoreline stabilization devices and methods

Advantages	*Disadvantages*
• *Alternative shoreline stabilization devices and methods may have the potential of being more effective and cheaper than traditional shoreline stabilization methods.* • *They could be proposed and built as experimental projects and subsequently modified as needed to gain experience.*	• *Most alternative shoreline stabilization methods are virtually untried, and there is little information available on their performance; consequently, there is little information on which to base a design.* • *A costly, major experimental/developmental program would have to be undertaken to obtain information on which to base a design. This might involve both laboratory and prototype studies.* • *Operations and maintenance costs are unknown because of the lack of long-term experience.* • *An alternative shoreline stabilization system, like any stabilization system, would have to be justified economically by the savings realised through increasing the time between periodic renourishments. Data to economically justify alternative methods are generally not available.*

(adapted from ASCE, 1994 [1])

An alternative solution with rather different morphological effects is e.g. the artificial lowering of the water table on the beach by using a dewatering system (e.g. Bird, 1996 [2]). This measure does not interfere with the littoral sediment transport processes, so it is in most cases no solution to a structural erosion problem. In cases where a widening of a stable equilibrium beach profile is wanted, this could be a possible solution because the beach profile can become steeper by applying a beach dewatering system, resulting in an increase of dry beach area. The water has to be continuously pumped out of the particularly stretch of beach using drains. In a ‘normal’ equilibrium beach profile a balance does exist between accreting (landward directed swash processes) and erosive processes (seaward swash) in the wave up-rush zone. With a dewatering system the seaward swash will decrease because the effect of the swash water is less on unsaturated sand and the seaward seepage is decreased. Figure 6 provides a sketch of a beach dewatering system.

Appendix B: Some practical examples

1. Introduction

In the context of an European Research programme called "SASME" (Surf And Swash zone MEchanics) various participants of that programme were asked to provide an actual problem case and the applied measures. They were also asked to review the success of the applied countermeasures. In this appendix some comments on actual engineering problems and solutions are presented. The request for additional information was accompanied by a form with questions and an example which was provided by dr. J. van de Graaff and is presented in this appendix in Paragraph 2.

2. Use of groynes at Scheveningen, The Netherlands

provided by dr. J. van de Graaff, Delft University of Technology

2.1 Photograph

2.2 Location

Scheveningen; west coast of the Netherlands, about 20 km north of the entrance to the port of Rotterdam.

The picture shows the recreation site during a sunny summerday.
Three coastal structures are shown:
A series of 3 groynes (out of a whole series), built in the period 1895 - 1896 (is discussed further).
A seawall (in order to create a clear distinction between the beach and the boulevard with at the landward side many hotels), built around 1900. This seawall serves its aim properly. During the severe storm surge of 1953, which hit the Dutch coast heavily, a severe scour in front of the seawall was observed. It is expected that during the present Dutch design conditions, which are much more severe than the conditions occurring during the 1953 storm surge, the seawall will probably collaps because of undermining the foundation of the seawall. (Not discussed further);
A recreation pier, built in the sixties of the 20th century (not discussed further).

2.3 Description of actual problem to be solved

The stretch of coast suffered from structural erosion (wave action and tidal currents). Already in 1776 our ancestors started to build the first groynes about 15 km southward of the location of the picture. The series of groynes was gradually extended in northerly direction. At the end of the 19th century the series 'reached' the site of the picture. From 'old' observations it could be seen that the scheme did work well; the rate of erosion was at least reduced.
It was, however, also seen that at northward side of the scheme, the slightly accreting tendecy in the time before the construction of the groynes, changed in a heavily eroding tendency; lee-side erosion. The lee-side eroding stretch concerns, however, an area with very wide dunes, so this was felt not to be a serious drawback of the scheme.

2.4 Motivation of selected tools

In the time of the design and the construction of the groynes, groynes were felt to be a good tool in solving the erosion problems as occurring.

2.5 Does selected solution behave as foreseen/predicted/expected?

The structural erosion problem is indeed (partly) solved. Nowadays from time to time artificial beach nourishments are carried out. The main objective is to maintain a rather wide beach for recreation purposes.

3. The use of offshore breakwaters at Norfolk, England

provided by Eur Ing Jesper S. Damgaard, HR Wallingford

3.1 Photograph

3.2 Location

Happisburgh to Winterton scheme
East Anglia
England

3.3 Description of actual problem to be solved

The problem to be solved was a significant recession (up to 2m/year) of the coastline along that frontage.

3.4 Motivation of selected tools

The offshore detached breakwaters were meant to slow down the coastal recession by reducing the littoral drift, which has an average net value of the order of magnitude 400,000 m^3/year in the south-easterly direction.

3.5 Does selected solution behave as foreseen/predicted/expected?

The scheme is not completed yet.

Mister Damgaard also gave me the address of an engineer from Halcrow consulting engineers who were related to the design of the new protection scheme. Mr. Ben Hamer from Halcrow consulting engineers also filled out the requested form and his comments are provided in the following paragraphes.

provided by: Ben Hamer, Halcrow consulting engineers

3.6 Location

Happisburgh to Winterton, Norfolk
England

3.7 Description of actual problem to be solved

Since the late 1800s, coast protection measures to the cliffs located north-west of this frontage have gradually reduced sediment feed to the beaches. There is now insufficient beach material entering the system, to sustain normal sand transport under wave and current action. Beaches are highly volatile in both the longshore and cross-shore directions. Up to 2m of beach height is lost during winter storms.

As the beach erodes, it has the potential to undermine the integrity of the concrete seawall that extends for the full study frontage. A failure in the seawall would result in flooding the vast area of low-lying hinterland. Within the flood plain area of 6,000 hectares, there are numerous towns and villages and areas of environmental importance, which include the Norfolk Broads freshwater habitats.

3.8 Motivation of selected tools

The preferred solution for this frontage is to afford adequate protection to the beaches from cross-shore losses, whilst minimizing the impact of those defence measures on the longshore transport regime. In addition, any long-term plans to maintain coastal defence to this area must include for a commitment to manage beach supply through a combination of beach nourishment and supporting measures to remove any unnecessary cliff protection to the shoreline further to the north-west.

A sea defence strategy that comprised beach management and the construction of a series of offshore breakwaters was selected, as this attenuated the wave conditions reaching the beach, whilst allowing some continued transport of sand along the shoreline.

3.9 Does selected solution behave as foreseen/predicted/expected?

The strategy has been implemented in stages. In Stage One (1993), the first four reefs were constructed to a height of +3.0 m OD, some 1.3 m above Mean High Water Springs. This design sought to ensure that beach losses during the severe winter storms were not substantial. However, after two years of observations, it was apparent that future reefs could be lower, to reduce the impact on longshore transport whilst still affording adequate protection to the beaches.

Stage Two (1996) comprised five further reefs, at a lower level of +1.2 m OD, which have provided good protection to the beaches whilst allowing some continued longshore transport of sand in their lee. The effects of these reefs has been predicted in computational models, the results of which have been presented at conferences, such as the ICE Breakwaters Conference in March 1998.

Stage Three is planned for 2001, and predictions of beach movements made in 1996 have been validated against observations.

4. Use of offshore breakwaters at Skagen, Denmark

provided by: Julio A. Zyserman, DHI

4.1 Photograph

4.2 Location

The Kattegat (East) coast of Jutland, Denmark. The first picture shows the stretch of coast extending from South of the Grey Lighthouse (Gråfyr) to the North of Skagen harbour before 1989. The second picture shows the situation North of the Grey Lighthouse after 1991 (situation in March 2006).

In 1991, an artificial cliff was built to protect the back of the beach from floods due to storm surge. The T-shaped breakwaters were replaced by shore-parallel structures starting in 1991. In addition to this, nourishment has been placed on the beach every year.

4.3 Description of actual problem to be solved

The coast North of Skagen harbour suffers from structural erosion that originates from a zero net-transport point located immediately North of the port. Directions for yearly net littoral transport are southwards (towards the harbour) South of this point and northwards (towards the Skaw spit) North of the inflection point.

A series of coastal protection structures (T-groynes) were constructed over the years until almost the whole stretch between the zero-transport point and the Skaw spit became covered by structures. The T-shaped groynes were replaced afterwards by shore-parallel breakwaters.

4.4 Motivation of selected tools

At the time the structures shown in the photograph were constructed, it was felt that the T-groynes were a technically feasible tool for the control/solution of the erosion problem. At the same time, these structures permitted to keep construction costs at a reasonable level, as the structures were placed in not too deep waters.

4.5 Does selected solution behave as foreseen/predicted/expected?

The solution showed in the photograph did not perform 100% as expected. In some situations the salient behind the structure became detached from stem of the T-groyne. The structures were later on replaced by shore-parallel breakwaters combined with periodic beach nourishment. Recently, a number of alternative coastal protection schemes (some involving removal of most existing structures) that would allow decreasing the required frequency for nourishment have been investigated.

Appendix C: Example case with computational model UNIBEST

1. Introduction

1.1 General

In coastal engineering practice the use of computer models to aid the design process is becoming more and more common. Relatively simple models can be a great help in forecasting large scale morphological effects. The output data of the models may not be fully accurate but still a rough estimate of the effects of an intervention in the morphological system can be of great interest to the designer. To illustrate the use of existing computer models, which can be used to design a protection scheme, a very simple practical case has been worked out while using the computer model UNIBEST (Delft Hydraulics, 1994). In coastal engineering practice there are numeral computer models, various authors have published about the differences between the various models and there applicability (e.g. ASCE, 2001 or EUROSION, 2004).

1.2 The computational model UNIBEST

The UNIBEST software suite is an integrated modelling package with diagnostic and prognostic capabilities in the study and simulation of longshore and cross-shore sediment transport processes and related morphodynamics of beach profiles and beach platform shapes (coastline evolution).

The UNIBEST software suite consists of three separate modules, as follows:

UNIBEST_LT: UNIform BEach Sediment Transport – Longshore Transport,
for the computation of tide and wave- induced longshore currents and sediment transport

UNIBEST_TC: UNIform BEach Sediment Transport – Time-dependent Coastal profile model, for the computation of wave-induced cross-shore transport and resulting beach changes along a coastal profile

UNIBEST_CL: UNIform BEach Sediment Transport – Coast-Line dynamics,
for the computation of coastline changes due to longshore sediment transport gradients.

In this example the modules LT and CL are being used.

UNIBEST_LT is designed to compute tide- and wave-induced longshore currents and sediment transports on an alongshore beach with an arbitrary shape of the cross-shore profile.
The surf zone dynamics are derived from a built-in random wave propagation and decay model (ENDEC), which transforms offshore wave data to the coast, taking into account the principal processes of linear refraction and non-linear dissipation by wave breaking and bottom friction. The longshore sediment transports and cross-shore distribution are evaluated according to various formulae, which enables a sensitivity analysis for local conditions.
The computational procedure may take into account any pre-defined wave climate and tidal regime in order to enable an assessment of gross and yearly transports, seasonal variations and even storm events.

The module UNIBEST_LT is, apart from stand-alone applications for littoral problems, also to be used to generate input data for the coastline dynamics module UNIBEST_CL.

UNIBEST_CL is designed to compute coastline changes due to longshore sediment transport gradients of an alongshore nearly uniform coast, on the basis of the single line theory. Various initial and boundary conditions may be introduced as to represent a variety of coastal situations. Along the coast sediment sources and sinks may be defined at any location, in order to represent e.g. river sediment yields, subsidence, offshore sediment losses, beach nourishments, beach mining, etc.

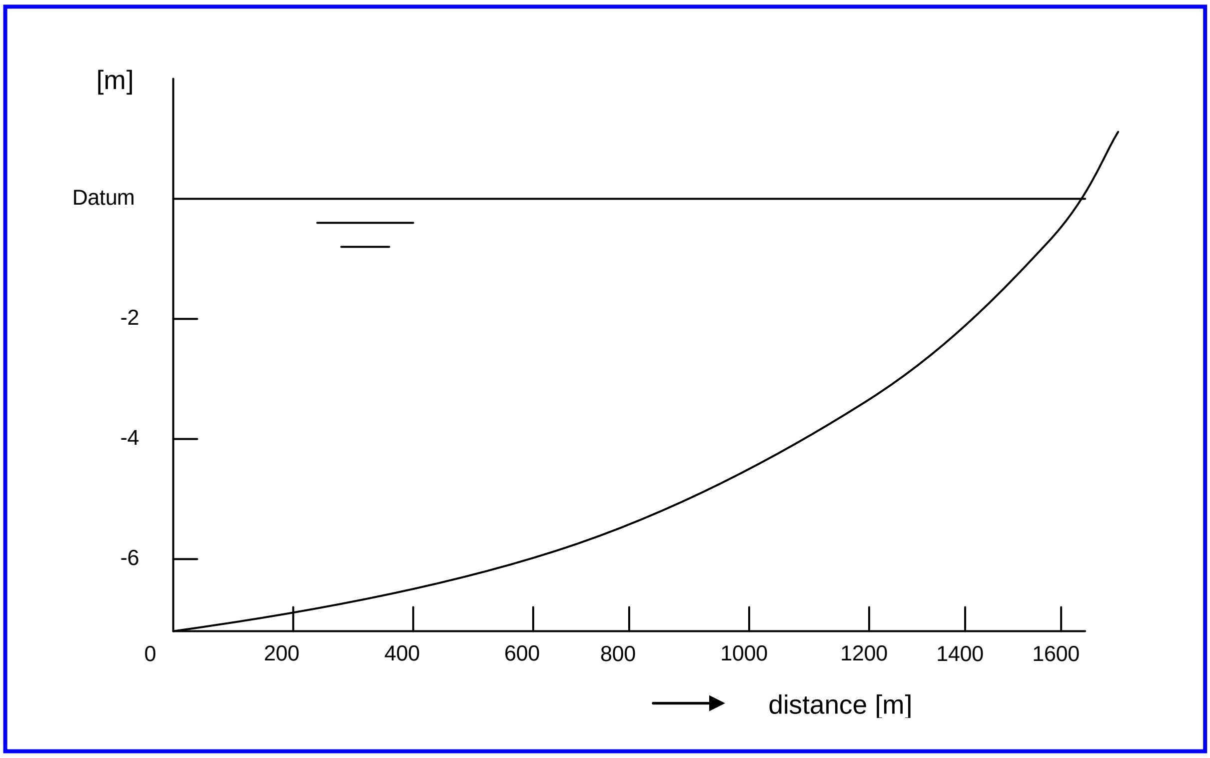

Figure 1: Sketch of the cross-shore profile

UNIBEST_CL is capable of modelling the morphological effects of various coastal engineering measures, such as headlands, permeable and non-permeable groynes, coastal revetments and seawalls, breakwaters, harbour moles, rivermouth training works, artificial sand by-pass systems and beach nourishment. The effect of wave shielding (diffraction, directional wave spreading) behind coastal structures can be incorporated in UNIBEST_CL. The module may thus be used for study and analysis of feasible erosion control measures as well as for their conceptual design (location, dimensions and spacing) and impact assessments on adjacent coastal stretches.

The basic input data for the module UNIBEST_CL is generated with the UNIBEST_LT module. Between these modules an output/input link via file transfer has been established. The utility programs SHOWTS and STRUCT can be used to generate input in situations where wave shielding effects behind coastal structures have to be incorporated in UNIBEST_CL.

2. Description of the example case

In this example case a very simple structural erosion problem based on Case 1 as discussed in Chapter 4 is treated. The following conditions and parameters are given:

- Cross-shore profile: (see Figure 1)
- $D_{50} \approx 200$ µm
- Wave parameters only: $H_s = 2$ m
$T_p = 7$ s

- Occurrence of these waves: 50 days a year
  other days no wave action

- Stretch of coast 5 km; coastline is slightly curved (see Figure 2):
  200,000 m^3/year IN and 300,000 m^3/year out of stretch A-B
  Structural erosion of 100,000 m^3/year ==> 20 m^3/m year (severe structural erosion)

3. Objective of this example study

Design, with the help of the UNIBEST computer model, a groyne system along the 5 km stretch of coast A-B. Objective is to design a protection scheme that maintains the initial situation best.

- Only a 'solution' for stretch A-B is required
- Lee-side effects will occur but the main emphasis is on the solution of the problem on stretch A-B.
- Determine the length and spacing of the various groynes in the groyne scheme.

A schematisation of the initial situation is presented in Figure 2.

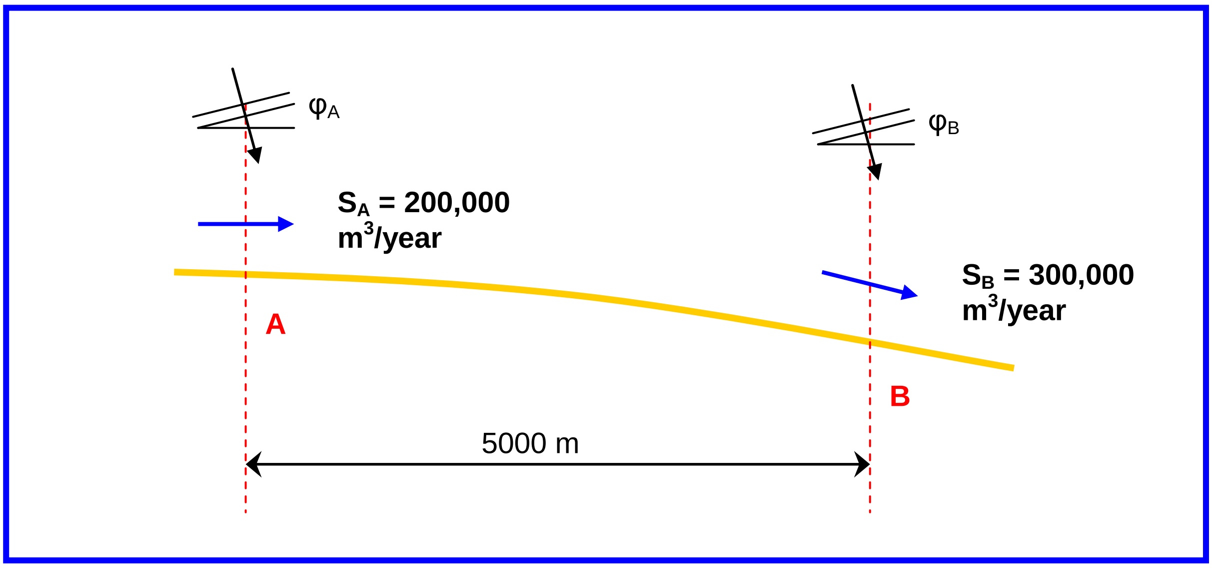

Figure 2: Stretch of coast A-B

4. The UNIBEST_LT module

4.1 Cross-shore profile and calculation grid

As can be seen in Figure 3 the calculation grid is chosen narrower in the nearshore area than in the offshore part of the cross-section.

the interval Δx is 60 m in the zone: $-2000 < x < 1000$ m
the interval Δx is 10 m in the zone: $1000 < x < 1600$ m

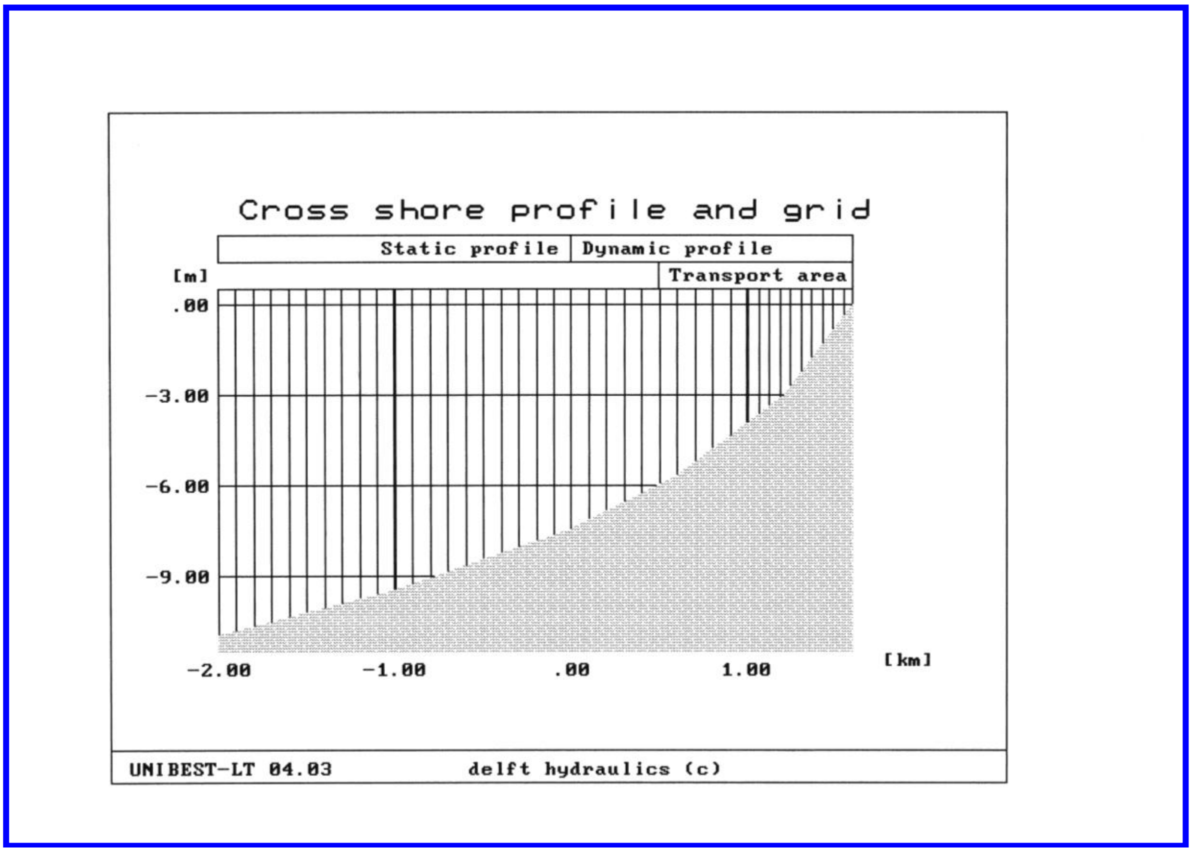

Figure 3: Cross shore profile and calculation grid in UNIBEST_LT

The transport area is defined in UNIBEST as that part of the cross-shore profile where the sediment transport is thought to take place. In the static part of the profile the depth contours are considered to be constant during the calculation in contrary to the dynamic part of the profile where the orientation of the depth contours is adjusted during the calculation. The cross-shore profile is enlarged compared to Figure 1, so the boundary of the calculation area (x = -2000 m) is situated far out of the area of interest (0 < x < 1600 m).

4.2 Schematisations used for calculations in UNIBEST

The UNIBEST_LT module calculates the occuring sediment transports under certain conditions. Because in the example case the sediment transport rate of 200,000 m^3/year through ray A is prediscribed, one has to determine the angle of incidence of incoming waves which induces such a transport (given the H_s and T_p of the waves). This is done iteratively making use of the SHOWTS utility program. The angle of incidence of incoming waves at the edge of the calculation area should be 6.5° in order to achieve a sediment transport rate of 200,000 m^3/year through ray A.

The program approximates the sediment transport using a formula that describes the relation between the angle of incidence φ and the sediment transport integrated over the cross shore profile S (the S-φ curve), see Figure 4.

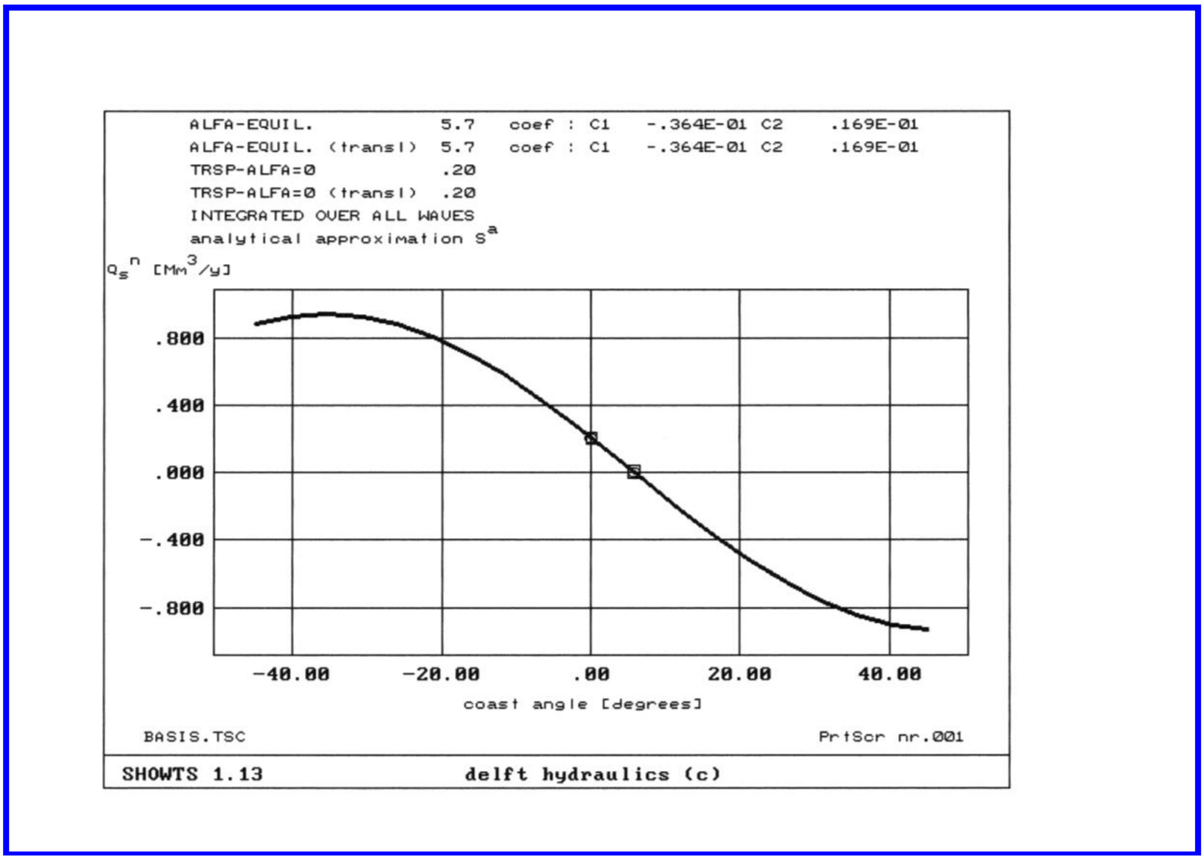

Figure 4: S-φ-curve

The relation between these two parameters is expressed by the following equation:

$$Q_s^a(\varphi) = c_1 \cdot \varphi_r \cdot e^{-(c_2 \cdot \varphi_r)^2} \qquad \text{[B.1]}$$

where:

$$\varphi_r = \varphi - \varphi_e \qquad \text{[B.2]}$$

The following coefficients are calculated resulting in a sediment transport of 200,000 m^3/year through ray A:

c_1 = -0.0364
c_2 = 0.0169
φ_e = 5.7˚

Using these coefficients the coast angle resulting in a sediment transport of 300,000 m^3/year through ray B can be determined. The angle of incidence at deeper water of incoming waves is assumed to be the same, so a gradual change of the orientation of the coastline has to be determined. The change in the coastline orientation can be calculated and is 2.48˚ in this example case.

The calculation is carried out to investigate the effect of a solution on stretch A-B with a length of 5 km. To computate the situation on stretch A-B accurately the boundaries of the computational model have to be chosen at a considerable distance from the boundaries of the actual problem area (stretch A-B). In this example the problem area is extended on both sides with a straight stretch of coast of 15 km. These extensions are straight lines so the sediment transport is constant along these stretches.

The boundary conditions at the updrift and downdrift boundary (x=0 km and x=35 km) are that at x=0 km a constant transport of 200,000 m^3/y occurs and on x=35 km a constant transport of 300,000 m^3/y occurs.

The change in coast orientation between rays A and B (at x=15 km to x=20 km) is 2,48˚. The shape of the coastline along stretch A-B is assumed to be part of a circle. This results in an approximately linear increase of the sediment transport from 200,000 m^3/y at ray A to 300,000 m^3/y at ray B. The position of the coastline at ray A is approximately 108 m further seaward than the coastline position at ray B.

The data calculated by the UNIBEST_LT module can be used as input data in the UNIBEST_CL module.

The UNIBEST_CL module is used to predict the impact of implementing groynes in the coastal zone. The program schematizes groynes as lines that are impermeable for sediment transport; the sediment transport distrubution becomes zero where a groyne is situated. This very simple schematisation can be used to predict the large scale effects, but on a more detailed level this will not describe the situation properly.

5. Situation without the use of groynes

At first a calculation is carried out with the UNIBEST_CL module of the situation when no measures are taken to prevent the coast from being eroded. This calculation is carried out so the results of other calculations can be compared with the situation where nothing is done to prevent erosion.

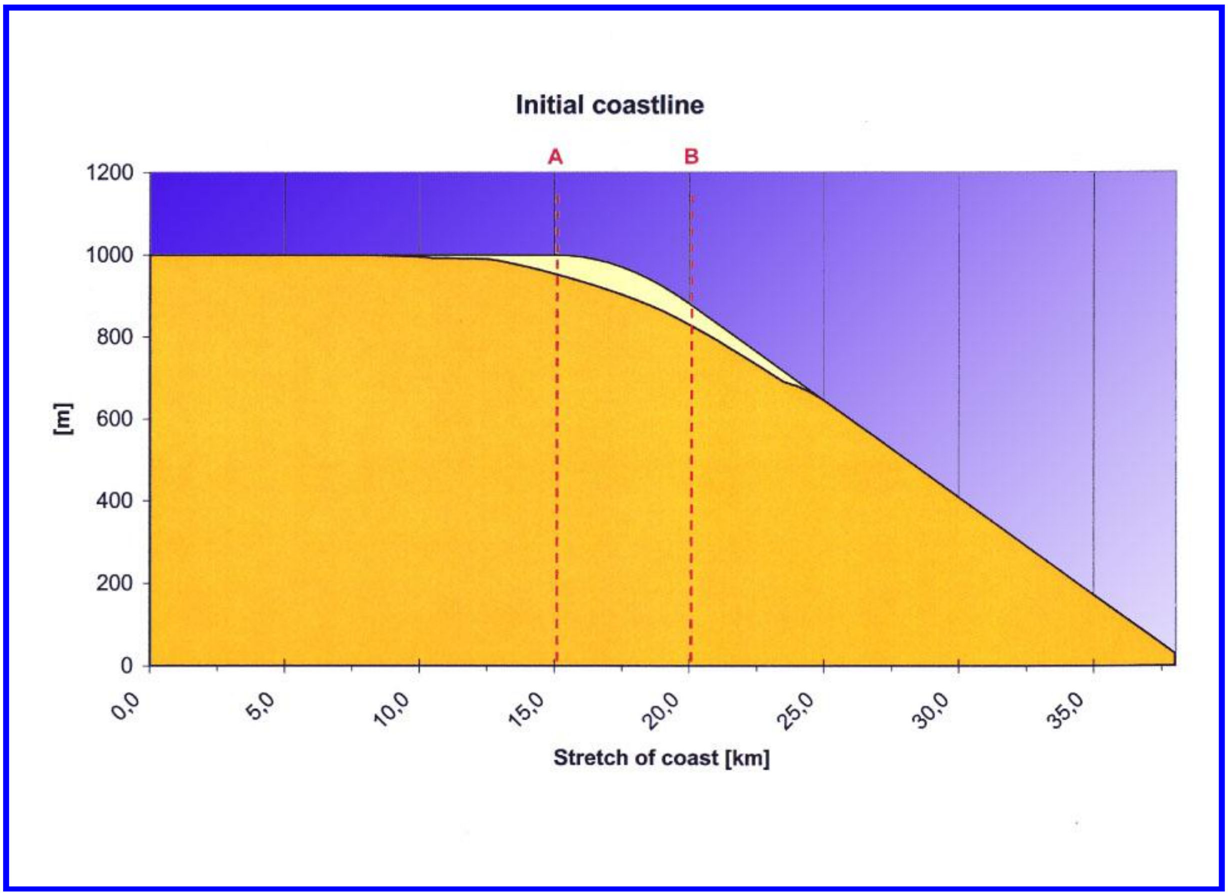

Figure 5: Situation without the use of groynes after 50 years

The result of this calculation can be compared to the following very rough approximation of the expected retreat of the coastline:
*The erosion rate on a stretch of coast of 5 km is 100,000 m^3/y, so the erosion is 20 m^3/m per year. If the active layer where erosion takes place is supposed to be 8 meters thick (as defined in the UNIBEST_CL model) and a period of 50 years is considered and every year is the same this will result in a retreat of the coastline of: 20/8 * 50 = 125 m.*

Calculation with UNIBEST_CL gives the result as presented in Figure 5.

The retreat of the coastline is approximately 100 meters (at the most eroded section) in a period of 50 years. It can be understood that the calculated retreat with the UNIBEST_CL module is smaller than the approximated retreat, because during the considered period of time the shape of the coastline is changing and therefore the erosion rate decreases during this periode, while in the estimation the situation is considered to be the same every year. The erosion will take place over a much larger stretch of coast than the considered 5 km between rays A and B due to the dynamic character of the erosion/accretion mechanisme, as can be seen in Figure 5.

6. Implementation of various schemes of groynes

To protect stretch A-B from being eroded groynes will be applied. The first scheme that is calculated in UNIBEST is a situation where one very long groyne is situated in ray B with a length of approximately 108 meters, just so that the head of the groyne is at the position of the straight coastline left from ray A, see Figure 6. It is intended that this one long groyne will trap all the sediment that is transported longshore resulting in an accretion of sediment on stretch A-B untill a horizontal coastline is reached (a constant sediment transport of 200,000 m^3/year). Trapping of all of the longshore sediment will lead to severe downdrift erosion as well. A reference period of 25 years has been chosen to reach a new situation with clear accretion on stretch A-B.

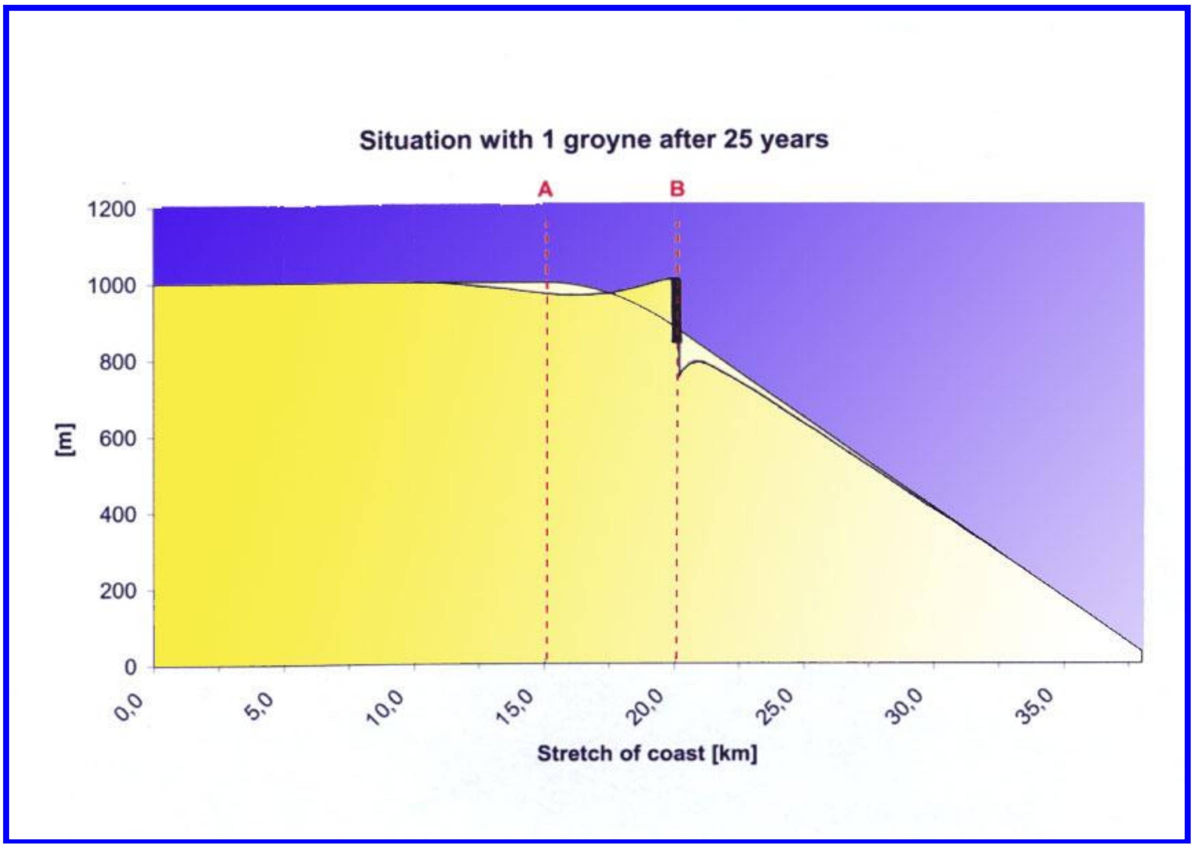

Figure 6a: Situation with one long groyne - simulation during 25 years

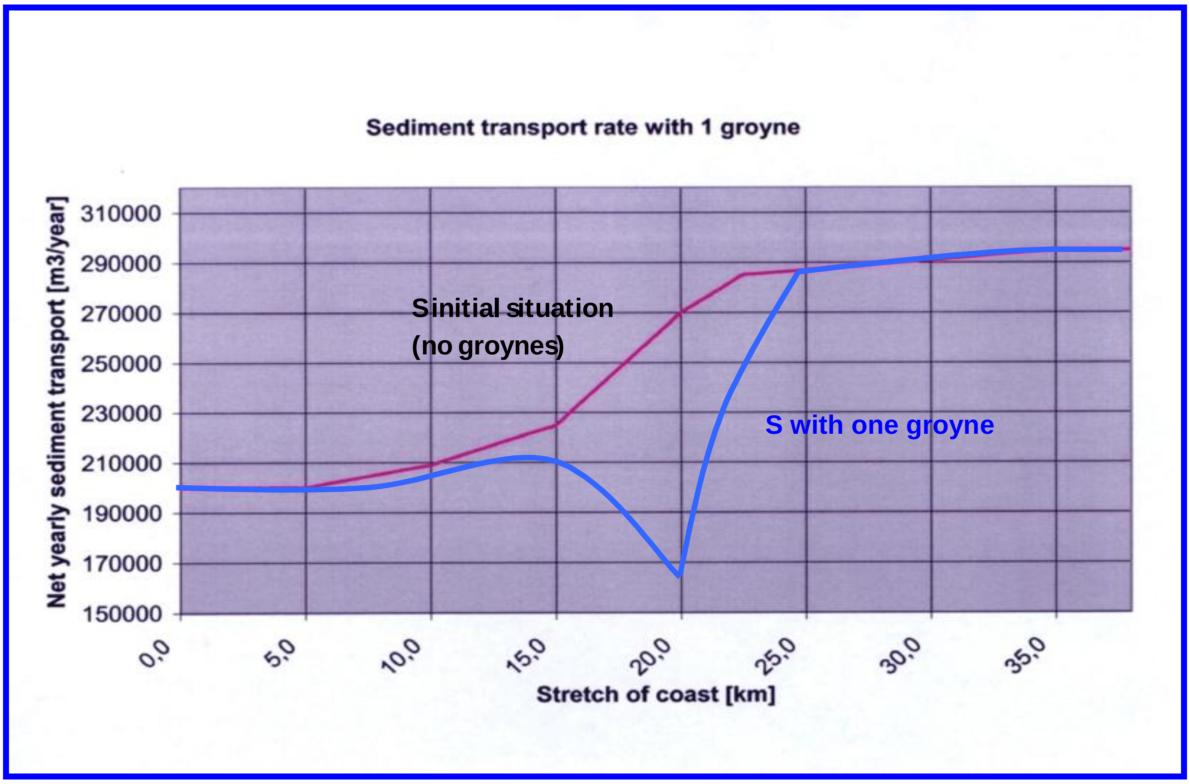

Figure 6b: Sediment transport rate after 25 years

Figure 6 shows that after 25 years some erosion occurs from ray A to approximately 2/3 of stretch A-B and some accretion occurs directly updrift of the long groyne. Lee-side erosion to some extent can be seen too. It is clear that the solution does not meet the requirements of a constant transport of 200,000 m^3/year on stretch A-B. Therefore another solution is tried. Two groynes, each of 50 meters length are applied. The first is situated in the middle between ray A and ray B, the other is situated in ray B, this solution can be seen in figure 7.

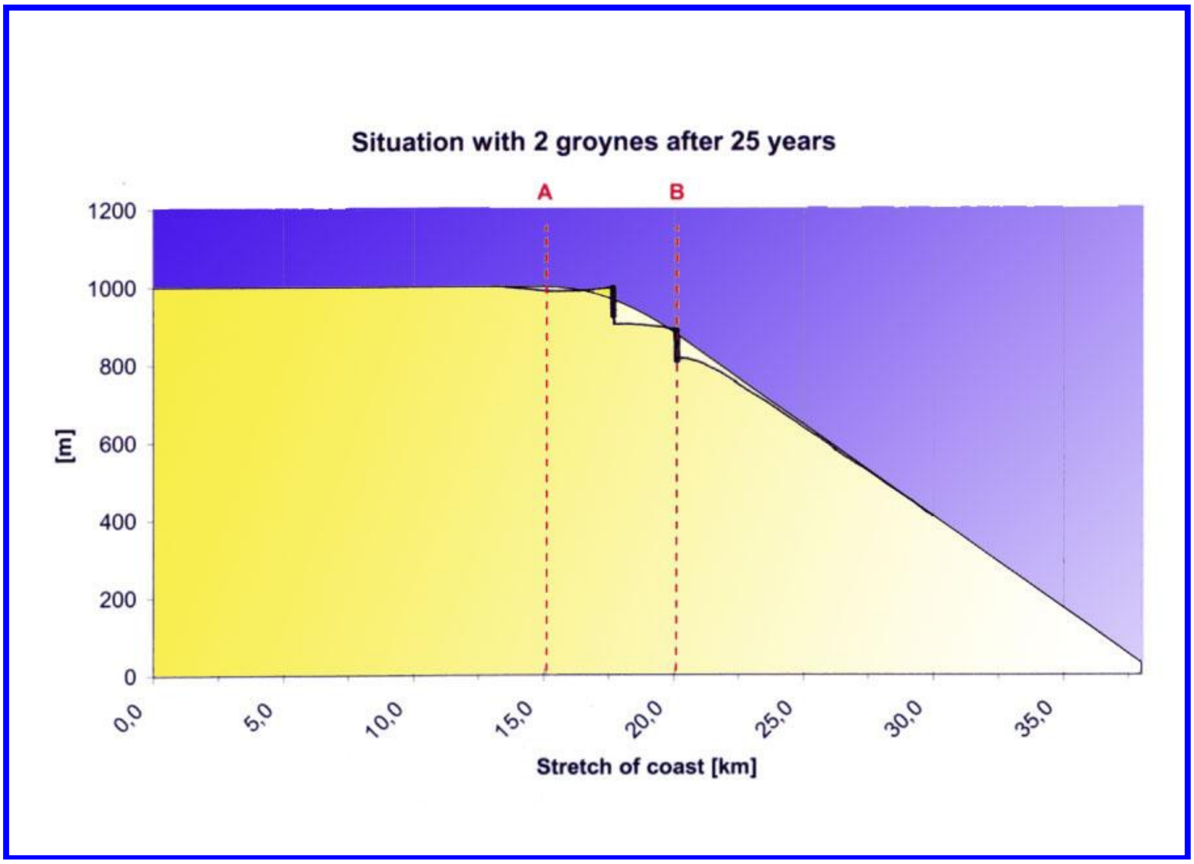

Figure 7a: Situation with 2 groynes

Figure 7b: Sediment transport rate after 25 years

25 years afters construction it can be seen, from Figure 7, that the situation on stretch A-B is stabilizing. The shape of the coastline has changed compared to the initial situation but transports are reduced and this situation can be expected to remain for a longer period. Downstream of the protected area severe lee-side erosion can be seen, the situation as sketched in figure 7 is not entirely correct because of the limitations of the hydraulic model, but probably after 25 years lee-side erosion will become a problem that has to be solved by countermeasures in some way. To reduce the adverse effects of lee-side erosion the groyne scheme will be changed to a situation with more but shorter groynes. The next computations are carried out with 5 groynes on stretch A-B.

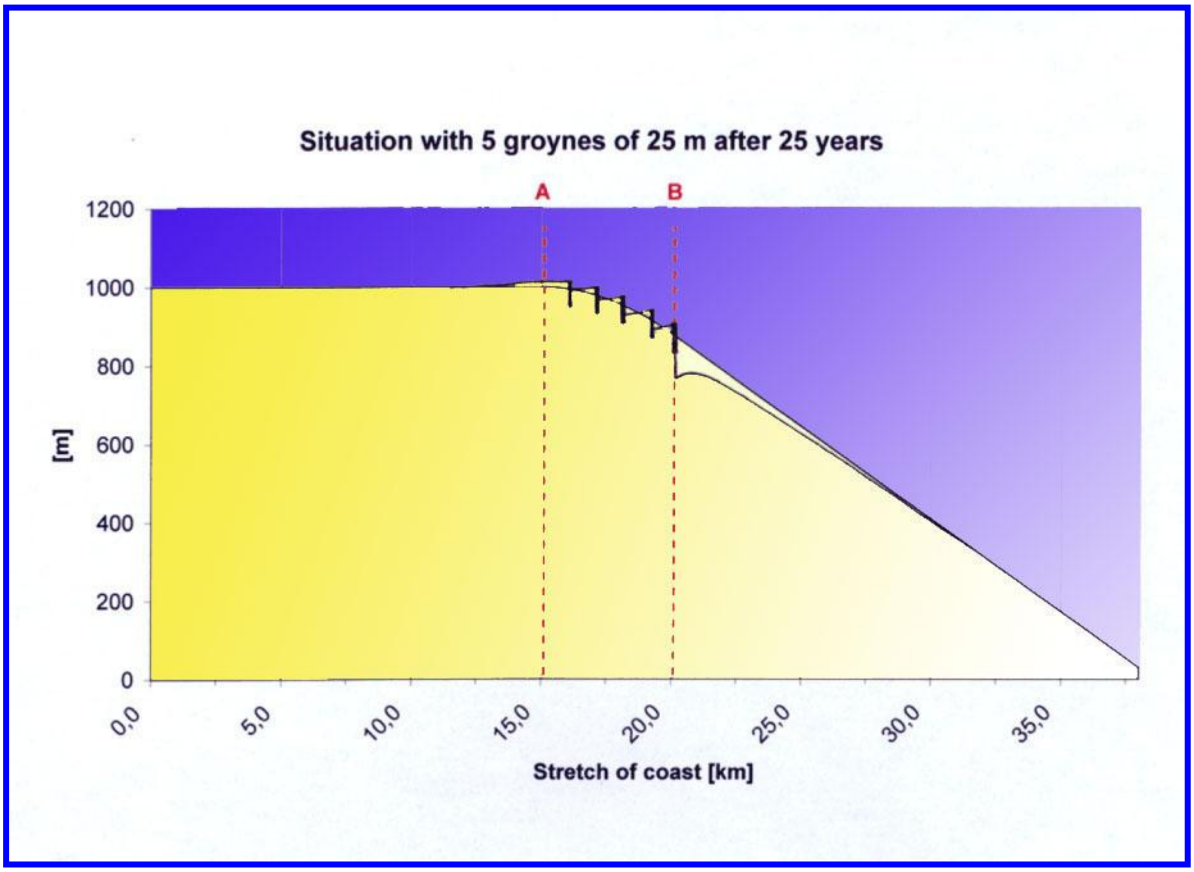

Figure 8a: Situation with 5 groynes of 25 m

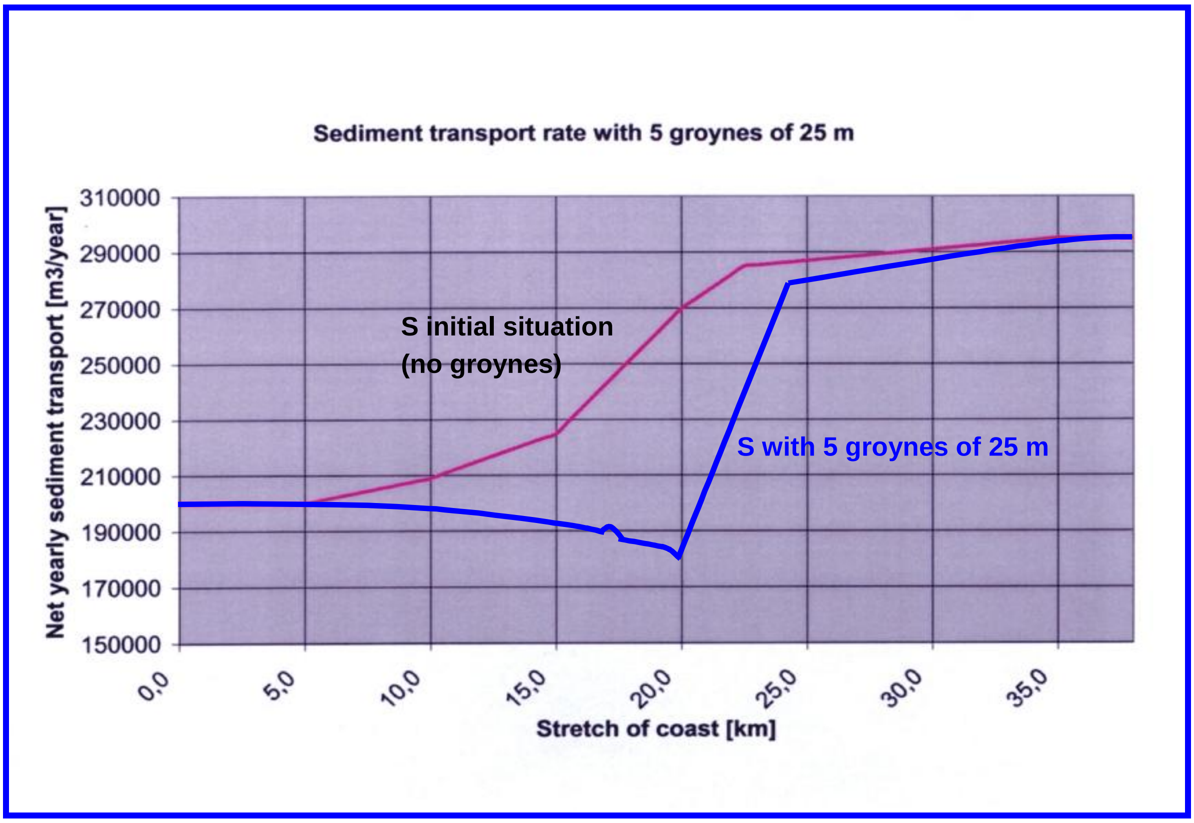

Figure 8b: Sediment transport rate after 25 years

Five groynes each of a length of 25 meters are being applied as can be seen in Figure 8. The situation on stretch A-B is practically the same as in the previous case, as can be seen from Figure 8. This means the situation on stretch A-B is reasonably stable. Lee-side effects have grown to become a serious problem, the amounts of erosion are even bigger as in the previous case with 2 longer groynes. To reduce the erosion on the lee-side shorter groynes might be effective so less sediment is trapped behind the groynes. This situation is calculated in the next case, five groynes of 10 meters are applied here. The results of this calculation are shown in Figure 9.

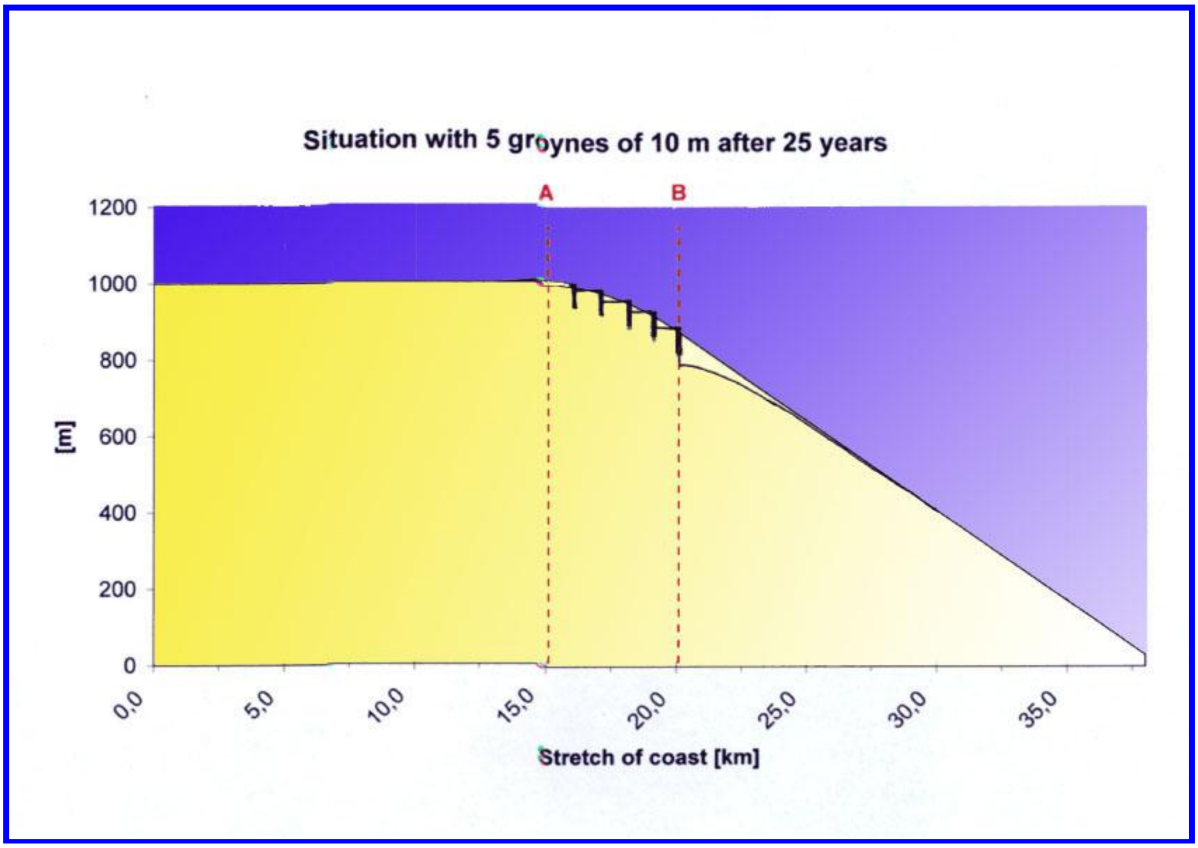

Figure 9a: Situation with 5 groynes of 10 m

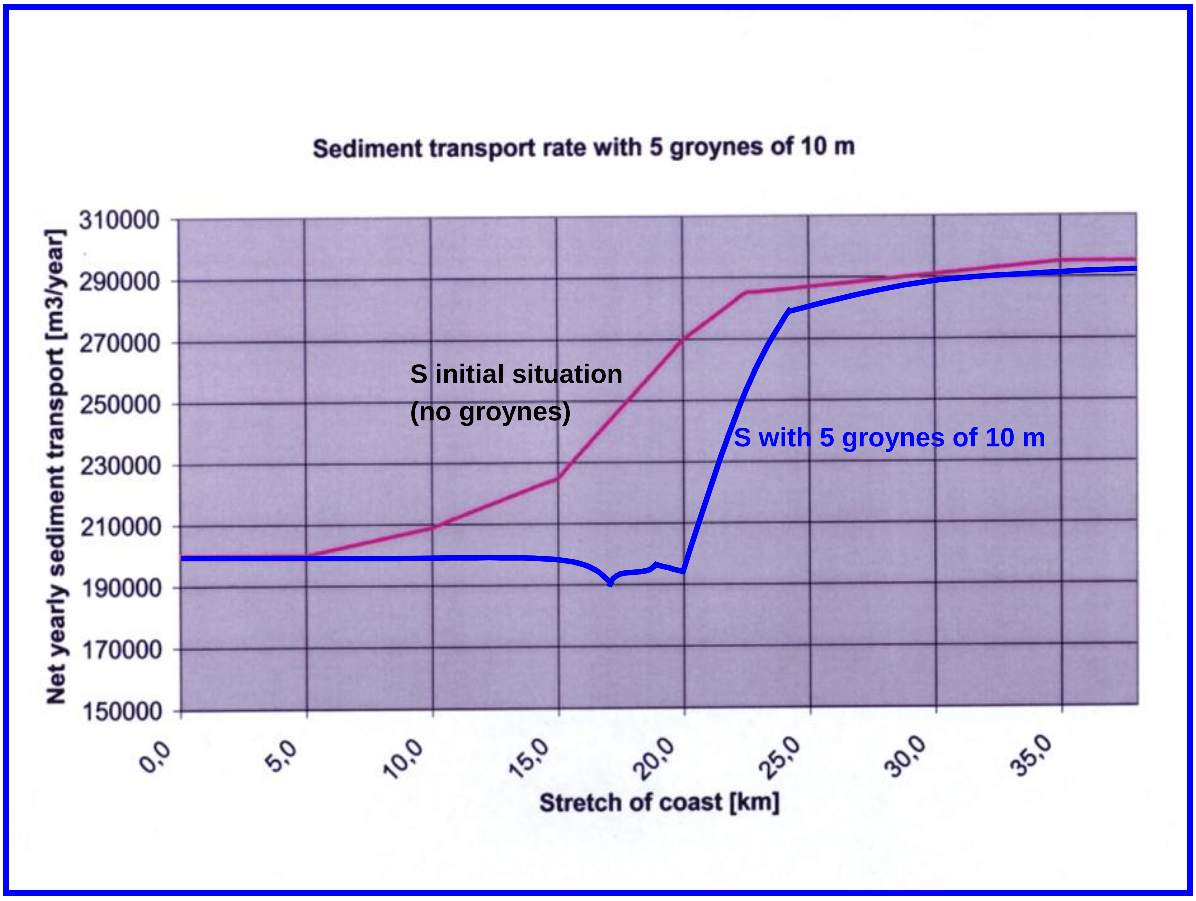

Figure 9b: Sediment transport rate after 25 years

It can be seen from figure 9 that this protection scheme meets the requirements very well. A constant sediment transport of approximately 200,000 m^3/year on stretch A-B and a reduction of the lee side erosion compared to the previous run. To reduce the lee-side erosion even further another run is made. This time the number of groynes is increased, the distance between the groynes is approximately 400 m. The results of this calculation are presented in Figure 10.

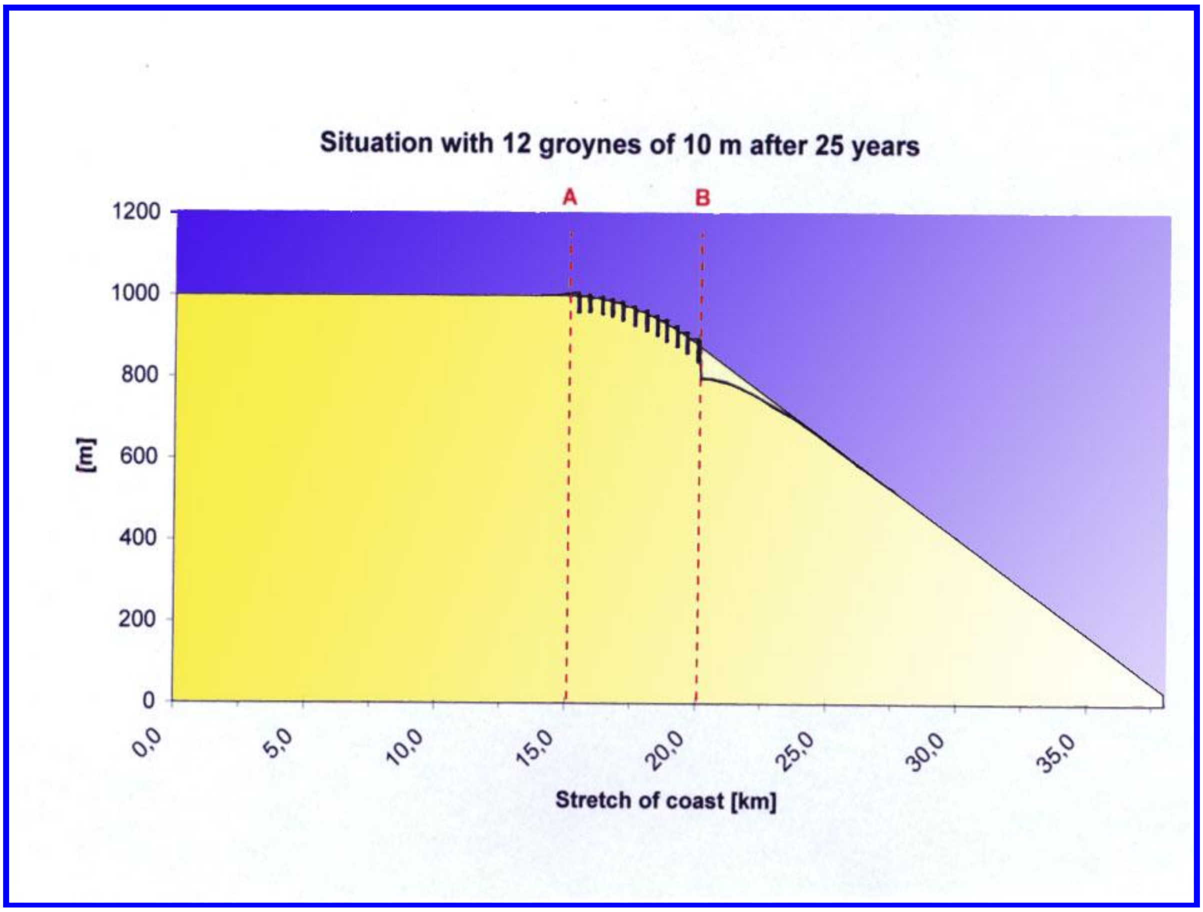

Figure 10a: Situation with 12 groynes of 10 m

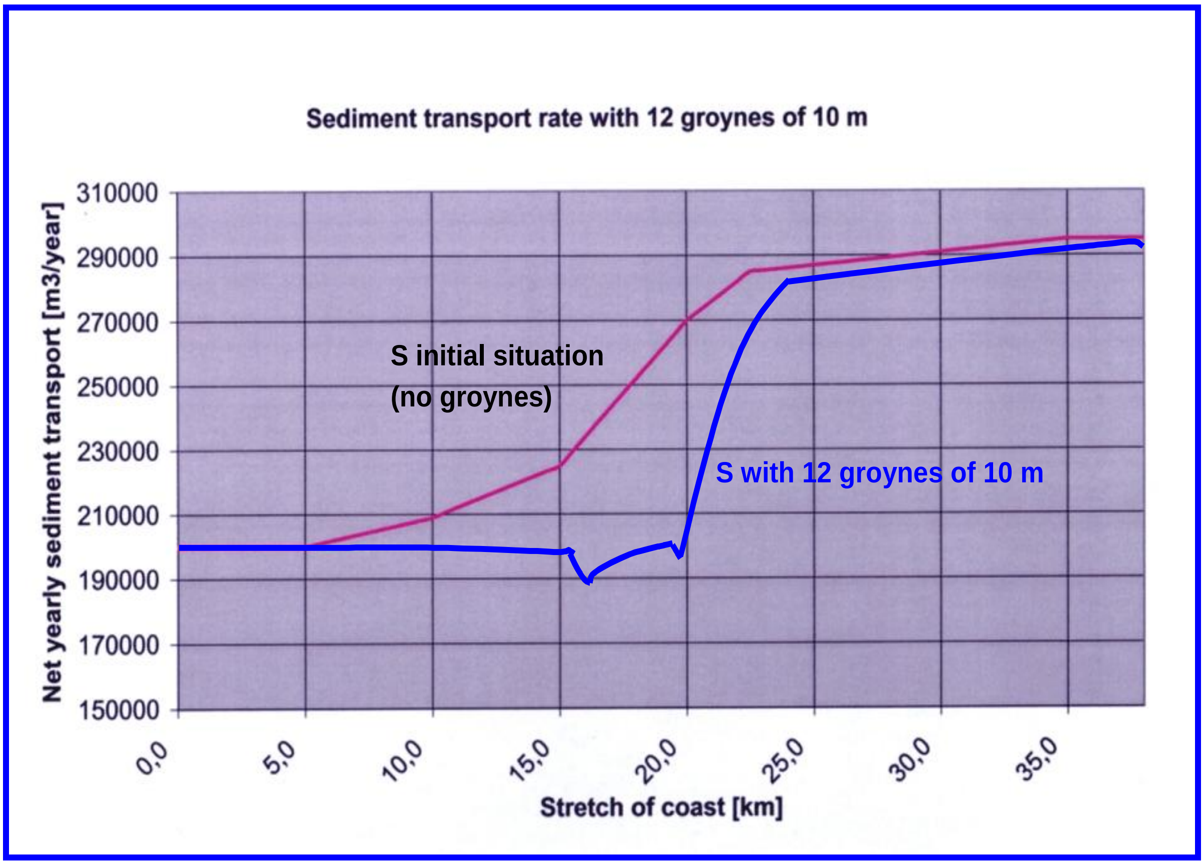

Figure 10b: Sediment transport rate after 25 years

The results of this calculation meet the requirements very well, the lee side erosion has decreased compared to the previous case and a constant transport on stretch A-B has been achieved. It seems that this solution would be effective and further study to increase the amount of groynes does not seem useful because the costs will increase considerable and the expected situation will not change much. A more severe study of the costs of all the considered solutions will be necessary to determine what is the “ideal” solution, but so far the solution as presented in Figure 10 is considered to fulfil the requirements best.

In general it can be seen that the higher the number of groynes applied the better the original shape of the coast is maintained. The solution that is best in every practical situation depends heavily on the requirements. If one accepts little change to the position of the coastline one has to design many groynes but the groynes can be relatively short. If the change to the coastline is not important one can choose to apply fewer groynes, but considerable changes in coastline orientation can be expected. A morphological model such as UNIBEST can be used to give an indication of the effects of a protection scheme.

7. Conclusions

The possibilities of using groynes in this particular case and the adverse lee-side effects become clear from this example. It must also be understood that the results of the calculations can not be used in a design study. The results just give an indication of the shape an orientation of the coast and the extents of the amounts of erosion and accretion that can be expected. Study in more detail has to follow this calculation.