Ingleses – Brazil

Solutions to urban problems due to coastal morphology

MSc Project
Hydraulic Engineering

September 2008
Project group CF83

UNIVALI

Faculty of Civil Engineering and Geosciences
Section Hydraulic Engineering

TU Delft

General notice to the reader:

In the academic programme for Hydraulic Engineering we have in the 4th year (i.e. in the first year of the Master Programme) the requirement that students should do in a group of four to six persons a so-called "groupwork". It is also called "Master Project". During this groupwork they should make a full design of something. The work should be integral, starting with terms of reference, and ending with the real design. This can be a structure, but also it can be a harbour lay-out, a policy plan design, etc. The total time available for the project is in the order of two months and will provide 10 European Credits. It has to be practical and applied.
It is certainly not an M.Sc. thesis assignment (the thesis work is individual, 6 months and more focussed on research or advanced design work on details). But it is also not an apprenticeship, internship or traineeship where the student has to work together with a group of experienced people. For this groupwork they have to solve the problem on their own (of course with guidance).

This report is the result of such a Master Project. This report has been assessed by staff of TU Delft. It has been provided with a passing mark (i.e. a mark between 6 and 10 on a scale of 10), and consequently considered sufficient for publication.

However, this work has not been fully corrected by TU Delft staff and therefore should be considered as a product made in the framework of education, and not as a consultancy report made by TU Delft.

The opinions presented in this report are neither the opinions of TU Delft, neither of the other sponsoring organisations.

Department of Hydraulic Engineering
Delft University of Technology

Ingleses – Brazil

Solutions to urban problems due to coastal morphology

Final Report

September 2008

MSc Project Hydraulic Engineering

Project group CF83

Delft University of Technology,

Faculty of Civil Engineering and Geosciences, section Hydraulic Engineering.

Universidade do Vale do Itajaí,

Centro de Ciências Technológicas da Terra e do Mar.

Project group CF83 "Ingleses 2008"

Jan-Willem Bardoel

Jack Geerlings

Bas Hoonhout

Arco van Sabben

Robert Zuidgeest

Supervisors

Prof. dr. A.H.F. Klein

Ir. H.J. Verhagen

Prof. dr. ir. M.J.F. Stive

Cover photograph "Ingleses Beach" by Project Ingleses 2008.

Preface

This report is a result of a research and design project of five students from the Delft University of Technology. As part of the two-year MSc-study Hydraulic Engineering, students can choose to participate in such a multidisciplinary project. The purpose is to apply the knowledge obtained during the study to an actual civil engineering problem.

From April to June 2008, the students performed research to the coastal morphological problems in Ingleses, Santa Catarina, Brazil and designed a practical solution for these problems. This project has been a follow-up project of the research performed by Project Ingleses 2007, last year. The research has been done at the Universidade do Vale do Itajaí (UNIVALI).

During the research it became clear that a full understanding of the coastal system around Ingleses, with the currently available data, is not possible. Therefore, aspects of the coastal system for which reasons exist to believe that the currently available information is not entirely correct, but the possibilities to improve this information are limited, are not investigated in detail. This concerns especially the suspected underestimation of the significant wave height and the possible sediment bypass. Instead, the focus has been on the design of a practical solution within the uncertain circumstances known. At the end of this report some remarks and recommendations are placed alongside these decisions.

We like to use this opportunity to thank all people that supported us during this project for their assistance. We especially like to thank our supervisor from UNIVALI Antonio Klein, for the opportunity and assistance he gave us, and all other people from UNIVALI that helped us by sharing their expertise even when they were actually fully occupied by their own projects. We are very pleased by the great hospitality showed by the university, professors and students.
We also like to thank Henk Jan Verhagen for his help with the organization of this project as well as our other supervisor Marcel Stive. Last but not least we like to thank our sponsors for making this project financially possible.

Delft, September 2008,

Jan-Willem Bardoel
Jack Geerlings
Bas Hoonhout
Arco van Sabben
Robert Zuidgeest

Sponsors

Abstract

This report describes the research done by the authors to the erosion and dune migration problems in the town Ingleses. Ingleses is located in the north of *Ilha Santa Catarina* in *Brazil*. This report describes a follow-up research on the research in 2007 of project group CF71 from Delft University of Technology. The beach erosion in the embayed beach threatens the buildings at the southern stretch of the beach. Furthermore, a large dune field, *Moçambique Dune*, is migrating towards the north and encroaches houses in the southern part of Ingleses. The aim off this report is to give better insight in the problem and present a solution.

Research has been done to investigate the migration speed of the dune and the erosion rate of the beach. This is done by a photo analysis. Aerial photographs from several years and a *Geographical Information System* are used for this purpose. The average migration speed since 1938 of Moçambique Dune is a little more than three meters per year. In the southern part of Ingleses, the beach erodes one to two meters per year since 1960.

The zero-solution is also a part of this research. Using the migration speed of the dune, the damage is quantified in case no measures are taken. Also the damage at the coast is quantified with the use of the erosion rates. Especially the damage at the coast will be significant. This zero-solution is a reference situation for the solution presented in this report and gives insight in the scale of the problems. A maximum loss of 1,5 million euro's per year is expected in case no actions are taken.

The solution presented in this report is a beach nourishment. For the nourishment, sand will be used from Moçambique Dune. This way, two problems are solved at the same time. For the design fill a beach width of 38 meter will be constructed. Also an advanced fill is calculated for a design lifetime of 10 years. The design fill is calculated with the erosion rates calculated with the photo analysis. The fill sand from the dune is coarser then the sand from the native beach. For this reason the beach will be steeper after the nourishment.

In the report the construction method for the nourishment is also considered. Two construction methods are elaborated, the use of trucks and the use of pumps and pipelines. For both methods an estimation is made for the construction time and the construction costs. Both construction methods are compared in a *Multi Criteria Analysis* (MCA). In this comparison the pipelines turned out to be the better method. However, this method is more expensive. The zero-solution and the nourishment are also

compared in a MCA. In this comparison the nourishment turned out to be the better solution. The nourishment is also the cheaper solution.

Another aim of this project is the improvement of the numerical model made in 2007. Some scenarios are modelled in this research. The first scenario is the situation from 1938 when the sand from Moçambique Dune was an input of the system. Other scenarios are investigated to analyze the bypass at the northern headland. Finally, the scenario with the designed nourishment is modelled.
The numerical model appeared to still be extremely sensitive to several parameters that still are not well-known like the wave characteristics and sediment bypass. Further extensive research to these parameters is necessary in order to obtain a reliable model.

During this research a lot of additional data about the coastal system around Ingleses is collected and analyzed. Assumptions are verified and a better insight in several important parameters is given. It is concluded that a nourishment is a suitable and feasible solution for the erosion problems. The sand from the Moçambique Dune can be used for this nourishment which is a suitable solution for the encroachment problems as well.

Table of Contents

List of Figures

List of Tables

List of Symbols

Breaker height

h	=	*depth [m]*
A_N	=	*native sediment scale parameter [$m^{1/3}$]*
A_F	=	*nourishment material scale parameter [$m^{1/3}$]*
d_{50}	=	*Mean grain size [mm]*
y	=	*breaker índex [-]*
H_b	=	*wave height [m]*
h_b	=	*depth when wave breaks [m]*
β	=	*beach slope [^{o}]*
H_0	=	*deep water wave height [m]*
L	=	*wave length [m]*
T	=	*wave period [s]*

Aerial photographs

RMS_{limit}	=	*maximum RMS error according to NSSDA standard [m]*
σ	=	*standard deviation [m]*
N	=	*number of control points [-]*
x_i	=	*individual position of control point [m]*
$\overline{x}$	=	*arithmetic mean of control point positions [m]*
SE	=	*standard error [m]*
IP	=	*imprecision [%]*
P	=	*precision [%]*

Nourishment

d_{50}	=	*mean grain size [mm]*
V_{adf}	=	*volume of sand needed for advanced fill [m^3]*

Numerical Model

d = *depth [m]*

y = *distance to the coastline [m]*

Zero-solution

$P_{m2building}$ = *price for a square meter of building [R$/m^2]*

$P_{realEstate}$ = *total price of the real estate (Table F-7, column 6) [R$]*

$P_{bare\ land}$ = *price for a square meter bare land (values of Table F-6 used) [R$/m^2]*

S_{parcel} = *total parcel surface [m^2]*

$S_{BuildingOnParcel}$ = *total surface which is covered by the building on the parcel [m^2]*

Borrow area

φ = *grain size*

Beach nourishment

V = *volume of sand needed for nourishment [m^3]*

W = *beach width [m]*

D_{oc} = *closure depth [m]*

B = *berm height [m]*

H_b = *breaker height [m]*

g = *gravitational acceleration [m/s^2]*

T = *wave period [s]*

A_N = *native sediment scale parameter [m^{1/3}]*

A_F = *nourishment material scale parameter [m^{1/3}]*

μ = *dynamic viscocity [g/cm*s]*

r = *particle radius [cm]*

ρ = *density [g/cm^3]*

W_s = *fall velocity [m/s]*

Dune field

h_{avg}	=	*height of average level plus Imbituba Datum [m]*
$V_{above\ 1,86m+ID}$	=	*volume of Santinho dune field above Imbituba Datum +1,86m [m^3]*
$Surf_{San.dune}$	=	*2D surface of part of Santinho dune field [m^2]*

Dune migration

$H_{m;t;min}$	=	*lowest trough level above MSL [m]*
$V_{m,migrating}$	=	*volume above lowest trough level [m^3]*
L_m	=	*length dune [m]*
W_m	=	*width dune [m]*
$A_{m;migrating;avg}$	=	*average cross-section area [m^2]*
$H_{m;avg}$	=	*average height of total dune [m]*
$f_{m;d}$	=	*migration speed correction factor [-]*
$u_{avg;time;ridges}$	=	*average migration speed [m/s]*
$V_{Santinho}$	=	*input volume Santinho dune [m^3]*

Sediment bypass

$S_{in;Santinho}$	=	*sediment input from Santinho dune [m^3]*
$S_{in;Mocambique}$	=	*sediment input from Moçambique dune [m^3]*
$S_{out;North}$	=	*sediment bypass around northern headland [m^3]*

1 Introduction

This report describes the research of *Project CF83 Ingleses* in the period April until June 2008. This research has been done at *Universidade do Vale do Itajaí*, Santa Catarina, Brazil. This chapter gives a brief overview of the content and structure of this report.

The problems that arise in the town Ingleses, that lies on *Ilha de Santa Catarina* close to *Florionopólis*, are beach erosion and dune migration. The beach erosion in the embayed beach threatens the buildings at the southern stretch of the beach. Furthermore, a large dune field is migrating towards the north and encroaches houses in the southern part of Ingleses. More about the project area, hypothesis and the problems is described in chapter 2.

The project is a continuation of the research by last year's project, *CF71 Ingleses 2007*. This project mainly focused on the quantification, underlying processes and the scope of the problems. Their report is meant to be a starting point for design studies. This project tries to focus on designing practical solutions for the problems that Ingleses suffers from. Several solutions are proposed. Not all of the solutions are fully elaborated. The focus is on the design of a nourishment and the question if the sand from the dunes can be used for this nourishment. The economical damage that results from these problems, if nothing is done to stop these problems, is also investigated.

To calculate the volumes of sand involved in a nourishment and the volumes that are present in the dune, a *Geographical Information System* (GIS) is used. GIS is also used to rectify and analyze aerial photographs provided by several authorities in Brazil. This is explained in chapter 3. The migration speed of the two dunes in the area surrounding Ingleses and the coastal development through the years are examined using the aerial photograph analysis as described in chapters 4 and 5.

In chapter 6 the damage to the cultivated area along the beach and in the vicinity of the dunes is quantified, the zero-solution. In this chapter a rough estimation is given of this damage with the information collected during fieldtrips, from real estate agents and from aerial photographs.

The nourishment design is another scenario that is elaborated in detail. This is explained in chapter 7. The kind of sand that is needed, is an important item in the design. Sand samples from last year and newly collected sand samples are examined to determine which source suites the needs for a good nourishment. Information about the desired grain size, where it is found and potential locations for a borrow area are also described in this chapter.

A *Multi Criteria Analysis* (MCA) is used to select the optimal solution. This analysis and its results is described in chapter 8.

The attempts to improve the numerical model and the results of the modeling of several scenarios is described in chapter 9.

Finally, the conclusions of this project are presented in chapter 10, followed by the discussion and the recommendations in chapter 11. Appendices are referenced throughout the report and can be found at the end of this report

2 Project description and hypothesis

In this chapter the project area is described and the problem itself is explained in more detail. After these descriptions, the hypothesis of this case study is further explained.

2.1 Area description

The project area is described with increasing detail. First, the general aspects of the area are described where after several important locations within the project area are highlighted.

2.1.1 Brazil

Brazil is the largest country in South-America and the fifth-largest country in the world. It covers over 8,5 million km^2 and borders almost every country on the continent. It has a coastline of over 7000 km along the Atlantic Ocean and an extensive river system of which all rivers are draining to this ocean. The largest rivers are the Amazone, São Francisco and the Paraná (Rió de la Plate). The climate in Brazil is generally speaking tropical, although further divisions can be made.

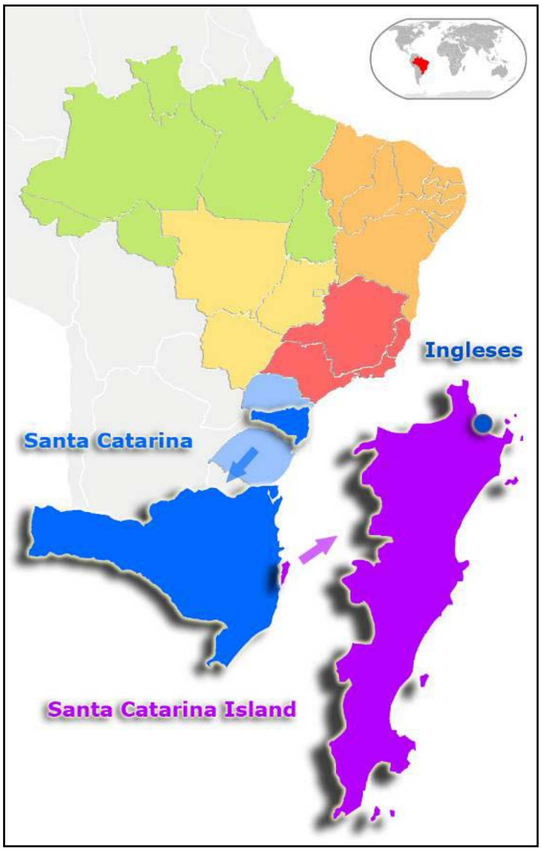


Figure 2-1 Location of Santa Catarina State, Santa Catarina Island and Ingleses

Until the end of the nineteenth century, Brazil has been under the reign of Portugal. Both as a colony and as a part of the Portuguese empire. The official language is Portuguese as well, but differs a lot from the Portuguese that is used in Portugal.

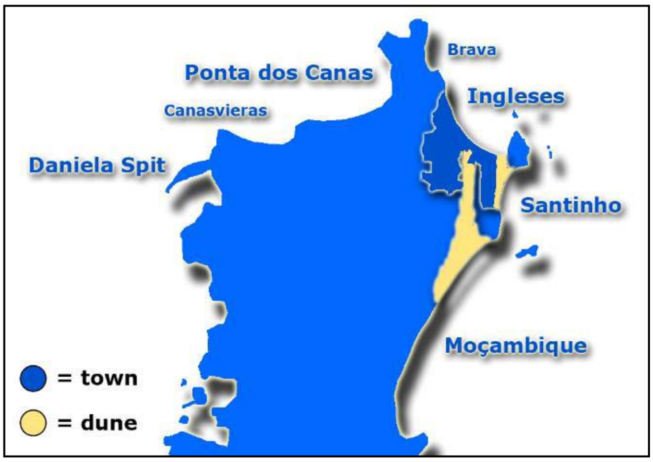


Figure 2-2 Town of Ingleses, dune ridges and surrounding beaches

Nowadays, Brazil is a republic divided in 5 regions and 26 states (estados). The project area is located in the Santa Catarina state which is located in the most southern region (South Region).

2.1.2 Santa Catarina State

Santa Catarina is located in the wealthy south of Brazil (Figure 2-1). It has almost 600 km of coast containing a lot of beaches that attract a lot of tourists. The largest part of the population are descendants of European settlers. The inheritance of especially the German immigrants, is still visible in this state.

The state capital is Florianópolis which is located on the Santa Catarina Island (Ihla Santa Catarina). At this island the project area is located as well.

2.1.3 Santa Catarina Island

Santa Catarina Island is located half-way the coast of Santa Catarina state (Figure 2-1). Because of its beauty it's a great attraction to tourists from all over Brazil and from neighbouring countries. The island contains many embayed beaches like Ingleses Beach (Praja dos Ingleses).

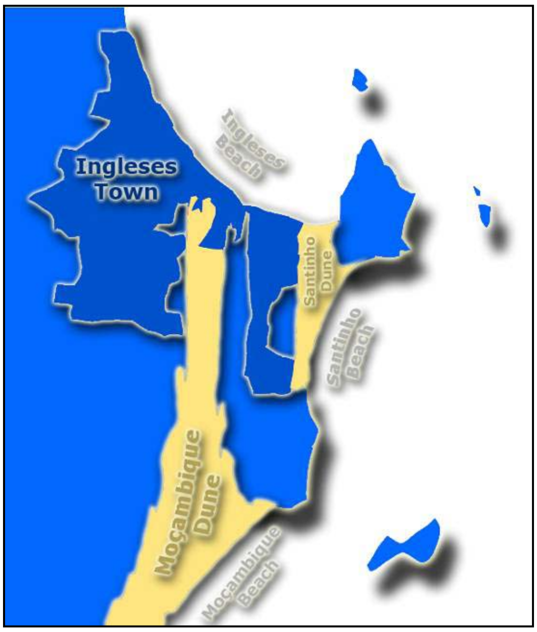


Figure 2-3 Names of dunes and beaches around Ingleses

2.1.4 Ingleses

Ingleses Beach is located at the north-east corner of Santa Catarina Island. It forms the coastline of the town of Ingleses (Figure 2-4). In high season, it is very popular to especially Argentinean tourists. At the southern side of the town, two dune ridges are located. These dune ridges are supplied with sand from the Santinho and Moçambique beaches respectively. In agreement with the previous research to this area in 2007, the dune ridges are named after the beaches that supply their sediment (Figure 2-3). From now on, the eastern and western dunes are therefore called Santinho and Moçambique dunes respectively.

Ingleses Beach, Ingleses Town and the two dune ridges form the actual project area. The system area to be investigated during this project is somewhat larger. In the system area, two other areas are included. First, areas that supply sediment directly to Ingleses are included and second, areas that are influenced by the output of sediment from Ingleses are included. The Santinho and Moçambique beaches are examples of the first type of areas while the Daniela Spit and the Ponta dos Canas Beach and Spit (see Figure 2-2) are an example of the second type of areas.

The Daniela Spit and the Ponta dos Canas Beach and Spit are located at the north-west and north side of the Santa Catarina Island respectively. Both locations are located downstream the prevailing littoral current with respect to Ingleses.

Figure 2-4 Ingleses Beach

2.2 Problem description

As stated in the previous paragraph, the town of Ingleses is very popular among beach tourists. Nevertheless, the amount of beach surface at Ingleses is decreasing. At high water, almost no beach is left. Especially at the southern side of the beach the problems are severe. Since several years, buildings located along the beach are threatened by the water as well.

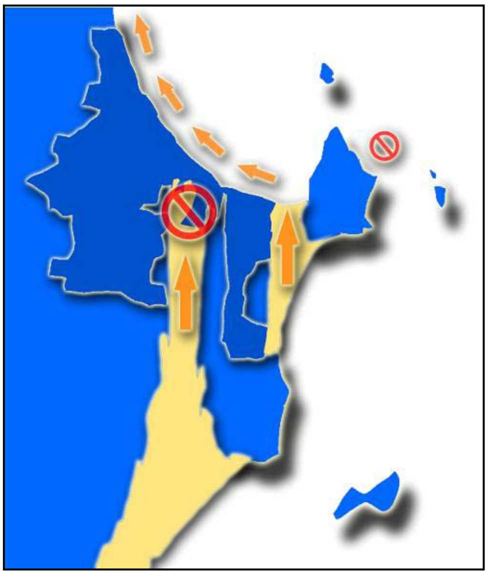


Figure 2-5 Problem description at Ingleses

While buildings at the north-eastern side of the town are threatened by a shortage of sediment, the buildings at the southern side of the town are threatened by an excess of sediment. Sediment from the Santinho and Moçambique beach are blown in the direction of Ingleses forming two migrating dunes. The direction of the migration is obviously north. While the Santinho dune migrates into the bay of Ingleses directly (Figure 2-6), the migration of the Moçambique dune is blocked by the buildings of the town of Ingleses resulting in the encroachment of these buildings (Figure 2-7).

The main sediment transport directions are given in Figure 2-5. As can be seen from this figure, sediment is leaving the bay of Ingleses beach in the north while a lot of sediment from Moçambique Beach do not reach Ingleses Beach at all.

Figure 2-6 Santinho Dune entering directly in the bay of Ingleses

2.3 Hypothesis

The hypothesis of this project is that in the past, the sediment from the Moçambique Beach reached the Ingleses Beach by means of being transported by the Moçambique dune. This transport, together with the transport by the Santinho Beach created an equilibrium with the sediment output caused by the littoral current in northern direction (see Figure 2-5).

Figure 2-7 Shed being encroached by Moçambique Dune

Once the town of Ingleses started to expand, more and more sediment was blocked by the new buildings. This blockage resulted in a disturbance of the equilibrium and thus an overall loss of sediment and beach surface at Ingleses Beach. Since the transport of sediment by the Moçambique dune did not stop, the buildings that cause the blockage are encroached by the dune.

2.4 Objectives

Since the 2007 project stated that the hypothesis described above and first described by Klein [Klein, 2004] is false, the objective of this project is threefold:

1. More detailed verification of the hypothesis.
2. Improvement of the numerical model
3. Formulating practical solutions to the problems.

2.4.1 Verification of hypothesis

One of the objectives of this project is to verify the hypothesis, that has been rejected by the 2007 project, again. The reason that the hypothesis still might be verified as being true is firstly that the 2007 project made a few assumptions that are unlikely to be true and secondly that the 2008 project has more reliable data available.

The two most important *assumptions* from 2007 that will not be used in this project are:

1. *The Moçambique dune never reached the beach of Ingleses and therefore couldn't be a source of sediment.* This assumption is a direct rejection of the hypothesis. This assumption has been made based on aerial photographs from 1978. Additional aerial photographs from 1938 proves this assumption to be wrong.
2. *The bay of Ingleses can be modeled as a closed cell, meaning that no sediment enters or leaves the bay.* Although the sediment transported by the Moçambique dune might not enter the bay anymore, the sediment from the Santinho dune still provides an input of sediment into the bay of Ingleses. Furthermore, the development of spits downstream the littoral current (Ponta dos Canas and Daniela, see Figure 2-2) proves that longshore sediment transport occurs and therefore sediment leaves the bay of Ingleses.

The *data* that is available now, but was not available during the 2007 project is among others:

1. Aerial photographs of the project area from 1938 and 1957.
2. Aerial photographs of the project area from 1978 in a higher resolution.
3. Wave statistics from the Argoss database, with a higher resolution and more measuring points closer to the area of interest.
4. Geographic Information System (GIS) information of the dunes for calculating volumes more accurately.
5. GIS information for a more accurate description of the bathymetry.

2.4.2 Numerical model

The first objective will lead to more knowledge about the coastal and dune system around Ingleses. This information will be used to modify the numerical model from the 2007 project. Especially the effects of discarding the closed cell assumption will be investigated. The model will be checked and calibrated using a larger series of photographs compared to the 2007 project and will eventually be used to simulate the practical solutions designed by this project.

2.4.3 Practical solutions

One of the objectives of this project is to formulate practical solutions for the problems at Ingleses. The definition of a *practical solution* is considered a economical solution that will be acceptable for the inhabitants, visitors and local politicians of the town of Ingleses. The following two solutions will be considered during this project:

1. *Zero-solution.* Nothing will be done, only the expected damage will be calculated. This solution will be used for comparison with the other solutions.
2. *Beach nourishment.* A permanent or periodic beach nourishment will be designed with or without the use of the excess of sediment in the south. The nourishment should provide a solution to the lack of beach surface and the dangers to which the houses along the beach are currently exposed.

Two other possible solutions suggested by Project Ingleses 2007 are:

1. *Dune fixation.* A permanent or periodic fixation will be designed to stop the migration of the Moçambique dune.
2. *Dune remobilization.* In order to restore the equilibrium mentioned in the hypothesis, the migration of both the Santinho dune can be stimulated. For the Santinho dune this probably just means removal of vegetation.

The last two solutions are not considered extensively during this project, because the first fieldtrip (see Appendix E) showed that these solutions are not expected to be successful. A project for dune fixation has been executed by the local government in the past and is proven not to be sufficient. Dune remobilization will not be considered because at this moment there is not much vegetation on the Santinho dune that can be removed.

2.4.4 Overview

The entire project is visually presented in the following diagram:

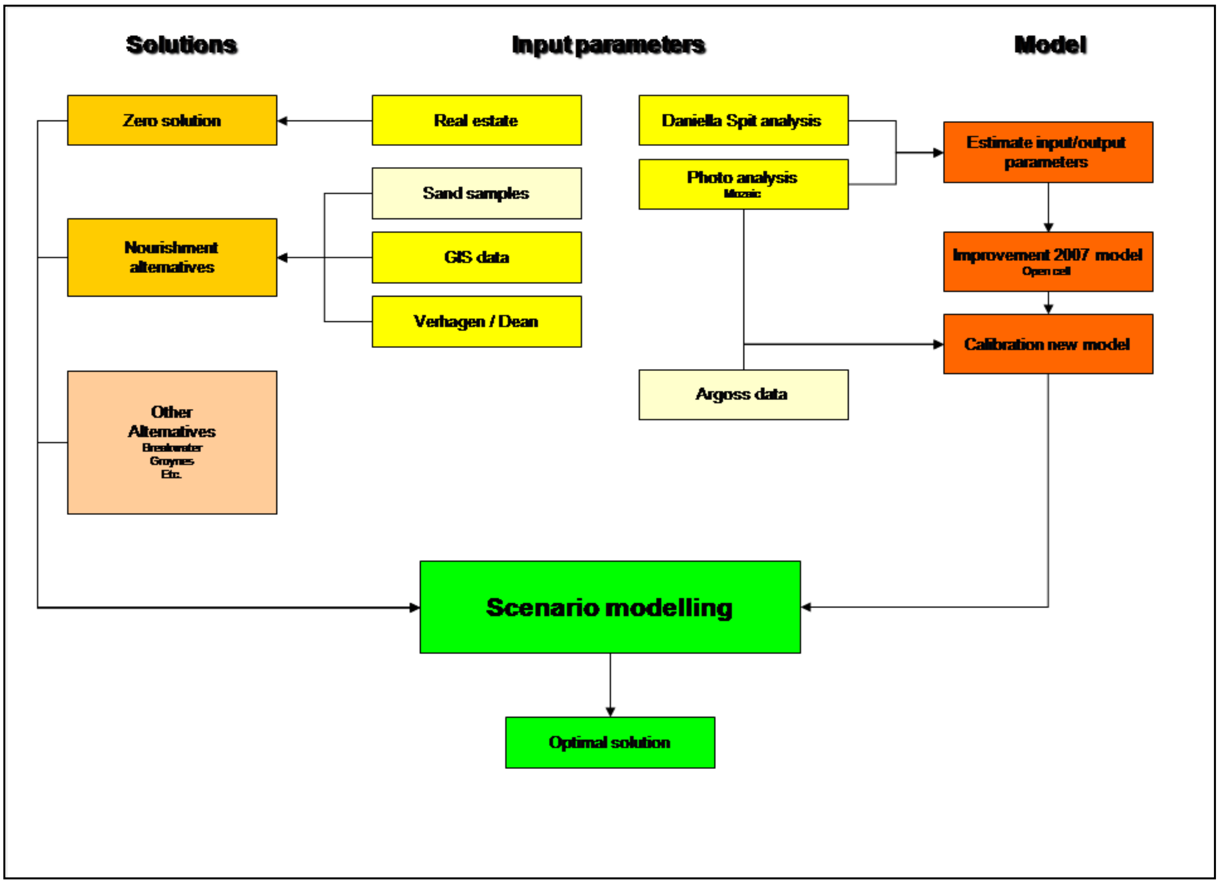


Figure 2-8 Project objectives diagram

3 Aerial photographs

During the 2007 research at Ingleses Beach, an aerial photograph analysis has already been made in order to determine the coastline development and the migration speed of both the Santinho and the Moçambique dune field. The reliability of the results of this analysis is not investigated. This is one of the subjects of this chapter. The improvements of this analysis compared to that from last year are also discussed in this chapter.

3.1 Sources

One of the available options to improve the photo analysis is to increase the number of photos. Especially photos from different moments in time provide a more accurate description of the movements of the coastline and dunes. Additional photos are obtained from several authorities in Brazil. Not all additional photos provide information about an extra moment in time. Some photos provide similar information, but in a different quality. The resolution, colour or greyscale and the quality of the scans influence this quality. The photos presented in Figure 3-1 to Figure 3-6 are selected for the analysis and calculations. Figure 3-3 and Figure 3-5 are used by Project Ingleses 2007 as well, the other photos are additional.

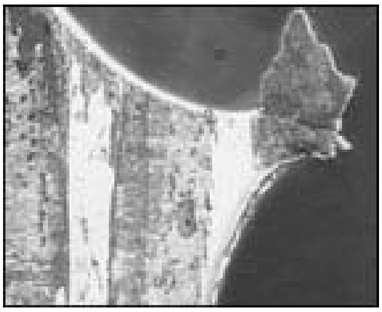


Figure 3-1 Ingleses 1938

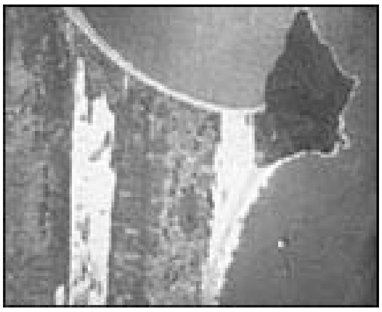


Figure 3-2 Ingleses 1957

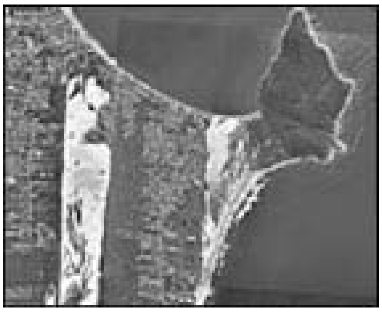


Figure 3-3 Ingleses 1978

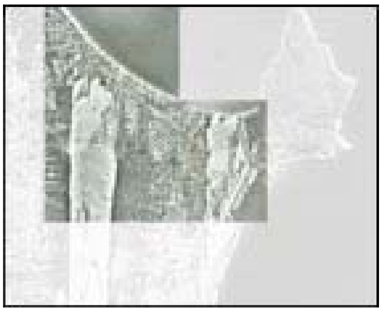


Figure 3-4 Ingleses 1994

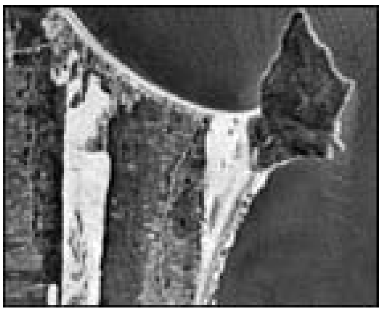


Figure 3-5 Ingleses 1998

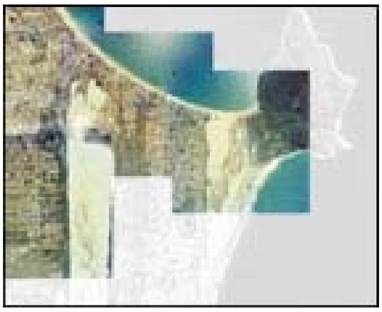


Figure 3-6 Ingleses 2004

The available photos and the decisions made concerning these photos are further discussed in section A.1 of Appendix A.

3.2 Rectification

Another available option to improve the photo analysis is to use computer applications to rectify the photos for different kinds of errors that are present in aerial photographs. Errors are introduced by several sources like the lens of the camera and the flight of the airplane. As reference for rectification is a *Geographical Information System* (GIS) used. The procedure of rectification does not compensate for all the errors present, but gives a good insight in the reliability and accuracy of the corrections and the photos.

The accuracy of the aerial photograph rectification is, among others, influenced by the resolution of the scans used and the ease of recognizing specific points in both the photo and the GIS data, *control points*. The distortion of the photo compared to the GIS data is measured using these control points.

There are a few methods available to quantify this accuracy with a single number. For this project, the National Standard for Spatial Data Accuracy (NSSDA) of the United States of America is used. This standard provides an accuracy of the control points with a high confidence level of 95%, but has strict requirements concerning the rectification procedure. Especially the photo from 1938 cannot fulfil these requirements. Therefore another quantification method is used next to the NSSDA method. This method provides a percentage of control points that have a certain precision. The results of the rectifications of the photographs are given in Table 3-1.

Year	**Resolution**	**Accuracy (pixel)**	**Number of control points**	**RMS error**	**Accuracy**	**Precision**
	[dpi]	[m]	[-]	[m]	[m]	[%]
1938	700	0,90714	15	4,95097	NA	89,364%
1957	600	1,05833	20	2,38217	4,12306	90,762%
1978	600	1,05833	20	3,64423	6,30743	93,424%
1994	600	0,33867	20	1,56935	2,71622	89,554%
1998	300	2,11667	20	1,85613	3,21258	88,165%
2004	600	0,33867	20	1,28492	2,22393	89,165%

Table 3-1 Accuracy and precision of rectifications

The procedures of rectification and determination of the accuracy and precision of these procedures are explained in section A.2 of Appendix A.

3.3 Conclusions

The additional photos make it possible to analyze the coastal phenomena in Ingleses over a period of almost 70 years instead of the 20 years that were analyzed until now. The rectification procedure also shows that the accuracy of the aerial photographs is good: with a 95% certainty the positional errors are smaller than 2 to 6 meters or almost 90% of the control points have an positional error smaller than 2 to 5 meters, depending on the time interval observed.

The rectified photos are used to determine the historical migration speed of the dune fields and the historical developments of the coastline. The procedures involved are described in chapter 4 and chapter 5.

4 Coastline development

The development of the coastline in the bay of Ingleses as occurred in the past is an essential part of this research. Quantifying the regression speed of the coastline makes it possible to quantify the coastal problems in Ingleses in terms of loss of soil and properties, the zero-solution (see chapter 6). Furthermore, the historical regression can be used to check and calibrate the numerical model created in this project and for the design of a the advanced fill of the beach nourishment.

First year	Last year	Interval
1938	1957	19
1957	1978	21
1978	1994	16
1994	1998	4
1998	2004	6

Table 4-1 Overview of comparisons

Year	Part	Resolution	Scale
1938		700	25000
1957		600	25000
1978		600	25000
1994	new part 1	600	8000
1994	new part 3	600	8000
1998	upper left	300	25000
1998	middle	300	25000
2004	new part 6	600	8000
2004	new part 7	600	8000
2004	new part 8	600	8000
2004	new part 9	600	8000

Table 4-2 Photos used for coastline analysis

4.1 Source data

The rectified aerial photographs are used to determine the development of the coastline through time, see Table 4-2 and chapter 3. A comparison is made of several available photos. In the beginning of the observed period the time interval between the photos is 20 years, later it decreases to 4 to 6 years, a complete overview of the comparisons made is given in Table 4-1.

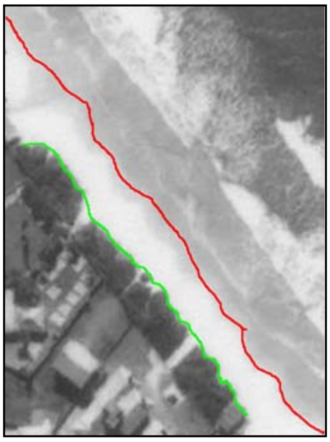


Figure 4-1 Distinction between high water line and vegetation line

There are several definitions of a coastline available. To determine the development of the coastline, a definition that can be used to distinguish the coastline on the several photos is needed. The visible representation of the coastline based on this definition is used as indicator of the development. For this research the border between light and dark sand, which is assumed to be the high water line, is taken as indicator. The vegetation is another indicator that is analysed, but not used. This is assumed to be the border between the dark areas along the shoreline, see Figure 4-1. Both indicators have their advantages and restrictions. More information about the indicators and the considerations involved is described in section B.1.1 of Appendix B.

4.2 Analysis

To determine the speed of transgression or regression of the coastline a *Geographical Information System* (GIS) is used. More about this software and the way it is applied in this research is described in Appendix N.

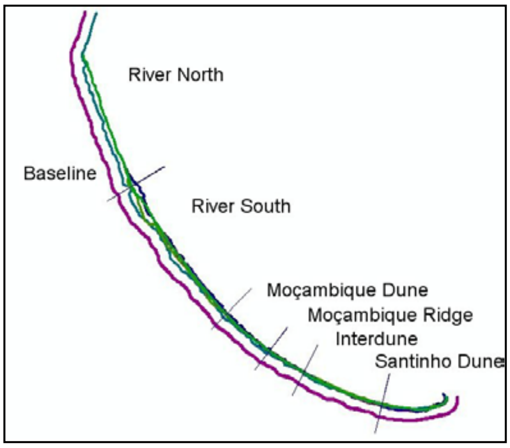


Figure 4-2 Baseline and vegetation line including sections

Several preparations are needed before the analysis to estimate the coastline development can be started. A *baseline* has to be defined as reference for the calculations. The baseline is based on the longest available coastline. From this line, *transects* are drawn which intersect with two or more coastlines. These preparations are explained in section B.2.1 of Appendix B and Appendix N. Finally, the average speed of the coastline in meters per year between two photographs can be calculated by the GIS.

To analyse the result obtained, the coastline is split up in several parts. In this part a certain number of transects determine the average regression of that part. It is more convenient and useful to analyse averages of certain sectors than 60 or more transects individually.

4.3 Results

The results are presented as an average rate of change per year per section. The rates of change of the transects are averaged over their sections and assumed to be linear between the successive time intervals.

4.3.1 Vegetation line

Based on the analysis the development of the vegetation line seems to be a damped version of the development of the high water line. The vegetation line was taken into account to use as a verification of the high water line data. After the analysis it appears that the value of the vegetation line for this project is minimal. More results concerning the vegetation line are described in section B.3.2 of Appendix B.

4.3.2 High water line

The high water line shows until 1960 transgression in the south and regression in the north part of the bay of Ingleses. Until 1990, regression took place along the whole coastline. After 1960 the behaviour of the coastline changes and the regression in the southern part of the bay becomes larger than the regression in the northern part, finally resulting in transgression of the northern part around 1990, see Figure 4-4. This change in coastal behaviour is known as *beach rotation*.

The results in Table 4-3 show an overall transgression from the year 2000 onwards. This is entirely due to the coastline that is found on the photographs from 2004. These photographs show, compared to the photograph from 1998, an enormous beach. This does not match with the observations and the experience of the inhabitants. This deviation could be induced by an extremely low tide at the moment the picture was taken. Another explanation could be found in the effects of the El Niño and La Niña phenomena (see Appendix B).

The situation in 1998 seems more realistic and agrees more with the result from Faraco (2006). If the results are averaged over a longer time period with the photo from 2004 in the results, the deviating results of the 2004 photo seems to be of less importance, see Figure 4-3.

Period	**Section**						**Average**
	Santinho Dune	*Interdune*	*Moçambique Ridges*	*Moçambique Dune*	*River South*	*River North*	
1938-1957	1,17500	1,11500	0,33000	-0,16800	-1,23800	-2,27000	*0,24280*
1957-1978	-0,98571	-0,75143	-0,35400	-0,42600	-0,49467	-0,11250	*-0,60236*
1978-1994	-1,61429	-1,74750	-1,10250	-1,16400	-0,63600		*-1,25286*
1994-1998	-1,61833	-0,62625	-3,84250	-1,34000	1,12333		*-1,26075*
1998-2004	2,17500	1,04286	2,31250	1,27800	0,11833		*1,38534*

Table 4-3 Development of high water line per time interval and section

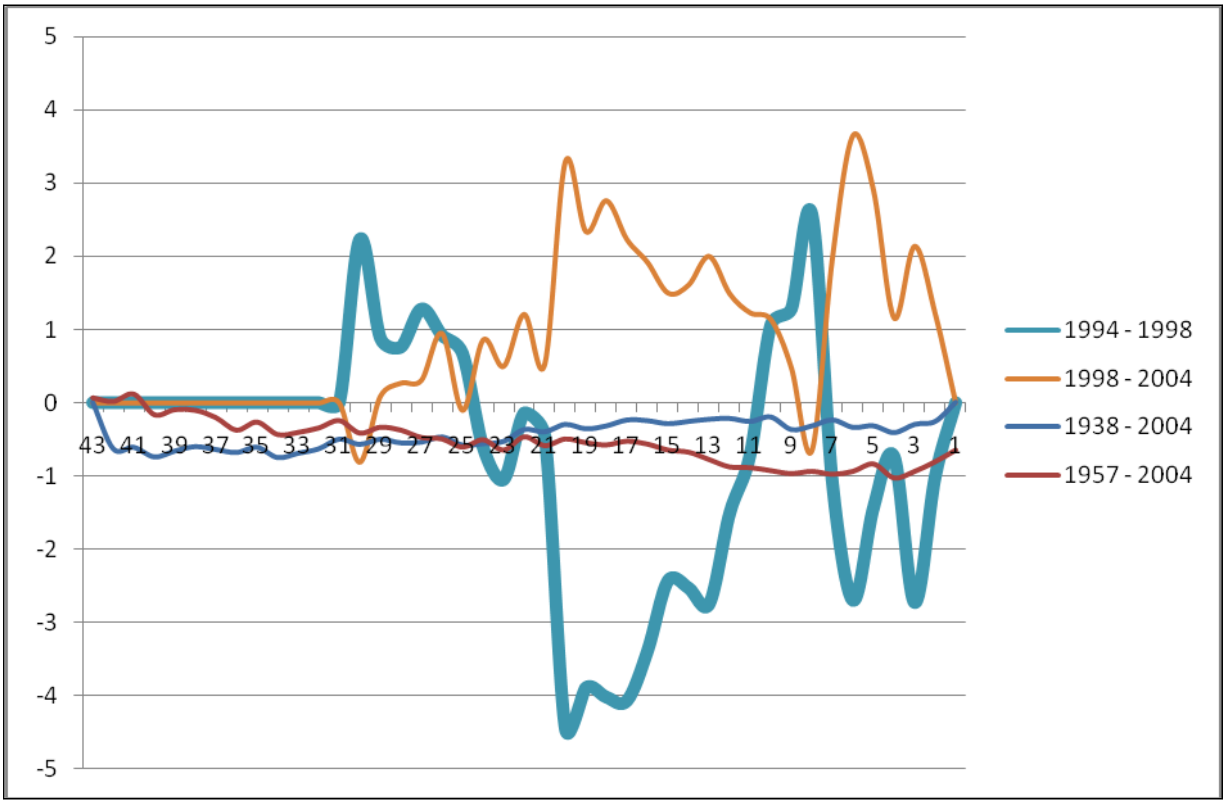


Figure 4-3 Influence of the deviating results of the 2004 photo analysis

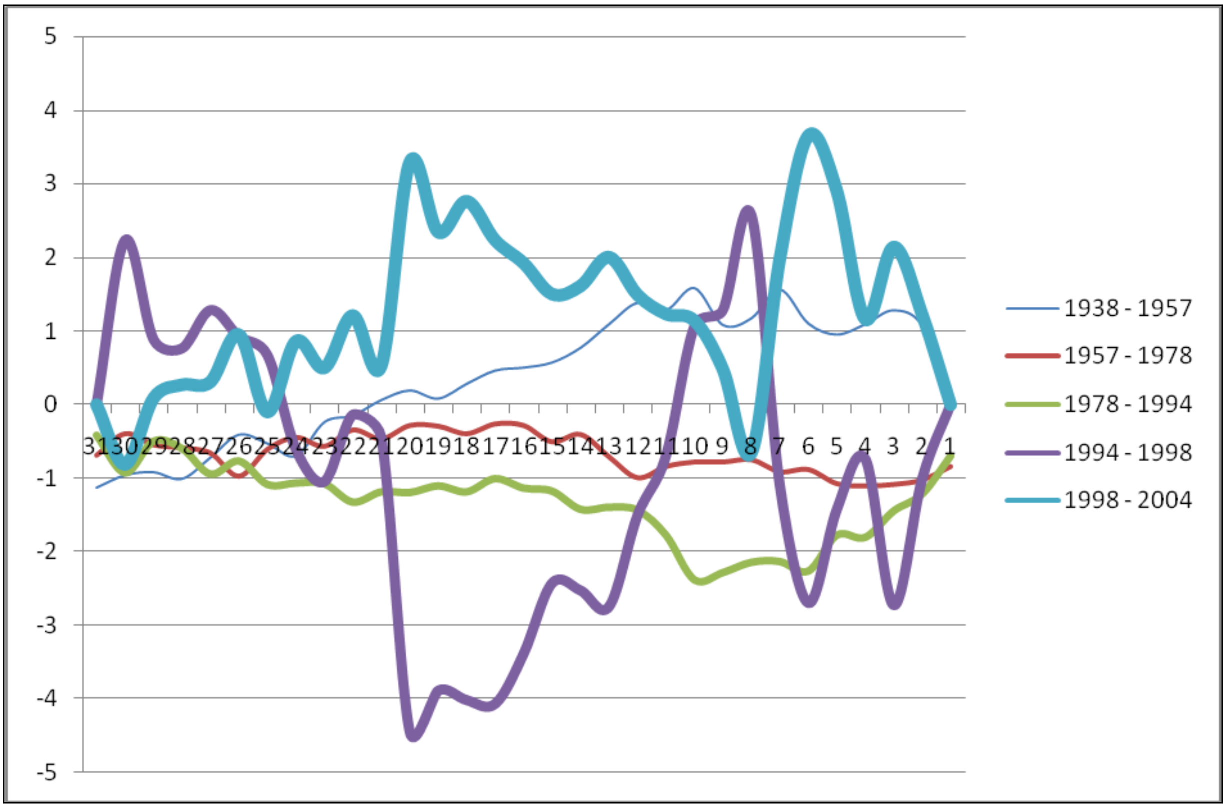


Figure 4-4 Development of high water line per time interval

5 Dune migration

Two prevailing wind directions are present in the area of interest. The wind direction is influenced by the headlands and landscape around Ingleses. This results in a migration of the dunes Moçambique and Santinho to the north.

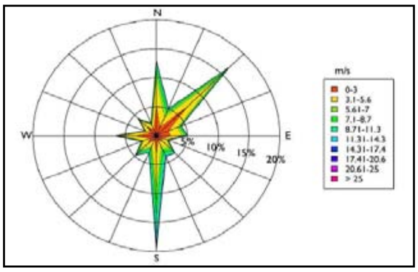


Figure 5-1 Wind rose with prevailing wind directions

Besides the direction of the migration, the speed is also an important parameter for this project. The migration speeds are used as input for the real estate analysis, the decision to use the dune as borrow area for the nourishment and give an indication of historical sediment input in the system from Moçambique Dune.

5.1 Data sources

The historical aerial photographs are the main source used to determine the migration speed of the dunes. On these photos it is possible to find physical aspects that indicate the movement of the dunes. Not all indicators can be used to quantify the migration speed. On the aerial photographs, dune ridges are visible and a progression of these ridges can be distinguished between succeeding photos. It is assumed that the dune movement can be determined based on the movement of the dune ridges.

Figure 5-2 Parts of Moçambique Dune and its ridges

The front of the dunes is subject to human interventions. Migration speeds obtained from this part would be unreliable. The use of the back of the dune is also not reliable because of the great scatter of ridges in this area.

The migration speed is determined based on the distance travelled by a dune ridge in a certain time interval. The time interval is determined by the aerial photos available. The dune ridges on two succeeding photos need to have a sort of similarity in order to be interpreted as one and the same dune ridge.

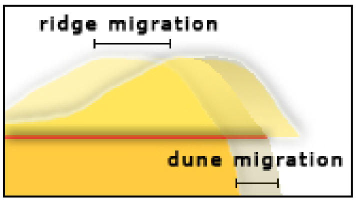


Figure 5-3 Ridge versus dune migration

The similarity is determined based on location and shape.

Choosing the right indicators and successive ridges introduces errors in the analysis. In section C.1 of Appendix C a full description is given of the ridges as indicators, selected ridges, their similarity and the accuracy of this analysis.

5.2 Analysis

A analysis similar to the analysis of the coastline development is made for the dune ridges, also using DSAS. Some modifications are made in the procedures to give a better representation of the migration speed of the dunes. The modifications consist of neglecting the ridge shape by averaging and working with multiple, straight baselines.

The speeds of the several ridges per time interval are presented in section C.2 of Appendix C. These speeds are averaged over the ridge widths and the mutual ridges to obtain a final value in meters per year for each dune for further calculations. These averaged speeds are the speeds of the ridges, which are different from the speeds of the dune fronts. The speeds of the dune fronts are smaller since it is unlikely that the grains at the bottom of the dune migrate, if not, with a significant smaller speed than the ridges. The translation from ridge migration speed to a dune migration speed is further elaborated in section C.3 of Appendix C. For Moçambique this differs almost a factor two.

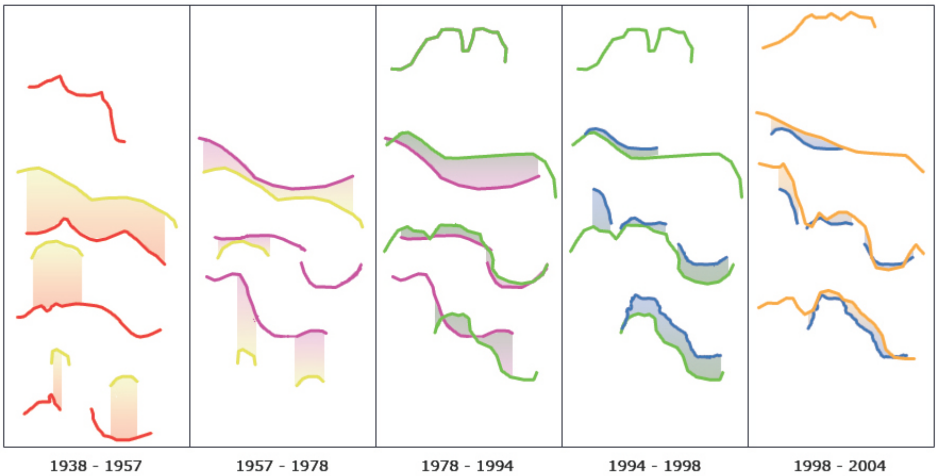


Figure 5-4 Progression of dune ridges on top of Moçambique Dune

5.3 Results

The ridge migration speed averaged over time and ridges of Moçambique Dune is 6,5 meter per year. The ridges of Santinho Dune migrate with 12,4 meter per year on average. The ridge speed of Santinho Dune appear to be higher than from Moçambique. Moçambique Dune is more vegetated than Santinho Dune, which could be a reason for the lower speed. Also the blockage of Moçambique Dune by Ingleses might be of influence on the overall migration speed of this dune.

The conversion of the ridge migration speed of Moçambique Dune to the speed of the dune front results in a speed of 3,2 meter per year in northward direction. A historical sediment input is calculated based on this speed in order to be able to say something about the situation before the cultivation of the town Ingleses. This results in an input of 56000 m^3 per year.

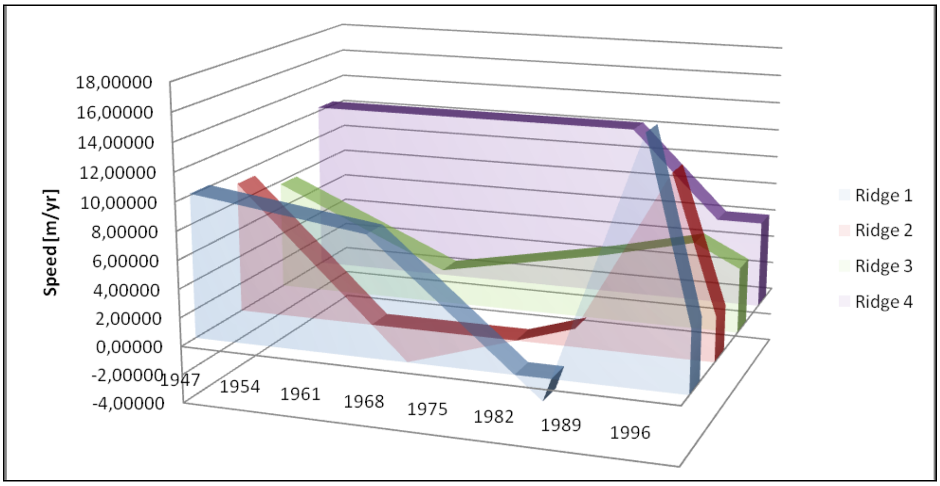


Figure 5-5 Yearly average ridge migration speed per time interval and ridge for Moçambique Dune

The speed of the Santinho Dune is less interesting for this project. The throughput of sediment by this dune is more important as it determines almost the entire sediment input to the bay of Ingleses. For Santinho Dune also a conversion from ridge migration to dune migration is applied. This conversion is slightly different to the conversion used for Moçambique Dune in order to compensate for the more irregular ridge formations observed at Santinho Dune. The total sediment input by Santinho is about 15.000 m^3 per year, which is an educated guess based on the upper and lower boundaries of the calculation.

6 Zero-Solution

6.1 Objectives

To be able to compare the proposed solutions to a reference situation, the zero-solution is defined. The zero-solution describes the situation in case nothing is done against the coastal problems. The losses and costs involved in this scenario are representative for the costs of the zero-solution and will therefore be analyzed. The losses and costs give also some insight in the scale of the problems.

6.2 Method

The costs and losses of the zero-solution are determined in several steps. First the areas which are involved in the morphological process are classified. This is done visualy on a map. This results in four different classes (see section F.2.1 of Appendix F). Two for the areas in front of the Moçambique Dune (*favela* and normal residential areas) and two for the coastal zone (centre of Ingleses and the other parts). For each class the distribution of surface use is determined. For each type of surface use a price per square meter is determined. This is done with the use of real estate data obtained from several real estate agents. Combining the distribution of surface use and the price per square meter of surface use, for every class a price per square meter surface can be found. By multiplying the expected loss of area by its corresponding square meter value it is possible to get an approximation for the costs of the zero-solution.

The amount of area that will be lost in the future, is predicted with the determined speed of the Moçambique Dune and the coastline regression rate (see chapters 4 and 5). For the costs and losses due to the Moçambique Dune, as well as the losses due to the coastline regression, a lower and upper limit and average of the costs is predicted. All calculations, used data and a more precize description of the method can be found in Appendix F.

6.3 Results

In section F.3 of Appendix F the predicted surface losses per class and the costs for a square meter surface of that class are determined. From these results it is possible to calculate an average and lower and upper limit for the loss of value per year. These values are shown in Table 6-1.

	Lower limit	Average	Upper limit
	[R$]	*[R$]*	*[R$]*
Dune field	250.282,50	732.041,49	4.938.667,92
Coast	1.607.385,63	3.104.463,05	6.047.546,27
Total	1.857.668,13	3.836.504,54	10.986.214,19

Table 6-1 Limits for the annual loss of value

6.4 Discussion

In Table 6- percentages are shown for which part the dune field migration and coastline regression contribute to the total losses. The contribution of the lower limit and average of the dune field are of minor importance.

	Lower limit	Average	Upper limit
Dune field	13,47%	19,08%	44,95%
Coast	86,53%	80,92%	55,05%

Table 6-2 Percentages of total losses

For both the dune field and the coast, the range between the lower and upper limit is around 4,5 million R$, which is the same order as the value of the upper limit of both areas. The difference in lower and upper limit for the total losses will become about 9 million R$.

There are several aspects that have to be taken into account and which make it possible to assume an average development of the costs of the zero-solution. Firstly it must be said that the calculated costs are averaged over the years. In reality the loss of buildings is a discontinuous process. A building does not collapse meter by meter but once in its lifetime.

Secondly, for several sections in front of the dune field and along the coast, the losses will start with a delay. Besides that it must be taken into account that many buildings are in danger of getting lost. Not only cheap buildings will be lost, and not only expensive buildings will be lost. It is a mix of cheap, average and expensive buildings. This calls for the use of the average costs, especially for the coastal area. The buildings in front of the dune field are expected to be cheaper (see Appendix E) because of the threat of the dune, so this calls for the use of the average or lower limit. It seems that the dune migration speed slowed down in the last years. If this is true, the minimum dune migration rate is more realistic than the average or maximum dune migration rate.

It is not completely clear how the coastline will develop in the future. It is possible that the coastline will erode until a certain equilibrium state. This means that after several years the loss of land and property will stop.

6.5 Recommendations

For a better prediction of the costs of the zero-solution, more extensive research can be done to the prices of the real estate. A way to investigate the prices of the involved buildings is by registering them. Also the costs for roads can be added.

7 Nourishment

7.1 Borrow area

For this project three possible borrow areas where considered to provide sediment for the nourishment. The first possible borrow area is the Santinho Dune. This borrow area will not be used, because this would disturb the natural influx of sand in the system. The second possibility, the use of an offshore borrow area, will also not be considered as a possible borrow area because no suitable location is found during this research. In this report Moçambique Dune is chosen as the borrow area, because this is both a solution for the dune migration as well as for the erosion of the beach. Another more important reason is the grain size. The sand on the Moçambique Dune is compatible with the native sand on the beach. The native grain size on the beach has a d_{50} of 0,193mm. In this project the expectation is that the main grain size (d_{50}) of the total dune will be around 0,25 mm. But there is also a big grain size found in some sand samples with a d_{50} of 0,463mm. The big grain size is only found on the top of the dunes. In the calculations in this chapter the big grain size will still be used to estimate the maximum beach steepness and the minimum volume of the beach nourishment. More detailed information about the borrow area is given in Appendix H.

7.2 Nourishment design

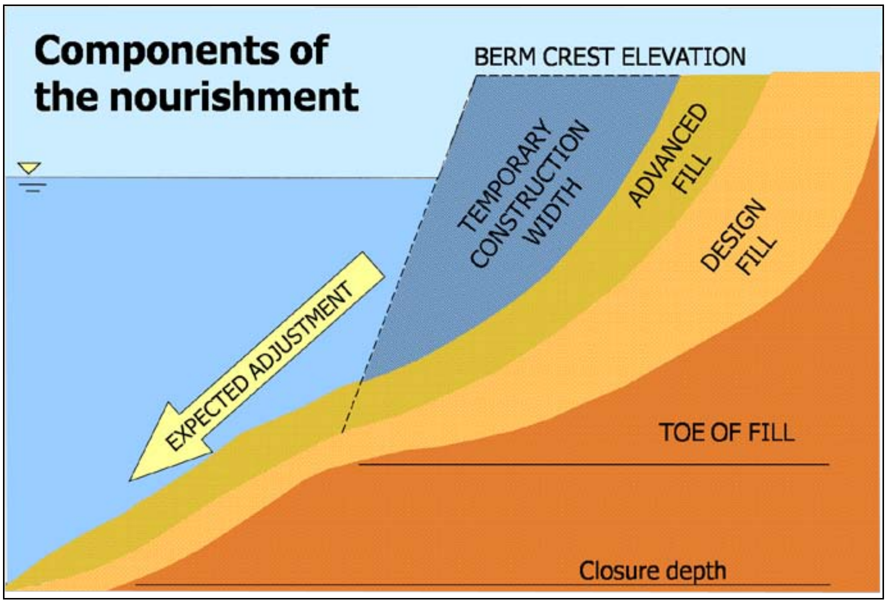


Figure 7-1 nourishment desing source [Benedet, 2004]

As shown in Figure 7-1, the nourishment consists of three parts. The first part is the design fill, this is the volume of sand that is needed to widen the beach to the desired beach width. The second part is the advanced fill, this is the amount of sediment that is necessary to maintain the design fill until the next nourishment. The last part is the temporary construction profile, this is the shape directly after construction, before the shape is naturally adjusted to the equilibrium profile. A more detailed description of the nourishment design is given in Appendix I.

7.2.1 Design fill

To determine the volume of the design fill the desired beach width has to be estimated. Research has shown that a volume of more than 175 m^3/m leads to the best nourishment results. In America a volume of 250 m^3/m is advised by Dean [1990]. In this report the volume of 250m^3/m is used, this leads to a beach width of 38m. For the nourishment a different grain size will be used than the native grain size, because off this the steepness of the beach will change. This is calculated with the use of the equilibrium profile described by Dean [1977]:

$$h(y) = A(d_{50})y^{2/3}$$

This equilibrium profile is calculated for d_{50} is 0,25 this results in an A-value of $A = 0,115m^{1/3}$ and for d_{50} is 0,463 this results in an A-value of $A = 0,155m^{1/3}$. The equilibrium profiles for the native grain size and both fill grain sizes are shown in figure Figure 7-2 Equilibrium profiles.

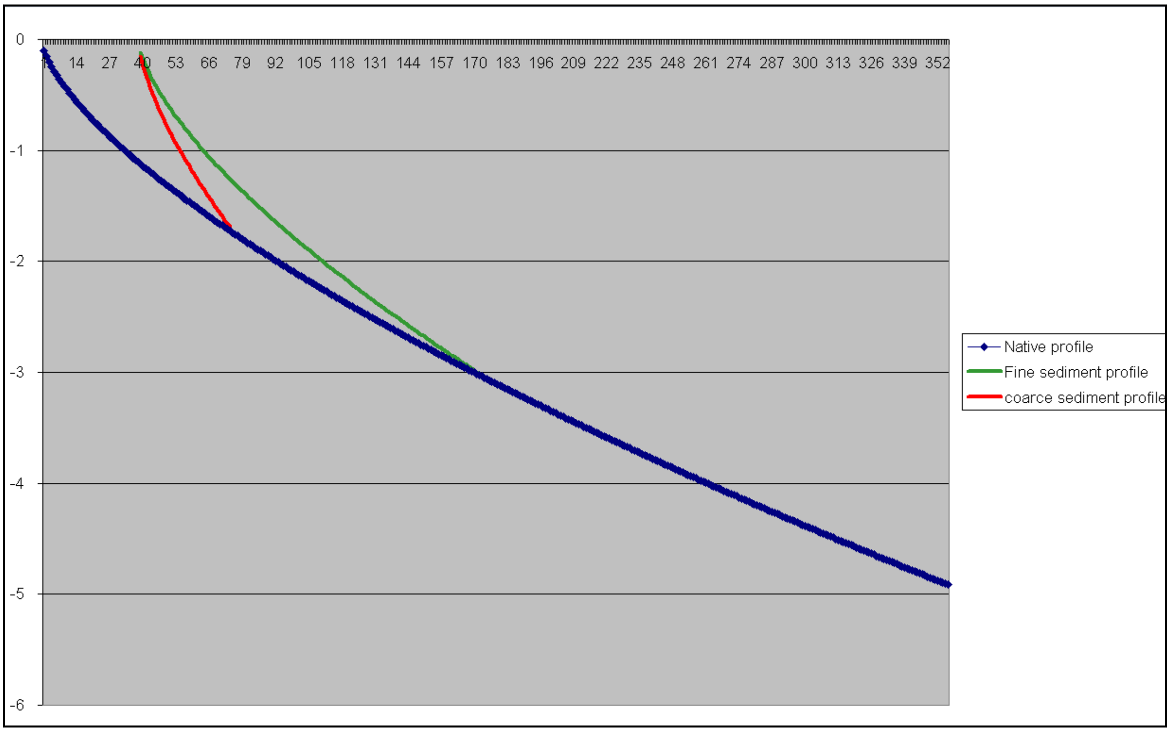


Figure 7-2 Equilibrium profiles

The resulting volumes for the design fill using the two main grain sizes from the Moçambique Dune are shown in Table 7-1.

	d_{50}=0,25		d_{50}=0,463
Surface area native profile	215,97	Surface area native profile	53,520
Surface area fine sediment	286,04	Surface area coarse sediment	93,567
Required volume of fill [m^3/m]	98,57	Required volume of fill (m^3/m)	68,547
Required volume of fill [m^3]	492850	Required volume of fill (m^3)	342735

Table 7-1 Required volume of the design fill

7.3 Advanced fill

The Verhagen method [Roelse; Verhagen, 1990] is a method that is used in the Netherlands to calculate the volume of the advanced fill. The advanced fill is the amount of sediment that is necessary to maintain the design fill until the next nourishment, in a formula this comes down to:

$$V_{adf} = annual.losses * length.of.the.project * design.lifetime$$

The Verhagen method states that this amount of sand has to be increased by 20% for a coarse fill. The annual losses are not constant over the total beach length. For this reason the beach is split up in 6 parts. For these parts the erosion speed is determined by photo analyses (chapter 3 and Appendix I) and presented in Table 7-2.

	Santinho Dune	Interdune	Mocambique Ridges	Mocambique Dune	River South	River North
Erosion rate	-1,61631	-1,18688	-2,47250	-1,25200	0,24367	0

Table 7-2 Erosion rate per year

In this report a design lifetime of 10 years is chosen, see Appendix I. The total advanced fill volume can now be calculated for each section of the beach using the Verhagen method, see Table 7-3.

	Santinho Dune	Inter dune	Mocambique Ridges	Mocambique Dune	River South	River North
Volume in 10 years [m^3/m]	105,4	77,4	161,2	81,6	0,0	0,0
Volume in 10 years including extra 20% [m^3/m]	126,5	92,9	193,4	98,0	0,0	0,0

Table 7-3 Total volume advanced fill

7.4 Total volumes

The total volume of the nourishment is a summation of the design fill and the advanced fill and will be calculated for each section. The total volumes of the nourishment for each section are given in Table 7-4.

	Santinho Dune	Inter dune	Mocambique Ridges	Mocambique Dune	River South	River North
Volume of the design fill [m^3/m]	98,57	98,57	98,57	98,57	98,57	98,57
Volume of the advanced fill [m^3/m]	126,5	92,9	193,4	98,0	0,0	0,0
Volume of advanced fill [m^3]	82704,9	73174,5	75058,0	51916,9	0,0	0,0
Total volume of the nourishment [m^3/m]	225,0	191,4	292,0	196,5	98,6	98,6

Table 7-4 Volumes per meter beach length per section

The total volume of the nourishment of Ingleses beach is the summation of the total volume for each section times the length of each section. The total volume of the nourishment for Ingleses beach is given in Table 7-5.

	Santinho Dune	Inter dune	Mocambique Ridges	Mocambique Dune	River South	River North
Length of section [m]	654	788	388	530	1482	1158
Volume of nourishment [m^3/m]	225,0	191,4	292,0	196,5	98,6	98,6
Volume of nourishment [m^3]	147170	150848	113303	104159	146081	114144
Volume of nourishment [m^3]	775704					

Table 7-5 Total volume

7.5 Renourishment

The renourishment consists of the advanced fill that has to be renewed every 10 years. The volumes of this renourishment are presented in Table 7-6. The total volume of sand that has to be renourished every ten years is equal to 282854 m^3. This is as calculated at this moment for a better renourishment design the erosion of the first nourishment has to be monitored closely.

	Santinho Dune	Inter dune	Mocambique Ridges	Mocambique Dune	River South	River North
Volume advanced fill [m^3/m]	105,4	77,4	161,2	81,6	0,0	0,0
Volume including extra 20% [m^3/m]	126,5	92,9	193,4	98,0	0,0	0,0

Table 7-6 Renourishment volumes

7.6 Construction

For the construction of the nourishment two possible methods of sand transport are considered. First a rough estimation of the costs and duration of transport by trucks will be given in paragraph 7.6.1. In paragraph 7.6.2 an estimation of the cost and duration of the transport by pipelines is given. In paragraph 7.6.4 an estimation of the renourishment costs is given. More detailed information about these paragraphs is given in Appendix L.

7.6.1 Transport by trucks

For the nourishment 775704 m^3.have to be transported. This has to be done in 8 months, because in the summer many tourists come to Ingleses. To transport this amount off sand in this time 45 truckloads/hr are required. This means 90 movements an hour, which is a lot for the local people. The cost for the trucks including the use of two loaders, a bulldozer and 20% unforeseen costs is 2,74 €/m^3. The total costs then comes down to: 775704*2,74 = 2,1 million euro’s.

7.6.2 Transport by pipelines

For the transport by pipelines a dredging pontoon is needed. For the use of this pontoon first a excavation pit has to be constructed. After the construction the dredging pontoon can be mobilized in the pit and the pontoon can start pumping. A dredging pontoon can pump approximately 0,133 m^3/s. With this capacity the sand transport will take 28 weeks. With this construction method the sand transport can easily be done during low season. A rough estimation of the total costs for this method is €3.453.000. The mobilization is a big part of the total costs, for this reason it can be interesting to increase the design lifetime.

7.6.3 Evaluation of methods

Evaluation criteria	Weight	Trucks	Pipelines
Inconvenience inhabitants Ingleses	5	0	2
Duration	4	1	3
Inconvenience Tourists	2	1	2
Environment	2	3	3
Total		**12**	**32**

Table 7-7 Multi Criteria Analysis of the construction methods

To compare both construction methods a multi criteria analyses (MCA) is used. The first criterion is the inconvenience for the inhabitants of Ingleses, this is the most important criterion and has weight 5. One truck every 40 seconds is a lot, this is why truck transport scores a 0, pipelines are a lot better and score a 2. The second criterion is the duration this is an important criterion, because the longer it takes the longer inhabitants and tourists have inconvenience. This criterion has weight 4. The transport by pipelines takes 28 weeks and scores a 3, the transport by trucks takes longer and scores a 1 for duration. The third criterion is the inconvenience for tourists and has weight 2, because the inconvenience is in low season when there are not much tourists in Ingleses. Both methods are inconvenient. Transport by pipelines scores a 2 and transport by trucks a 1, because transport by pipeline disturbs one location and trucks are al over the town. The last criterion is environment and has weight 2. The methods have a different influence on the environment but the both score a 3 for environment. Another criterion is the influence on the fresh water substation around Ingleses. More research has to be done to these influences (see Appendix L). So at this point it won't be taken into account for the multi criteria analyses.

Transport by trucks scores a total of 12 and transport by pipelines scores a total of 32. Transport by pipelines is better but more expensive, the transport by pipelines costs €3.435.000 against transport by trucks €2.100.000. This will be a decision the initiator will have to make.

7.6.4 Renourishment

The volume of the renourishment is a lot smaller than the initial nourishment. The initial nourishment is already cheaper to construct with trucks than with pipelines. This is why the renourishment costs and duration is only given for transport by trucks. The total renourishment costs are €775.020. For a duration of 8 months 17 truckloads/hr are required. This means 34 movements an hour, which is still a lot but acceptable.

8 Evaluation of solutions

8.1 MCA

To make a comparison between the nourishment and the zero-solution, a *Multi Criteria Analysis* (MCA) is made. This is a method to compare different alternatives for a number of criteria. The evaluation criteria get a different weighing factor (1 is not important, 5 is very important) to give them a relative importance. This is done in the opinion of the author. The different solutions get a score (5 is positive, 0 is negative) for each criterion, which will be multiplied by the weight of the criterion. The results are summed to get a total score for each solution. This way, a better solution gets a higher score.

Evaluation criteria	Weight	Nourishment	Zero-solution
Inconvenience inhabitants Ingleses	5	3	0
Tourists (long term)	5	5	1
Environment	3	2	5
Tourists (short term)	2	0	3
Total		**46**	**26**

Table 8-1 Evaluation criteria

The first criterion is the inconvenience for the inhabitants of Ingleses. This criterion has a weighing factor of five. The zero-solution will result in loss of property which is very inconvenient for the inhabitants and scores zero. The nourishment will cause inconvenience for the inhabitants for a few months during the execution of the project. The nourishment scores three points on this criterion.

Another important criterion is the long term inconvenience for tourists, the weighing factor for this criterion is five as well. The zero-solution scores one, because the beach will disappear in time. The nourishment scores a five, because on the long run there will only be advantage for the tourists.

The third criterion is environment and has weighing factor of three. In the zero-solution there is no interference in the environmental system, therefore the zero-solution scores five. The nourishment has a big impact on the environment and scores two.

For tourism on the long run the nourishment scored five, but during the construction of the nourishment it is very inconvenient for the tourists and this solution scores zero. The zero-solution is not very inconvenient, but there is only a small beach available for tourism. Therefore the zero-solution scores three. Because this criterion is only for a short period the weight is two.

As shown in Table 8-1, the total score for the zero-solution is 26 and the total score for the nourishment is 46. This shows that the nourishment is the preferred solution. The nourishment is also expected to be the cheaper solution. As can be seen by comparison of chapter 6 and chapter 7, is the expected cost of the zero-solution in the first 10 years 15 million euro's while the most expensive variant of the nourishment has an expected cost of 3,45 million euro's.

9 Numerical model

9.1 Scenario setup

Different scenarios are modelled with UNIBEST to check the hypothesis and to simulate the development of the beach after the nourishment. The conditions for the different scenarios are given in Table N-1 of Appendix N. The values of the input parameters of the longshore module are the same as were used during the simulations of 2007 (for more about the longshore and coastline module, see Appendix O). The most important differences with the simulations of 2007 are the boundary conditions and sources in the coastline module. The first two scenarios are done to reproduce the results of the 2007 project and to obtain the same starting point. An equal starting point is needed in order to be able to recognize the effects of the adaptations of the model. In the third and fourth scenario there are adaptations made to check the hypothesis. The main difference with the first two scenarios is the sediment bypass at the northern boundary. The fifth scenario is used to gain insight in the development of the nourishment. The coastline is adapted by changing the width of the beach.

9.2 Results

The results of scenarios 3 and 4 are shown in Figure 9-1 and Figure 9-2. The results of the other scenarios can be found in Appendix N. The figures show high erosion levels around the northern headland and accretion in front of the sediment inputs from the dunes. Also visible is the reduced erosion around the Moçambique Dune even if there is no sediment input from Moçambique Dune.

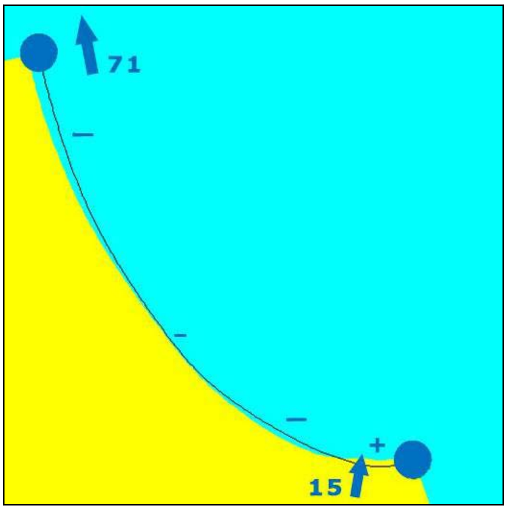


Figure 9-1 Result scenario 3

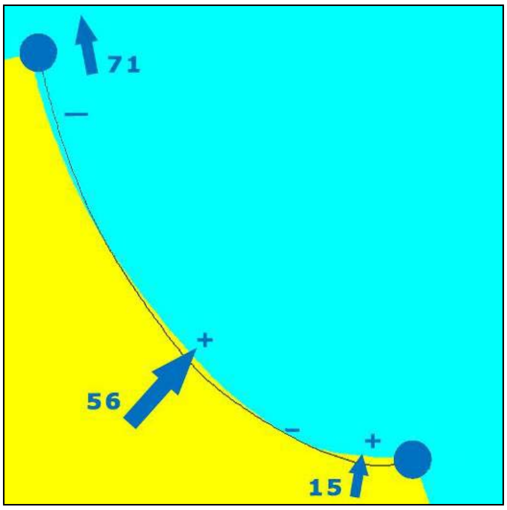


Figure 9-2 Result scenario 4

9.3 Conclusions

The different scenarios that are simulated lead to the conclusion that the sediment bypass strongly influences the development of the coastline. The rotation of the coastline in the simulations is opposite to what is observed in the photo analysis. It can be concluded that the assumed sediment bypass is too big or that there is no sediment bypass at all.

The input from the dunes result in accretion of the beaches in front of the dune fields which is not in agreement with the results of the photo analysis. The accretion in front of the dunes can have two causes. The inputs might be too high or the reshaping of the coast by the wave climate differs from what is assumed.

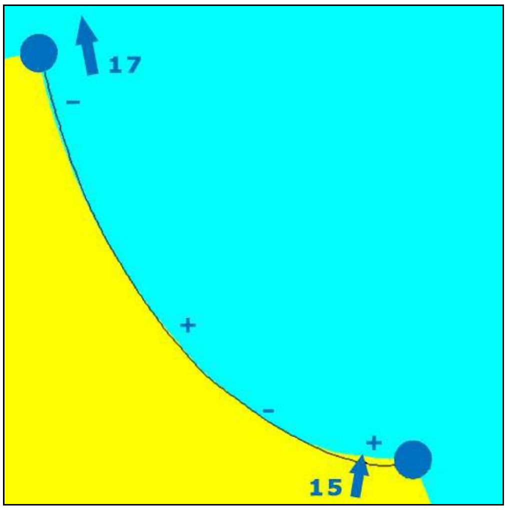


Figure 9-3 Result scenario 5

According to the model results of scenario 5 it is questionable if the advanced fill is placed in the right sections. It seems that the northern sections will erode as a result of the sediment bypass, instead of the southern part as was assumed. Because the assumed sediment bypass in the north is unreliable, it is difficult to say whether this scenario is realistic.

9.4 Remarks

Besides the fact that the assumed sediment bypass is incorrect, there are other reasons for differences in the results of the simulations compared to the results of the photo analysis.

The longshore sediment transport is highly influenced by the wave climate and the bathymetry. Because the used wave climate is based on one year of observations it might be a reason for the differences.

The bathymetry that is used during the simulations is obtained from a combination of two different sources [Project Ingleses 2007]. From one of the sources it is unknown when the data is collected and the density of the data points is very low compared to the length of the beach. The resulting bathymetry is used for all scenarios.

10 Conclusions

Before the final conclusions are drawn from the research conducted in this report, first the hypothesis, as stated in chapter 2, is recalled:

1. Moçambique Dune used to supply sediment to Ingleses Beach in the past.
2. Due to input from Moçambique and Santinho Dune, the beach of Ingleses was stable in the past.
3. Development of Ingleses led to blocking of the input of sand from Moçambique Dune.

The objectives of this project accompanying the hypothesis were:

1. More detailed verification of the hypothesis.
2. Improvement of numerical model.
3. Design of practical solutions to the problems.

Based on the data collected and analyzed during this research, the first and third point of the hypothesis can be confirmed. Furthermore, the following conclusions about the general behaviour of the coastal system around Ingleses can be drawn:

1. Moçambique Dune supplied sediment to Ingleses Beach in the past.
2. Urbanization initiated blockage of sediment input which led to erosion of the southern coast.

An attempt is made to reconstruct the situation of 1938 using a numerical model to get more insight in the behaviour of the system and to check if the system was indeed stable in the past. Unfortunately the model doesn’t correspond with the behaviour visible on the aerial photographs. Therefore, no definite conclusions can be drawn yet about the stability of the beach in the past and therefore also the quantification of the sediment bypass around the northern headland stays an unknown parameter.

From the results of the zero-solution can be seen that the scale of the problems is significant. Nourishing the beach with sand from the Moçambique Dune is a feasible and durable solution for both problems. The proposed solutions are cheaper than the maximum expected loss in case no actions are taken.

11 Discussion and recommendations

11.1 Discussion

The authors of this report like to mention several decisions that has been made and sources that has been used during this research, that might deserve a more careful consideration. It is therefore advised to any follow-up research to reconsider the following list by considering their importance in the final result.

- *Wave data from only one year.* The wave scenarios in the model are based on one year of observations. These observations might not represent the current situation. More research to the wave climate can lead to a better model and could explain the apparent beach rotation of Ingleses Beach.
- *Uncertainty about bathymetry.* The bathymetry that is used during the simulations is obtained from a combination of two different sources [Project Ingleses 2007]. From one of the sources it is unknown when the data is collected and the density of the data points is very low compared to the length of the beach.
- *The uncertainty about the bypass.* A very rough estimation has been made of the bypass around the northern headland. This is used as input for the model. The assumption of the bypass around the headland is based on the grow of the Canas Spit and several other spits on the other side of the northern headland. It is questionable if these spits actually support this assumption since the model results do not.
- *Sediment input from Santinho Dune.* The quantification of the input of sediment by Santinho Dune is based on dune ridges visible on aerial photographs. These ridges show a lot of scatter in time and space. Therefore it is questionable if these ridges are a good indicator of this sediment input.
- *Calibration numerical model.* The quality of the calibration of the numerical model and determination of several properties of the model depend on the reliability of the available data. A very limited amount of data is available of the area of interest. This makes it hard to create a reliable model.
- *Aerial photograph from 2004.* Although the photograph from 2004 is not really trend breaking, it deviates a lot from the expected and observed situation. The cause of the unexpected results from the analysis of this photo is still unknown. The moment at which the photo is taken might be of influence, but also the El Niño and La Niña phenomena can be the cause.

11.2 Recommendations

Several improvements of the analyses and collection of additional data could improve the results of this research. Recommendations on these improvements for future studies of the coastal system around Ingleses are listed below.

- As stated before, the waves have a very big influence on the development of the beach. A wave buoy in the neighbourhood of Ingleses beach can give specific wave data of the area of interest. This data could also be used to improve the numerical model.
- Collecting more data not only holds for the beach profile and the waves, but also for the bathymetry in deeper water. Collecting more data and using more measure points in the area of interest might lead to a more reliable model.
- The influence of the El Niño and La Niña phenomena on the system is not yet fully understood. Research to El Niño and La Niña effects could be an explanation of unexpected beach behaviour in 2004. The period and effects of these phenomena are not investigated in this project, but should be to obtain a better understanding of the coastal system of Ingleses.
- Collecting data from the beach of Ingleses is advisable. The dune field could also be subject to a measuring program to obtain more information about the migration speed and the scale of the human interventions. With this data a more precise indication of the expected damage can be given.
- Sand from Moçambique Dune is usable for the nourishment. The sieve curves shows two prevailing grain sizes. The origin of these two specific grain sizes is still not clear. More sand samples should be taken in the area around Ingleses Town and at Moçambique en Santinho Beach.
- A regular monitoring of Ingleses beach and surroundings is advisable. In this way more data is gathered about Inglese. This can be used in future research. Measuring the beach profiles every year to give an estimation about the development of these profiles gives more accurate data than is obtained from the aerial photographs.
- Not all mentioned solutions of the report are investigated. Investigation of several of these solutions or other solutions can be done.
- After the project questions came up about the fresh water reservoir in the dunes. More research is needed to the excavation plans to give insight into the effects on this reservoir. The effects can influence the execution method to be used to excavate the sand for the nourishment.

References

Litrature

Allender, W., 2008, *GEOG 484 Project 3, Georeferencing Raster Images, Registering an Image for the Purpose of Data Creation*.

Araujo, R.S.; Freitas, D.; Klein, A.H.F.; Silva, G.V., 2008, *Georreferenciamento de Fotografias Aéreas e Análise da Variação da Linha de Costa*. In: Alcántara-Carrio, J.; Correa, I.D.; Isla, F.; Alvarado, M.; Klein, A.H.F.; Cabrera, J.A., 2008, *Metodologías en Teledetección Aplicada a la Prevención de Amenazas Naturales en el Litoral*.

Benedet, L., 2004: see Data, PowerPoint presentation.

Bigarella, J.J., et al., 2006, *Southern Brazilian Coastal Dunes Movement and Structures*, Journal of Coastal Research, Special Issue, 39, Proceedings of the 8th International Coastal Symposium.

Boeyinga, J.; Dusseljee, D.; Pool, A.; Schoutens, P.; Verduin, F.; Van Zwicht, B., 2007, *Ingleses - Urban Problems caused by Coastal Morphology*.

Campbell, T.J.; Dean, R.G.; Melha, A.J.; Wang, H., 1990, *Short Course and Principles and Applications of Beach Nourishment*.

CEM: see United States Army Engineer Research and Development Center, 2003.

Cooper, N.J., 1998, *Assessment and Prediction of Poole Bay (UK) Sand Replenishment Schemes: Application of Data to Fuhrboter and Verhagen models*, Journal of Coastal Research.

Cooper, J.A.G.; Pilkey, O.H., 2002, *Longshore Transport Volumes: a Critical View*, Journal of Coastal Research Special Issue 36.

Dean, R.G., 1977, *Equilibrium Beach Profiles: U.S. Atlantic and Gulf Coasts*.

Dean, R.G., 1987, *Coastal Sediment Processes: Toward Engineering Solutions, Proceedings Coastal Sediments*.

Dean R.G., 1991, *Equilibrium Beach Profiles: Characteristics and Applications*, Journal of Coastal Research 7.

Dean, R.G., 2002, *Beach Nourishment Theory and Practice*.

Delft University of Technology Environmental Fluid Mechanics Section, 2007, *SWAN User Manual*.

Diehl F.L., 1997, *Aspectos Geo-evolutivos, Morfodinâmicos e Ambientais do Pontal da Daniela, Ilha de Santa Catarina*.

Faraco, K.R.; Abreu de Castilhos, J.; Horn Filho, N. O., 2006, *Morphodynamic aspects and El Niño oscillations in Ingleses beach, Santa Catarina Island, Southern Brazil*, Journal of Coastal Research 39

FGDC Subcommittee for Base Cartographic Data, 1998, *Geospatial Positioning Accuracy Standards, Part 3: National Standard for Spatial Data Accuracy*.

Gibbs, R. J., Link, D.A., Matthews, M.D., 1971, *Relationship between Sphere Size and Settling Velocity*.

Hoel, J.; Stauble, D. K., 1986, *Physical and Biological Guidelines for Beach Restoration Projects*.

Klein, A.H.F., 2004, *Morphodynamics of Headland-Bay Beaches: Examples from the Coast of Santa Catarina State, Brazil*.

Menegais, C., 2007, *Caracterização Morfológica Sedimentológica de Três Praias Arenosas no Litoral de Santa Catarina*.

Project Ingleses 2007: see Boeyinga, J.; Dusseljee, D.; Pool, A.; Schoutens, P.; Verduin, F.; Van Zwicht, B., 2007.

Robert Thieler, E., 2005, *User Guide & Tutorial for the Extension for ArcGIS v.9.0 (DSAS) version 3.2, Digital Shoreline Analysis System, Part of USGS Open-File Report 2005-1304*.

Roelse, P.; Verhagen, H.J., 1990, *Design of Beach Replenishment*, Conference on River and Coastal Engineering, Loughborough, U.K.

Schoonees, J.S.; Theron, A.K., 1995, *Evaluation of 10 cross-shore sediment transport morphological models*.

Sunamura, T.; Takeda, I., 1982, *Formation and Height of Berms*.

Swan User Manual: see Delft University of Technology Environmental Fluid Mechanics Section, 2007.

United States Air Force Center; Aeronautical Chart and Information Center, 1962, *Principles of error theory and cartographic applications*.

United States Army Engineer Research and Development Center, 2003, *Coastal Engineering Manual*, Part III, Chapter 1 and 3, Part V, Chapter 4 and Table III-3-3.

Van Rijn, L.C., 1993, *Principles of Sediment Transport in Rivers, Estuaries and Coastal Seas*.

Verhagen, H.J., 1992, *Method for Artificial Beach Nourishment*, International Conference on Coastal Engineering.

Verhagen, H.J., 1996, *Analysis of Beach Nourishment Schemes*, Journal of Coastal Research.

Data

Aerial photographs, Lobẽa C.C., Municipality of Florianopolis.

Aerial photographs, State Government Santa Catarina.

Aerial photographs, Project Ingleses 2007.

ArcGIS data Ilha Santa Catarina, UNIVALI.

Argoss wave statistics.

Beach and dune sand samples, Project Ingleses 2007.

Offshore sand samples, UNIVALI.

PowerPoint presentation, *Beach Nourishment: general theory and case studies*, Benedet 2004

Websites

http://encarta.msn.com/

http://www.wikipedia.org/

http://www.casaecia.imb.br/

http://www.jesusimoveis.com.br/

http://www.roverimoveis.com.br/

http://www.uniaoimoveissc.com/

Appendix A Aerial photograph analysis

During the 2007 research at Ingleses Beach, an aerial photograph analysis has already been made in order to determine the migration speed of both the Santinho and the Moçambique dune field. The reliability of the results of this analysis is not investigated, but can at least be improved.

A.1 Analysis improvements

A.1.1 Additional photographs

The 2007 analysis is based on a period of 20 years and on two photographs only (1978 and 1998, see Figure A-1 and Figure A-2). The photographs are digital scans of the originals. The resolution of the scans is 300 dots per inch (dpi), which results in a scale of approximately two meters per pixel.

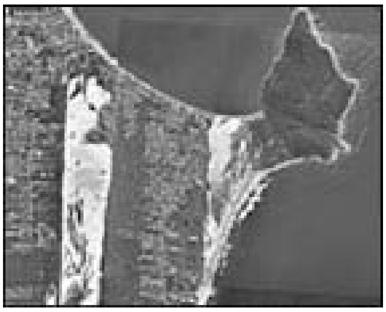


Figure A-1 Ingleses Beach 1978

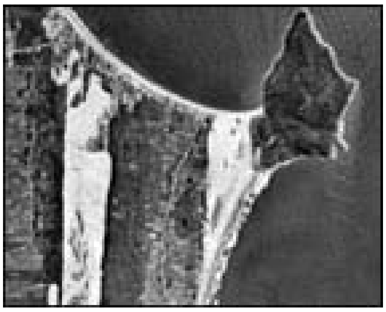


Figure A-2 Ingleses Beach 1998

This project has more photographs with a better quality at its disposal. Next to the photographs from the 2007 research, there are four additional photographs available from 1938, 1957, 1994 and 2004 (see Figure A-3 until Figure A-6). The resolution of the scans is 600 dpi to 700 dpi. Furthermore, the photo from 1978 is available in a better quality of 600 dpi. The scale of all these photos is therefore approximately one meter per pixel.

At this moment these are the aerial photos available in Brazil. Another source of aerial photos is *Google Earth*. These photos are from February 3, 2004 and have a resolution of 96 dpi. This resolution is too low for accurate calculations of dune migration and beach erosion. One pixel on the photo will approximately be six meters in reality.

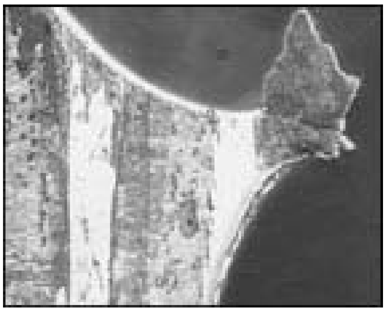


Figure A-3 Ingleses Beach 1938

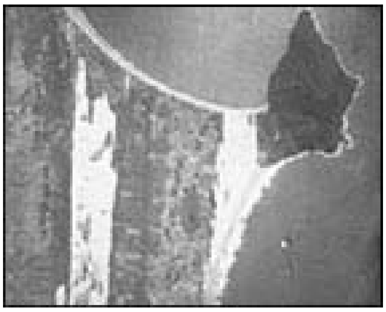


Figure A-4 Ingleses Beach 1957

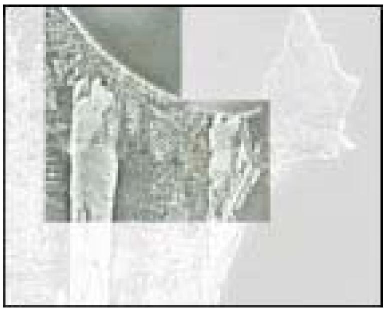


Figure A-5 Ingleses Beach 1994

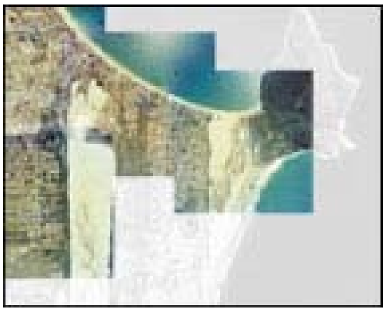


Figure A-6 Ingleses Beach 2004

A.1.2 Photograph correction

During the 2007 project, the scans of the original photos were used to give a rough approximation of the migration speed of the dunes. The photos were not corrected for any sources of errors. Several errors are introduced while making and processing the photos. These errors can be corrected to some extent using a Geographic Information System (GIS). Using such a system gives also insight in the size of the errors. In this project the photos are processed by a GIS application and therefore the resulting calculations can be improved and insight in the reliability of the calculations can be given.

A.2 Correction methods

Although aerial photographs might seem to be an ideal representation of the real world, several sources of errors are acknowledged. These errors need to be corrected in order to be able to make reliable calculations and comparisons. The correction method used during this project is called *georeferencing*. Georeferencing corrects the photo by fitting two curves (horizontal and vertical; first or second order) through a collection of known points in the photo and mapping the photo onto these curves. These known points are called *control points* and are defined by matching the photograph to a Geographic

Information System (GIS). The GIS information is, in this case, obtained by laser altimetry and considered to be a correct representation of reality, since there is no indication of errors in the GIS data.

The correcting of photographs with the GIS information introduces errors itself as well. These errors are made while defining the control points and while fitting the curve through these control points. Defining a control point is a subjective process. The possibility to accurately define a specific point both on the photo and in the GIS data depends on the resolution and the point chosen. Some points are easier to define than others and easier to find in the GIS data.

A.2.1 Accuracy and reliability

Since the photos are built up out of dots, details smaller than one dot are not visible on the photo. This also means that the control points cannot be defined with an accuracy larger than one dot. For photos with a resolution of approximately 600 dpi, this means an accuracy of about one meter in reality. Another error, made by fitting a curve through the control points is expressed as the Root-Mean-Square Error (RMS error) of the curve. This error is obtained by averaging the squares of the shortest distances from each known point to the curve and taking the root from the result.

Next to the one meter inaccuracy of the control point definition, the RMS error of the curve fitting introduces another inaccuracy of about two or three meters resulting in a total, inevitable inaccuracy of about three or four meters.

According to the NSSDA (see next section), a reliability of 95% of the error can be obtained by multiplying the RMS error with 1,7308 in case of at least 20 control points per photograph. In case there are less control points available, the reliability will be less. This limited reliability can be quantified using a newly developed procedure using percentages of precision instead of a confidence level.

A.2.1.1 NSSDA method

The National Standard for Spatial Data Accuracy (NSSDA) of the United States of America [FGDC, 1998] uses the RMS error to estimate positional accuracy. The method provides a RMS error within a 95% confidence level under the condition that there are at least 20 well-defined control points available. The different concepts mentioned above are explained in the document NSSDA [FGDC, 1998] from which quotes are given below.

“RMS error is the square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points.”

"Accuracy is reported in ground distances at the 95% confidence level. Accuracy reported at the 95% confidence level means that 95% of the positions in the dataset will have an error with respect to true ground position that is equal to or smaller than the reported accuracy value. The reported accuracy value reflects all uncertainties, including those introduced by geodetic control coordinates, compilation, and final computation of ground coordinate values in the product. A minimum of 20 check points shall be tested, distributed to reflect the geographic area of interest and the distribution of error in the dataset. When 20 points are tested, the 95% confidence level allows one point to fail the threshold given in product specifications."

"A well-defined point represents a feature for which the horizontal position is known to a high degree of accuracy and position with respect to the geodetic datum. For the purpose of accuracy testing, well-defined points must be easily visible or recoverable on the ground, on the independent source of higher accuracy, and on the product itself. Graphic contour data and digital hypsographic data may not contain well-defined points. The selected points will differ depending on the type of dataset and output scale of the dataset. For graphic maps and vector data, suitable well-defined points represent right-angle intersections of roads, railroads, or other linear mapped features, such as canals, ditches, trails, fence lines, and pipelines. For orthoimagery, suitable well-defined points may represent features such as small isolated shrubs or bushes, in addition to right-angle intersections of linear features. For map products at scales of 1:5000 or larger, such as engineering plats or property maps, suitable well-defined points may represent additional features such as utility access covers and intersections of sidewalks, curbs, or gutters."

A.2.1.2 Method of precision

Another, newly developed method, to quantify the accuracy of a georeferencing procedure calculates the percentage of control points that will have a RMS error equal or smaller than a given value. This is contrary to the NSSDA method where the RMS error is calculated with a fixed level of confidence. The advantage of this new method is that there are no restrictions to the number of control points, but that the precision is adjusted to the number of points available.

This method requires the individual RMS errors of all the control points, which should all be smaller than the NSSDA RMS limit (see Formula A-1), and their arithmetic mean ($\overline{x}$). The standard deviation (σ) of the individual RMS errors is calculated (see Formula A-2) based on which the standard error (see Formula A-3) is defined. Using the standard error, the imprecision and precision is calculated (see Formula A-4 and Formula A-5).

$$RMS_{\text{limit}} = 2.5\times10^{-4}\cdot scale \qquad \text{A-1}$$

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(x_i - \overline{x}\right)^2} \qquad \text{A-2}$$

$$SE = \frac{\sigma}{\sqrt{N-1}} \qquad \text{A-3}$$

$$IP = \frac{SE}{\overline{x}} \qquad \text{A-4}$$

$$P = 1 - IP \qquad \text{A-5}$$

The calculated precision represents the percentage of control points that has a RMS error equal or smaller than the average RMS error. The calculations will result in a higher precision in case more control points are used.

A.2.2 Error sources

Georeferencing can be used to correct error sources in the photographs. These errors include alternating heights of the aircraft, tilting of the aircraft, aberration of the lens, curvature of the earth, topography of the region, photogrammetric refraction and central perspective. The most important error sources are further explained in the list below.

1. *Alternating heights*. While making aerial photographs, the distance between the camera and the earth surface differs from photo to photo. This difference in altitude introduces scale differences. As can be seen from Figure A-7, the left

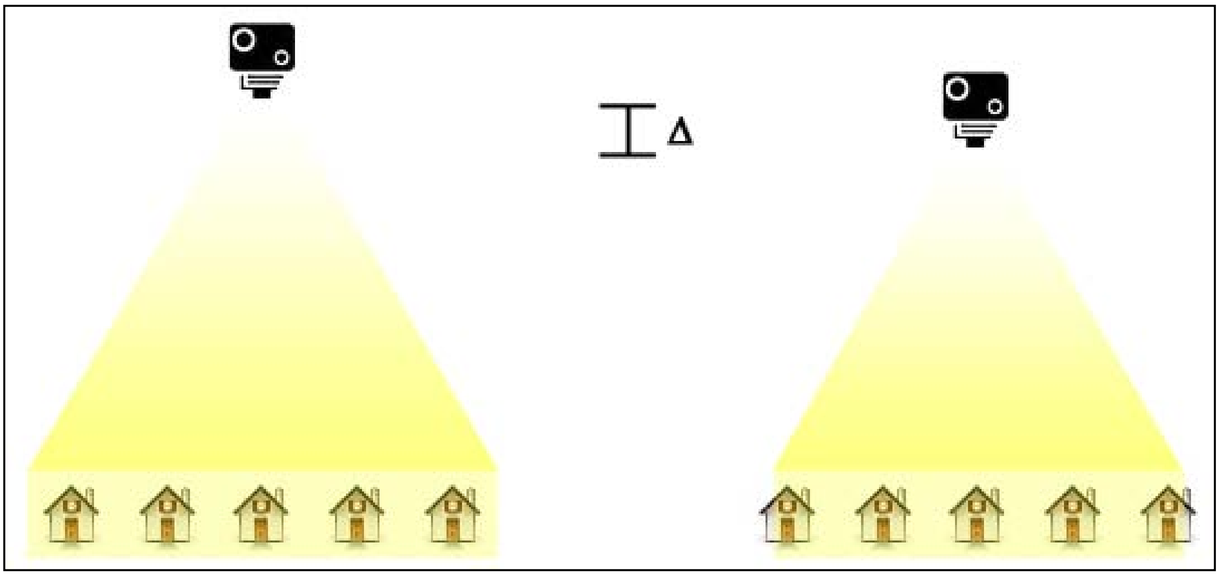


Figure A-7 Introduction of scale differences in aerial photographs due to alternating heights

camera is located higher above the houses than the right one. The left camera therefore captures a larger surface into one photo, while the resulting photos are equal in size. The scale of the photo from the left camera is therefore smaller than the scale of the photo from the right camera.
In case a composition of different photos needs to be made or different photos from different flights need to be compared, like in this case, the scale of all photos should be equal and the photos need therefore to be corrected.

2. *Tilting camera*. When making aerial photographs, the camera is never exactly perpendicular to the earth surface. An angle between the lens axis and the earth surface other than 90 degrees introduces distortion errors. As can be seen from Figure A-8, the left camera is positioned perpendicular to the row of houses while the right camera is tilted. The left camera makes a photo on which all houses occupies an equal surface, which is conform the reality since all houses are equal. The right camera, however, makes a photo on which the left house almost occupies a similar area as the two houses on the right side. This means that the scale in one photo differs as well. The scale on the left side is larger than on the right side of the photo. To be able to analyse the photos correctly, this distortion needs to be corrected.

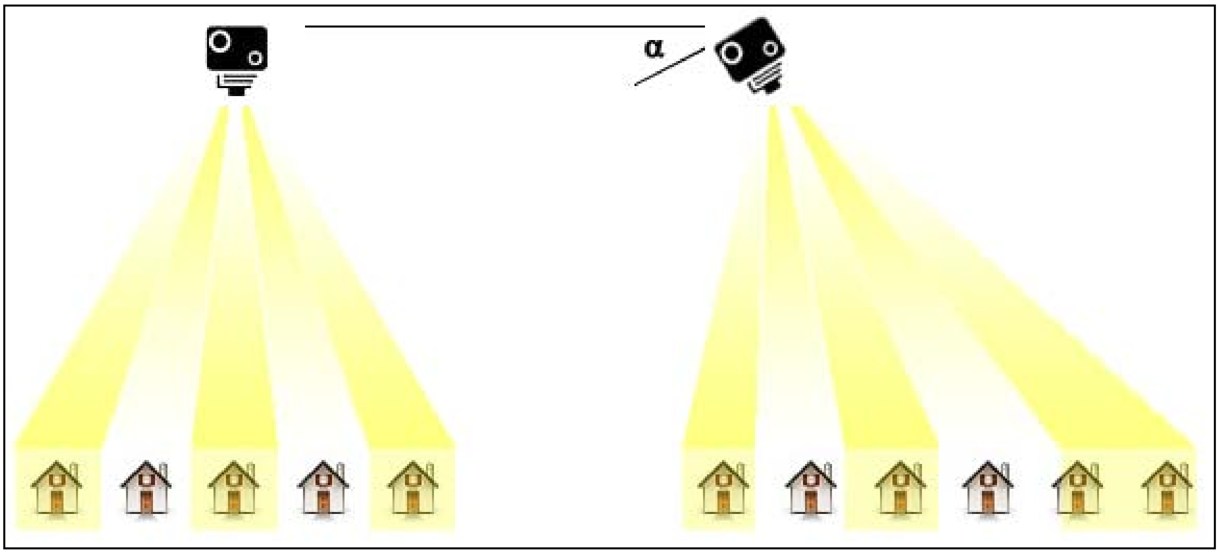


Figure A-8 Introduction of errors in aerial photographs due to tilting of the camera with respect to the earth surface

3. *Lens curvature*. Photo cameras use lenses to concentrate a large image into a small photograph. Any lens introduces errors due to their curvature. Mostly, the scale at the borders of any photo is somewhat smaller than in the middle of the photo.

A.3 Photo quality discussion

Although the analysis of the photos is improved compared to the 2007 research [Project Ingleses 2007], as discussed in the previous section, there are still sources of errors that are likely to influence the results. Several specific sources of errors and decisions made during this project involving the quality of the photos are discussed in this section.

A.3.1 Composition of 1998 photo

The photo from 1998 used by the 2007 project is a composition of multiple photos (see Figure A-9). The composition was very inaccurate since, for example, roads crossing the different parts were not well connected. Georeferencing this composition led to unacceptable RMS errors. The acceptable RMS error is further elaborated in section A.2.1.1. The unacceptable RMS error led to the decision to split the photo into multiple parts and thereby undoing the creation of the composition. After separation, the photo needed to be processed again. The photo has been divided in three interesting parts. Overall it appears to be possible to find enough control points in each part with an acceptable RMS error.

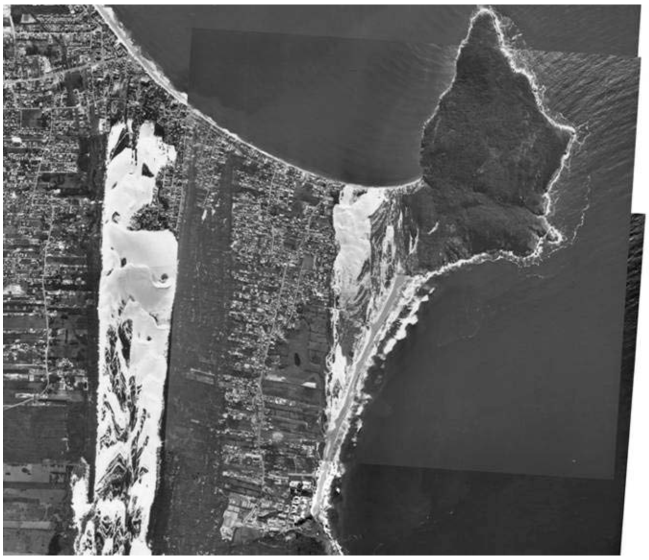


Figure A-9 Ingleses Beach 1998, original [Project Ingleses 2007]

Figure A-10 Blurred at edges and errors due to composition [Project Ingleses 2007]

The separated parts are blurred at the edges as shown in Figure A-10 and it is therefore harder to draw a good coastline. This introduces errors. The result of the separation is shown in Figure A-11 until Figure A-13. The first contains the central part of the original photo, Figure A-12 contains the top part of Ingleses beach while Figure A-13 contains the lower part of the Moçambique Dune.

Figure A-11 Ingleses Beach 1998, central part [Project Ingleses 2007]

Figure A-12 Ingleses Beach 1998, top left part [Project Ingleses 2007]

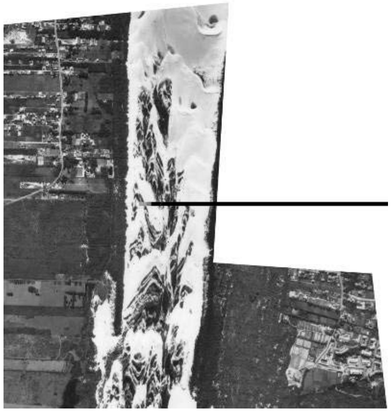


Figure A-13 Ingleses Beach 1998, lower left [Project Ingleses 2007]

A.3.2 Scans from municipality of Florianopolis

In a later stage of the project original photos from already analyzed years, but also from additional years, became available. These photos are scanned during the third fieldtrip to Ingleses. At the municipality of Florianopolis the aerial photos from 1998, 1977, 1957 and 2004 were available.

In this section the new scans are discussed. The photos from 1994 and 2004 are additional information and are processed in the same way as done so far. New photos from 1998 might increase the reliability of the results so far.

A.3.2.1 New scans 1998

The original photos consist of several images that cover different parts of the research area. Contrary to the composition of these photos that was available so far, these photos are still separated. At first glance, it seemed that the new scans had a higher contrast wherefore it should be easier to identify the coastlines and dune ridges. The fact that the resolution of the scans is twice as high as well, 600 dpi instead of 300 dpi, made it even more likely that using the new scans would improve the reliability of the results.

Four of the five scans can be analyzed with an acceptable RMS error. One of the scans, however, contains a larger RMS error. Since this scan is one of the two scans that cover the beach, it is questionable if these new scans will result in a better estimation. The increase in resolution doesn't compensate for this increase in RMS error since the RMS error increases with about a factor four and the resolution only with a factor two.

Furthermore, after rectifying, the contrast of the new scans appeared to be not as good as expected and would not lead to better results than using the ones which were analyzed already. Also after drawing the coastlines onto the photos it appeared that the rectified photos did not match each other at the borders. This also leads to big errors.

Based on the considerations above it is decided not to work with the new scans, but only with the composition that was already available. The blur at the edges of the earlier analyzed photos is therefore accepted.

A.3.2.2 Scans 1957 and 1977

A quick comparison between the new photos from 1957 and 1977 and the photos that were already available, shows that the photo from 1978 is actually identical to the one from 1977. Apparently, one of the dates is incorrect, but since the difference is small this is considered not to be a problem. Also, it can be seen that the contrast of the new scans compared to the scans that were already available is not better, especially not in the dune areas. Because the new scans of the 1957 photos are made to obtain a higher contrast in the dune area, these new scans are not further used during the research (Figure A-14).

Also the 1977 photos doesn’t result in a higher contrast, but they do give extra information about the northern part of the beach. Unfortunately, the rectified photo of this northern part doesn’t match the scale of the already analyzed part of 1978 (Figure A-15 en Figure A-16).

The new scans from 1957 and 1977 do not provide additional reliability or information. Since the reliability of the result obtained from the scans that were already available for these years is sufficient, these scans are not used further during this research.

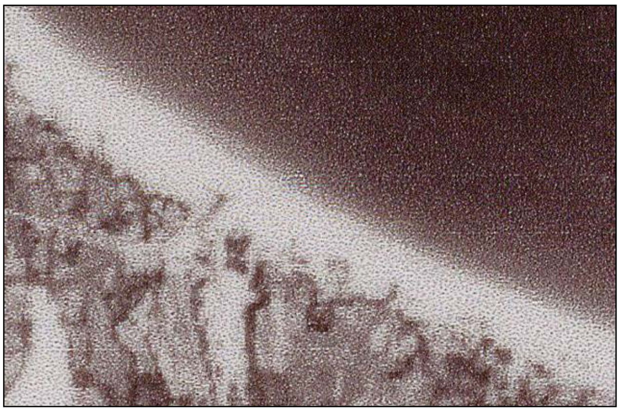


Figure A-14 Ingleses Beach 1957, unusable new scan

Figure A-15 Ingleses Beach 1977, new scan

Figure A-16 Ingleses Beach 1978, old scan

A.3.3 Scans 1938

The photos from 1938 contains almost no buildings and therefore it is very hard to find any control points. In the end 15 points with an acceptable RMS error are found. Adding more control points with a lesser quality would lead to a larger confidence level, but at the same time to a higher RMS error. The used standard of the NSSDA (see Section A.2.1.1) does not provide a solution for a situation with less than 20 control points. Therefore, the accuracy is also determined based on the method of Araujo et al. [2008] (see Section A.2.1.2).

When analyzing the other years it was possible to match roads and large buildings from the GIS data as well as the photos. In 1938 there are almost no buildings or roads visible and it is uncertain whether the roads from 1938 were still in the exact same place in 2002, the moment the GIS data is obtained. During the rectification of the photo of 1938 there is also made use of the headland. This was not necessary for the other photos, except in the photo of 1957. The headland is an area that is relatively hard to match and sensitive to errors. It is also located outside of the area of interest which might lead to undesired rectification curves.

Although the rectification of the photos of 1938 was difficult, the identification of the coastline and vegetation line in the rectified photos is easier than experienced with other photos. There are no buildings close to the coastline and the coastline is not yet influenced by human interventions.

A.4 Analysis methods

The aerial photographs are analyzed for several reasons. The historical transgression and regression of the coastline will be determined as well as the historical movements of the dune fields. Also, the throughput of sediment by the dunes in the past and present are distilled from the aerial photographs. In order to objectively quantify these phenomenon, certain analysis methods need to be defined. The methods are divided in methods for coast phenomena and dune phenomena.

For the coastal phenomena, two approaches are defined. These approaches are based on the vegetation and high water line respectively. The vegetation line is defined as the line between the beach and the landward, adjacent areas which are often bordered by vegetation. The movement of the vegetation line is a damped representation of the movement of the coastline. This is caused by the delay with which vegetation grows and retreats according to the coastline movement. The high water line is defined as the visible line on photographs that separates the wet and dry part of the sand. This line is considered to indicate the maximum water level during high water.

The vegetation line is well defined and therefore it’s movements are easy to analyze. The fact that the vegetation line follows a damped movement compared to the coastline, might also have a positive effect on the analysis since exceptional water levels cannot influence the result. The high water line is less well defined, but have a strong relation with the actual coastline.

The dune phenomena are characterized using the dune ridges. These ridges are visible on the photographs because of the shadows they drop on the rest of the dune. Ridges of photos from different years are visually matched based on position and shape. Only ridges in the middle part of the dunes are used for analysis. The tail of the dune is often scattered with blank areas and differ a lot between different photos, which makes visual matching of ridges almost impossible. The head of the dune is often influenced by human interventions for the parts the dune hits the town or otherwise by the disappearance of sediment into the sea.

A.5 Results

The aerial photograph analysis has resulted in both a regression curve of the coastline of Ingleses Beach and a migration curve of the Moçambique and Santinho dune field. From these curves an average speed can be deduced within a certain accuracy based on the error sources in the georeferencing procedure:

1. Resolution of the photographs
2. Number of control points
3. RMS error of the georeferencing

These parameters are given in Table for each photograph. The accuracy of a comparison of two photographs is equal to the summation of the accuracy of each photograph separately. For the year 1998, only a composition of several photographs was available. Since the composition was made very inaccurately, the composition is separated in three original parts resulting in three photographs from 1998: upper-left, middle and lower-left. The average accuracy of the three parts is used as representation of the accuracy of the whole year. Similar divisions have been made for the photos from 1994 and 2004, because these photos simply consist of several separate photos which are not joined into a composition. Separated photos are mutually compared by visually matching the parts from different years as good as possible.

As stated before in this appendix and can be seen in the Table , it was not possible to quantify the accuracy of the georeferencing of the photos from 1938 with the NSSDA method. Therefore, the accuracy is also investigated using the precision method. The results are presented in a separate column in Table .

Year		**Resolution**	**Accuracy (pixel)**	**Number of control points**	**RMS error**	**Procedure**	**Accuracy**	**Precision**	**Accuracy (comparison)**	
		[dpi]	[m]	[-]	[m]		[m]	[%]	[m]	
1938		700	0,90714	15	4,95097	Precision	NA	89,364%		NA
1957		600	1,05833	20	2,38217	NSSDA	4,12306	90,762%		NA
1978		600	1,05833	20	3,64423	NSSDA	6,30743	93,424%		10,43049
1994	Part 1	600	0,33867	20	1,31424	NSSDA	2,27469	89,973%	8,58212	
	Part 3	600	0,33867	20	1,95459	NSSDA	3,38300	89,885%	9,69044	
	Part 4	600	0,33867	20	1,43921	NSSDA	2,49098	88,804%	8,79842	9,02366
1998	Upper-left	300	2,11667	20	1,84151	NSSDA	3,18729	89,166%	6,57029	
	Middle	300	2,11667	20	1,25028	NSSDA	2,16398	89,669%	4,43867	
	Lower-left	300	2,11667	20	2,47659	NSSDA	4,28648	85,659%	6,77747	5,92881
2004	Part 4	600	0,33867	20	1,15801	NSSDA	2,00428	88,220%	6,29077	
	Part 6	600	0,33867	20	0,96849	NSSDA	1,67626	90,463%	4,86355	
	Part 7	600	0,33867	20	0,91692	NSSDA	1,58701	88,758%	4,77429	
	Part 8	600	0,33867	20	1,79605	NSSDA	3,10860	91,341%	5,27259	
	Part 9	600	0,33867	20	1,58511	NSSDA	2,74351	87,042%	4,90749	5,22174

Table A-1 Accuracy and precision of georeferencing

Appendix B Coastline development

The development of the coastline in the bay of Ingleses as occurred in the past is an essential part of this research. Quantifying the regression speed of the coastline makes it possible to quantify the coastal problems in Ingleses in terms of loss of soil and real estate, the zero-solution (see Appendix F). Furthermore, the historical regression can be used to check and calibrate the numerical model created in this project and for the design of a the advanced fill of the beach nourishment.

B.1 Aerial photographs

For the actual measurement of the coastline development through the years the rectified photos are used (see Appendix A),. This is done using the comparison between the several photos from the years available (see Table B-1). Each comparison is done between two succeeding photos. In Table B-2 an overview is given of the several comparisons made for the coastline development. The time interval between photos from 1938 until 1978 is larger than from 1994 until 2004. This larger time interval between the older photos excludes short-scale effects from the comparison. The moment that the time interval is starting to decrease is also the point in time that Ingleses is starting to develop.

First year	Last year	Interval
1938	1957	19
1957	1978	21
1978	1994	16
1994	1998	4
1998	2004	6

Table B-2 Overview of comparisons

Year	Part	Resolution	Scale
1938		700	25000
1957		600	25000
1978		600	25000
1994	new part 1	600	8000
1994	new part 3	600	8000
1998	upper left	300	25000
1998	middle	300	25000
2004	new part 6	600	8000
2004	new part 7	600	8000
2004	new part 8	600	8000
2004	new part 9	600	8000

Table B-1 Photos used for coastline analysis

B.1.1 Indicators

To be able to analyse the coastline development form the photographs, a definition of the coastline is needed that can be used for all photographs and that reasonably represent the actual coastline.

B.1.1.1 Recognition

The coastline is initially drawn on the boundary between the light and the dark sand (see Figure B-1). This is considered to be the high water line. This is a subjective way to represent the high water line, but the line is more or less visible on all photographs. Since the date and time on which the picture is taken is unknown, it is not possible to say anything about the tide or water level at that moment. This line between the light and dark sand changes less frequent than the actual water line and is therefore a better indication for the comparison of photographs made at different points in time. The error introduced by this assumption is accepted and has to be kept in mind when analysing the results.

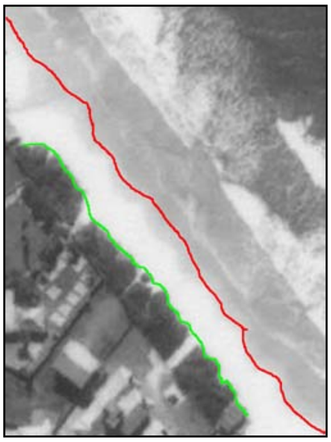


Figure B-1 Distinction between high water line and vegetation line

Another indicator for the coastline is the line of vegetation. This indicator is less sensitive to errors compared to the high water line, because the vegetation is more or less constant during a year. The line itself, however, is much more irregular than the coastline, this irregularity might lead to errors in the calculation. This line is also subject to human interventions especially in the case the cultivated area is approaching this line.

Figure B-2 Water reaching up to wall

The high water line and the line of vegetation are drawn into the photos using a separated shape-file (see Appendix O) for each year. The high water line is drawn, as stated before, on the border of dark and light sand when possible. Otherwise it is assumed that the high water line equals the vegetation line since nowadays that is often the case (see Figure B-2). The dark dots and areas close to the sea are considered to be vegetation line. The distinction between buildings, walls and roads is clear on all the photos, even on the ones with the lowest resolution.

Errors are also introduced due to different decisions when drawing a line along the coastline of Ingleses. When the coastline would be drawn twice in the same photo it is not possible to mark the exact same points. It is a subjective way to determine a certain border and therefore contains errors.

B.1.1.2 Consistency

In the photos of 1938 and 1957 there are not a lot buildings present in Ingleses. In these years it is possible to draw two separate lines for the high water line as well for the vegetation along the whole coast. As earlier mentioned, after 1978 the development of Ingleses as a touristic part of *Ilha de Santa Catarina* started. A lot of buildings bordering the sea are visible on the photos from this moment. In the photo of 1978, hard structures do not yet mark the edges of the parcels. This is the last year where a clear distinction can be made between the high water line and the vegetation line.

In the photos of 1994, 1998 and 2004 the centre of Ingleses is further developed. This development resulted in a large number of hotels and holiday houses close to the sea. Therefore it is not possible anymore to draw two different lines for the high water line and vegetation in the middle part of Ingleses Beach. In the vicinity of the buildings the coastline is equal to the line of the walls of the different parcels bordering the beach. In front of these walls there is no space left for any vegetation. That is why this line is considered to be the high water line in this stretch and at the same time the line of vegetation. This consideration has been confirmed during the fieldtrips to Ingleses (see Appendix E). This assumption is also in line with the known problems that these buildings have with the erosion. These problems result in the construction of large concrete structures in front of the buildings that protect the land. The lines in this part should almost stay the same in time after 1994, since a hard structure is the border between the beach and parcels.

On the part of the coastline located south of Santinho Dune, it is again possible to make a distinction between high water line and vegetation. This is also true for the northern part of Ingleses Beach. Here the buildings are located further away from the coastline and there is space again for vegetation.

B.2 Analysis

B.2.1 Digital Shoreline Analysis System (DSAS)

To determine the speed of transgression or regression of the coastline the tool *Digital Shoreline Analysis System* (DSAS) from U.S. Geological Survey is used. More about this program and the way it is applied in this research is described in Appendix O.

B.2.2 Baselines

As baseline for the high water line and vegetation line the lines of 1957 are chosen. These are the longest continuous lines available. Taking the longest lines ensures that the baseline always includes the parts of coastline that are compared in a specific comparison and therefore no information will be lost due to an insufficient long coastline. Another advantage of taking the longest line as baseline is that the begin point and end point is the same in all the calculations. This makes comparing the results easier.

The baseline is set at a distance of 100 meters landward of the coastline of 1957. The total length of the base line is approximately 5,5 kilometres. The DSAS tool is used to draw transects and determine the transgression or regression between two successive coastlines. In this analysis a transect spacing of 100 meter is chosen. This transect spacing leads to 56 transects for the high water line and 60 transects for the vegetation line. A transect length of 250 meter is enough to cover all the coastline shapes from the baseline.

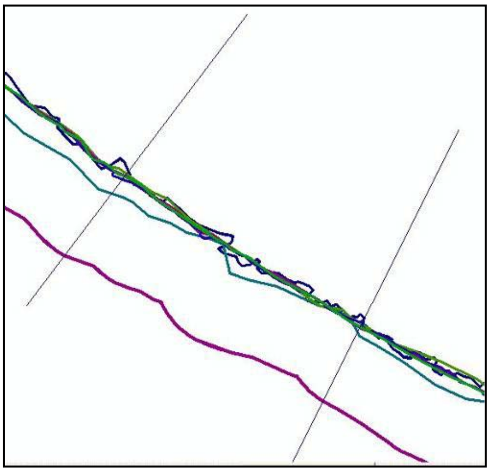


Figure B-3 Close-up baseline, vegetation lines and sections

Due to the irregular lines of the vegetation the smoothing tool is used during the drawing the transects. The irregular pattern (see Figure B-3) is more present in the vegetation than in the coastline. The smoothing tool draws the transects perpendicular to a line between two points at a preset distance from the original point, instead of one specific point (see Figure B-4). The smoothing distance is set to 150 meters. With this distance, based on try and error, no intersecting transects occur.

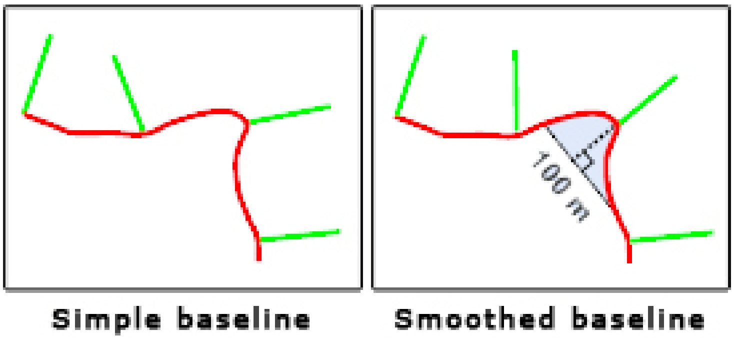


Figure B-4 Smoothing of baseline

B.2.3 Sections

To look at the behaviour of parts of the total coastline instead of the behaviour of all transects individually, sections are made in the analyses of the coastline (see Figure B-5). Based on the sections the transect numbers in each section are determined. In Table B-3 the numbers of the transects in each section are given. The first transect doesn't intersect two lines in all the comparisons. Therefore this transects doesn't contain any data. Most of the transects in the last sections also don't intersect two line in most comparisons. This is not a problem, because this is not in our specific field of interest.

Section	High water line		Vegetation	
	First transect	*Last transect*	*First transect*	*Last transect*
Santinho	1	7	1	9
Interdune	8	14	10	17
Mocambique Dune	15	19	18	21
Mocambique Ridge	20	24	22	27
River South	25	39	28	42
River North	40	56	42	60

Table B-3 Sections and transects for high water line and vegetation

B.3 Results

The results are presented as an average rate of change per year per section. For example, in the analysis between 1938 and 1957 the difference is divided by 19 years and given as a rate per year per transect. These transects are averaged over their sections and linearly interpolated between the successive time intervals. This is done with all the comparisons. The result is shown in Table B-4, Table B-5, Figure B-6 and Figure B-8. The results north of the river are not plotted at all, because most of the rectified photos don't cover this area.

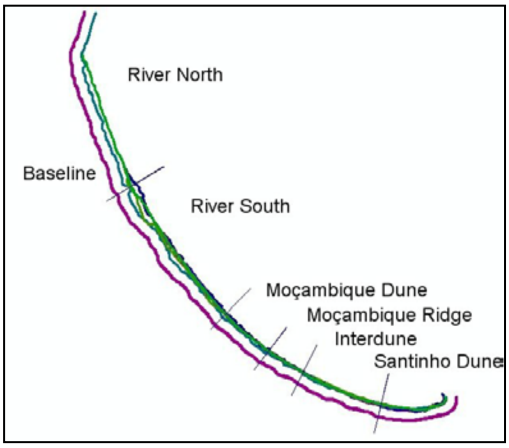


Figure B-5 Baseline and vegetation line including sections

B.3.1 High water line

The high water line shows until 1960 transgression in the south and regression in the north part of the bay of Ingleses. Until 1990, regression took place along the whole coastline. Around 1980 the behaviour of the coastline changes and the regression in the southern part of the bay becomes larger than the regression in the northern part, finally resulting in transgression of the northern part around 1990. This change in coastal behaviour is known as *beach rotation*.

Beach rotation can normally be explained by a change of direction of the waves. The wave direction can change due to a change of climate. Klein suggested that the erosion problems in Ingleses are due to the urbanisation of the area and the resulting decrease of sediment input from Moçambique Dune into the bay of Ingleses [Klein, 2004]. The additional aerial photographs used during this research support this theory and also the beach rotation might be explained using this theory. Since no detailed information about the climate in Ingleses in the past century is currently available, no definite conclusion can be drawn concerning the causes of the apparent beach rotation.

The results show an overall transgression from the year 2000 onwards. This is entirely due to the coastline that is found on the photographs from 2004. These photographs show, compared to the photograph from 1998, an enormous beach. Although the quality of these photographs is extremely good, the result is not likely to be very reliable. The experience of inhabitants as well as the experience of this project during the fieldtrips are that the beach shown on the 1998 photograph is more realistic. The large deviation in the 2004 coastline might be due to an extreme low tide during the flight that made the photos.

Project Ingleses 2007 mentioned already observations made by Faraco [Faraco, 2006] of the witdh of Ingleses Beach. He observed a transgressing coastline over the whole beach length between 1996 and 2001. His first observations were made in the period 1996 – 1997, during the El Niño event, while the second observations were made in the period 2000 – 2001, during the La Niña event. He suggested that these metrological phenomena caused the huge differences in beach width. This could also be an explanation of the unexpected results of the aerial photo analysis of the 2004 photographs. Further research is needed to quantify the influence of the El Niño and La Niña events on the development of Ingleses Beach.

Period	**Section**						**Average**
	Santinho Dune	*Interdune*	*Mocambique Ridges*	*Mocambique Dune*	*River South*	*River North*	
1938-1957	1,17500	1,11500	0,33000	-0,16800	-1,23800	-2,27000	*0,24280*
1957-1978	-0,98571	-0,75143	-0,35400	-0,42600	-0,49467	-0,11250	*-0,60236*
1978-1994	-1,61429	-1,74750	-1,10250	-1,16400	-0,63600		*-1,25286*
1994-1998	-1,61833	-0,62625	-3,84250	-1,34000	1,12333		*-1,26075*
1998-2004	2,17500	1,04286	2,31250	1,27800	0,11833		*1,38534*

Table B-4 Development of high water line per time interval and section

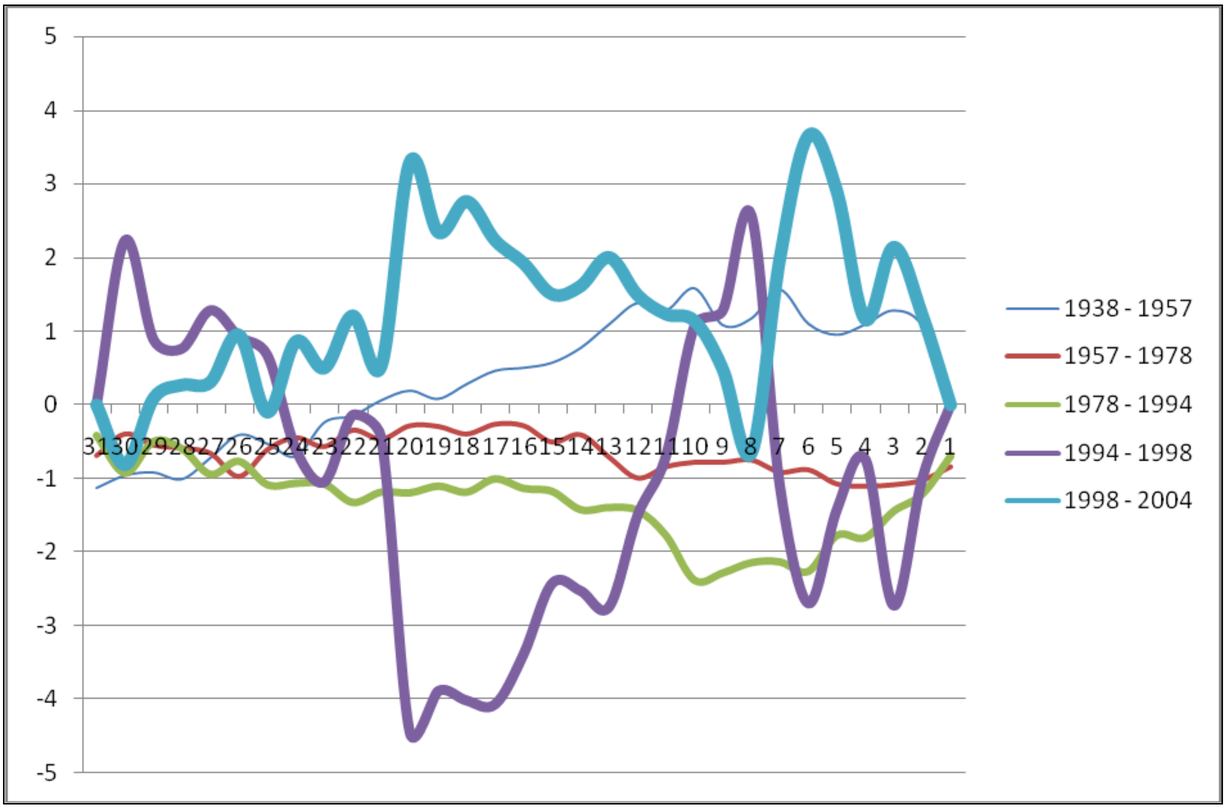


Figure B-6 Development of high water line per time interval

An analysis of the influence of the deviating results of the 2004 photographs shows that the influence is minimal when compared to a longer interval. In Figure B-7 is the development speed shown for the intervals 1994 – 1998 and 1998 – 2004, which differ a lot. In this figure is also shown that the coast shows a clear regression in case the 2004 photographs are compared to the photographs of 1938 or 1957. Therefore, the deviating photos from 2004 doesn't seem to cause a lot of trouble for the analysis as a whole. In other words: also in case the photos are not taken during extreme tide, the trend is not really influenced and thus the moment can be treated as a exceptional, but possible, situation under the conditions of the hypothesis.

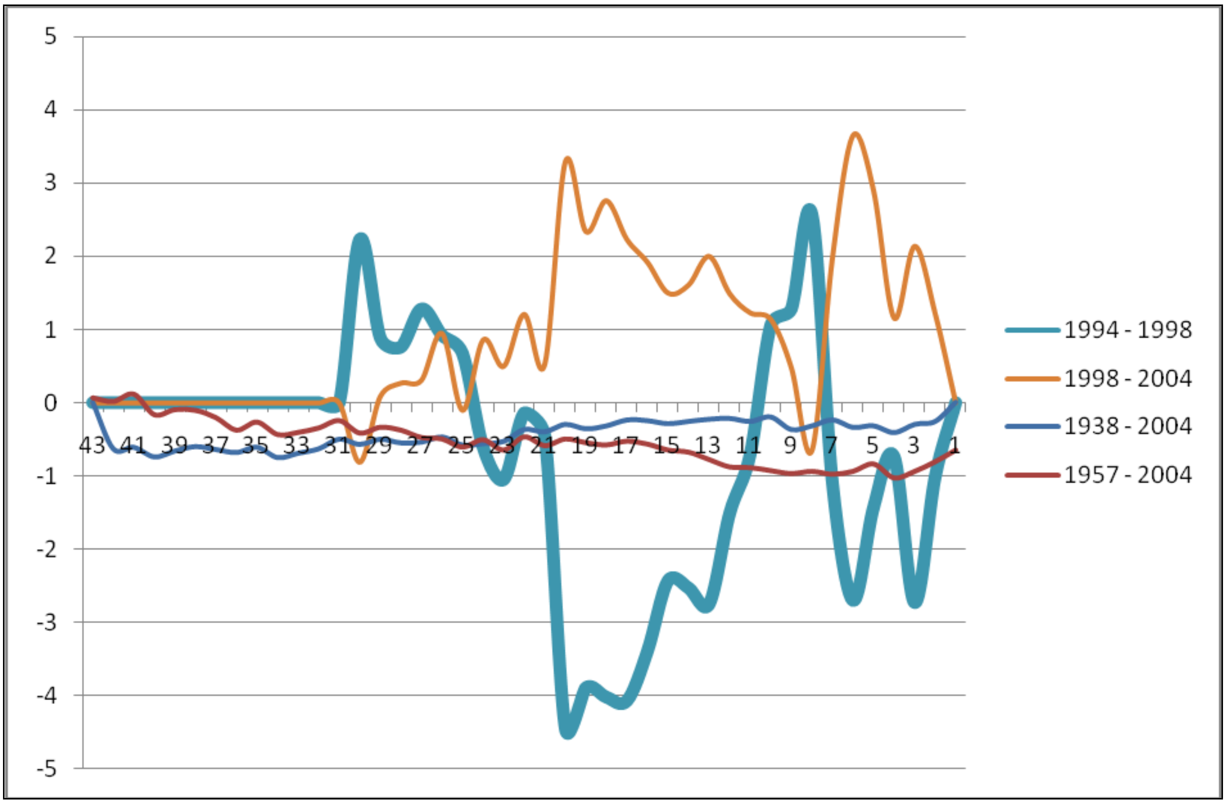


Figure B-7 Influence of the deviating results of the 2004 photo analysis

B.3.2 Vegetation

The vegetation line shows a regression from 1938 until approximately 1957. After that point in time most of the time intervals show transgression until the development of Ingleses has made considerable progress, around the year 1978. River south is the section which is above all other curves. This section is not the area where most of the problems due to coastal erosion or dune migration occur. Therefore this area will not be investigated any further, in the past it seems that there has been a lot of transgression. At the end of this graph the average movement seems to be landward.

The most interesting curves are Moçambique Ridges, Moçambique Dune and Interdune. The curves considering Moçambique show a regression starting around 1990. The Interdune curve, however, shows a strange bulb around 1995. The Santinho Dune shows transgression at the end and has not reached very large negative values in the past.

Period	Section						Average
	Santinho Dune	*Interdune*	*Moçambique Ridges*	*Moçambique Dune*	*River South*	*River North*	
1938-1957	-0,11500	-0,49625	-0,70500	-1,91500	-2,98333	-3,96500	- 1,69660
1957-1978	0,07125	0,75125	0,66250	1,09500	1,26533	1,99750	0,97381
1978-1994	-0,44375	-0,83875	-0,13750	0,23500	1,36556		0,03611
1994-1998	0,40625	1,09500	-0,36500	-0,14667	1,70333		0,53858
1998-2004	1,29500	0,00375	0,15000	-0,20000	-1,57333	*0,00000*	*- 0,05410*

Table B-5 Development of vegetation line per time interval and section

It seems like the vegetation behaviour is a damped version of the high water line changes. The vegetation changes are not as frequent as the changes to the high water line. This line was taken into account to use as a verification of the high water line data. After the analysis it appears that the behaviour of the two lines is very different and the value of the vegetation line, for this project, minimal.

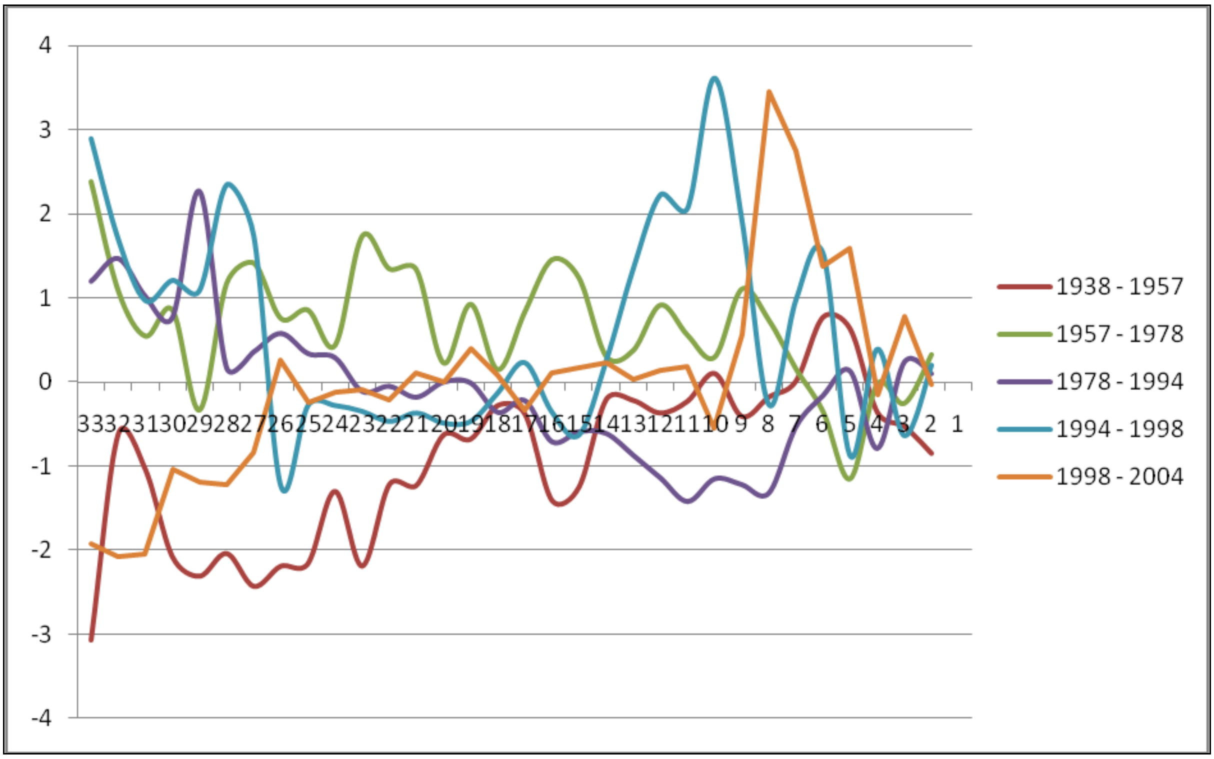


Figure B-8: Development of vegetation line per time interval and section

Appendix C Dune migration

The migration speed of the dunes, especially Moçambique Dune, and the volumes of sediment that are involved in this migration is valuable information for this research. These figures can be used to estimate the loss of real estate in case no actions are taken, the zero-solution. Furthermore, especially the migrating volumes that existed before urbanization of Ingleses provide an indication of the loss of sediment around the northern headland supposing that the bay of Ingleses was at some point in the past in static or near-static equilibrium (see Appendix D).

The migration speed of the dunes is estimated using an analysis of a series of historical, aerial photographs. From these photographs, a yearly average migration is derived. For further information about the photographs, their rectification and the analysis methods see Appendix A.

The migration direction of the dune fields is north. The migration is induced by wind. In the surroundings of Ingleses, two prevailing wind directions are noticeable: south and north-east (see Figure C-1). Since the dunes are located at the lee side of the southern headland in case of a north-eastern wind, the southern wind is prevailing concerning the dune migration [Bigarella et al., 2006]. This explains the migration direction of the dunes despite the prevailing wind directions.

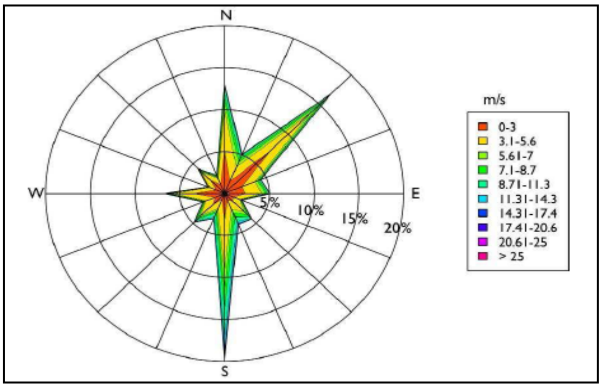


Figure C-1 Wind rose with prevailing wind direcions in the surroundings of Ingleses [Project Ingleses 2007]

C.1 Photos

The speed of the dunes is not obvious from the aerial photographs. It is necessary to find visible aspects of the dunes that are present on all photographs and not disturbed by human intervention in order to estimate the natural migration of the dunes.

C.1.1 Indicators

There are several indicators that show a northward movement. Not all indicators are reliable and not all indicators are present or otherwise visible on all photographs. For example, the front of the Moçambique Dune is an unreliable indicator. The front of this dune is in fact moving to the south while other aspects of this dune show a clear northward movement. This is caused by human activity. The front of Moçambique Dune has been removed for construction purposes, therefore, this indicator cannot be used for the dune migration.

Figure C-2 Parts of Moçambique Dune and its ridges (based on 1998 photo)

Another indicator is the ridges on top of the dunes. The ridges at the front of the Moçambique Dune also suffer from human intervention and the ridges at the back of this dune show a lot of scatter in time and space. The ridges in the middle (see Figure 5-2) of this dune are undisturbed and regular in time and space and therefore a good indicator for the Moçambique Dune migration.

Santinho Dune suffers less from human interventions. The front of this dune is located at the coastline. Therefore, the front does not move and therefore is neither a good indicator for the dune migration. The southern part of the Santinho Dune also shows a lot of scatter, but the front part of this dune is, because of the absence of human interventions, a fairly good indicator for the dune migration and therefore for the sediment input in the coastal system.

There are two disadvantages of using ridges. The first is that it is not obvious how to translate a speed in meters per year to a throughput in cubic meters per year. It is unlikely that the whole dune is migrating with the speed of the ridges. A grain at the bottom of the dune will probably not migrate at all. In order to obtain a throughput, the migration speed needs to be multiplied by a surface. This surface is defined by the migrating part of the vertical cross section of the dune.

The other disadvantage is that it might be difficult to decide which ridge in one photo corresponds to another ridge in another photo. Since there is no objective method available to support such a decision, ridges on different photos are linked by matching them based on visual similarity.

C.1.2 Similarity Moçambique Dune

Similarity of two dune ridges on two different photographs is found based on both the position and the shape of the ridges. As stated before, this procedure is subjective. First, the dune ridges are marked as lines in the photos using a GIS application (see Appendix O). The collection of marks from different years are displayed upon each other. Because of the difference in quality of the photos, on some photos more ridges can be distinguished than on others. Ridges that can only be distinguished on a few photos are

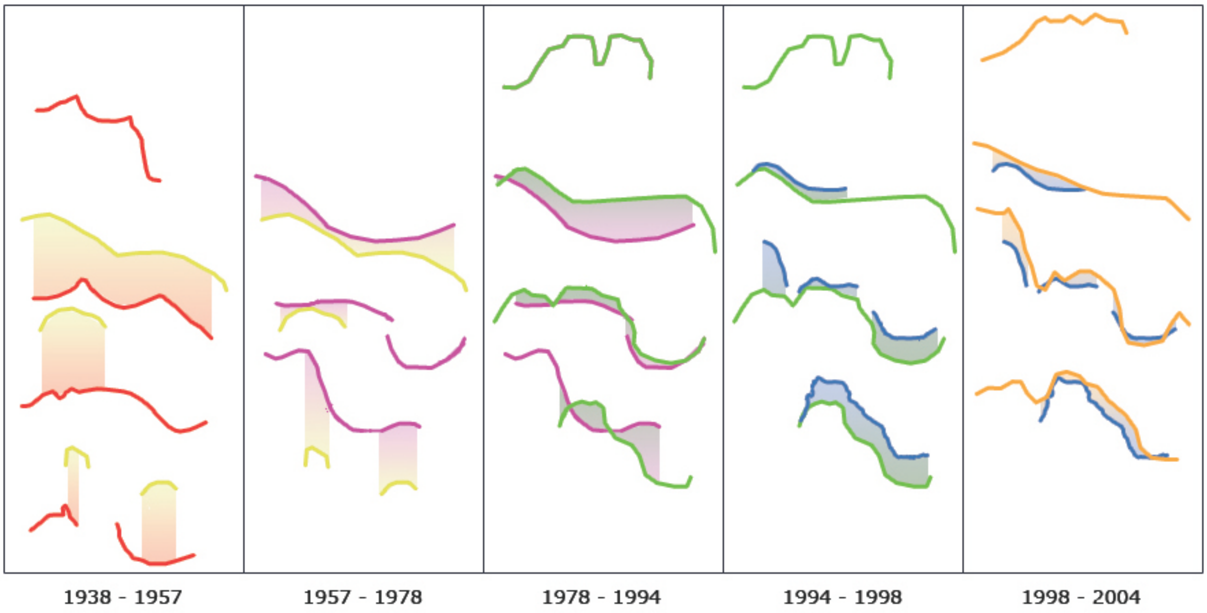


Figure C-3 Progression of dune ridges on top of Moçambique Dune

neglected. The resulting collection of ridges of the Moçambique Dune with their correlations is displayed in Figure C-3.

The most northern ridge (upper) is only visible on the 1938, 1994 and 2004 photographs. Since this ridge still might be interesting for the research, an extra analysis is made for this ridge including only these three photographs (see Figure C-4). The analysis comprehends therefore four dune ridges in total.

Figure C-4 Progression of front dune ridge

C.1.3 Similarity Santinho Dune

Most of the visible ridges of the Santinho Dune are located in the northern part. To make a good comparison, a selection of several ridges in this area is made. Only ridges that are visible on different photographs are selected. To select ridges using the similarity requirements, the ridges are printed on a big sheet of paper. Due to the lower quality of the photo of 1957 it is not possible to identify a lot of ridges. Therefore, this year is not taken into account in this comparison which results in a larger time step in the comparison 1938 – 1978. This period has only visible ridges in the most southern part of the dune and is therefore less representative for the input. This period is not further elaborated. The overview of comparisons that are made are marked green in Table C-1. The different areas are defined in Figure C-5.

Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7
					1938	1938
						1957
			1978		1978	1978
1994		1994	1994	1994		
1998	1998	1998		1998	1998	
2004	2004	2004		2004		

Table C-1 Overview visible ridges Santinho Dune. Green selection is used for comparison.

The total set of selected ridges is split in different parts whereby succeeding ridges are isolated. This is done to simplify the analysis and to make the positioning of the baseline easier. The ridges in areas 6 and 7 are visible on the photographs from the period 1938 – 1978. These ridges are located far from the beach and thus less representative for the input of Santinho Dune than the ridges in the northern part. The ridges in the northern part of Santinho are visible on photographs from 1994, 1998 and 2004. Therefore the ridges in areas 1, 4 and 5 are selected for this analysis. In Figure C-6 the ridges are drawn together for the two time intervals 1994 – 1998 and 1998 – 2004. The results of the analysis is further elaborated in section C.4.2.1.

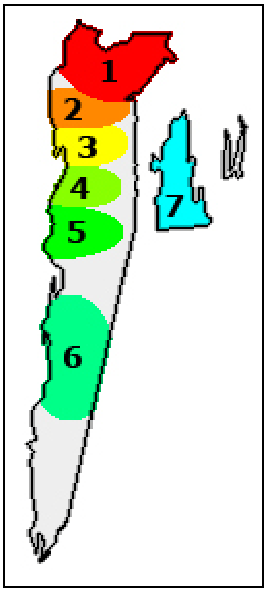


Figure C-5 Areas Santinho Dune

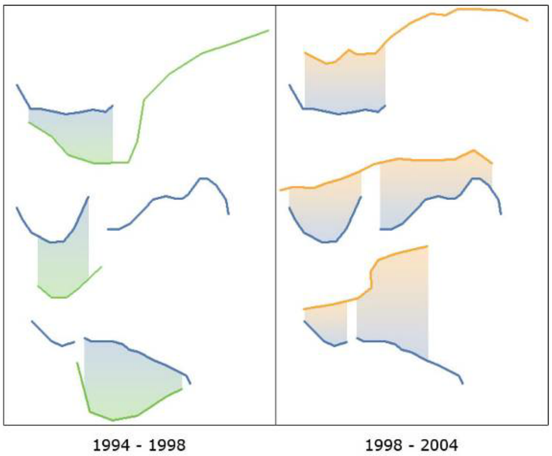


Figure C-6 Analysed dune ridges Santinho Dune

C.2 Analysis

As described in Appendix O a module named *Digital Shoreline Analysis System* (DSAS) is available for the GIS application *ArcGIS.* DSAS calculates the yearly average regression or transgression of a coastline, given two successive coastlines. In this analysis, the dune ridges are interpreted as coastlines as well and their progression is calculated using the same module.

C.2.1 Baselines

The DSAS module calculates the yearly average progression along transects that are drawn from a certain baseline. When calculating coastline developments, a baseline similar to the coastline is defined in order to minimize the errors caused by a curved coastline. When calculating the progression of dune ridges, however, this might be a disadvantage since the shapes of the ridges changes relatively fast. In the case of Moçambique and Santinho Dune this is the case (see Figure C-3 and Figure C-6). Therefore, the baselines are defined from west to east, perpendicular to the supposed migration of the dune.

In order to prevent the dune ridges to cross baselines, the baselines are moved along with the dune ridges or, in case of Santinho Dune, the several analyses are repeated for separate areas with only the ridges of interest. Since the DSAS module calculates the relative progression of the ridges, the exact position of the baselines is not important. Because the baselines are straight, moving the baselines during the calculations will not give different results.

C.2.2 Averaging

In comparison with coastlines, the shape of the dune ridges changes rapidly. This makes that the calculated yearly average progression differs highly per transects. In order to deduce a figure that can be used as overall progression speed, the calculated yearly average progression is averaged over the length of a ridge. This way, together with the straight baselines, a migration speed per dune ridge is obtained that is insensitive for shape changes.

C.3 Migrating part

Calculating the yearly average migration speed of the dune ridges is not enough to be able to quantify the original input of sediment to the bay of Ingleses by the two dune fields. Also the speed of encroachment of real estate cannot be calculated by the migration speed of the dune ridges only. In order to be able to quantify these processes the migration speed of the ridges needs to be translated to a throughput of sediment.

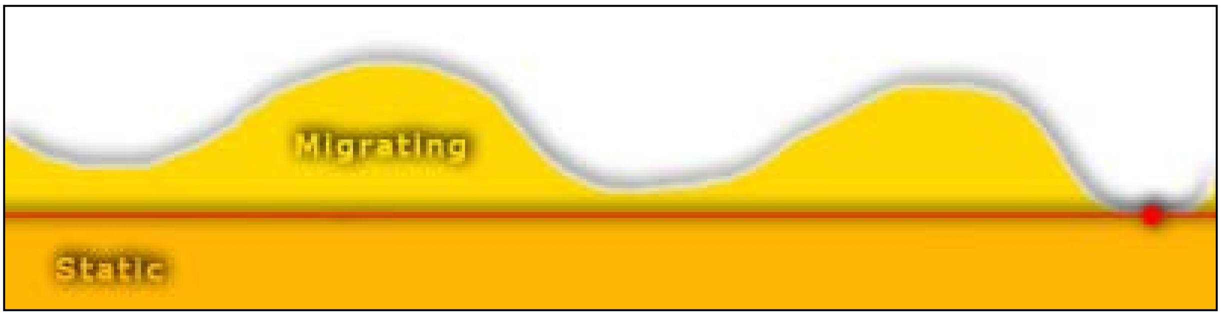


Figure C-7 Definition of the migrating part of the Moçambique Dune

The difficulty in this translation is that it is unlikely that the whole dune is migrating at the speed of the ridges. Only the top part of the dune is considered to be migrating in this way. The migrating part needs to be defined in order to be able to calculate the yearly average throughput.

C.3.1 Definition

An indication of the border between the migrating and static part of the dune can be the groundwater level. Since the groundwater level is not exactly known and probably not horizontal, and an horizontal border makes calculations much easier, this is not a useful level. This is why the migrating part of the dune is more or less arbitrarily defined as the part above the horizontal line that crosses the lowest trough of the wave formed by the dune ridges (see Figure C-7). The surface with which the migration speed is multiplied is the average vertical cross-section surface of this volume.

This surface can be extracted from the GIS data. For the middle part of the Moçambique Dune (see Figure 5-2) this surface is about 5700 m^2 large. This figure is a rough estimation obtained by extracting the total volume of this section of the dune and dividing this volume by the total length of this section (see Table C-2).

Name	Formula	Value	Unit
Lowest trough level above MSL:	$H_{m;t;min}$	10	m
Volume above lowest trough level:	$V_{m,migrating}$	4555505	m^3
Length:	L_m	800	m
Width:	W_m	600	m

Average cross-section area:	$A_{m;migrating;avg} = \frac{V_{m;migrating}}{L_m}$	5694	m^2
Average height of total dune:	$H_{m;avg} = \frac{A_{m;migrating;avg}}{W_m} + H_{m;t;min}$	19,5	m

Table C-2 Figures concerning migrating part of middle section of Moçambique Dune

The same is done for northern part of Santinho Dune, the part from the most southward ridge until the most northward ridge is selected for this analysis, see Table C-3. For Santinho Dune the focus is on the throughput of sand into the system of the embayed beach.

Name	Formula	Value	Unit
Lowest trough level above MSL:	$H_{m;t;min}$	1,86	m
Volume above lowest trough level:	$V_{m,migrating}$	1069765	m^3
Length:	L_m	530	m
Average cross-section area:	$A_{m;migrating;avg} = \frac{V_{m;migrating}}{L_m}$	2018	m^2

Table C-3 Figures concerning migrating part of nothern section of Santinho Dune

C.3.2 Ridge migration versus dune migration

The dune migration, until now, has been expressed in terms of a yearly average speed of the dune ridges. Since a migrating and static part of the dune has been defined, only the migrating part of the dune is available to extend the dune at the front end. Because at the front end, also the static area needs to be extended in order to let the front migrate, the migration speed of the dune front is lower than the migration speed of the dune ridges. This is the reason why, from now on, *ridge migration* refers to the motion of the ridges only and *dune migration* refers to the motion of the dune front (see Figure C-8).

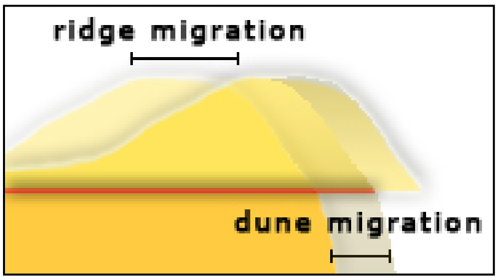


Figure C-8 Ridge versus dune migration

The ridge migration can be converted to a dune migration using a factor that is the quotient of the average cross section area of the migrating part of the dune and the average cross section area of the whole dune. Based on the figures in Table C-2 the formula for this factor for the Moçambique Dune reads:

$$f_{m;d} = \frac{A_{m;migrating;avg}}{W_m \cdot H_{m;avg}} = \frac{5694}{600 \cdot 19,5} = 0,49$$

Since the front of Santinho Dune is located at the coastline, this dune front does not really migrate, but only supplies sediment to the coastal system. The ridge migration is for this purpose enough and no conversion factor has to be calculated.

C.4 Results

The result of the analysis is a yearly average migration speed of the dune ridges per time interval per ridge. The time interval is equal to the intervals between the different photographs used in the analysis. As indication of the intervals, the median is used. The speed of the dune ridges is converted to a speed of the dune front and a yearly average throughput of sediment.

C.4.1 Moçambique Dune

For Moçambique Dune the dune migration, based on the ridge migration, is the most important parameter. It is used to calculate the potential loss of real estate by the dune. Furthermore, the historical sediment input in the bay of Ingleses is calculated using the sediment throughput, which is therefore important as well.

C.4.1.1 Ridge migration

The yearly average ridge migration speed, averaged per ridge is given in Table C-4 and Figure C-9. The values for the fourth ridge are interpolated since this ridge is only visible on the 1938, 1994 and 2004 photographs.

Year	Period	Migration speeds [m/yr]				Average
		Ridge 1	*Ridge 2*	*Ridge 3*	*Ridge 4*	
1948	*19*	10,10200	9,28667	7,76222	12,27857	9,85737
1968	*21*	8,41857	-2,44462	2,39680	12,27857	5,16233
1986	*16*	-1,57615	1,28211	4,65200	12,27857	4,15913
1996	*4*	16,43688	12,49000	6,10833	6,11611	10,28783
2001	*6*	4,32188	3,12571	4,55000	6,11611	4,52843

Table C-4 Yearly average ridge migration speed per time interval and ridge for Moçambique Dune

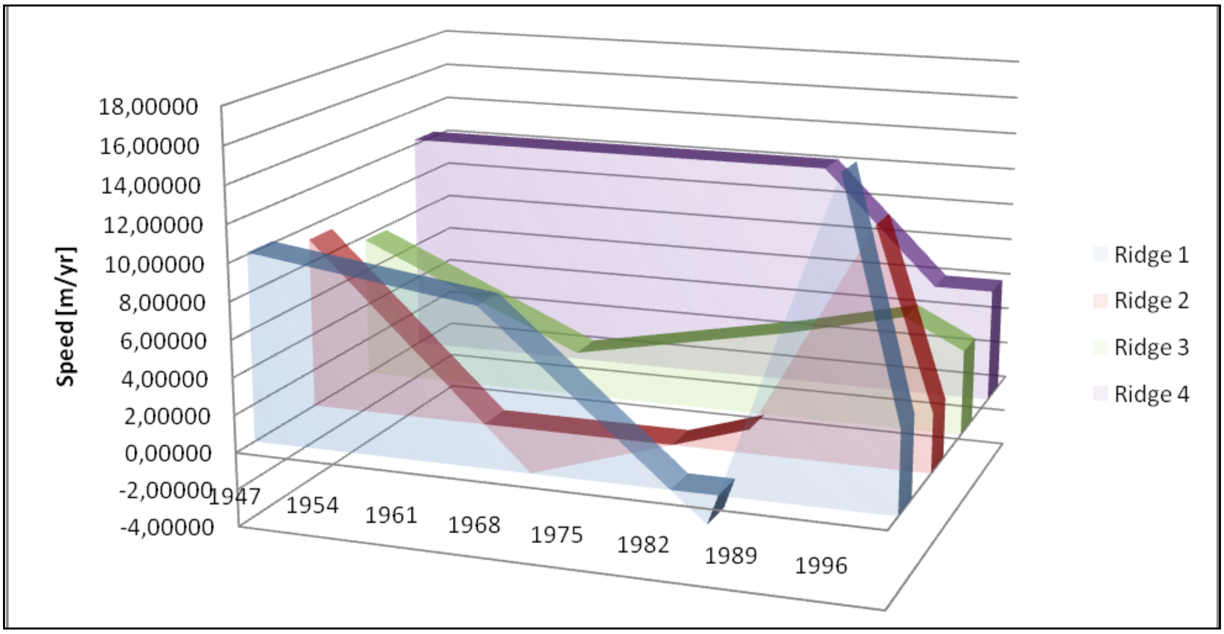


Figure C-9 Yearly average ridge migration speed per time interval and ridge for Moçambique Dune

Multiplying the yearly average migration speed with the period gives the total distance traveled by a ridge in that specific period. Averaging these numbers over the total period gives a weighted average of the yearly average migration speeds per ridge. The results of this calculation are given in Table C-5 and Figure C-10. The cumulative distribution of the total distance traveled per ridge is given in Table C-5 and Figure C-11.

Year	Period	Migration distances [m]				Average
		Ridge 1	*Ridge 2*	*Ridge 3*	*Ridge 4*	
1948	*19*	191,93800	176,44667	147,48222	233,29286	187,28994
1968	*21*	176,79000	-51,33692	50,33280	257,85000	108,40897
1986	*16*	-25,21846	20,51368	74,43200	196,45714	66,54609
1996	*4*	65,74750	49,96000	24,43333	24,46444	41,15132
2001	*6*	25,93125	18,75429	27,30000	36,69667	27,17055
Weighted average migration speed		6,59376	3,24754	4,90879	11,34487	6,52374

Table C-5 Total traveled distance by ridges per time interval and ridge for Moçambique Dune

Year	Period	Migration distances [m]				Average
		Ridge 1	*Ridge 2*	*Ridge 3*	*Ridge 4*	
1948	*19*	191,93800	176,44667	147,48222	233,29286	187,28994
1968	*21*	368,72800	125,10974	197,81502	491,14286	295,69891

1986	*16*	343,50954	145,62343	272,24702	687,60000	362,24500
1996	*4*	409,25704	195,58343	296,68036	712,06444	403,39632
2001	*6*	435,18829	214,33771	323,98036	748,76111	430,56687

Table C-6 Cumulative distance traveled by ridges per time interval and ridge for Moçambique Dune

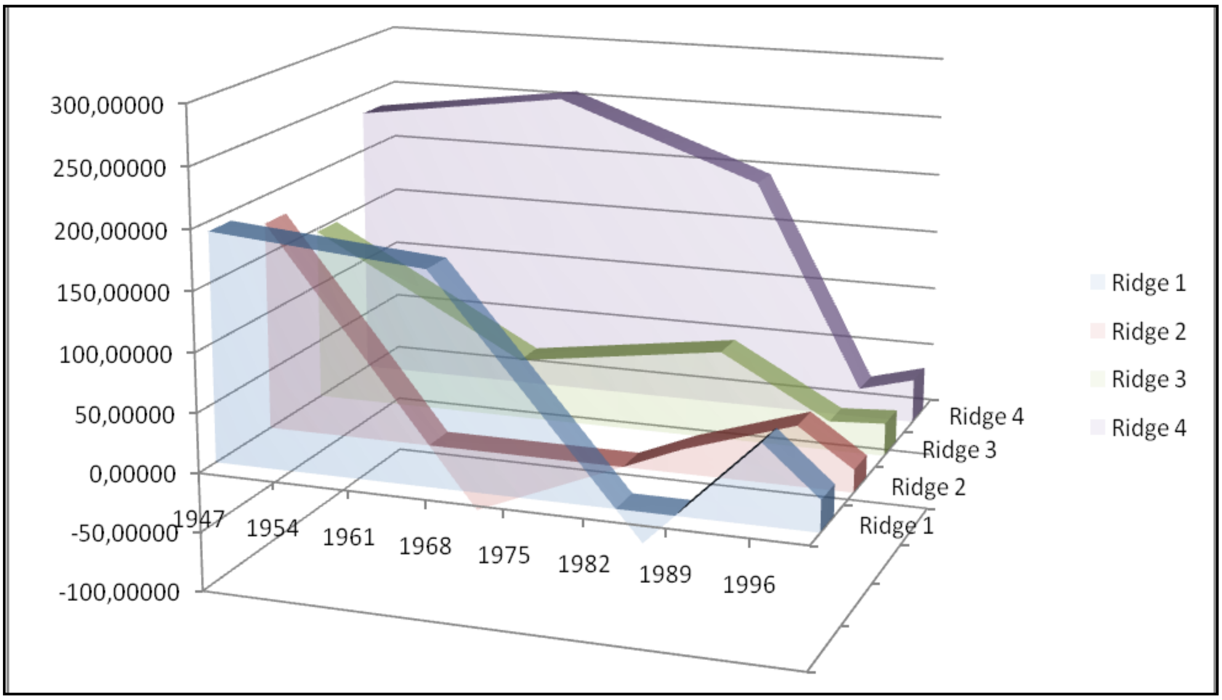


Figure C-10 Total traveled distance by ridges per time interval and ridge for Moçambique Dune

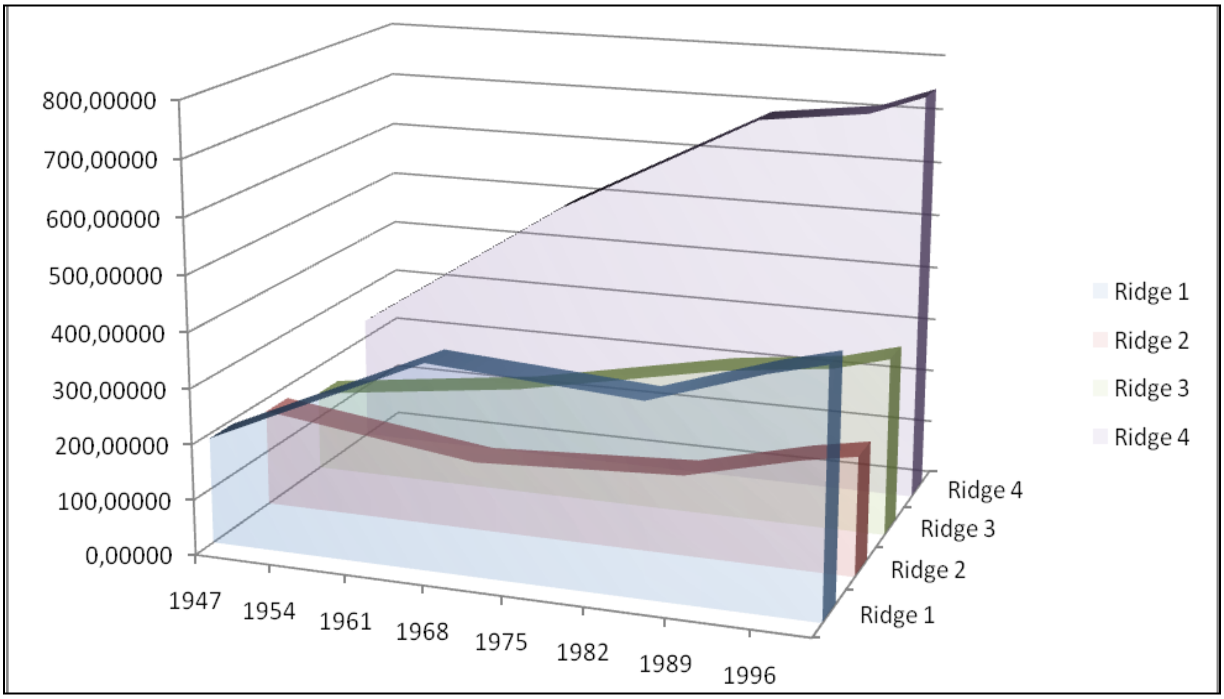


Figure C-11 Cumulative distance traveled by ridges per time interval and ridge for Moçambique Dune

C.4.1.2 Dune migration

As stated before, the ridge migration speed needs to be converted to a dune migration speed in order to get an estimation for the encroachment speed. This conversion is done with the factor calculated based on the definition of the migrating part: 0,49. The result of this conversion is given in the Table C-7 to Table C-9. Since the factor is constant, the graphs are equal to the graphs in the previous paragraph, except for the vertical axis.

Since the dune migration describes the progression of the front of the dune, it can be used to calculate the loss of surface area in front of the dune. Multiplication with the value of the this ground and the real estate that has been built on this ground gives an indication of the economic loss in case no measures are taken. This calculation is described in the reference solution in Appendix F.

Year	Period	Migration speeds [m / yr]				Average
		Ridge 1	*Ridge 2*	*Ridge 3*	*Ridge 4*	
1948	*19*	4,91900	4,52199	3,77968	5,97884	4,79988
1968	*21*	4,09928	-1,19036	1,16708	5,97884	2,51371
1986	*16*	-0,76748	0,62430	2,26521	5,97884	2,02522
1996	*4*	8,00366	6,08179	2,97435	2,97814	5,00948
2001	*6*	2,10446	1,52201	2,21555	2,97814	2,20504

Table C-7 Yearly average dune migration speed per time interval and ridge for Moçambique Dune

Year	Period	Migration distances [m]				Average
		Ridge 1	*Ridge 2*	*Ridge 3*	*Ridge 4*	
1948	*19*	93,46096	85,91772	71,81397	113,59801	91,19767
1968	*21*	86,08490	-24,99765	24,50871	125,55570	52,78791
1986	*16*	-12,27970	9,98879	36,24340	95,66148	32,40349
1996	*4*	32,01463	24,32718	11,89740	11,91255	20,03794
2001	*6*	12,62678	9,13208	13,29327	17,86882	13,23024
Weighted average migration speed		3,21072	1,58134	2,39025	5,52419	3,17663

Table C-8 Total distance traveled by dune front per time interval and ridge for Moçambique Dune

Year	Period	Migration distances [m]				Average
		Ridge 1	*Ridge 2*	*Ridge 3*	*Ridge 4*	
1948	*19*	93,46096	85,91772	71,81397	113,59801	91,19767
1968	*21*	179,54587	60,92007	96,32268	239,15371	143,98558

1986	*16*	167,26616	70,90887	132,56608	334,81520	176,38908
1996	*4*	199,28080	95,23604	144,46348	346,72774	196,42702
2001	*6*	211,90758	104,36813	157,75676	364,59656	209,65726

Table C-9 Cumulative distance traveled by dune front per time interval and ridge for Moçambique Dune

C.4.2 Santinho Dune

To be able to quantify the input from Santinho Dune more accurately than the 2007 project, a determination of its migration speed is necessary. The input might have been fluctuating around a certain average value in time. It is interesting to investigate the migration speed and to see how it develops in time.

C.4.2.1 Ridge migration

The yearly average ridge migration speed, averaged per ridge is given in Table C-10. The average ridge migration speed over the total period over the three ridges from 1994 until 2004 is 12,37 meter per year. The speed in all three ridges is around this average value and thus the spread is low and the reliability of this figure is high.

Year	Period	Migration speeds [m/yr]			Average
		Area 1	*Area 3*	*Area 4*	
1996	*4*	11,220	16,013	16,022	14,418
2001	*6*	10,608	8,791	11,544	10,314
1994 - 2004	*10*				12,366

Table C-10 Yearly average ridge migration speed per time interval and ridge for Santinho Dune

C.4.2.2 Sediment input

Figures from section C.3.1 are used to determine the sediment input of Santinho Dune. The average migrating cross section multiplied with the average ridge migration speed gives an average throughput of sediment:

$$V_{Santinho} = A_{m;migrating;avg} * u_{avg;time;ridges} = 2018[m^2]*12,366[m/year] = 24955[m^3/year]$$

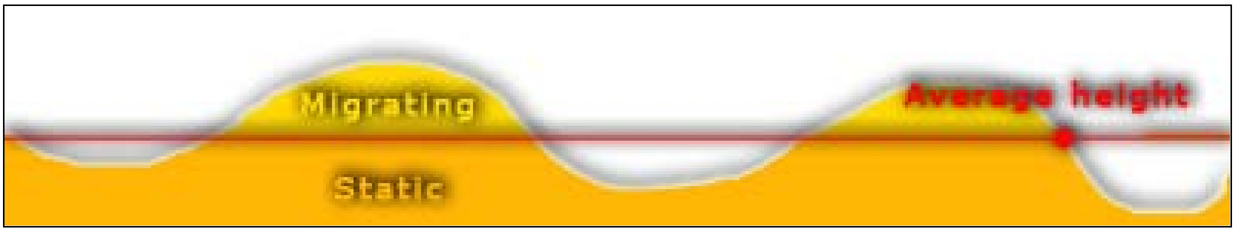


Figure C-12 Definition of the migrating part of the Santinho Dune

This estimation is based on the volume above the lowest trough of Santinho Dune. Santinho Dune has a very variable height and a less pronounced “wave”-shape as Moçambique Dune. This results in a lowest trough height for the dune , that might not be representative for the migrating part, because it is extremely low. The lowest troughs are located along the edges and in front of the dune. This is on the very border of the area of interest. Because of the troublesome application of the migrating part in the Santinho case, for Santinho Dune, the migrating part is calculated using the average height above the lowest point of the dune instead of the lowest trough (Figure C-12). This results in the figures presented in Table C-11.

Name	Formula	Value	Unit
Average height above MSL:	$H_{m;t;average}$	10,50	m
Volume above average height:	$V_{m,migrating}$	276490	m^3
Length:	L_m	530	m
Average cross-section area:	$A_{m;migrating;avg} = \frac{V_{m;migrating}}{L_m}$	522	m^2

Table C-11 Figures concerning migrating part of nothern section of Santinho Dune (average height)

The average cross section multiplied with the average migration speed now gives an average throughput of sediment based on the average height of area 1.

$$V_{Santinho} = A_{m;migrating;avg} * u_{avg;time;ridges} = 522[m^2]*12,366[m/year] = 6455[m^3/year]$$

The two values of sediment input from Santinho can be seen as an upper and lower boundary. The upper boundary is based on the assumption that the ridges, and thus the troughs, are formed by the wind and that the wind therefore migrates grains located in the troughs. The lower boundary, on the other hand, is based on the observation that the very strict definition of the migrating part of the dune might not be reasonable for the Santinho Dune. The truth might lie somewhere in the middle, although it is probable that it lies closer to the lower limit since the definition of the migrating part for this figure is adjusted to observed behavior of Santinho Dune. For this project, the sediment input from Santinho Dune is assumed to be 15000 m^3 per year.

Because of the relatively large margins in which the sediment input from Santinho Dune is calculated, it is advisable to investigate the definition of the migrating part of Santinho Dune more thoroughly. For example, it might be useful to define “the lowest trough” more wisely.

C.4.3 Historical sediment input

As proposed in Appendix D, the sediment bypass around the northern headland is first estimated using the historical sediment input. This means that, supposed that the bay of Ingleses was stable in the past, the sediment bypass is equal to the sediment input before the town of Ingleses was built. Because of the assumption that the sediment bypass around the southern headland is neglectable, the only sediment input comes from the dunes. To calculate this historical sediment input, the ridge migration speed needs to be multiplied by the average cross-section area of the migrating part. The result of this calculation for the Moçambique Dune is shown in Table C-12.

Year	Period	Migrating volumes [m^3/yr]				Average
		Ridge 1	*Ridge 2*	*Ridge 3*	*Ridge 4*	
1948	*19*	57525	52882	44201	69919	56132
1968	*21*	47939	-13921	13648	69919	29396
1986	*16*	-8975	7301	26490	69919	23684
1996	*4*	93598	71123	34783	34827	58583
2001	*6*	24610	17799	25909	34827	25787

Table C-12 Yearly average migrating volumes of sediment per time interval and ridge for Moçambique Dune

From the table can be seen that the historical sediment input in the period 1938 to 1957, before the town of Ingleses grew considerably, is about 56000 m^3 per year. This figure together with the sediment input from Santinho beach of approximately 15000 m^3 per year as calculated by the 2007 project, forms the supposed sediment bypass around the northern headland.

Appendix D Sediment bypass

During the 2007 research at beach Ingleses, the coastal morphological system is assumed to be a closed cell. In other words, assumed is that no sediment enters or leaves the system by long shore or cross shore transport. This assumption is highly unlikely to be true. One of the most pronounced phenomenon that indicates a significant long shore transport around the northern side of Santa Catharina Island (see Figure D-1) is the development of the Daniela spit.

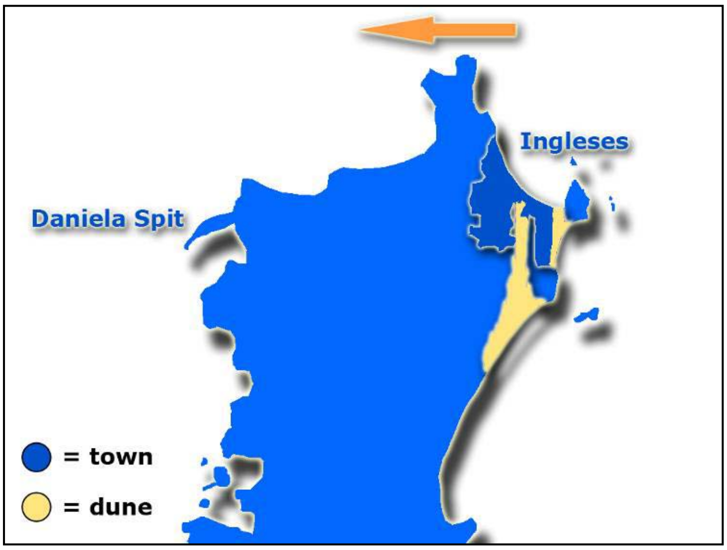


Figure D-1 Northern part of Santa Catharina Island with Ingleses Beach, the Daniela Spit and the littoral transport direction between these areas.

D.1 Daniela Spit

Extensive research has been done to the development of the Daniela Spit [Diehl, 1997]. This research does not accurately quantify the amount of long shore sediment transport. It is also questionable if any quantification of the long shore sediment transport at the Daniela Spit could be transformed to a reliable quantification of the transport at Ingleses Beach northern headland. Between the Daniela Spit and Ingleses beach are four embayed beaches located, of which three are categorised as *close to static* (Brava, Lagoinha do Norte and Ponta das Canas) and one is categorised as *dynamic* (Canasvieiras) [Klein, 2004]. Especially the dynamic beach makes a reliable transformation very difficult.

D.2 Ponta das Canas Spit

At the Ponta das Canas beach is also a spit development noticeable (see Figure D-2). Although no research has been done to this spit yet, it might provide a better indication of the long shore transport than any research to the Daniela Spit. Unfortunately, in general both theoretical and empirical quantification methods of long shore transport are still not reliable enough for design purposes [Schoonees and Theron, 1995; Pilkey and Cooper, 2002]. A solution to this problem is found by determining the long shore transport based on what is assumed to be the *historical sediment bypass*.

D.3 Historical sediment bypass

The historical sediment bypass is defined as the sediment bypass that occurred before any human intervention has taken place. It is likely and confirmed by the analysis of the aerial photograph from 1938 (see Appendix A), and thus assumed to be true, that before the town of Ingleses was established, the migration of the Mocambique dune field caused a sediment input to the Ingleses Beach.

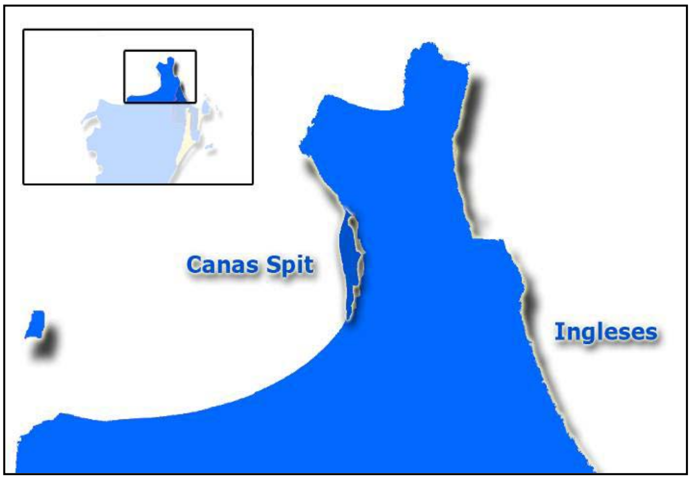


Figure D-2 Location of Canas Spit that might give a better indication of the long shore transport at Ingleses Beach than the Daniela Spit

The Santinho dune field is assumed to have provided a historical sediment input to Ingleses Beach with an amount that is similar to today's input. Furthermore, it is assumed that there is no significant sediment bypass along the southern headland and that the beach of Ingleses by that time was stable. These assumptions makes that the historical sediment bypass is equal to the historical sediment input.

$$S_{in;Santinho} + S_{in;Mocambique} = S_{out;North}$$

The assumption that the historical sediment bypass occurs still today, but the historical sediment input has been cut off by urbanisation at the town of Ingleses explains both the morphological changes at the beach of Ingleses as well as the development of the two spits at Ponta das Cansas and Daniela. To be able to quantify the historical sediment input an analysis of aerial photographs is made.

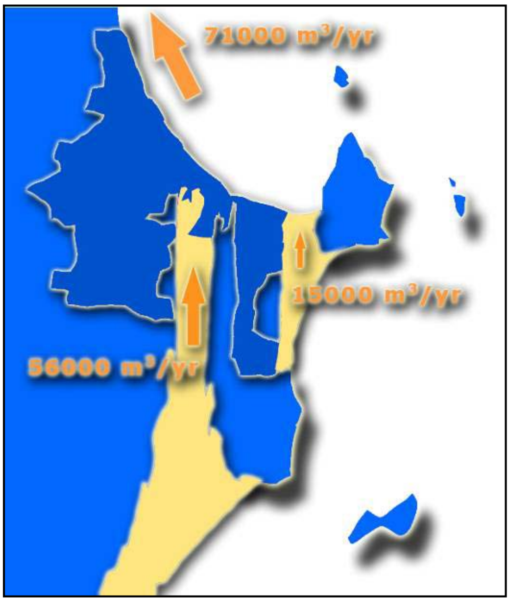


Figure D-3 Historical sediment input and output

D.4 Aerial photograph analysis

The 2007 research involved also a photograph analysis. Comments on this analysis and some arguments that support a new, more extensive analysis are given in Appendix A. Also, some general procedures involved with photograph analysis are described in this appendix.

On top of the dunes, sand ridges are located. These ridges are formed by the wind and form a wave pattern. The ridges are visible on most aerial photographs as long as the quality is sufficient. To obtain the migration speed of the Moçambique and Santinho Dune, these ridges are used as indication of the dune movement. In Appendix C is the analysis described in detail.

The result of the analysis shows that the historical sediment input from Moçambique Dune is about 56000 m^3 per year. The sediment input from the Santinho Dune is estimated to be 15000 m^3 per year. The total historical sediment input is therefore 71000 m^3 per year (see Figure D-3).

Appendix E Fieldtrips

E.1 Introduction

There have been several field trips to the area of interest in the months April and May of 2008. The first was to get an impression of the area and to become familiar with the situation and the occurring phenomena. Later on there have been two specific fieldtrips, one to collect sand samples and one to observe the real estate in the area.

E.2 Field trip 1: First impression

On the 8th of May we went on a fieldtrip to Ingleses to get a first impression of the area. First, we visited beach Ingleses where we got a good impression of the erosion of the beach. On several locations local people tried to protect their properties by dumping rock or asphalt in front of it, as shown in Figure E-1 and Figure E-2.

Figure E-1 Property protected by dump stones. Santinho Dune in the background.

Figure E-2 Property protected by dump stones and seawall. Northern headland in background.

After this, we visited the Santinho dune field. Here we saw the influx of the sand from the dune in the beach system. In the afternoon we went to see the Ponta das Canas spit. Project Ingleses 2007 assumed that there was no sediment outflow at the northern headland. We thought this wasn't true and wanted to check this at the Ponta das Canas spit. Growth of the spit would prove our theory of sediment outflow at the northern headland. At the spit we saw that the spit already travelled a distance in relation to our aerial photographs. We also had the opportunity to speak to a local fisherman who had been living there all his live. He told us that the spit was growing and the water became a lot shallower the past decades. This was already a bit of prove for our theory, but this had to be checked with aerial pictures. After this we went to visit the Moçambique dune field. Here we saw the enormous size of the dune. We also saw many of the measures that had been taken to try to stop the dune, like placing wooden windscreens and planting vegetation. We also visited one of the houses that was threatened by the dune. The Project Ingleses 2007 already visited this shed one year before us. Back then the shed was almost totally encroached by the migrating dune, but when we visited the shed, the house was excavated by the owners as shown in Figure E-3 and Figure E-4.

Figure E-3 Encroached shed in 2007

Figure E-4 Excavated shed in 2008

E.3 Field trip 2: Real estate

During the second field trip on the 30th of May, the real estate is observed. By comparing the buildings on the map with the buildings in reality, there is tried to get more insight in the different buildings and their properties in the area of interest.

There are several areas visited. One of these areas contains favelas. The houses in the favelas are built of all kind of cheap materials, self cut wood and waste material. Also the normal residential area in front of the dune field has been visited. This area contains only residential buildings. There are more valuable properties and less valuable properties but all buildings are of good quality.

The buildings along the beaches and in the centre of Ingleses are also observed. The special buildings in the centre of Ingleses (Figure E-5 and Figure E-6) have between 2 and 5 floors. Along the coast in the north (section *River South*, see Appendix C), there are significantly more special buildings, like hotels and apartments, then there are in the south along the coast (section *Moçambique Ridges*).

Figure E-5 Houses of class B

Figure E-6 Other buildings of class C

E.4 Field trip 3: Sand sampling

On the 6th of June we went to Ingleses to take some sand samples in the Moçambique Dune. Moçambique Dune is the borrow area of our choice. We wanted to take some samples of the borrow area and get some insight in the two different grain sizes in the dune. First we went to the borrow area of our choice and took three samples there. One sample was taken on the top of a dune ridge where we expected to find big grain sizes, another was taken at the toe of a dune ridge where we expected to find the smaller grain sizes. We also took one sample at the middle height of the dune ridge, we expected to find a mix of the both grain sizes here.

We also wanted to check if we would find both grain sizes at the Moçambique Beach, the source of the sand in the dune. And we wanted to take some samples between Moçambique beach and our borrow area to see if we would find both grain sizes here as well. The results of these samples are represented in Appendix G.

Appendix F Zero-solution

F.1 Introduction

The zero-solution describes what happens if nothing is done with the dune field to prevent further encroaching, or with the beach to prevent beach erosion. The costs and losses involved when nothing is done are needed as reference for the different solutions. In this appendix will be explained how the costs of the zero-solution are determined.

F.1.1 Method

To determine the costs and losses in case of the zero-solution, the loss of property per year due to the encroaching dunes and due to coastline regression have to be determined. The area that will be lost every year due to the encroaching dune can be derived from the migration speed of the dune. In the case of the loss of land based on the coastline regression, the coastline regression speed is used to determine the area that will be lost. The value of these areas depends on the value of the bare land and the value of the buildings on it. The determination of the speed of the encroaching dune is explained in Appendix C and the determination of the coastline regression is described in Appendix B. When the loss of area per year and the value of this area are known, the total loss can be calculated by multiplying the lost area with the corresponding value.

F.1.2 Classes of real estate

Because there are different kinds of real estate with different values, the areas in front of the dunes and near the coast are divided in several classes. Every class has its own specific properties. This is done to make a better and more accurate prediction of the total loss of value per year. The different properties are: the value per square meter bare land, the value per square meter building, the building cover ratio and the percentage of roads per square meter land. It is expected that the value of a square meter bare land is higher at the seaside and closer to the centre than in the areas more inland. The same holds for the value of a square meter building. The reason for this is that more wealthy people live at the seaside and wealthy people are capable of buying land at nicer spots and build more expensive buildings on this land.

Below, a list with definitions of some properties is given.

1. The value per square meter bare land: This is the price to buy one square meter of bare land.
2. The value per square meter building: This is the price to buy (or build) a square meter (in plan form) of building.

3. The building cover ratio: This is the percentage of buildings per square meter. A distinction is made between the final building cover ratio and the starting building cover ratio. The starting building cover ratio is the building cover ratio attained from the real-estate data. The final building cover ratio is the building cover ratio which is calculated taking into account the percentage of roads and bare land.

F.1.3 Properties of real estate classes

To be able to predict the loss of value, every class should have the right properties. The value per square meter bare land and the value per square meter of building can be determined from advertisements for real estate which are for sale. The building cover ratio is partly determined from advertisements of real estate agents and partly from the map of the area. The percentage of roads per square meter land is determined from a *Geographical Information System* (GIS, see Appendix O) only.

F.1.4 Annual loss

By drawing annual moving contour lines of the dune, the number of squared meters can be determined which will be buried under the dune every year. These annual moving contour lines are lines which represent the movement of the dune in one year. For every year the value of the buried area can be calculated by multiplying the buried area with a certain value of a square meter depending on the class of that area. The total loss of property per year is calculated by adding together the values of the buried areas of all different classes.

At the seaside the same method can be applied. But now the regression of the coastline is used as annual moving contour line.

F.2 Application method

F.2.1 Description of classes

The area is divided in four different real estate classes. Class A is the class with the lowest value per square meter; it contains *favelas*[1]

The classes C and D are the classes with the highest value per square meter but there is some difference in the building cover ratio between these two classes. These classes are the only ones which contain hotels, apartments, shops and restaurants. Therefore these classes will have an extra property: the special building cover ratio, this is the percentage of area that contains these special buildings like shops, hotels etc. Besides

[1] Favela = a residential area where people live with a very low living standard

that, class D is only threatened by the sea and class C can also be threatened (not in the near future) by the dune field.

Class B is the class for common inland real estate. The buildings are located between the front of the dune field and the centre of Ingleses or the coastline. It contains a mix of relatively cheap buildings and more expensive ones. The cheap and expensive buildings are mixed through the whole area so it is difficult to separate them. Because it is quite a big area, a good approximation for the different properties is expected.

All different classes and the areas they cover are presented in Figure F-1 and Figure F-2 below. No other areas are relevant because of the fact that only the areas in front of the dune and close to the shoreline are in threatened by the phenomena treated in this research.

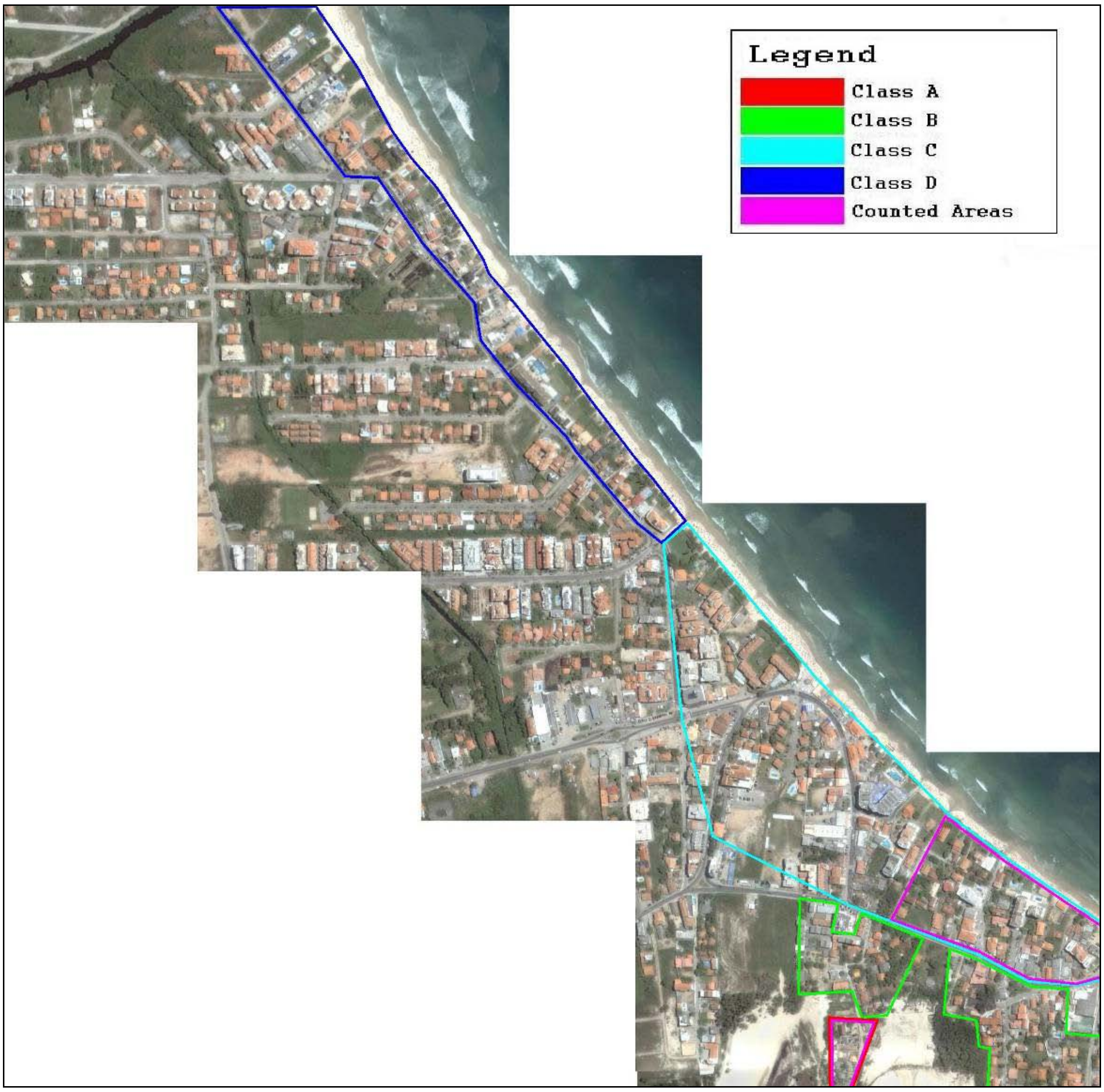


Figure F-1 Areas with definition of different classes (north)

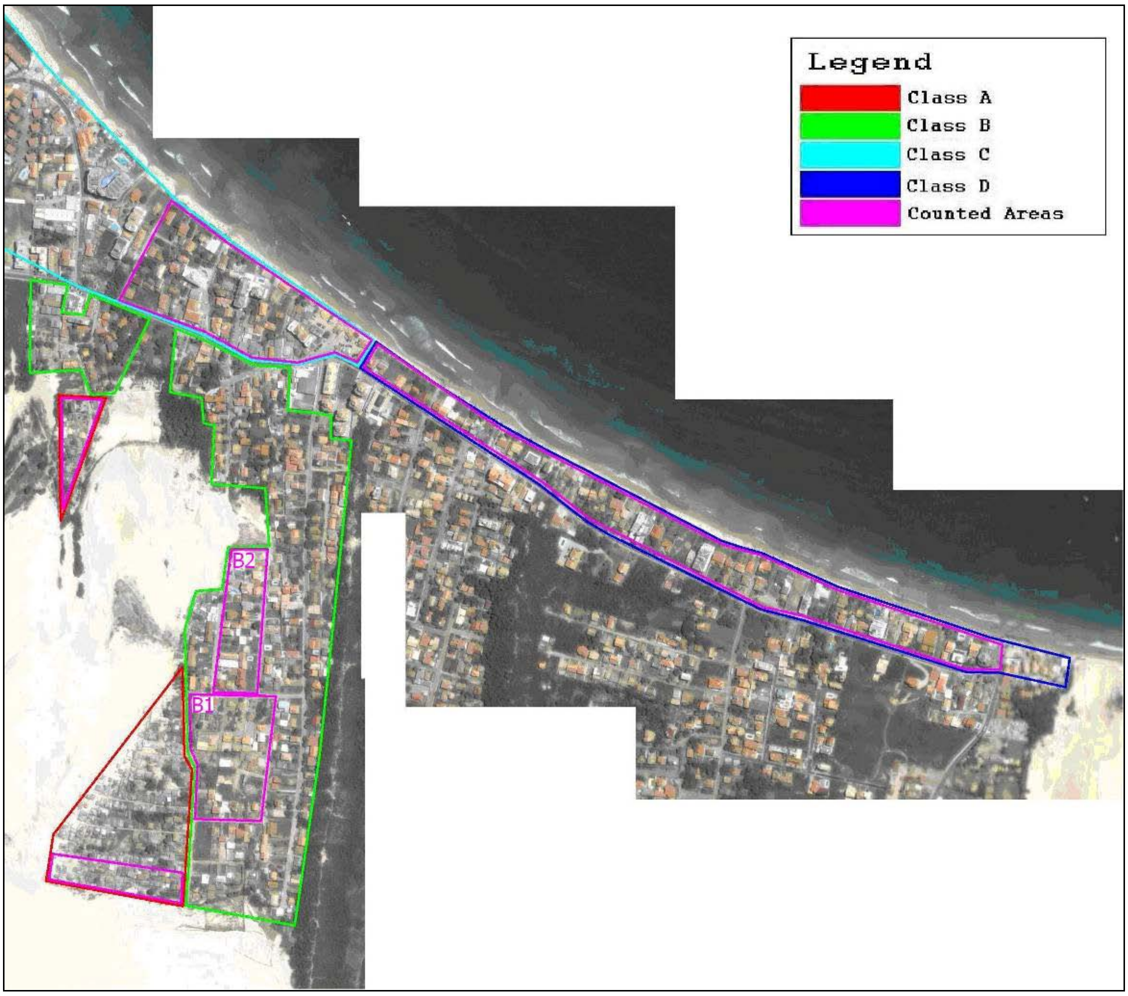


Figure F-2 Areas with different classes (south)

F.2.2 Value of bare land

The average value per square meter of bare land is determined from advertisements of real estate agents. In Table F-1 twenty areas that are used are listed. The areas are numbered to ease referencing. The second column gives the distance to the beach, if known. There are not a lot of advertisements that contain information about the distance to the beach. Because of that, no separation is made between bare land at the sea and bare land inland. The third column gives the total surface of the area while in the fourth column you can find the price to buy the area. In the fifth column you can find the price per square meter of land. Prices are given in the Brazilian currency: Real. The range in the fifth column is quite big; especially the first and the last (number 1 and number 20) are outliers. The last column gives the name of the agent from which the information is obtained.

Nr Area	Distance to beach	Total surface	Total value	Value	Source
	[m]	*[m²]*	*[R$]*	*[R$/m²]*	
1		51.800	1.500.000	28,96	Uniao
2		36.000	2.500.000	69,44	Casa & Cia
3		13.200	1.200.000	90,91	Casa & Cia
4		1.360	150.000	110,29	Uniao
5		405	53.000	130,86	Uniao
6		1.500	212.000	141,33	Uniao
7		1.566	250.000	159,64	Casa & Cia
8		1.833	300.000	163,67	Casa & Cia
9		8.033	1.400.000	174,28	Uniao
10	700	630	110.000	174,60	Uniao
11		398,4	70.000	175,70	Casa & Cia
12		252	45000	178,57	Casa & Cia
13		752	140.000	186,17	Casa & Cia
14		457	100.000	218,82	Casa & Cia
15	50	5.200	1.200.000	230,77	Uniao
16		365	85.000	232,88	Casa & Cia
17		3.160	800.000	253,16	Casa & Cia
18		13.000	3.300.000	253,85	Uniao
19		560	165.000	294,64	Casa & Cia
20	0	1.068	1.100.000	1.029,96	Casa & Cia

Table F-1 Information bare land (2008)

From the data of Table F-1 several statistics can be calculated. In Table F-2 several statistical values are given. As mentioned before, the maximum and minimum are outliers but are real data and are taken into account to determine a 95% confidence interval for the value per square meter bare land.

Property	Value [R$/m²]
Average	214,93
Maximum	1.029,96
Minimum	28,96
Average without maximum	172,03
Average without minimum	224,71
Average without maximum and minimum	179,98

Mean according to LogNorm,Distr,	169,80
Lower critical value	46,11
Upper critical value	625,26

Table F-2 Statistical information bare land

To determine the confidence interval, the data is analyzed with the computer program *BESTFIT* (see Appendix O). As said before, all data is handled at once and there is no separation made between seaside and inland in spite the seaside is expected to be much more expensive. Because of the fact that the value of a square meter of area cannot be negative, a lognormal distribution is expected. Therefore, first the natural logarithm is taken from the data (third column of Table F-3) so that the outcome of this transformation is expected to have a normal distribution. These values are analyzed with BESTFIT. The results are given in Table F-5 and Figure F-3. It seems that the assumption for a lognormal distribution is not that bad compared to the other distributions, according to the Chi-Squared and Kolomogorov-Smirnov tests. These tests are a measure how well a certain distribution fits to the data. From the result, a confidence interval can be calculated. This confidence interval is back transformed by taking the exponent of the results to critical values of a square meter of bare land.

Nr Area	Value [R$ / m^2]	Ln(Value)	Nr Area	Value [R$ / m^2]	Ln(Value)
1	28,96	3,37	11	175,70	5,17
2	69,44	4,24	12	178,57	5,18
3	90,91	4,51	13	186,17	5,23
4	110,29	4,70	14	218,82	5,39
5	130,86	4,87	15	230,77	5,44
6	141,33	4,95	16	232,88	5,45
7	159,64	5,07	17	253,16	5,53
8	163,67	5,10	18	253,85	5,54
9	174,28	5,16	19	294,64	5,69
10	174,60	5,16	20	1.029,96	6,94

Table F-3 Input BESTFIT

Property	Value
Minimum	3,370000
Maximum	6,940000
Mode	5,330126
Mean	5,134651

Std Deviation	0,678916
Variance	0,460927
Skewness	-0,058480
Kurtosis	5,023859

Table F-4 Statistical information input BESTFIT

Function	Chi-Square	Rank	K-S Test	Rank	A-D Test	Rank
Logistic(5,13;0,37)	0,53096	1	0,156758	1	0,666335	1
Triang(3,37;5,30;6,94)	0,565779	2	0,234602	7	1,864976	8
Weibull(7,59;5,53)	0,60042	3	0,261571	8	1,489651	7
Normal(5,13;0,68)	0,617696	4	0,176123	2	0,885526	2
Erlang(57,00;9,01e-2)	0,686964	5	0,194998	4	0,989653	4
Gamma(57,16;8,98e-2)	0,688716	6	0,194917	3	0,987572	3
Lognormal2(1,63;0,13)	0,736751	7	0,204347	6	1,078485	6
Lognormal(5,14;0,70)	0,736751	8	0,204347	5	1,078485	5
Beta(2,30;2,02) * 3,57 + 3,37	0,786662	9	0,287896	9	2,380144	9
HyperGeo(7,00;29,00;43,00)	0,996963	10	N/A		N/A	
Poisson(5;13)	2,443311	11	N/A		N/A	
Pareto(1,29;3,37)	3,513376	12	0,459681	11	5,273802	11
Chisq(6,00)	3,858561	13	0,404342	10	4,922982	10
Expon(5,13)	7,901046	14	0,512109	12	7,25642	12
NegBin(1,00;0,16)	7,932652	15	N/A		N/A	
Geomet(0,16)	8,776038	16	N/A		N/A	
Erf(9,26e-2)	14,49208	17	0,689984	13	13,09308	13
Binomial(6,00;0,86)	1,00E+34	18	N/A		N/A	

Table F-5 Results BESTFIT

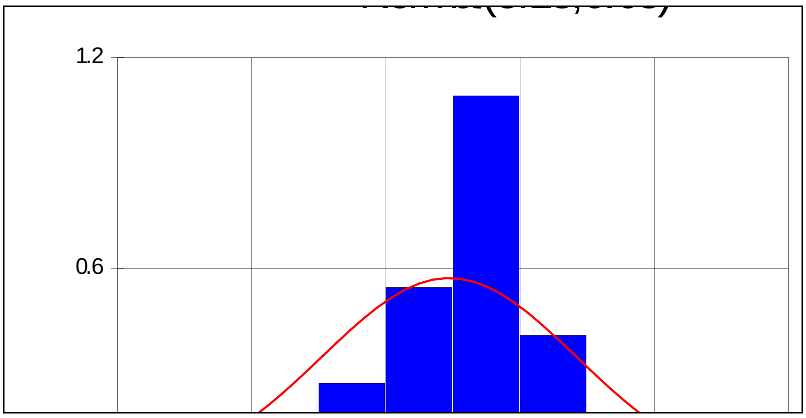


Figure F-3 Comparison of logarithm of data and normal distribution

In Table F-6 you can find which values are used for further calculations concerning bare land in this report. The lower and upper limits for the 95% confidence interval and the mean of the distribution are used. The maximum price per square meter bare land will not be used in further calculations because it is more than three times larger than the preceding value. Therefore it is expected that the maximum value is an outlier. As maximum value, the value one before the highest will be taken into account. The average and mean values are also included in this calculation.

Property	**Value**
Lower critical value	46,11
Mean (acc, To LogNorm,Distr,)	169,81
Average	214,93
One before maximum	294,64
Upper critical value	625,26

Table F-6 Values per square meter bare land, used for further calculation

F.2.3 Value of real estate

F.2.3.1 Dune encroachment area

In Table F-7 information is presented of the data which is used for the determination of the value of real estate, located inland. In Table F-7 there is a column added which gives the distance from the building to the centre of Ingleses. The first column gives numbers to ease make referencing. The fourth column gives the area of the parcel which contains buildings. Column five gives the total area of the parcel and column six gives the total price to buy it. The seventh column gives the percentage of build area. In the last column shows the name of the agent from which the information is obtained.

Nr building	**Distance to centre**	**Distance to beach**	**Total building surface**	**Total surface**	**Total value**	**Building cover ratio**	**Source**
	[m]	*[m]*	*[m^2]*	*[m^2]*	*[R$]*	*[%]*	
1	0	100	200	473	240.000	42,28%	Casa & Cia
2		150	300	450	210.000	66,67%	RoverImoveis
3		150	436	540	700.000	80,74%	Uniao
4	200	200	135	650	135.000	20,77%	Casa & Cia
5		280	450	1500	650.000	30,00%	Jesus Imoveis
6		850	140	360	110.000	38,89%	RoverImoveis
7		900	180	450	190.000	40,00%	Casa & Cia

8		2000	104	393	130.000	26,46%	Uniao
9	0		90	180	106.000	50,00%	Casa & Cia
10	0		90	600	195.000	15,00%	Casa & Cia
11	0		100	174	230.000	57,47%	Casa & Cia
12	50		110	450	150.000	24,44%	Casa & Cia
13	50		180	450	240.000	40,00%	Casa & Cia
14			170	381	200.000	44,62%	Uniao
15			120	536	210.000	22,39%	Uniao
16			173	375	250.000	46,13%	Uniao
17			300	600	1.100.000	50,00%	Uniao
18			60	364	75.000	16,48%	Casa & Cia
19			108	391	130.000	27,62%	Casa & Cia
20			110	360	135.000	30,56%	Casa & Cia
21			160	268	138.000	59,70%	Casa & Cia
22			120	370	160.000	32,43%	Casa & Cia
23			140	360	160.000	38,89%	Casa & Cia
24			125	300	230.000	41,67%	Casa & Cia
25			180	360	240.000	50,00%	Casa & Cia
26			240	360	270.000	66,67%	Casa & Cia
27			160	185	300.000	86,49%	Casa & Cia

Table F-7 Information real estate, inland (2008)

For the real estate given in Table F-7, a calculation of the price of a square meter of building is made. This is done by dividing the parcel in a part containing the building and a part that does not contain buildings. First, the price to buy the bare land is subtracted from the total price of the real estate. The price to buy the bare land is equal to the price of a square meter of bare land times the total parcel surface. The total price of the real estate can be found in Table F-7, column 6. The remaining part of the total price for the real estate is assumed to be the price for a building. The total surface which is covered by this building can be found in column 4 of Table F-7. The price per square meter building is obtained by dividing the price for the building by the total surface which is covered by this building. This can be done for several different prices for a square meter of bare land.

In formula form it looks like:

$$P_{m^2 building} = \frac{P_{realEstate} - P_{bareland} * S_{parcel}}{S_{BuildingOnParcel}}$$

$P_{m2building}$ = price for a square meter of building

$P_{realEstate}$ = total price of the real estate (Table F-7, column 6)

$P_{bare\ land}$ = price for a square meter bare land (values of Table F-6 used)

S_{parcel} = total parcel surface

$S_{BuildingOnParcel}$ = total surface which is covered by the building on the parcel

Table F-8 gives the results for this calculation. In the first row the prices for a square meter of bare land are displayed which are taken from Table F-6. In the first column the reference number of the building is given. In the following columns the prices for a square meter of building are given.

Nr Building	Lower critical value	Mean	Average	One before maximum	Upper critical value
	[46R$/m²]	*[170R$/m²]*	*[215R$/m²]*	*[295R$/ m²]*	*[625R$/m²]*
1	1.090,95	798,40	691,69	503,18	*-278,74*
2	630,84	445,29	377,61	258,04	*-237,89*
3	1.548,40	1.395,19	1.339,31	1.240,58	831,10
4	777,99	182,40	*-34,85*	*-418,64*	*-2.010,51*
5	1.290,74	878,41	728,01	462,31	*-639,76*
6	667,15	349,06	233,04	28,07	*-822,10*
7	940,28	631,03	518,23	318,96	*-507,59*
8	1.075,76	608,31	437,81	136,60	*-1.112,76*
9	1.085,56	838,16	747,92	588,50	*-72,74*
10	1.859,27	1.034,60	733,80	202,40	*-2.001,73*
11	2.219,77	2.004,53	1.926,02	1.787,33	1.212,05
12	1.175,00	668,96	484,38	158,29	*-1.194,25*
13	1.218,06	908,81	796,01	596,73	*-229,82*
14	1.073,13	795,90	694,77	516,13	*-224,85*
15	1.544,04	991,52	789,98	433,94	*-1.042,83*
16	1.345,14	1.077,00	979,20	806,42	89,75
17	3.574,45	3.327,05	3.236,81	3.077,39	2.416,15
18	970,27	219,82	*-53,91*	*-537,48*	*-2.543,24*
19	1.036,77	588,93	425,58	137,00	*-1.059,97*
20	1.076,37	671,53	523,87	263,00	*-819,03*
21	785,27	578,07	502,49	368,98	*-184,81*

22	1.191,16	809,75	670,63	424,86	*-594,55*
23	1.024,29	706,20	590,18	385,21	*-464,95*
24	1.729,34	1.432,46	1.324,17	1.132,86	339,38
25	1.241,11	993,71	903,47	744,05	82,81
26	1.055,84	870,29	802,61	683,04	187,11
27	1.821,69	1.678,66	1.626,49	1.534,32	1.152,04

Table F-8 Price / m^2 building for different values of bare land (inland)

Table F-9 gives some statistics of the prices for a square meter of building, determined from the data in Table F-8. The last column gives many negative values which is not possible in reality. The highest price for a square meter building is highly influenced by the lowest value for a square meter bare land. It is expected that the highest price for a square meter building is not valid for the real estate in front of the migrating dune field because these areas are close to favelas and the price will be influenced by the presence of the favelas. The maximum value for a square meter building (see Table F-9) seems implausible because the maximum value for a square meter building at the coast, there where the wealthy people live, is much smaller than the maximum value for a square meter building of the areas in front of the dunes. (Table F-12).

Property	**Lower critical value**	**Mean**	**Average**	**One before maximum**	**Upper critical value**
	[46R$/$m^2$]	*[170R$/$m^2$]*	*[215R$/$m^2$]*	*[295R$/ m^2]*	*[625R$/$m^2$]*
Average	1.298,10	943,85	814,64	586,37	*-360,43*
Maximum	3.574,45	3.327,05	3.236,81	3.077,39	2.416,15
Minimum	630,84	182,40	*-53,91*	*-537,48*	*-2.543,24*
Average without max	1.210,54	852,19	721,48	490,56	*-467,23*
Average without min	1.323,76	973,14	848,05	629,60	*-276,48*
Average without max and min	1.233,73	878,98	752,50	531,69	*-384,19*
Average without 2 highest and min	1.192,65	832,09	703,60	479,37	*-450,70*
Average without 2 highest and 2 lowest values	1.202,32	858,71	736,53	523,58	*-359,71*

Table F-9 Statistics price / m^2 building, inland

F.2.3.2 Coastal area

For the real estate next to the beach there is also some information found, see Table F-10. The column with information about the distance to the centre is removed because there was not enough information available. All buildings are situated along the coastline. The table has the same lay-out as Table F-7.

Nr Building	Total building surface	Total surface	Total value	Building cover ratio	Source
	[m^2]	*[m^2]*	*[R$]*	*[%]*	
28	290	450	500.000	64,44%	RoverImoveis
29	650	1.500	1.500.000	43,33%	Uniao
30	220	540	350.000	40,74%	Uniao
31	200	430	300.000	46,51%	Patricia Correa
32	216	558	350.000	38,71%	Casa & Cia
33	520	1.160	1.300.000	44,83%	Casa & Cia

Table F-10 Information real estate, coast (2008)

For the real estate next to the beach the value per square meter building is calculated. The same bare land prices are used as for the calculation which is done for the buildings in front of the dune. The results are represented in Table F-11.

Nr Building	46R$/$m^2$	170R$/$m^2$	215R$/$m^2$	295R$/$m^2$	625R$/$m^2$
28	1.652,59	1.460,64	1.390,63	1.266,94	753,91
29	2.201,28	1.915,82	1.811,70	1.627,75	864,78
30	1.477,73	1.174,10	1.063,35	867,70	56,18
31	1.400,86	1.134,91	1.037,90	866,52	155,69
32	1.501,25	1.181,69	1.065,13	859,22	5,12
33	2.397,14	2.121,19	2.020,54	1.842,73	1.105,19

Table F-11 Price/m^2 building for different values of bare land, coast

The statistics for the values per square meter building, which are obtained from the results in Table F-11, are presented in Table F-12. The minimums are much higher for this area than for the buildings in front of the dune field. This satisfies the expectation that the real estate near the beach is more expensive. The maximums are much lower, which confirms the rejection of the maximum value per square meter for the buildings in front of the dune.

Property	46R$/$m^2$	170R$/$m^2$	215R$/$m^2$	295R$/$m^2$	625R$/$m^2$
Average	1.771,81	1.498,06	1.398,21	1.221,81	490,14

Maximum	2.397,14	2.121,19	2.020,54	1.842,73	1.105,19
Minimum	1.400,86	1.134,91	1.037,90	859,22	5,12
Avr. without maximum	1.646,74	1.373,43	1.273,74	1.097,63	367,14
Avr. without minimum	1.846,00	1.570,69	1.470,27	1.294,33	587,15
Avr. without max. and min.	1.708,21	1.433,06	1.332,70	1.157,23	457,64

Table F-12 Statistics price / m^2 building, coast

F.2.4 Building cover ratios, roads and other buildings

To be able to calculate the total loss of value per year it is also needed to know what the building cover ratio, the percentage of bare land and roads is.

From the building cover ratios of Table F-7 and Table F-10, building cover ratio statistics are calculated, which are presented in Table F-13. The biggest range is found inland. Inland is the average building cover ratio some percentages lower than in the coastal area. This can be explained by the bigger popularity of the coastal area. However, the averages of Inland, Coast and All differ not much.

Property	Inland	Coast	All
Minimum	15,00%	38,71%	15,00%
Average	42,46%	46,43%	43,18%
Maximum	86,49%	64,44%	86,49%

Table F-13 Building cover ratios

Table F-14 gives some properties for the different classes of real estate which are defined in paragraph F.2.1. In the favela (class A) there are no bare parcels. Only the classes C and D contain other buildings like shops, hotels, apartments and restaurants. From class B are two parts measured, area B_1 and B_2 (see Figure F-2 for areas). B_{total} is the average of the measurements of B_1 en B_2.

Class	Measured surface	Nr of parcels	Nr of bare land	% of bare land	Nr of other buildings	% of other buildings
	[m^2]					
A	11.466	36	0	0%	0	0%
B_1	21.937	40	6	15,00%	0	0%
B_2	12.933	32	2	6,25%	0	0%
B_{total}	34.870	62	8	12,90%	0	0%
C	46.499	25	0	0%	8	32,00%
D (with main road)	62.652	38	3	7,89%	7	18,42%

D (without main road)	57.322	38	3	7,89%	7	18,42%

Table F-14 Percentage of bare land and special buildings

In Table F-15 percentages of the total measured area that contains roads are given for the classes B_1 and D. A distinction is made in class D concerning the inclusion of the main road (the road on the landside behind the buildings) in the calculations. A calculation is done in which the main road is taken into account and a calculation in which the main road is not taken into account. It is assumed that the percentages of road surface differ not much per class, so an average is taken as representative for all classes inland. The coastal zone (class D) differs from the other classes because of the fact that the main road will only be threatened when the buildings of class D are lost.

Class	Surface of road (m^2)	% of road
B_1	1.743,15	13,48%
D (without main road)	1.033,50	1,80%
D (with main road)	6.363,65	10,16%
Average (all inland classes (A,B and C)	-	10,73%

Table F-15 Percentage of road

F.2.5 Resulting cover ratios

All the numbers which are represented in the foregoing paragraphs can be converted to percentages of surface use. These percentages represent the distribution of surface use, per class.

From the total measured surface, first the road surface is subtracted. After that, the surface of bare land is calculated. The surface that remains from the total surface is the area that contains the parcels with buildings. Together with the building cover ratio (Table F-13), the total area which is covered with buildings can be calculated. The left over is the area that contains gardens etcetera and can be added to the area of bare land to get the total area of bare land. From all these areas, the percentage of buildings, roads and bare land can be calculated.

Class	A	B	C	D
Index road (%)	10,37%	10,37%	10,37%	1,80%
Index bare land (%)	0%	9,32%	8,25%	7,19%
Total measured area (m^2)	11.466	34.870	46.499	57.322
Total road surface	1.230	3.740	4.987	1.034
Total bare parcel surface	0	3.659	3.601	4.119

Total parcel area	10.236	27.471	41.512	52.170
Lower limit total bare surface (m^2)	1.383	3.711	14.762	18.552
Upper limit total bare surface (m^2)	8.701	23.350	25.443	31.975
LL building surface (m^2)	1.535	4.121	16.069	20.195
UL building surface (m^2)	8.853	23.760	26.750	33.618
Average total bare surface (m^2)	5.890	15.807	22.238	27.947
Average building surface (m^2)	4.346	11.664	19.274	24.222
Lower Final Building Cover Ratio	13,39%	11,82%	34,56%	35,23%
Average Final Building Cover Ratio	37,91%	33,45%	41,45%	42,26%
Upper Final Building Cover Ratio	77,21%	68,14%	57,53%	58,65%

Table F-16 Surface use per class

The numbers given in the last three rows of Table F-16 show per class, the percentage of a square meter that contains buildings (further called the final building cover ratio). In the table an upper limit, average and lower limit is given for every class.

F.2.6 Value of a square meter

With the final building cover ratios, the percentage of road and the prices for a square meter bare land and building, it is possible to calculate the value of a square meter of a specific class. The value of one square meter consists of the worth of the bare land plus the final building cover ratio times the costs of a square meter of built-up area. Officially the value of a square meter of road times the percentage of roads have to be added but this is not done here because the value of a square meter of road is much lower than that of the buildings and bare land. The contribution to the total value is negligible compared to the other properties and therefore assumed to be zero.

The value of a square meter of land for a specific class is calculated as follows:

$$R\$/m^2 = 1 * R\$/m^2 Bareland + FinCoverRatio * R\$/m^2 building$$

This calculation can be made for every combination of values for a square meter of bare land and building from Table F-9 and Table F-12 and for every final building cover ratio given in the last three rows of Table F-16. For class B, Table F-9 is used and for the classes C and D, Table F-12 is used. The calculation for class A is skipped because there are no prices available for a square meter of built-up area. This is because class A contains favelas and the buildings there are build of all kind of low quality materials and will not be sold by a real estate agent (see Appendix E).

Price bare land [R$/m²]	**46**	**170**	**215**	**295**	**625**
Average [R$/m²]	930,64	812,95	770,03	694,19	379,66
Maximum [R$/m²]	2.481,74	2.436,86	2.420,49	2.391,57	2.271,62
Minimum [R$/m²]	475,96	294,10	178,20	-71,60	-1.107,70
Average without max [R$/m²]	870,97	750,49	706,55	628,91	306,89
Average without min [R$/m²]	948,12	832,91	792,79	723,65	436,87
Avg. without max and min [R$/m²]	886,77	768,75	727,68	656,93	363,47

Table F-17 Values per square meter (for maximum final building cover ratio, class B)

Price bare land [R$/m²]	**46**	**170**	**215**	**295**	**625**
Average [R$/m²]	480,32	485,53	487,43	490,78	504,70
Maximum [R$/m²]	1.241,76	1.282,71	1.297,64	1.324,03	1.433,46
Minimum [R$/m²]	257,13	230,82	196,90	114,85	-225,45
Average without max [R$/m²]	451,04	454,87	456,27	458,73	468,97
Average without min [R$/m²]	488,91	495,33	498,60	505,24	532,78
Avg. without max and min [R$/m²]	458,79	463,83	466,64	472,49	496,75

Table F-18 Values per square meter (for average final building cover ratio, class B)

Price bare land [R$/m²]	**46**	**170**	**215**	**295**	**625**
Average [R$/m²]	199,55	281,37	311,22	363,95	582,66
Maximum [R$/m²]	468,61	563,07	597,52	658,39	910,85
Minimum [R$/m²]	120,68	191,37	208,56	231,11	324,65
Average without max [R$/m²]	189,20	270,54	300,21	352,62	570,03
Average without min [R$/m²]	202,58	284,84	315,17	369,06	592,58
Avg. without max and min [R$/m²]	191,94	273,71	303,88	357,49	579,85

Table F-19 Values per square meter (for minimum final building cover ratio, class B)

For the classes C and D an extra factor is added for the special buildings that are placed in these areas. The factor that is added, consist of the number of *extra* floors that the special buildings have. An assumption is made for the number of extra floors that these buildings have. Based on the observations of the fieldtrip (see Appendix E) there are three extra floors added. The assumed values for the different parameters which are used in the calculation of the increased price due to special buildings are shown in Table F-20. The values in the second row are obtained from the values of the last row of Table F-14.

The factor that is added to the value per square meter is:

$$AddedR\$/m^2 = FinCoverRatio * \%OtherBuildings * R\$/m^2 building * Nr.ExtraFloors$$

Class	C	D
% other buildings	32,00	18,42
Nr. Extra Floors	3	3

Table F-20 Assumed values for parameters to calculate the additional factor

Price bare land [R$/m^2]	46	170	215	295	625
Average [R$/m^2]	2.043,98	1.859,00	1.791,53	1.672,34	1.177,94
Maximum [R$/m^2]	2.749,10	2.561,64	2.493,27	2.372,48	1.871,46
Minimum [R$/m^2]	1.625,70	1.449,52	1.385,25	1.263,49	631,03
Average without max [R$/m^2]	1.902,95	1.718,47	1.651,18	1.532,31	1.039,24
Average without min [R$/m^2]	2.127,64	1.940,90	1.872,79	1.754,11	1.287,32
Avg. without max and min [R$/m^2]	1.972,27	1.785,71	1.717,67	1.599,52	1.141,29

Table F-21 Values per square meter (for maximum final building cover ratio, class C)

Price bare land [R$/m^2]	46	170	215	295	625
Average [R$/m^2]	1485,56	1386,86	1350,86	1287,26	1023,46
Maximum [R$/m^2]	1993,59	1893,11	1856,46	1791,71	1523,14
Minimum [R$/m^2]	1184,20	1091,83	1058,14	992,69	629,42
Average without max [R$/m^2]	1383,95	1285,61	1249,74	1186,38	923,53
Average without min [R$/m^2]	1545,84	1445,87	1409,41	1346,18	1102,27
Avg. without max and min [R$/m^2]	1433,89	1334,06	1297,64	1234,80	997,06

Table F-22 Values per square meter (for average final building cover ratio, class C)

Price bare land [R$/m^2]	46	170	215	295	625
Average [R$/m^2]	1246,29	1184,56	1162,04	1122,26	957,27
Maximum [R$/m^2]	1669,88	1606,65	1583,60	1542,86	1373,89
Minimum [R$/m^2]	995,02	938,57	917,98	876,66	628,73
Average without max [R$/m^2]	1161,57	1100,14	1077,73	1038,15	873,95
Average without min [R$/m^2]	1296,55	1233,76	1210,86	1171,39	1022,98
Avg. without max and min [R$/m^2]	1203,21	1140,53	1117,67	1078,52	935,25

Table F-23 Values per square meter (for minimum final building cover ratio, class C)

Price bare land [R$/m^2]	46	170	215	295	625
Average [R$/m^2]	1659,52	1533,94	1488,14	1407,22	1071,58
Maximum [R$/m^2]	2228,95	2101,37	2054,83	1972,63	1631,65

Minimum [R$/m^2]	1321,73	1203,26	1160,04	1077,05	629,92
Average without max [R$/m^2]	1545,63	1420,46	1374,80	1294,14	959,58
Average without min [R$/m^2]	1727,08	1600,08	1553,76	1473,26	1159,92
Avg. without max and min [R$/m^2]	1601,61	1474,75	1428,49	1348,41	1041,99

Table F-24 Values per square meter (for maximum final building cover ratio, class D)

Price bare land [R$/m^2]	**46**	**170**	**215**	**295**	**625**
Average [R$/m^2]	1208,65	1152,73	1132,34	1096,30	946,85
Maximum [R$/m^2]	1618,94	1561,58	1540,66	1503,71	1350,41
Minimum [R$/m^2]	965,25	914,46	895,93	858,40	628,62
Average without max [R$/m^2]	1126,58	1070,96	1050,67	1014,83	866,15
Average without min [R$/m^2]	1257,32	1200,38	1179,62	1143,89	1010,51
Avg. without max and min [R$/m^2]	1166,92	1110,08	1089,35	1053,93	925,53

Table F-25 Values per square meter (for average final building cover ratio, class D)

Price bare land [R$/m^2]	**46**	**170**	**215**	**295**	**625**
Average [R$/m^2]	1015,26	989,22	979,72	962,95	893,36
Maximum [R$/m^2]	1357,30	1330,06	1320,13	1302,58	1229,78
Minimum [R$/m^2]	812,35	790,58	782,64	764,62	628,06
Average without max [R$/m^2]	946,85	921,05	911,64	895,02	826,08
Average without min [R$/m^2]	1055,84	1028,95	1019,14	1002,61	946,42
Avg. without max and min [R$/m^2]	980,47	953,67	943,89	927,62	875,58

Table F-26 Values per square meter (for minimum final building cover ratio, class D)

From Table F-17 until Table F-26 (excluding Table F-20) it is possible to attain a minimum and maximum price per square meter. These prices are shown in Table F-27. Besides that, also the price per square meter which is attained by the combination of the mean price per square meter bare land, average building price per square meter and the average final building cover ratio is given. This shows that the minimum price per square meter land for class B is negative, which is not possible. In paragraph F.3 will be explained what is done with this negative minimum price per square meter.

Class	**B**	**C**	**D**
Minimum price/m^2 [R$]	-1107,70	628,73	628,06
Mean bare land, average building [R$]	485,53	1386,86	1152,73
Maximum price/m^2 [R$]	2481,74	2749,10	2228,95

Table F-27 Statistics of values per square meter

F.2.7 Annual moving contour lines

The determination of the dune movement is described in Appendix C. To determine the annual loss of surface, a calculation is made with a lower limit dune movement rate and with an upper limit dune movement rate. The used values of the dune movement rates are shown in Table F-28. The last row shows the approximation for the dune movement rate which is based on the most recent data. This is also the minimum value for the dune movement rate.

Property	Rate
Loss/year (average [m])	3,31
Loss/year (max [m])	5,01
Loss/year (1998-2004 [m])	2,21

Table F-28 Dune movement rates

It is assumed that the annual dune-moving contours have the present-day dune field shape. In Figure F-4 the Moçambique dune field is shown. There are also some lines displayed which show the parts of the dune field that will harm the buildings. The red lines give the dune field parts that harm the favelas. The green lines give the parts of the dune fields that will harm the buildings of class B.

The length of the lines is taken the same as the width of de migrating section of the dune field. This results in a total loss of surface that is equal to the length of the line times the dune movement rate. The width of the different sections is measured in a *geographical information system* (GIS) (see Appendix O). Section B_b has the same width as section A_a. Section B_b is located behind section A_a, thus when the favela is buried, the dune will move further over the buildings of class B. This means that section B_b is not in direct danger of being encroached by the dune field but section A_a is. This means also that the buildings behind the line of section B_b will be lost only after several years. The same is valid for section A_a because the favela is build in a kind of dune valley which starts about 80 meters further dune inward (rough estimate).

Figure F-4 Moçambique dune field with different migrating dune sections

Section	A_a	A_b	B_a	B_b	B_c	B_d
Width [m]	71	209	42	71	170	157

Table F-29 Migrating dune sections and their width

With the dune movement rates given and the different sections defined it is possible to calculate the annual loss of surface per section. Table F-30 and Table F-31 give the results for the class A respectively class B. In the last column of the tables a rough estimate of the time before the dune will move over the section is given. For section B_b the time before the dune will move over is 53 years minimum, which is much more then the time span for which other solutions are calculated. Because of this, section B_b is not taken into account for the calculation of the loss of annual value.

Dune section	Min. loss/year	Avg. loss/year	Max. loss/year	Time delay
	[m^2]	*[m^2]*	*[m^2]*	*[years]*
A_a	156,91	235,01	335,71	16 á 36
A_b	461,89	691,79	1047,09	0
A_{total}	618,8	926,8	1402,80	-

Table F-30 Values of loss of surface, class A

Dune section	Min. loss/year	Avg. loss/year	Max. loss/year	Time delay
	[m^2]	*[m^2]*	*[m^2]*	*[years]*
B_a	92,82	139,02	210,42	0
B_b	*179,01*	*268,11*	*405,81*	*54 á 122*
B_c	375,7	562,7	851,7	0
B_d	316,03	473,33	716,43	0
B_{total}	784,55	1175,05	1778,55	0

Table F-31 Values of loss of surface, class B

For the coastal zone, the coastline regression is taken as the annual moving contour line. The coast is divided in several parts (see Appendix B for the definition of the different parts.) For each of these parts a specific value of annual coastline regression is taken into account, see Table F-32. More about how these values are calculated can be found in Appendix B. The last two sections show a negative regression which means that there is accretion of the beach, there is no loss of property so these sections are not taken into account any further.

Section	Annual coastline regression	Length of section
	[m/year]	*[m]*
Interdune (Class D)	1,19	788
Mozambique Ridges (Class D)	2,47	388
Mozambique Dunes (Class C)	1,25	530
River South (Class C)	-0,24	425
River South (Class D)	-0,24	1057

Table F-32 Coastline regression rates

From the annual coastline regression and the length of the coastline for which the value is representative, the yearly loss of land (in square meters) can be calculated. The results are shown in Table F-33. In the last column of the table a rough estimate for the time delay before the loss of the parcels will start is given. In front of the buildings is some beach left which have to be eroded away before the parcels itself start to erode.

Coast	Loss/year	Time delay
	[m/year]	*[years]*
Interdune (Class D)	937,72	8,65
Mozambique Ridges (Class D)	958,63	5,67
Mozambique Dunes (Class C)	662,50	11,20
River South (Class C)	*-102,00*	*0*
River South (Class D)	*-253,68*	*0*
Total Coast	2558,58	-

Table F-33 Values of loss of land for the classes C and D

F.3 Calculation of the annual loss

In paragraph F.2.6 there are values calculated of a square meter of land for the classes B until D. In Table F-27 the results are given. Because there are no values available for class A and the minimum price per square meter for class B is negative, some assumptions are made. The minimum price for the classes C and D are about half of the averaged. The same is done for class B (and A). So the minimum price per square meter for class B becomes about 250 R$. The values for class A are estimated. The values which are used to calculate the annual loss of property are displayed in Table F-34.

Class	A	B	C	D
Minimum price/m^2 [R$]	*75*	*250*	628,73	628,06
Mean bare land, average building [R$]	*150*	485,53	1386,86	1152,73

Maximum price/m^2 [R$]	*250*	2481,74	2749,10	2228,95

Table F-34 Values of prices/m^2, used to calculate annual property loss

The lost value per year is calculated by multiplying the annual lost area with the price of that area. This can be done for every section in front of the dune field and for every combination of price per square meter and dune movement rate. The results for the dune field are shown in Table F-35 until Table F-37. In Table F-35 the minimum prices per square meter are used to determine the annual losses. In Table F-36 and Table F-37 are respectively the average and maximum prices per square meter given. The last row of every table shows the total loss due to the dune movement for that specific combination of price per square meter and dune movement rate.

Section	Lost value per year for minimum dune movement rate	Lost value per year for average dune movement rate	Lost value per year for maximum dune movement rate
	[R$]	*[R$]*	*[R$]*
A_a	11.768,25	17.625,75	26.678,25
A_b	34.641,75	51.884,25	78.531,75
B_a	23.205,00	34.755,00	52.605,00
B_c	93.925,00	140.675,00	212.925,00
B_d	86.742,50	129.917,50	196.642,50
Total	250.282,50	374.857,50	567.382,50

Table F-35 Lost value per year calculated with minimum price per square meter

Section	Lost value per year for minimum dune movement rate	Lost value per year for average dune movement rate	Lost value per year for maximum dune movement rate
	[R$]	*[R$]*	*[R$]*
A_a	23.536,50	35.251,50	53.356,50
A_b	69.283,50	103.768,50	157.063,50
B_a	45.066,89	67.498,38	102.165,22
B_c	182.413,62	273.207,73	413.525,90
B_d	168.464,34	252.315,38	381.903,33
Total	488.764,86	732.041,49	1.108.014,46

Table F-36 Lost value per year calculated with average price per square meter

Section	Lost value per year for minimum dune movement rate	Lost value per year for average dune movement rate	Lost value per year for maximum dune movement rate
	[R$]	*[R$]*	*[R$]*
A_a	39.227,50	58.752,50	88.927,50
A_b	115.472,50	172.947,50	261.772,50
B_a	230.355,11	345.011,49	522.207,73
B_c	932.389,72	1.396.475,10	2.113.697,96
B_d	861.089,33	1.289.685,83	1.952.062,23
Total	2.178.534,15	3.262.872,42	4.938.667,92

Table F-37 Lost value per year calculated with maximum price per square meter

For the coastline, the same can be done. Now there is only a variation in the price per square meter. The results are shown in Table F-38.

Section	Minimum costs	Average costs	Maximum costs
	[R$]	*[R$]*	*[R$]*
Interdune (Class D)	588.944,42	1.080.937,98	2.090.130,99
Mozambique Ridges (Class D)	601.907,58	1.104.730,32	2.136.136,52
Moçambique Dunes (Class C)	416.533,63	918.794,75	1.821.278,75
Total	1.607.385,63	3.104.463,05	6.047.546,27

Table F-38 Annual lost value, coast

F.4 Conclusions

F.4.1 Final results

From the results of paragraph F.3 it is possible to calculate an average and lower and upper limit for the loss of value per year. These limits are shown in Table F-39.

	Lower limit	Average	Upper limit
	[R$]	*[R$]*	*[R$]*
Dune field	250.282,50	732.041,49	4.938.667,92
Coast	1.607.385,63	3.104.463,05	6.047.546,27
Total	1.857.668,13	3.836.504,54	10.986.214,19

Table F-39 Limits for the annual loss of value

F.4.2 Discussion

In Table F-40 percentages are shown for which part the dune field migration and coastline regression contribute to the total losses. The contribution of the lower limit and average of the dune field are of minor importance.

	Lower limit	Average	Upper limit
Dune field	13,47%	19,08%	44,95%
Coast	86,53%	80,92%	55,05%

Table F-40 Percentages of total losses

For both the dune field and the coast, the range between the lower and upper limit is around 4,5 million R$, which is the same order as the value of the upper limit of both areas. The difference in lower and upper limit for the total losses will become about twice 4,5 million R$.

There are several aspects that have to be taken into account and which make it possible to assume an average development of the costs of the zero-solution. Firstly it must be said that the calculated costs are averaged over the years. In reality the loss of buildings is a discontinue process. A building doesn't collapse meter by meter but once in its lifetime. Secondly, for several sections in front of the dune field and along the coast, the losses will start with a delay. It must be taken into account that many buildings are in danger of getting lost. Not only cheap buildings will be lost, and not only expensive buildings will be lost. It is a mix of cheap, average and expensive buildings. This calls for the use of the average costs, especially for the coastal area. The buildings in front of the dune field are expected to be cheaper (see Appendix E) because of the threat of the dune, so this calls for the use of the average or lower limit. From the values of Table F-28 it looks if the dune migration speed slowed down in the last years. If this is true, the minimum dune migration rate is more realistic than the average or maximum dune migration rate.

It is not completely clear how the coastline will develop in future. It is possible that the coastline will erode until a certain equilibrium state. This means that after several years the loss of land and property will stop.

F.4.3 Recommendations

For a better prediction of the costs of the zero-solution, more extensive research can be done to the prices of the real estate, the dune field movement rate and the coastline regression speed. A way to investigate the prices of the involved buildings is by registering them. Also the costs for roads can be added.

Appendix G Sand sampling

For the calculation of the nourishment, much information about grain sizes is needed. The first part of that information is found in the report of Project Ingleses 2007. During the 2007 project there wasn't enough time to sieve all the sand samples that were collected. During this project the data of these samples became available. The results of all the samples is shown in paragraph G.1. The samples taken during this project on the fieldtrip of the 6th of June are presented in paragraph G.2.

G.1 Sand samples2007

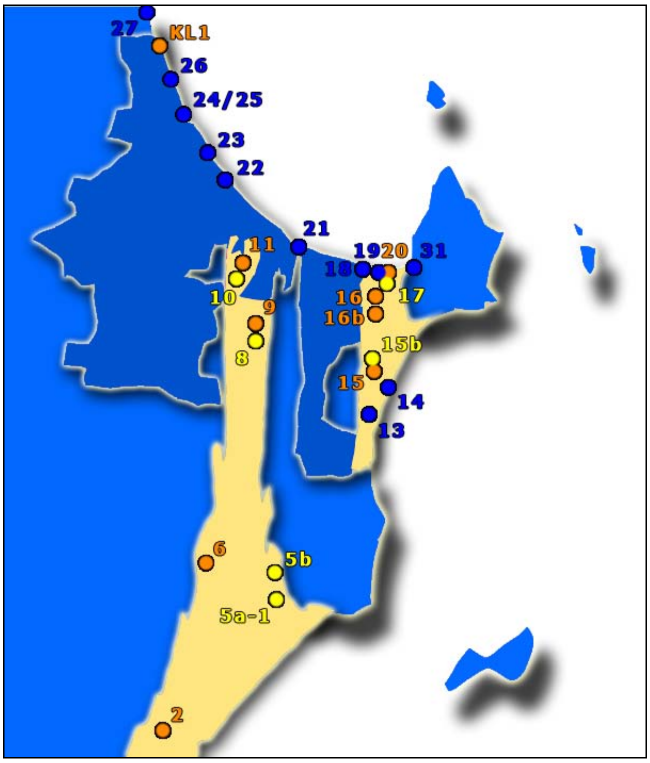


Figure G-1 Sample locations [Project Ingleses 2007]

Location	d_{50} (μm)	Location	d_{50} (μm)
KL1	168	16	207
2	289	16b	215
5a 1	336	17	200
5a 2	233	18	188
5b	210	19	195
6	260	19b	178
8	257	20	201
9	235	21	193
10	250	22	190
11	463	23	195
13	200	24/25	194
14	194	26	201
15	177	27	207
15b	196	31	188

Table G-1 d_{50} Sand samples

G.2 Sand samples 2008

G.2.1 Location

On the fieldtrip of the 6th June, 8 samples are taken. Three samples are taken on Moçambique Beach, the source of the sand in the Moçambique Dune. Two samples are taken between Moçambique Beach and the possible borrow area. These samples are taken to investigate the origin of the two grain sizes in the dune. Another three samples are taken at the borrow area. These samples are taken to obtain more information about the distribution of big and small grain sizes in the dune. The exact locations of the sand samples are shown in Table G-2 and Figure G-2. The results of these samples are shown in Table G-3.

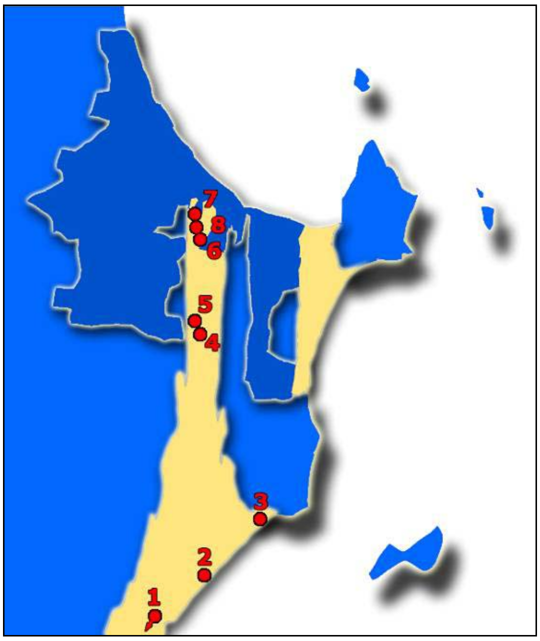


Figure G-2 Sample locations

Name location	Z	W
Location 1 Moçambique Beach	27º 30,292'	48º 24,288'
Location 2 Beach blow out	27º 29,959'	48º 24,033'
Location 3 Moçambique Beach	27º 29,052'	48º 23,166'
Location 4 low dune (middle off field)	27º 27,186'	48º 23,559'
Location 5 Top dune (middle off field)	27º 27,170'	48º 23,565'
Location 6 low dune (borrow area)	27º 26,521'	48º 23,404'
Location 7 Top dune (borrow area)	27º 26,486'	48º 23,400'
Location 8 Middle dune (borrow area)	27º 26,495'	48º 23,400'

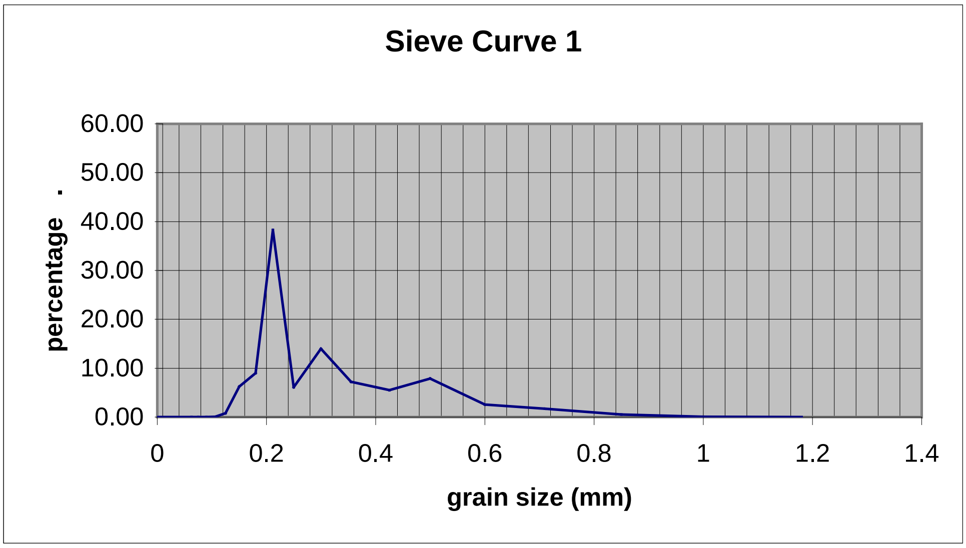
Table G-2 Sample locations

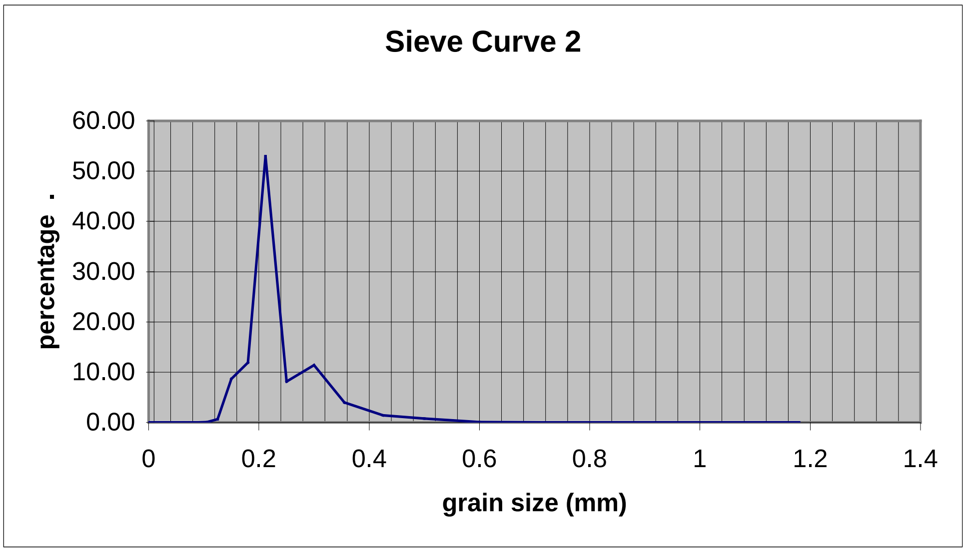
G.2.2 Results and grain size distribution

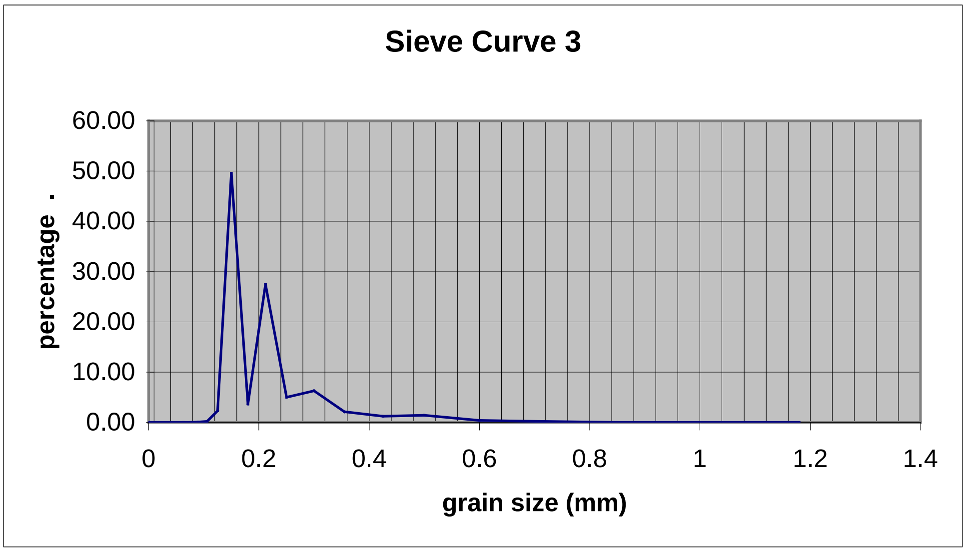
In Table G-3 de ϕ_{50} and d_{50} are presented. In Table G-4 the sieve fractions are presented.

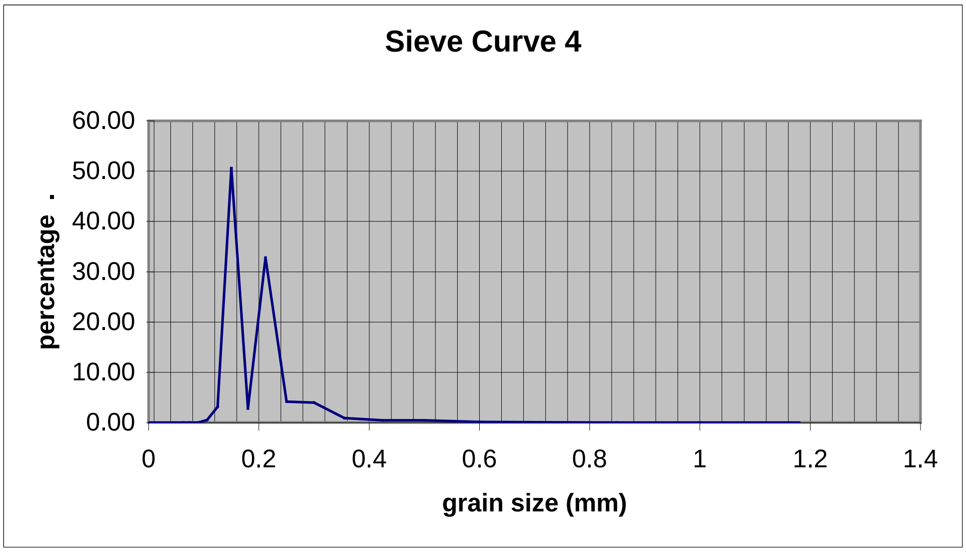
Sample	Φ_{50}	d_{50}	Sample	Φ_{50}	d_{50}
1	2.0286	0.245	5	2.1453	0.226
2	2.1142	0.231	6	2.2589	0.209
3	2.5109	0.175	7	2.0643	0.239
4	2.5210	0.174	8	1.6883	0.310

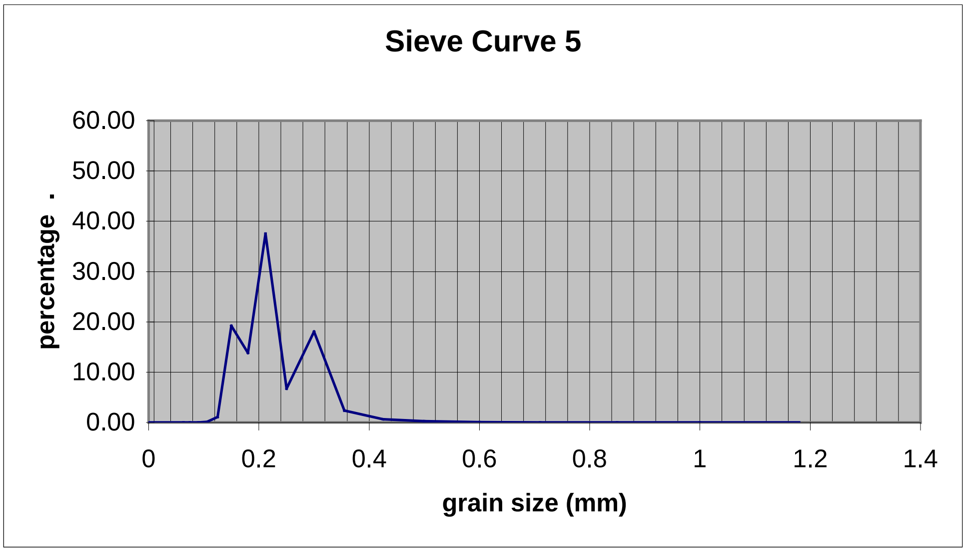
Table G-3 d_{50} Sand samples

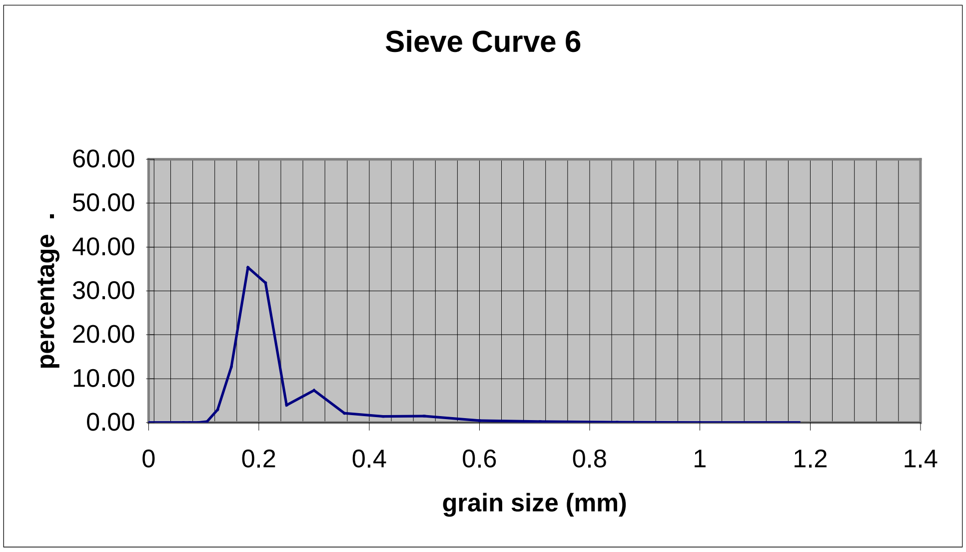

Sieve Curve 1
percentage .
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
0.2
0.4
0.6
0.8
1
1.2
1.4
grain size (mm)

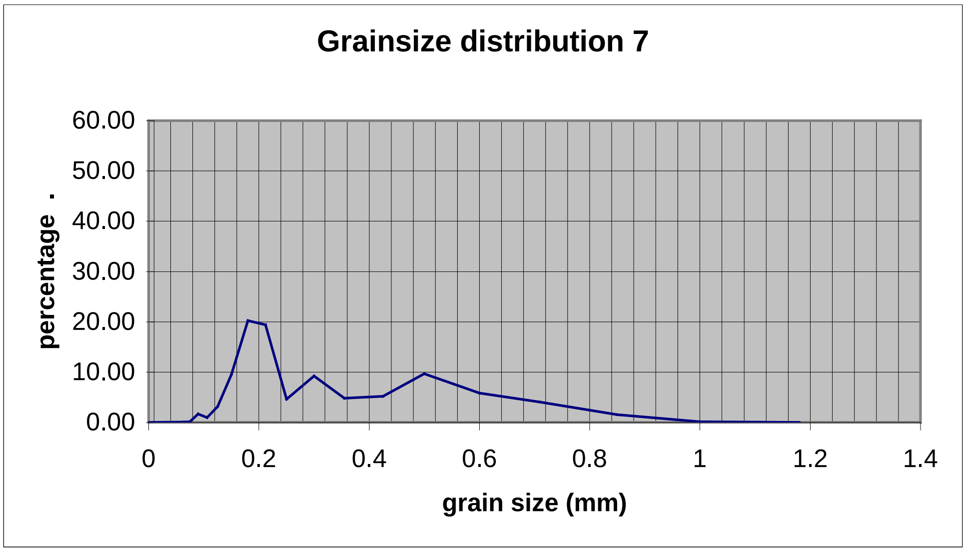

Sieve Curve 2
percentage .
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
0.2
0.4
0.6
0.8
1
1.2
1.4
grain size (mm)

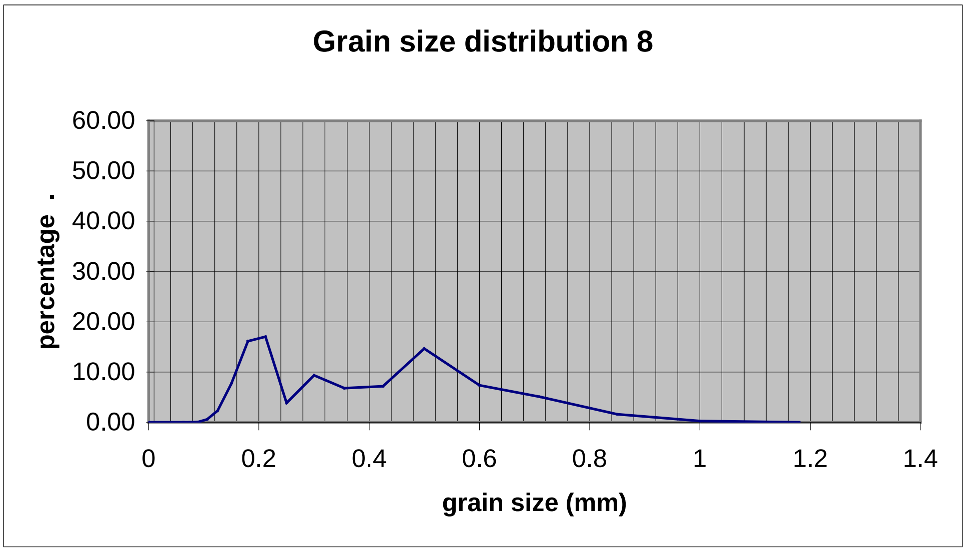

Sieve Curve 3
percentage .
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
0.2
0.4
0.6
0.8
1
1.2
1.4
grain size (mm)


Sieve Curve 4
percentage .
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
0.2
0.4
0.6
0.8
1
1.2
1.4
grain size (mm)


Sieve Curve 5
percentage .
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
0.2
0.4
0.6
0.8
1
1.2
1.4
grain size (mm)


Sieve Curve 6
percentage .
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
0.2
0.4
0.6
0.8
1
1.2
1.4
grain size (mm)


Grainsize distribution 7
percentage .
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
0.2
0.4
0.6
0.8
1
1.2
1.4
grain size (mm)


Grain size distribution 8
percentage .
60.00
50.00
40.00
30.00
20.00
10.00
0.00
0
0.2
0.4
0.6
0.8
1
1.2
1.4
grain size (mm)

Location	total fractions	1180 µm [gr]	1000 µm [gr]	850 µm [gr]	710 µm [gr]	600 µm [gr]	500 µm [gr]	425 µm [gr]	355 µm [gr]	300 µm [gr]	250 µm [gr]
1	39.8492	0.0118	0.0242	0.2152	0.6704	1.0188	3.1433	2.1967	2.879	5.5823	2.4363
2	39.9465	0	0	0	0.0075	0.0266	0.3126	0.5665	1.5845	4.5659	3.2518
3	39.8061	0	0	0.012	0.082	0.1644	0.5624	0.494	0.8459	2.4977	1.9845
4	39.9097	0	0	0.0048	0.0153	0.0571	0.178	0.1884	0.3594	1.5887	1.6732
5	42.8751	0	0	0	0.0081	0.0177	0.1186	0.2864	1.0225	7.7496	2.8908
6	39.8142	0	0.0022	0.0203	0.0931	0.1609	0.589	0.5638	0.8329	2.9106	1.5733
7	39.9494	0.005	0.0524	0.6035	1.6239	2.325	3.8582	2.0823	1.9162	3.6805	1.8347
8	39.9369	0	0.0918	0.645	2.0245	2.9408	5.8611	2.8723	2.7134	3.7438	1.5396

Location	212 µm [gr]	180 µm [gr]	150 µm [gr]	125 µm [gr]	106 µm [gr]	90 µm [gr]	75 µm [gr]	63 µm [gr]	fundo
1	15.2599	3.5925	2.4767	0.3067	0.0281	0.0049	0.001	0.0009	0.0005
2	21.146	4.7562	3.4411	0.2667	0.0168	0.0043	0	0	0
3	10.9355	1.4646	19.7203	0.9269	0.082	0.0215	0.0124	0	0
4	13.0846	1.1125	20.1911	1.2474	0.193	0.0057	0.0081	0.0024	0
5	16.0769	5.929	8.2501	0.4559	0.0585	0.0071	0.002	0.0019	0
6	12.6611	14.0741	5.0608	1.1577	0.1012	0.0087	0.002	0.0025	0
7	7.7444	8.0925	3.7842	1.2432	0.3734	0.6598	0.0486	0.0165	0.0051
8	6.7976	6.4512	3.0581	0.9266	0.2199	0.0334	0.0118	0.0036	0.0024

Table G-4 Sieve fractions

Appendix H Borrow areas

H.1 Grain size beach Ingleses

For a beach nourishment it is best to use a grain size as close as possible to the native grain size, this way the steepness of the beach and the breaker height will not differ much. Project Ingleses 2007 has taken some samples on the beach see Figure H-1

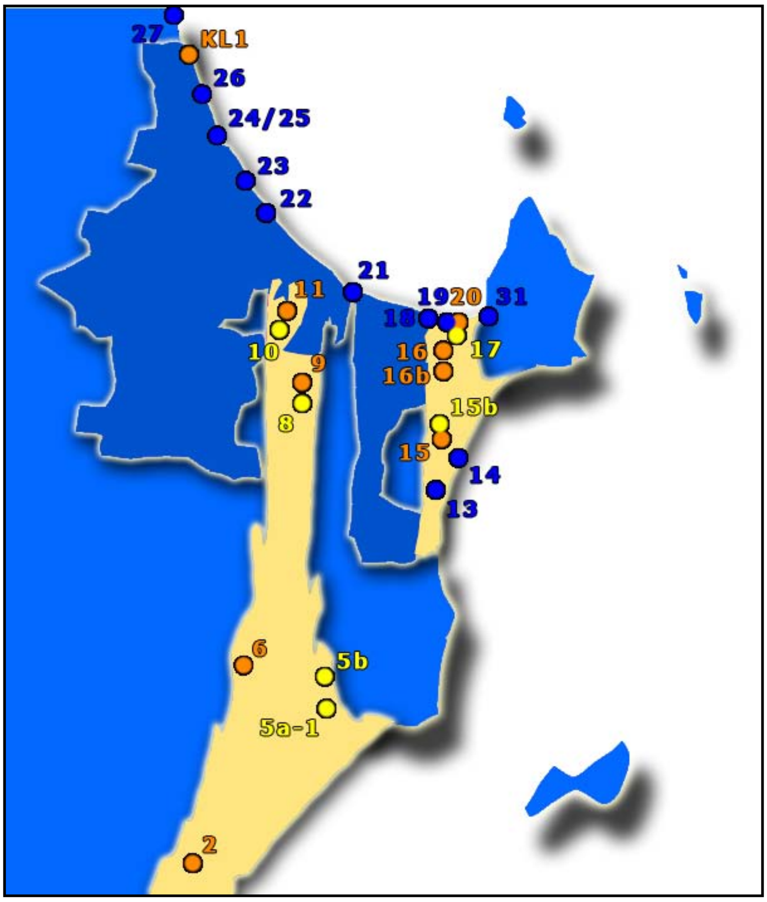


Figure H-1 sample locations [Project Ingleses 2007]

For the native grain size (d50) of Ingleses beach, the average of the d50's of samples 20, 21, 22, 23 and 31 will be used. These are the samples that where available in this stage of the project.

$$\frac{0,201+0,193+0,190+0,195+0,188}{5}=0,193\text{ mm}$$

This is the native grain size used in calculating the nourishment volume.

In a later stage the other samples also became available. The average of all the samples from Ingleses beach 18, 19, 19b, 20, 21, 22, 23, 24/25, 26, 27 and 31 is equal to:

$$\frac{0,188+0,195+0,178+0,201+0,193+0,190+0,195+0,194+0,201+0,207+0,188}{11}=0,1936\text{ mm}$$

This shows that 0,193 is a good estimation for the native grain size.

H.2 Borrow area

For the nourishment of beach Ingleses there has to be a borrow area, the source of the sand that will be used for the nourishment. The borrow area has to be close to the beach, otherwise the transport costs will be to high. For a possible borrow area there are tree possibilities, Moçambique dune, Santinho dune and an offshore borrow area.

The Santinho and Moçambique dune are migrating dunes, both dunes are migrating to the north. The migration of the Santinho dune already reached beach Ingleses and this leads to an inflow of sand in the beach system. This way there is a natural inflow in the system. The sand from the Santinho dune could be used for the nourishment of the beach but this would disturb the natural influx. The disturbance of the natural influx is undesired and that is why in this report the Santinho dune will not be used as a borrow area.

The Moçambique dune also migrates to the north but this migration is stopped by the urbanization of Ingleses. In fact the migration forms a threat to the urbanization. This is why the excavation of the Moçambique dune will have a positive influence on Ingleses.

The third option is an offshore borrow area, this option will be studied but this option isn't a solution for the threat to the cultivation of Ingleses. This is why in this project the main focus is on the use of sand from the Moçambique dune. The offshore borrow area will be studied, but the criteria will be more strict because of the disadvantage over Moçambique dune.

H.3 Sand from dune Moçambique

H.3.1 Origin of the sand

The main force behind the transport and deposition of sediment particles is wind. At low wind velocities, loose material rolls downwind, staying in contact with the surface. This is called creep. At higher wind velocities loose material is removed from the bed and carried by the wind, before being transported back to the surface. Furthermore there are some features that influence the wind velocity and therefore the aeolian transport. The local topography can have influence on the direction and the velocity. Inside the dune field the surface slope of the independent dunes have their effect on the wind direction and wind velocity. Changes in slope can produce wind velocity acceleration or deceleration, promote turbulence, and potentially act to create the development of internal boundary layers and even flow separation. In addition, increasing slope angles tend to enhance the effect of gravity, potentially reducing sand transport rates (SHORT, 1999). The amount of sediment transport is also related to the grain size. For bigger grain sizes more wind energy is needed to transport the sediment particles. On the top of the dunes the wind energy is high, here the finer particles will be blown out, this is why on the top of the dune the bigger grain sizes are found. In the lower parts of the dune field the wind energy is less then on the tops of the dune field, this is why here the finer particles are found. For this reason it is expected that different grain sizes will be found on the different sample locations.

H.3.2 Grain size in the borrow area

With the estimation of the equilibrium profile, the grain sizes of Project Ingleses 2007 are used. Project Ingleses 2007 took two samples of the north part of the Moçambique dune. The two main grain sizes (d50) are 0,250 mm and 0,463 mm. In Figure H-2 the grain size distribution of the bigger fill is shown. With these grain sizes the equilibrium profile is calculated. In a later stage more sampling is done. The grain sizes found here where smaller then expected. As stated above in the lower parts of the dune the smaller grain size will be found. The grain size in the lower parts was 0,209 mm. In the higher parts the bigger grain size is found. Here a d50 of 0,239 mm was found. This is much smaller than expected, but the d50 alone shows not always enough information, the distribution is just as important. The distribution in Figure H-3 shows that there are two peaks in the distribution of the grain size. One is around 0,2 mm and one around 0,5 mm. This shows that there is a large amount of coarse sediment on this location. It is possible that in the time before the sampling the wind velocities where low and the coarse particles where covered by smaller particles. The distribution also shows that for a good estimation of the nourishment more research have to be done to estimate the percentages of the different grain sizes in the dune.

In the later stage there is also a sand sample taken from the middle of the slope of the dune. The grain size distribution of this sample, Figure H-4, shows more clearly the two peaks in the distribution. The peaks in this distribution are also around 0,2 mm and 0,5 mm. The peak around 0,5 mm is even bigger compared to the distribution of the sample from the top of the dune. As stated before more research has to be done to estimate the percentages of the different grain sizes in the dune.

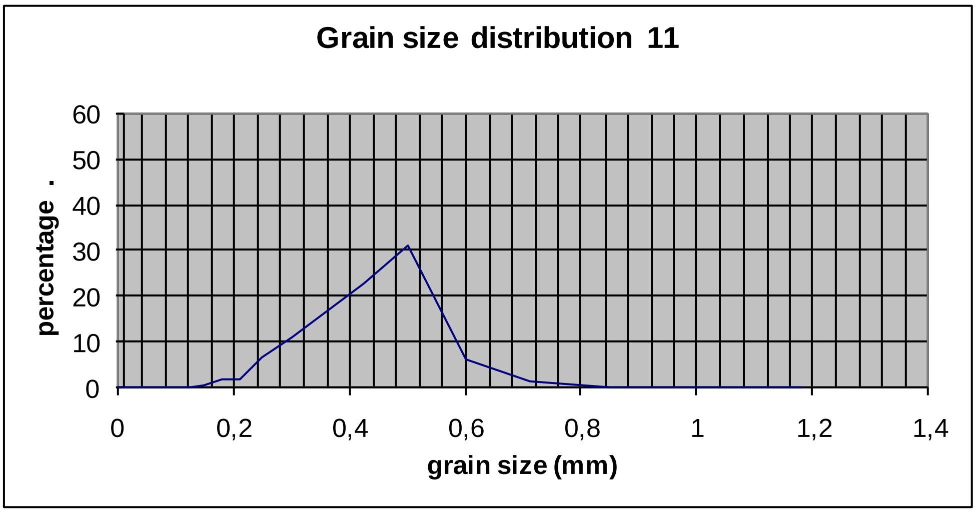


Figure H-2 Top of the dune sample 11 [Project Ingleses 2007]

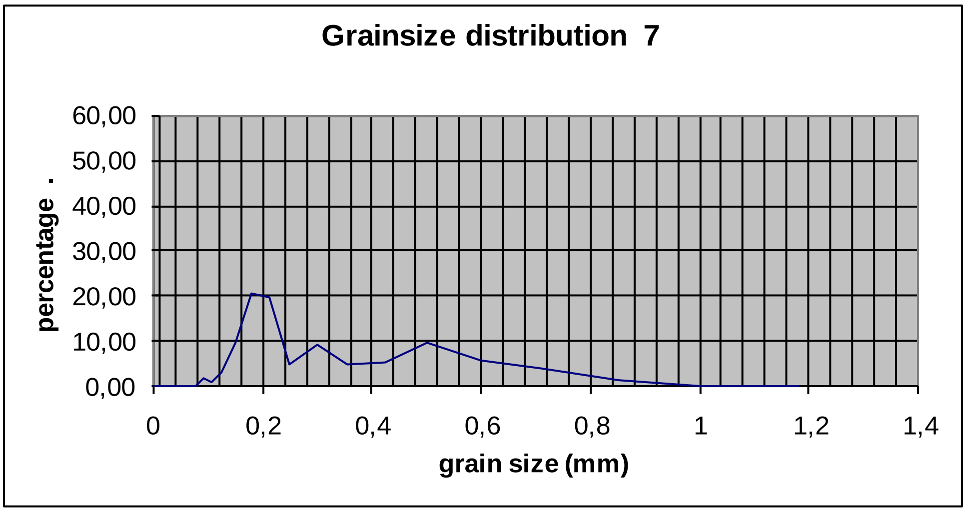


Figure H-3 Top of the dune sample 7

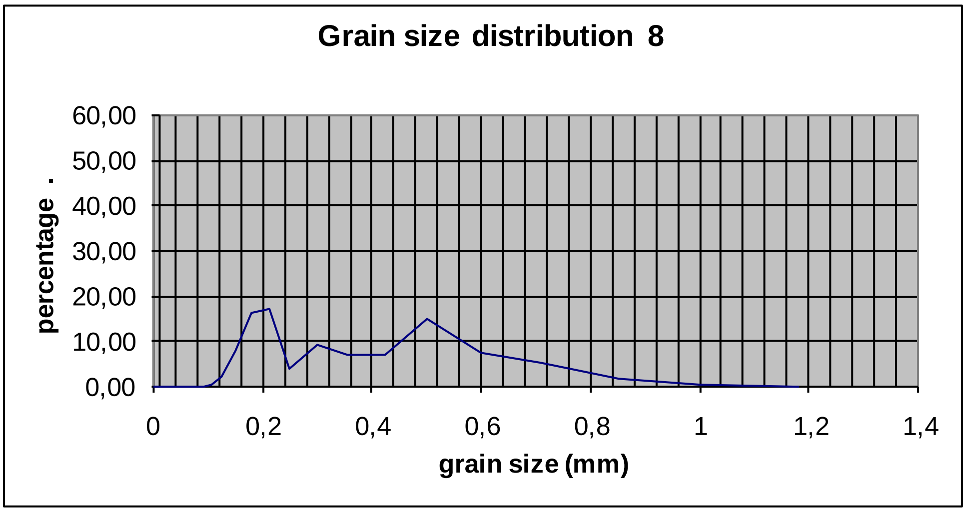


Figure H-4 middle dune height sample 8

H.3.3 Grain size at Moçambique beach

To estimate the ratio between the small and big grain sizes, some samples are taken at the source of the dune, Moçambique beach. All the sand in the dune is coming from Moçambique beach. During transport different grain sizes are deposited at different locations. This is why it is difficult to take a representative sample in the dune. The samples at Moçambique beach will be to some extent representative for the sand in the dune field. The samples taken at beach Moçambique are shown in Appendix G, sieve curves one, two and three. These sieve curves show a large amount of sediment particles around 0,2 mm. sediment particles around 0,5 mm are also represented, especially in sieve curve one, but in a much smaller percentage. This shows that in the total borrow area probably a big amount of sediment particles around 0,2 mm and a small amount of sediment particles around 0,5 mm will be found. The big sediment particles in grain size distribution 11, Figure H-2, can be explained by the unprotected location of the sample. At this location the wind velocities are the highest and the smaller sediment particles will be blown out. Sample 7, Figure H-3, is taken on a similar location but at a different time, it is possible that in the time before the sampling the wind velocities where low and the top was covered with small sediment particles.

H.3.4 Conclusion

In this project the expectation is that the main grain size (d50) of the total dune will be around 0,25 mm, because the big grain size is only found on the top of the dune in the borrow area. In the calculations the big grain size will still be used to estimate the maximum beach steepness and nourishment volume in case of a high percentage of course sand.

H.4 Offshore borrow area

H.4.1 Data

The data, of sand samples taken offshore in the area surrounding Ilha de Santa Catarina, is obtained from a sheet provided by UNIVALI. In this sheet data is gathered which is processed in other studies or at different institutes like CECO and UNIVALI. Since the data is made by different institutes and used for different studies it is not complete. The samples which are processed by UNIVALI only give information about the composition of the sample and not about the occurring grain diameters. The samples from CECO are taken more offshore and it is questionable if these samples can be used to represent a possible borrow area near Ingleses beach.

An overview of the several samples, their source and distance to Ingleses is given in Table H-1

PROJECT	Institute	Sample	Latitude	Longitude	Distance	Depth
REMAC (LEG 1 A 7)	CECO	3017	-	-48,30000	40	60
PROSAR	UNIVALI	21	-	-48,09167	40	?
PROSAR	*UNIVALI*	*21*	-	*-48,09167*	40	?
Arvoredo	UNIVALI	20	-	-48,27806	8	?
Arvoredo	UNIVALI	21	-	-48,33389	8	?
Arvoredo	UNIVALI	22	-	-48,35722	8	?
Arvoredo	UNIVALI	23	-	-48,39306	8	?
Arvoredo	UNIVALI	24	-	-48,43472	8	?
LH 071/77	CECO	67	-	-47,85833	50	87
LH089/81	CECO	5829	-	-47,93333	44	102
REMAC (LEG 1 A 7)	CECO	3014	-	-48,28333	30	55
REMAC (LEG 1 A 7)	CECO	3015	-	-48,26667	11	57
REMAC (LEG 1 A 7)	CECO	3016	-	-48,26667	15	60
REMAC (LEG 1 A 7)	CECO	3132	-	-47,73300	63	121
REMAC (LEG 1 A 7)	CECO	3133	-	-47,56667	80	136

Table H-1 Source and location offshore sand samples [UNIVALI]

The latitude and longitude are imported in *Google Earth* to get an idea of the locations of the samples. In Figure H-5 an overview is given of the location of the samples. Besides analyzing the grain size and the composition of the sand it is also important to take the distance to a offshore borrow area and the depth at that point into account. This also influences the suitability of an offshore borrow area.

Figure H-5 Overview sand samples [UNIVALI]

From this figure we can conclude that the UNIVALI samples from the project Arvoredo are all taken on a line from east to west 8 kilometer north of Ingleses. These samples are all located very close to the project area. It might even be within the system boundaries of the coastal processes, depending on the depth of these locations. As earlier mentioned, these samples only contain information of the composition of the samples and not about the occurring grain sizes. In this research we are mostly interested in the grain size of the sand that we can use to nourish beach Ingleses. The grain size of the material from the borrow area can have a large influence on the shape of the beach. Sample 3014 from the REMAC project of CECO is the only sample with a grain size close to the grain size of the native beach.

H.4.2 Selection useful sand samples

The sand used to nourish the beach should not be to coarse, because this will lead to an undesired steep profile. The grain size should also not be too small, because this will lead to a lot of loss of material due to wash out and will be therefore very expansive. In this case the criteria are stricter then in the case of the Moçambique dune, because this solution only solves one problem. It doesn’t solve the problem of the migration of the dune.

The median grain size of the native material is approximately 0,193 millimeter with a allowable rang of 0,01 millimeter. This lead to an upper and lower limit of the sand that is desired as showed in Table H-2.

Desired (Native)	d50 mm	Phi(50)	remarks
Upper limit	0,203	2,300	Otherwise too large
Mean diameter	0,193	2,373	
Lower limit	0,183	2,450	Otherwise too small

Table H-2 Desired range sand for nourishment

Based on the sorted data showed in Table H-3 all samples are not even close to the desired range of grain size. The samples only represent the upper layers, more research has to be done for the lower layers.

CECO 3014 is the sample which is closest to the UNIVALI Arvoredo samples. These samples show sediment which is much smaller than the mean diameter of beach Ingleses. This will result in a very large required volume for the nourishment because the fine sediment will wash out very quickly.

CECO 3133 is a sample at 80 kilometers distance with very coarse sand. This sand is also not suitable for the nourishment. Besides the grain size this sample is taken at a depth of 136 meter, which is a depth that is not economically usable for a borrow area.

Project	Institution	Sample	Mean phi	Mean diameter [mm]	Remarks
REMAC (LEG 1 A 7)	CECO	3133	-0,020	1,014	Very coarse sand
REMAC (LEG 1 A 7)	CECO	3017	3,300	0,102	Very fine sand
REMAC (LEG 1 A 7)	CECO	3132	3,760	0,074	Very fine sand

REMAC (LEG 1 A 7)	CECO	3015	4,400	0,047	Coarse silt
REMAC (LEG 1 A 7)	CECO	3014	5,000	0,031	Medium silt
REMAC (LEG 1 A 7)	CECO	3016	6,800	0,009	Fine silt
PROSAR	UNIVALI	21	6,945	0,008	Fine silt
PROSAR	UNIVALI	21	7,085	0,007	Very fine silt
LH089/81	CECO	5829	7,850	0,004	Very fine silt
LH 071/77	CECO	67	8,010	0,004	Coarse clay

Table H-3 Overview samples and their mean diameter

The CECO 3017 sample has a mean grain size which is approximately half of the desired grain size. This also isn't an option for the nourishment. If this borrow area would be used for the nourishment a large volume is needed for the nourishment. This would make the nourishment with sand from this borrow area an uneconomical solution. At the location of this sample the depth is approximately 60 meters, this is also a large depth to dredge material from.

H.4.3 Conclusion

An offshore borrow area would be interesting if there would be a location which was easy to dredge and the grain size would match the native grain size. From these sea bottom samples can be concluded that there is no spot near the beach for a good borrow area. More research has to be done to find other possible borrow areas at sea. This information is not available for this project. For this reason the offshore borrow area will not be discussed further as a possible alternative in this project.

H.5 Conclusion

For this project three possible borrow areas where considered. The first possible borrow area is Santinho Dune. This borrow area will not be further considered, because this would disturb the natural influx of sand in the system. The second possibility, the use of an offshore borrow area, will also not be considered as a possible borrow area because no suitable location is found in this report. Still more research for a possible offshore borrow area is needed. In this report Moçambique Dune is chosen as the borrow area, because the grain size is compatible and this is both a solution for the dune migration as well as for the erosion of the beach

Appendix I Beach nourishment

In this appendix will be discussed what steps need to be taken to calculate the volume of sand that is needed for the nourishment of Ingleses Beach. For the calculations of the nourishment the width of the desired beach has to be determined, this will be done in paragraph I.1. Using this width, an estimation of the design fill can be made, see paragraph I.2. After this, the design fill will be calculated more accurate using the equilibrium beach profiles in paragraph I.3. In paragraph I.4 the advanced fill will be calculated. Finally in paragraph I.5 the total volumes will be calculated.

I.1 Width of the beach nourishment

For the first estimation of the sand volume that is necessary for the beach nourishment the method of Campbell is generally accepted [Campbell et al., 1990]:

$$V = W * (D_{OC} + B) \qquad I\text{-}1$$

The volume depends on the desired beach length W, the closure depth D_{oc} and the berm height B. The average closure depth is determined by Project Ingleses 2007 and is equal to 5,77m.

This method is designed for nourishments which consist of the same mean grain size as the native beach. The mean grain size from Moçambique Dune is bigger than the native grain size Appendix G. The Campbell method can still be used as a first estimate of the design fill volume.

Equation I-1 is generally used to calculate the volume of the design fill. It can also be used to calculate the width of the nourishment when the volume of the nourishment is given. Research has shown that a volume of $175-250m^3/m$ leads to the best nourishment results. $250m^3/m$ is advised by Dean [2002] and is an average value for the United States. Fill volumes that are greater than $175m^3/m$ were found to provide retention greater than 70% after one year, based on reviews of several projects (Hoel and Stauble, 1986). For the calculations of the beach width, Dean's advice will be used. So the estimate of the volume of the nourishment is $250m^3/m$.

The berm height can be derived with the formula from Sunamura and Takeda [1982]:

$$B_h = 0{,}125 H_b^{5/8} (gT^2)^{3/8}$$

Where B_h is the berm height, H_b is the breaker height of the wave, g is the gravitational acceleration and T is the wave period.

The wave breaker height is derived with SWAN (see Appendix J) and is equal to 0,396m.

The wave period is equal to 8 seconds and is determined by Project Ingleses 2007.

With these values the berm height can be calculated:

$$B_h = 0,75m$$

In practice a berm height of 0,75 will not be used because the nourishment can't be constructed this accurate. Therefore a berm height of 1m is more commonly used. In our project 0,75m will still be used for calculations.

The desired beach length can be calculated using formula I-1. The desired beach length W is equal to 38m.

I.2 First estimate for the design fill

The design fill is the volume of sand that is needed to widen the beach to the desired beach width. To calculate the volume of the design fill, the future beach profile has to be calculated and the type of profile has to be determined.

A first estimate of the design beach fill can be made with the following equation [CEM, 2003]:

$$V = WB + \frac{\frac{3}{5} W^{5/3} A_N A_F}{(A_F{}^{3/2} - A_N{}^{3/2})^{2/3}} \qquad \textit{I-2}$$

The volume in this equation depends on the desired beach length W, the berm height B, A-value (a value which corresponds with mean grain size) from the native beach A_N and the A-value from the fill sediment A_F.

For the A-value of the fill sediment there are two values because there are two grain sizes found by Project Ingleses 2007. For the first estimate of the design fill both main A-values will be used to estimate the volume. The results from equation I-2 can be found in Table I-1.

d50	Volume design fill (m3/m)	Volume design fill (m3)
0,250	98,70	493499,59
0,463	68,58	342922,18

Table I-1 Volume estimates of the design fill

I.3 Design fill

I.3.1 Intersecting / Non-intersecting.

Dean [1991] defines three basic types of beach nourishments (Figure I-1): an intersecting-, non-intersecting-, and submerged profile. An intersecting profile is a profile that after nourishment intersects with the native profile at a depth that is smaller than the closure depth. A non-intersecting profile is a profile that after nourishment intersects with the native profile after the closure depth. The third profile the submerged profile where there is no dry beach after equilibrium. A submerged profile is a special kind of non-intersecting profile which occurs when insufficient sand is used for the nourishment.

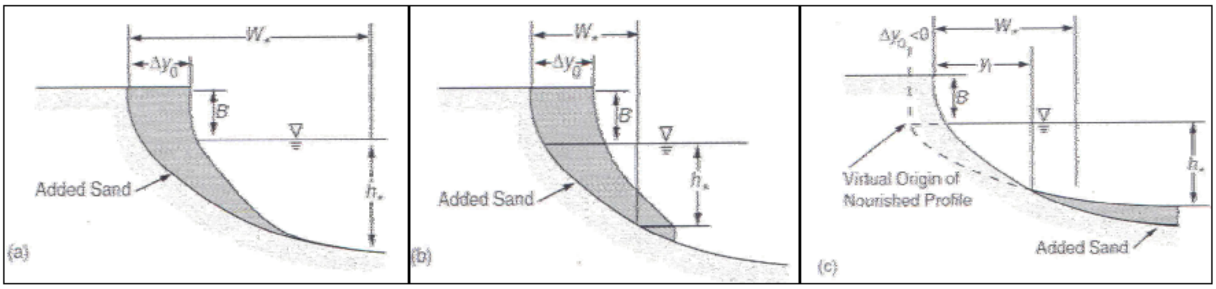


Figure I-1 Three basic nourishment profiles adapted from Dean [1991]

Dean [1991] suggested the following formula to determine if a profile will be intersecting or non-intersecting:

$$W\left(\frac{A_N}{D_{OC}}\right)^{3/2}+\left(\frac{A_N}{A_F}\right)^{3/2}<1$$ Intersecting profile

$$W\left(\frac{A_N}{D_{OC}}\right)^{3/2}+\left(\frac{A_N}{A_F}\right)^{3/2}>1$$ Non-intersecting profile

From the dune that will be used as borrow area, Moçambique, there are two different grain sizes found. Both grain sizes will be tested separately on their suitability as fill sediment for the nourishment (see Appendix H).

To calculate the A-value as described by Dean the fall velocity has to be calculated.

The d_{50} of the sand on the beach is 0,193mm [Project Ingleses 2007, see Appendix H]. The formula for the fall velocity according to Gibbs [1971] is:

$$w_s = \frac{-3\mu + \sqrt{9\mu^2 + gr^2\rho(\rho_s - \rho)(0,015476 + 0,19841r)}}{\rho(0,011607 + 0,14881r)}$$

With the formula from Dean [1987] the A-value can be calculated:

$$A = 0,067W_s^{\,0,44}$$

The results are presented in Table I-2.

	d50	Ws	A
Native beach	0,193	2,11756	0,09321
Location 10 dune	0,250	3,07819	0,10988
Location 11 dune	0,463	6,73061	0,15503

Table I-2 A-values from location 10 and 11, sample locations from Project Ingleses 2007.

Both grain sizes lead to an intersecting profile (Table I-3).

	d50	A	Dc	W(m)	Intersecting <1 / Non-intersecting >1	
Native beach	0,193	0,09784	5,77			
Location 10 dune	0,250	0,115	5,77	25	0,83994533	intersecting
Location 11 dune	0,463	0,15508	5,77	25	0,55632063	intersecting

Table I-3 Intersecting / non intersecting

I.3.2 Equilibrium beach profile

For the nourishment a different grain size will be used than the native grain size, because off this the steepness of the beach will change. In this paragraph the change in steepness will be calculated for the two grain sizes which can be found in dune Moçambique.

The d_{50} of the native sand on the beach is 0,193mm [Project Ingleses 2007]. And according to the CEM [2003] tables this leads to an A-value of $A = 0,09784m^{1/3}$. The resulting equilibrium profile is described by Dean [1977]:

$$h(y) = A(d_{50})y^{2/3}$$

And therefore $h = 0,09784y^{2/3}$

The small d_{50} of the sand from the Moçambique Dune is 0,25mm [Project Ingleses 2007]
Using the CEM table this gives an A-value of $A = 0{,}115 m^{1/3}$. The resulting equilibrium profile is equal to:

$$h = 0{,}115 y^{2/3}$$

The large d_{50} of the sand from the Moçambique Dune is 0,463mm [Project Ingleses 2007]. Using the CEM table this gives an A-value of $A = 0{,}155 m^{1/3}$. The resulting equilibrium profile is equal to:

$$h = 0{,}155 y^{2/3}$$

Now a graph can be created with the native beach profile and the two equilibrium profiles from the two main grain sizes from the Moçambique Dune (Figure I-2). The profile of the beach after the nourishment should be between the two equilibrium profiles, in case Moçambique Dune is used as a borrow area. By calculating the surface under both profiles the boundaries for the volume of sediment that is necessary for the nourishment can be determined.

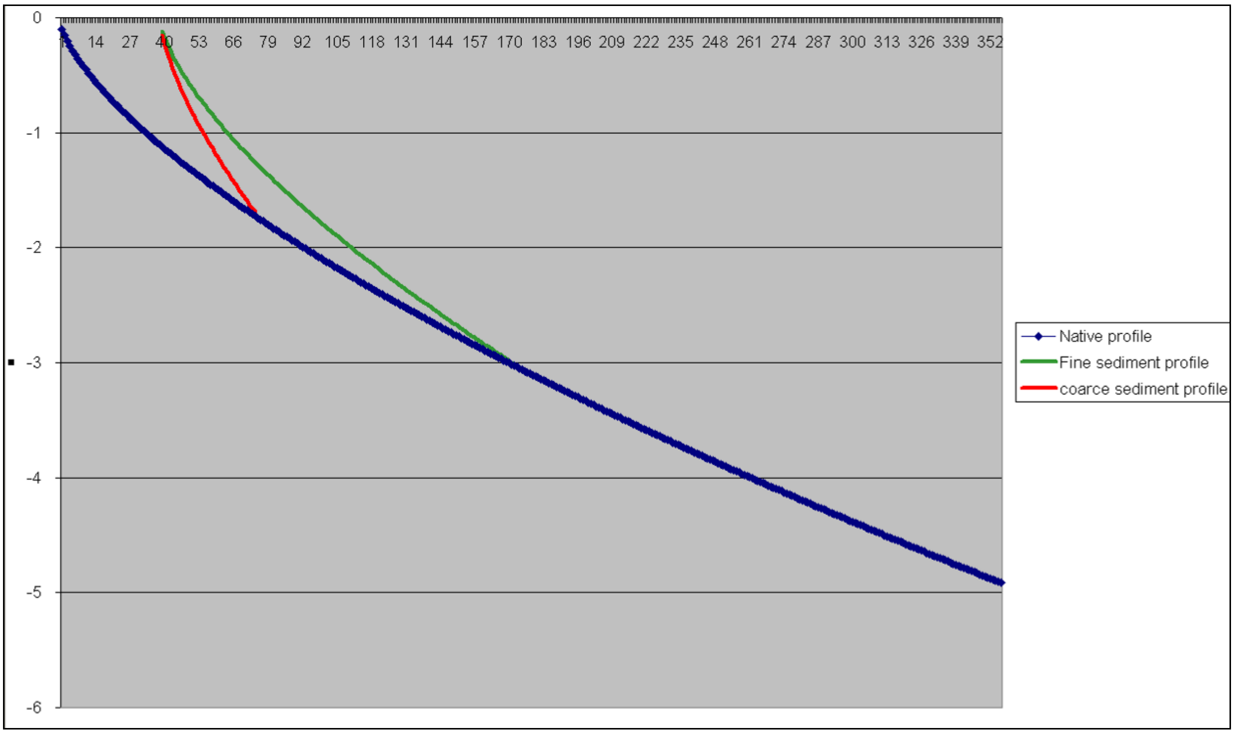


Figure I-2 Native beach profile and equilibrium profiles from the two main grain sizes

The resulting volumes for the design fill using the two grain sizes from the Moçambique Dune are shown in Table I-4.

	d50=0,25		d50=0,463
Surface area native profile	215,97	Surface area native profile	53,520
Surface area fine sediment	286,04	Surface area coarse sediment	93,567
Required volume of fill (m3/m)	98,57	Required volume of fill (m3/m)	68,547
Required volume of fill (m3)	492850	Required volume of fill (m3)	342735

Table I-4 Required volumes of the design fill

I.4 Advanced fill

The Verhagen method [Verhagen, 1990] is a method that is used in the Netherlands to calculate the volume of the advanced fill. The advanced fill is the amount of sediment that is necessary to maintain the design fill until the next nourishment. The Verhagen method is not a very complex method but it is proven to be very effective in practice.

For the use of the Verhagen method the average erosion of the beach is necessary of at least the last ten years. When the average loss per year is calculated the volume of the advanced fill can be calculated with:

$$V_{adf} = annual.losses * length.of.the.project * design.lifetime$$

The volume calculated with the formula above has to be increased with 20% to 40% according to Verhagen. The volume has to be increased with 20% if the sediment from the borrow area is coarser than the native sediment and 40% if the sediment from the borrow area is finer than the native sediment. The sediment from the borrow area in Moçambique Dune is coarser (0,25mm) than the sediment of the native beach (0,193mm), this is why the volume has to be increased with 20%.

The length of the beach is five kilometres. A design lifetime of ten years is chosen for the nourishment.

The annual losses are determined with the photo analysis (see Appendix A). The results of the photo analysis can be found in Table I-5.

	Interval	Section					
		Santinho Dune	Interdune	Mocambique Ridges	Mocambique Dune	River South	River North
1938-1957	19	1,17500	1,11500	0,33000	-0,16800	-1,23800	-2,27000
1957-1978	21	-0,98571	-0,75143	-0,35400	-0,42600	-0,49467	-0,11250
1978-1994	16	-1,61429	-1,74750	-1,10250	-1,16400	-0,63600	
1994-1998	4	-1,61833	-0,62625	-3,84250	-1,34000	1,12333	

1998-2004	6	2,17500	1,04286	2,31250	1,27800	0,11833	

Table I-5 Results from the photo analysis

The beach is divided in six sections (Figure I-3) that differ in morphological characteristics. In the years from 1938 until 1978 Ingleses was very different from today, qua cultivated area and erosion profile. The erosion derived from the photo analyse of the period from 1998 until 2004 is very different from the other periods and is also unexpected (see Appendix A). The period of 1978 until 1998 will therefore be used to determine the advanced fill. The average values (in m/year) of each section for this period are given in Table I-6. The value of the section “River North” where not successfully derived for this period, it is expected that this part of the beach will only grow in the coming years. The value of the section “River South” is positive which means that this section is also expected to grow in the coming years. This is why the advanced fill will be set to zero for this section.

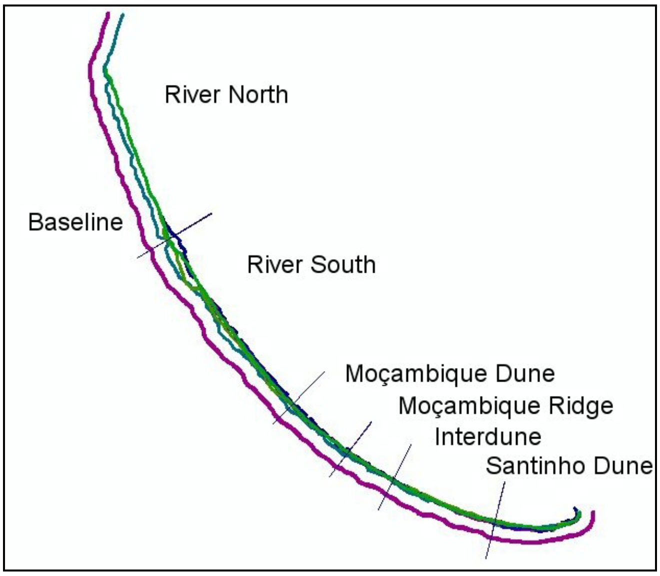


Figure I-3 Sections of Ingleses beach

Years	Santinho Dune	Interdune	Mocambique Ridges	Mocambique Dune	River South	River North
1978-1998	-1,61631	-1,18688	-2,47250	-1,25200	0,24367	0

Table I-6 Average values for the period of 1978-1998

The total advanced fill volume can now be calculated for each section of the beach using the Verhagen method, see Table I-7.

	Santinho Dune	Interdune	Mocambique Ridges	Mocambique Dune	River South	River North
Volume in 10 years (m^3/m)	105,4	77,4	161,2	81,6	0,0	0,0
Volume in 10 years including extra 20% (m^3/m)	126,5	92,9	193,4	98,0	0,0	0,0

Table I-7 Volumes of the advanced fill (m^3/m)

I.5 Total volumes

I.5.1 Total volume of the nourishment

The total volume of the nourishment is a summation of the design fill and the advanced fill and will be calculated for each section. The total volumes of the nourishment for each section are given in Table I-8.

	Santinho Dune	Interdune	Mocambique Ridges	Mocambique Dune	River South	River North
Volume of the design fill (m^3/m)	98,57	98,57	98,57	98,57	98,57	98,57
Volume of the advanced fill (m^3/m)	126,5	92,9	193,4	98,0	0,0	0,0
Total volume of the nourishment (m^3/m)	225,0	191,4	292,0	196,5	98,6	98,6

Table I-8 Volumes for each section

The total volume of the nourishment of Ingleses beach is the summation of the total volume for each section. The total volume of the nourishment for Ingleses beach is given in Table I-9.

	Santinho Dune	Interdune	Mocambique Ridges	Mocambique Dune	River South	River North
Length of section (m)	654	788	388	530	1482	1158
Volume of nourishment (m^3/m)	225,0	191,4	292,0	196,5	98,6	98,6
Volume of nourishment (m^3)	147169,7	150847,7	113303,1	104159,0	146080,7	114144,1
Volume of advanced fill (m^3)	82704,9	73174,5	75058,0	51916,9	0,0	0,0
Volume of nourishment (m^3)	775704,3					

Table I-9 Total volumes of the nourishment

I.5.2 Total volume of the renourishment

The renourishment consists of the advanced fill that has to be renewed. In the case of this project the design lifetime is ten years, so the beach has to be renourished every ten years. The volumes of this renourishment are again presented in Table I-10.

	Santinho Dune	Interdune	Mocambique Ridges	Mocambique Dune	River South	River North
Volume advanced fill (m^3/m)	105,4	77,4	161,2	81,6	0,0	0,0
Volume including extra 20% (m^3/m)	126,5	92,9	193,4	98,0	0,0	0,0

Table I-10 Volumes of the renourishment

The total volume of sand that has to be renourished every ten years is equal to 282854 m^3.

Appendix J Breaker height

To calculate the desired beach width, the breaker height at the beach has to be known. To calculate the breaker height the relation between the wave height and the depth have to be known. This relation is calculated by swan Appendix O.

J.1 Swan input

The input consists of two parts:

- The bottom profile
- The boundary conditions

J.1.1 The bottom profile

For the bottom profile Dean [1977] is used:

$$h(y) = A(d_{50})y^{2/3}$$

The sand from the Mocambique dune consists of two grain sizes. For the profile the fine grain size is used, because the fine sand spreads more over the total profile and thus will lead to a bigger required volume of sand.. The fine grain size is 0,25mm [Project Ingleses 2007]. And according to the CEM [2003] tables $A = 0{,}115m^{1/3}$. The resulting equilibrium profile is described as Dean [1977]:

$$h = 0{,}115y^{2/3}$$

J.1.2 The boundary conditions

The second part of the input data is the boundary conditions. The beach is orientated north-east and the wave direction at the beach is perpendicular to the beach so that direction is 45º. The significant deep water wave height is 1,25m with a period of 8s and a main direction NNE (22,5º) [Project Ingleses 2007].

J.2 Swan output

The output consists of two parts:

- Table
- Graph

J.2.1 Table

In Table J-1 a part of the output is shown. This is only the important part around the breaker depth.

x(m)	H(m)	h(m)
12	0,477	0,594
11	0,429	0,562
10	0,410	0,530
9	0,390	0,489
8	0,369	0,448
7	0,347	0,407
6	0,322	0,366
5	0,296	0,325

Table J-1 Output table

J.2.2 Graph

In Figure J-1 the output graph is shown.

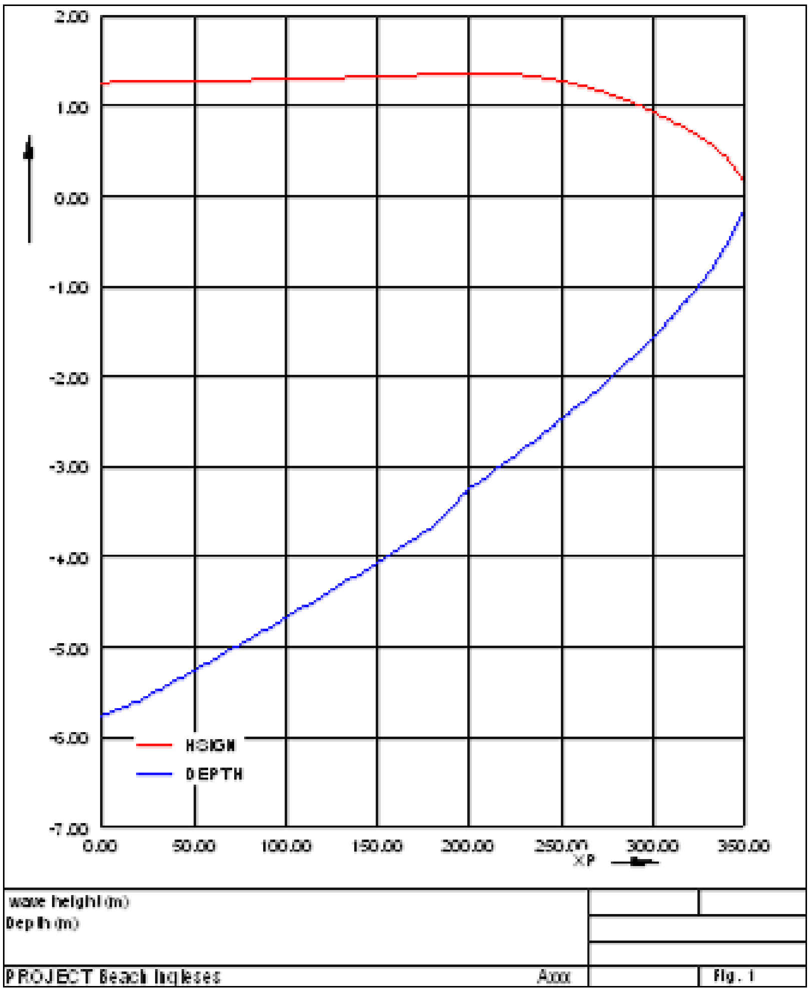


Figure J-1 Output graph

J.3 Breaker height

The breaker height is related to the depth, according to Van Rijn [1993] this relation is $H_b = \gamma h_b$ where H_b is the wave height and h_b is the dept when the wave breaks, γ is the breaker index. The value of γ is related to $\frac{\tan(\beta)}{H_0 / L}$, where H_0 is the deepwater wave height 1,25m and L is the wavelength, with $L = 1,56T^2$ you find $L = 99,84m$. And β is the angle of the slope in the breaker zone. According to the profiles in Menegais [2007] this is 3°. so $\frac{\tan(3)}{1,25/99,84} = 4,2$. With use of Table J-2 this gives a γ =0,83.

$\frac{\tan(\beta)}{H_0 / L}$	γ
0	0,45
0,25	0,55
1	0,70
3	0,80
10	1,00

Table J-2 Relation slope-breaker index

From the swan output table we find iteratively H_b is 0,369m.

Appendix K Dune fields

K.1 Introduction

For the analyses of the dune fields, a *geographical information system* (GIS) (see Appendix O) containing a part of Ingleses is used. The GIS information is obtained by laser altimetry in 2002.

K.2 Reference level

The reference level of the GIS data that is used for calculations of properties of the dune field is assumed to be *Imbituba Datum* [UNIVALI]. Imbituba Datum is the average annual mean sea level determined between 1949 and 1957 at Imbituba, Santa Catarina in Brazil. Imbituba Datum currently is approximately 0,09 m below actual mean sea level [Project Ingleses 2007].

K.3 Nourishment Results

One of the important properties of the Moçambique dune field is the volume of sediment it contains. The Moçambique dune field is a possible borrow area for the nourishment. It is important to know if the amount of sand is enough for the whole nourishment To be able to determine which part of the dune field is needed for the nourishment, the dune field is divided in four different parts, see Figure K-1. Part 1 is the head of the dune field which encroached a part of the town. The borders of parts 2 and 3 are taken as the troughs between two succeeding dune ridges. Part 4 is the remaining part which starts at the Moçambique beach and is mostly vegetated and thus less mobile and located further away from Ingleses beach.

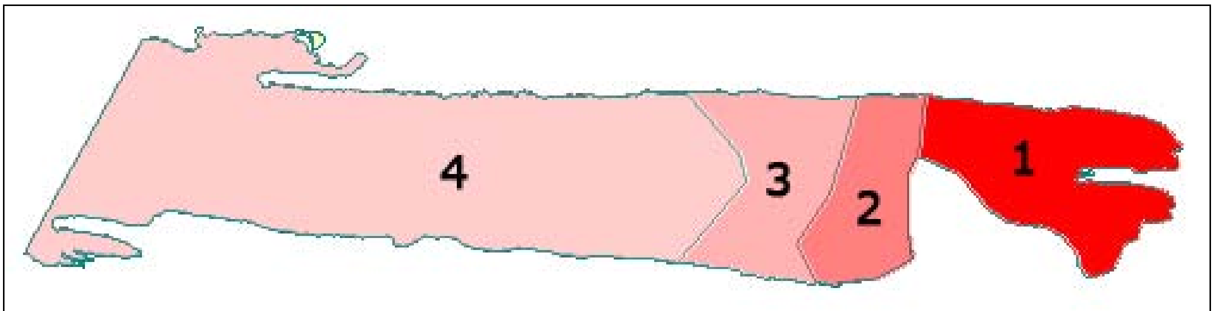


Figure K-1 Different dune parts Moçambique Dune

For every part, the volume of sand is calculated above a specific level. The GIS application automatically takes the lowest point of the surface as level above which the volume of sand is calculated. For part 1 of the Moçambique dune field, the lowest point is

7,24m above Imbituba Datum. For the other parts, the volume above the level of 10 meter above Imbituba Datum is taken. The results are shown in Table K-1. Comparing the required amount of sand for the nourishment (776.000m^3, see Appendix I) with the available amount of sand in the Moçambique dune field leads to the conclusion that the volume of part one is more than enough for the whole nourishment.

Dune part	Estimated volume
	[m^3]
Part 1, Imbituba Datum +7.24m	1.490.573
Part 1, Imbituba Datum +10m	910.083
Part 2, Imbituba Datum +10m	2.119.067
Part 3, Imbituba Datum +10m	1.850.702
Part 4, Imbituba Datum +10m	7.165.940

Table K-1 Volumes of sand in different parts of Moçambique dune field

K.4 Other calculations

For the determination of the dune migration speed, the sand volumes of the moving part of the dunes need to be known. For a part of the Moçambique dune field and the Santinho dune field, the volume of the moving part is calculated The moving part of the dune is assumed to be the volume above the lowest point of the dune surface. Also the length of the dune part is measured. The parts for which the volumes are calculated are shown in Figure K-2 and Figure K-3. In Table K-2 and Table K-3 the results are given for the moving parts of Moçambique and Santinho dune field respectively.

The great elevation differences in the Santinho dune field causes that the lowest point of the surface lies very low. This results in a (too) big moving sand volume. It is questionable if it is true that the whole calculated volume above the plane of Imbituba Datum +1,86m moves. For this reason, an averaged level of the Santinho dune field is calculated and it is assumed that only the upper half of the dune field, the part above the calculated averaged level, is moving. The volume of this upper half is also calculated. The height of the average level is calculated with the formula below.

$$h_{avg} = 1{,}86\,m + \frac{V_{above1,86m+ID}}{Surf_{San.dune}}$$

In which:

h_{avg} = height of average level plus Imbituba Datum

$V_{above\ 1,86m+ID}$ = volume of part of Santinho dune field above the level of Imbituba Datum +1,86m

$Surf_{San.dune}$ = 2D surface of part of Santinho dune field

This results in a height of the average level of Imbituba Datum +10,50 m.

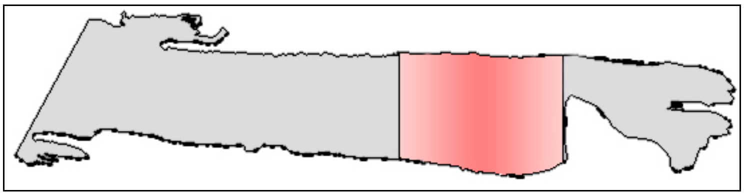


Figure K-2 Used part of Moçambique dune field to determine the moving volume

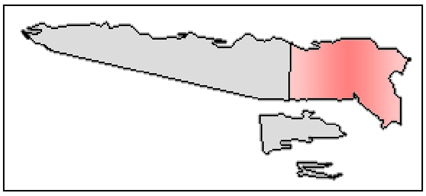


Figure K-3 Used part of Santinho dune field to determine the moving volume

Section	**Estimated volume**	**Length**	**Width**
	[m³]	*[m]*	*[m]*
Moçambique North (ID +10 m)	4.555.505	800	600

Table K-2 Results moving part of Mocambique dune field

Section	**Estimated volume**	**Area**	**Length**
Santhino North (ID +1.86m)	1.069.765	123.800	530
Santhino North (ID +10,50m)	276.490	57.087	530

Table K-3 Result moving part of Santhino dune field

K.5 Remarks on used data and method

The GIS data is used to calculate the amount of sand in the dune field. As said before, the data is obtained in the year 2002 by laser altimetry. Another remark is that there is no objective definition of the edge of the dune. In the GIS data of Ingleses, there is a description given of the borders of the dune field. This description is used as definition for the edges of the dune.

To calculate the volume, it is necessary to convert the contour lines to a grid. In this grid, every cell has its own height and with this information the volume can be calculated. The grid size is set to 10 by 10 meter. Only the cells which lay for more then 50% inside the boundaries of the dune fields will be taken into account.

The properties mentioned above are sources of errors in the volumes. Therefore the calculated volumes are estimations and can be improved.

Appendix L Construction

This appendix gives a rough estimation of the costs and construction time from the different construction methods.

L.1 Trucks

L.1.1 Truckloads

The total amount of sand that has to be moved is equal to 775704,3 m^3. The construction of the beach has to be done in the off season so the tourists are not disturbed. The off-season is 8 months long. A week has 5 working days. There are 10 effective work hours a day. This comes down to1740 hours. This means that the trucks have to move 446 m^3/hr. With trucks off 10 m^3 there are 45 truckloads/hr required for the construction of the nourishment. This means 90 movements an hour, which is a lot for the local people.

L.1.2 Costs

L.1.2.1 Sequence time

Loading a 10 m^3 will cost 2 minutes. The mean distance from the borrow area is 3,5 km. The average speed of a truck will be 30 km/hr. This means that the traveling time will be 7 minutes. The unloading of the truck will take 1 minute. The truck has to drive back 7 minutes. This comes down to a total of 17 minutes. This means that 1 truck can transport 35 m^3/hr.

Loading	2 minutes
Drive to the beach	7 minutes
Unloading	1 minute
Drive back to borrow area	7 minutes
Total cycle	**17 minutes**

Table L-1 Sequence times

L.1.2.2 Costs

The equipment needed for the transport by trucks are: loaders, trucks and bulldozers. 45 truckloads/hr are required and loading a truck will take a loader 2 minutes, this means that 1,5 loader is needed. In practice this means that there are 2 loaders needed. At the beach there is 1 bulldozer needed to egalize the sand. There will be added 20% for unforeseen costs.

Equipment	Price per hour (€/hr) (including operator)	Price per cubic meter (€/m³)
Loaders	65	0,28
Truck	65	1,86
Bulldozer	65	0,14
Total		2,28
Total including 20%		**2,74**

Table L-2 Costs of truck transport

The total costs of the nourishment with the use trucks comes down to: 775704,3*2,74 = 2,1 million euro's.

L.2 Pipelines

L.2.1 Method

To transport the sand from the dune to the beach, pipelines and pumps can also be used. For this method first a big excavation pit has to be excavated till 3 meters under groundwater level. In this excavation pit a dredging pontoon can be placed. This dredging pontoon can excavate and pump up the sand as a sand water mixture. The sand water mixture will then be pumped trough a pressure pipeline to the beach. The pipeline will enter the beach as close as possible to the excavation pit, here it will be split in two (North and South). At the drop site bulldozers will egalize the sand. To transport the sand true the pipelines booster stations will be needed.

L.2.2 The excavation pit

The first stage in this construction method is the excavation of the excavation pit. For this method the dredging pontoon HAM 250 will be used as a reference for the measurements. The pit will have to be at least 3 meter beneath the groundwater level and will have a radius of 30 meter at the bottom of the pit and the sides will have a slope of 1:4.

L.2.3 Pipelines

The pipelines used by the HAM 250 are 500 mm diameter. The maximum distance from the borrow area to the beach is 1000 m. The maximum length on the beach is 3 km. There will also be needed 100 m of floating pipeline. The pump can transport a mixture of 15% at a speed of 4,5 m/s. This gives a sand capacity of 0,133 m^3/s. Each week has 84 service hours of witch 70% are operational hours. The total transport of the nourishment fill will take 28 weeks. This construction method can easily be done during low season. Because the costs of the mobilization of the equipment is high for this method it can be wise to increase the design lifetime.

L.2.4 Feasibility

A subject of further consideration is the drink water subtraction around Ingleses. Around Ingleses 22 wells with a total discharge of 300 l/s are located, however the locations are confidential. This is why it is very difficult to estimate the consequences of subtracting groundwater from the Dune. Further research has to be done to estimate the influences of this construction method to the groundwater. Possible problems that can occur when this construction method is chosen are: pollution of the groundwater and possible depletion of the fresh water bubble.

L.2.5 Costs

For this method it is very difficult to determine the costs because it strongly depends on the mobilization costs of the dredging pontoon. As a rough estimation €500.000 will be taken for the mobilization costs of the pontoon and support equipment. In the Table L-3 below estimations of the costs per week and the total costs will be given.

Equipment	**Costs / Week (€)**	**Total costs**
Dredging pontoon	60.000	1.680.000
Booster station	25.000	700.000
Bulldozers	65*84 = 5460	153.000
Pipelines (100m floating included)	5000	140.000
Staff	10.000	280.000
Mobilization		500.000
Total		**3.453.000**

Table L-3 Costs of pipeline transport

L.3 Renourishment

L.3.1 Costs

The volume of the renourishment is a lot smaller than the initial nourishment. The initial nourishment is cheaper to construct with trucks than with pipelines. This is even more the case with the renourishment because the mobilization costs are a lot higher for construction with pipelines. The costs of a renourishment is shown in the table below (Table L-4).

Price per cubic meter (€/m)	Cubic meters renourishment (m³)	Total costs
2,74	282854,2	775.020,5

Table L-4 Total costs renourishment

L.3.2 Required time

The total volume of sand required for the renourishment is 282854,2. As estimated in L.1.1 there are 50 working hours in a week. The off season of 8 months can be used for the renourishment. This comes down to:1740 hours. This means that the trucks have to move 163 m^3/hr. With trucks from 10 m^3 there are 17 truckloads/hr required for the construction of the nourishment. This means 34 movements an hour, which is still a lot but acceptable.

L.4 Conclusion

Evaluation criteria	Weight	Trucks	Pipelines
Inconvenience inhabitants Ingleses	5	0	2
Duration	4	1	3
Inconvenience Tourists	2	1	2
Environment	2	3	3
Total		**12**	**32**

Table L-5 Multi Criteria Evaluation

To compare both construction methods a multi criteria analyses (MCA) is used. The first criterion is the inconvenience for the inhabitants of Ingleses, this is the most important criterion and has weight 5. One truck every 40 seconds is a lot, this is why truck transport scores a 0, pipelines are a lot better and score a 2. The second criterion is the duration this is an important criterion, because the longer it takes the longer inhabitants and tourists have inconvenience. This criterion has weight 4. The transport by pipelines takes 28 weeks and scores a 3, the transport by trucks takes longer and scores a 1 for duration. The third criterion is the inconvenience for tourists and has weight 2, because the inconvenience is in low season when there are not much tourists in Ingleses. Both methods are inconvenient. Transport by pipelines scores a 2 and transport by trucks a 1, because transport by pipeline disturbs one location and trucks are al over the town. The last criterion is environment and has weight 2. The methods have a different influence on the environment but the both score a 3 for environment. Another criterion is the influence on the fresh water subtraction around Ingleses. As stated before more research has to be done to these influences. So at this point it won't be taken into account for the multi criteria analyses.

Transport by trucks scores a total of 12 and transport by pipelines scores a total of 32. Transport by pipelines is better but more expensive, the transport by pipelines costs 3,44 million euro's against 2,10 million euro's for transport by trucks. This will be a decision the initiator will have to make.

Appendix M Wave data reliability

One of the conclusions of the research to the coastal morphologic problems around Ingleses in 2007 was that the available data is outdated, not measured close enough to the area of interest or measured during a too short period. Especially the wave and wind data suffered from a high unreliability. Since the 2008 project has more data sources at its disposal, the reliability of the 2007 data can be investigated. The additional data sources consist of the online wave climate database of Argoss and a hard copy of the Global Wave Statistics from BMT.

M.1 Data 2007

The wave data used in the 2007 research was obtained from a research of Araujo in 2003. The basic data used for further analysis is given in Table M-1 and Figure M-2.

Height	*Spring*	*Summer*	*Autumn*	*Winter*	*Total*	*Height*	*Spring*	*Summer*	*Autumn*	*Winter*	*Total*
0,00 0,25	*0,00*	*0,00*	*0,00*	*0,00*	***0,00***	*3,00 3,25*	0,20	0,90	0,50	2,40	***1,00***
0,25 0,50	0,10	0,00	0,20	0,60	***0,23***	*3,25 3,50*	0,30	0,50	0,60	1,40	***0,70***
0,50 0,75	3,80	3,40	0,70	1,80	***2,43***	*3,50 3,75*	0,20	0,00	0,40	0,80	***0,35***
0,75 1,00	16,90	22,40	6,90	4,10	***12,58***	*3,75 4,00*	0,10	0,00	0,00	0,50	***0,15***
1,00 1,25	21,20	29,70	19,80	15,00	***21,43***	*4,00 4,25*	0,20	0,00	0,00	0,20	***0,10***
1,25 1,50	16,30	18,00	27,20	15,60	***19,28***	*4,25 4,50*	0,00	0,00	0,00	0,00	***0,00***
1,50 1,75	16,50	8,90	20,80	12,60	***14,70***	*4,50 4,75*	0,00	0,00	0,00	0,00	***0,00***
1,75 2,00	12,00	7,40	10,80	13,20	***10,85***	*4,75 5,00*	0,00	0,00	0,00	0,00	***0,00***
2,00 2,25	6,80	3,90	6,60	11,60	***7,23***	*5,00 5,25*	0,00	0,00	0,00	0,00	***0,00***
2,25 2,50	3,80	2,20	2,60	10,40	***4,75***	*5,25 5,50*	0,00	0,00	0,00	0,00	***0,00***
2,50 2,75	1,40	1,40	1,80	5,80	***2,60***	*5,50 5,75*	0,00	0,00	0,00	0,00	***0,00***
2,75 3,00	0,20	1,30	1,10	4,00	***1,65***						

Table M-1 Seasonal wave height occurrences obtained from research of Araujo in 2003.

M.2 Argoss

The online wave climate database of Argoss consists of accurate, long term measurements. The database contains both wave and wind data per month. The data is un-directional. There are two measurement locations that are much closer to the area of interest than the data from the 2007 research, as indicated in Figure M-1. The measurement locations represent the centre of a 50 by 50 kilometres large surface from which the data is collected. The wave records of both locations are very similar. Therefore, only the closest wave record is used in the reliability analysis.

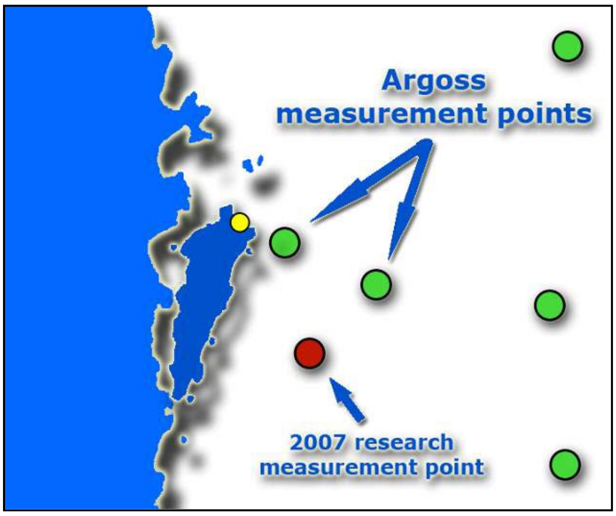


Figure M-1 Wave and wind measurement locations. Green locations are part of the Argoss database while the red location is the origin of the 2007 data. The yellow dot indicates Beach Ingleses.

The Argoss data is not thoroughly time stamped. Therefore, it is not possible to extract a subsection of the data from the same period as the 2007 data. Since the period of the 2007 data measurements is included in the Argoss data and the overall period of measurements included in the Argoss data is limited, the comparison is nevertheless allowed.

The Argoss data has the smallest wave height intervals, or highest resolution, of all three sources. In order to be able to compare this data with the other sources, the resolution is down scaled using a simple linear interpolation. Furthermore, the data is transformed from monthly to seasonal data. The original data and the transformations are presented in Table M-2, Table M-3, Table M-4 and Figure M-3.

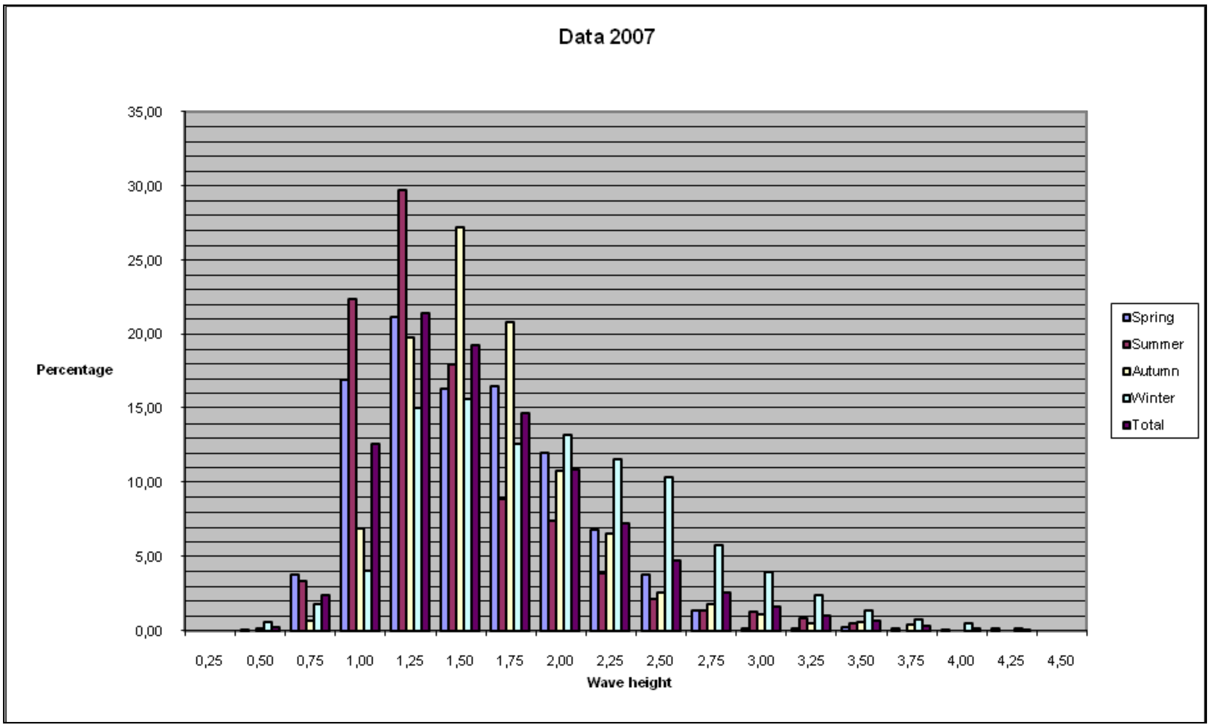


Figure M-2 Seasonal wave height occurrences obtained from research of Araujo in 2003.

Height		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
0,00	*0,20*	0,00	0,00	0,57	0,42	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	***0,08***
0,20	*0,40*	0,47	0,00	0,00	0,00	0,45	0,00	0,00	0,00	0,00	0,00	0,00	0,00	***0,08***
0,40	*0,60*	1,41	6,81	5,68	3,81	1,36	0,86	0,00	0,44	0,00	0,00	2,04	0,00	***1,87***
0,60	*0,80*	1,41	4,19	7,39	2,54	2,26	5,58	2,71	2,65	0,00	0,90	3,57	1,28	***2,87***
0,80	*1,00*	3,29	13,61	7,95	8,90	5,88	8,15	4,98	3,10	0,90	5,41	7,65	7,26	***6,42***
1,00	*1,20*	7,51	7,85	6,25	11,86	5,43	5,58	4,98	7,52	2,70	3,60	5,10	5,13	***6,13***
1,20	*1,40*	23,47	17,28	26,70	19,07	20,81	17,60	19,00	32,74	9,01	22,07	27,04	20,09	***21,24***
1,40	*1,60*	7,51	9,42	5,11	5,51	8,60	8,58	8,14	6,19	9,46	9,46	9,18	5,56	***7,73***
1,60	*1,80*	15,96	7,85	7,39	10,59	14,48	12,02	18,10	8,85	13,06	14,86	7,14	11,97	***11,86***
1,80	*2,00*	14,08	9,95	9,09	11,44	9,50	14,16	16,74	9,73	8,56	16,67	3,57	11,11	***11,22***
2,00	*2,20*	14,55	1,57	10,80	5,93	9,95	9,01	9,05	9,73	21,17	11,71	7,65	13,68	***10,40***
2,20	*2,40*	3,76	7,85	7,39	7,20	4,52	7,73	4,07	3,54	13,51	5,41	4,08	10,26	***6,61***
2,40	*2,60*	5,16	5,76	0,57	2,97	4,98	7,73	1,81	3,10	5,41	4,50	5,61	3,85	***4,29***
2,60	*2,80*	1,41	3,66	0,57	5,93	4,98	2,58	4,52	3,10	5,86	3,15	5,61	3,85	***3,77***
2,80	*3,00*	0,00	1,57	0,57	0,85	0,45	0,00	0,00	1,77	0,90	0,45	1,02	2,56	***0,85***
3,00	*3,20*	0,00	2,09	0,00	1,69	0,90	0,00	2,26	1,77	1,80	0,45	4,59	1,28	***1,40***
3,20	*3,40*	0,00	0,52	2,84	1,27	1,36	0,00	0,00	2,21	0,45	1,35	4,59	1,28	***1,32***
3,40	*3,60*	0,00	0,00	1,14	0,00	2,26	0,43	1,36	1,33	2,25	0,00	1,02	0,43	***0,85***
3,60	*3,80*	0,00	0,00	0,00	0,00	0,90	0,00	0,45	1,33	4,50	0,00	0,51	0,43	***0,68***
3,80	*4,00*	0,00	0,00	0,00	0,00	0,45	0,00	0,00	0,44	0,00	0,00	0,00	0,00	***0,07***
4,00	*4,20*	0,00	0,00	0,00	0,00	0,00	0,00	0,45	0,00	0,00	0,00	0,00	0,00	***0,04***
4,20	*4,40*	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,44	0,00	0,00	0,00	0,00	***0,04***
4,40	*4,60*	0,00	0,00	0,00	0,00	0,00	0,00	0,45	0,00	0,45	0,00	0,00	0,00	***0,08***
4,60	*4,80*	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	***0,00***
4,80	*5,00*	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	***0,00***
5,00	*5,20*	0,00	0,00	0,00	0,00	0,00	0,00	0,45	0,00	0,00	0,00	0,00	0,00	***0,04***
5,20	*5,40*	0,00	0,00	0,00	0,00	0,45	0,00	0,45	0,00	0,00	0,00	0,00	0,00	***0,08***
5,40	*5,60*	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	***0,00***

Table M-2 Monthly wave height occurrences obtained from the Argoss database.

Height		Winter	Spring	Summer	Autumn	Total	Heigth		Winter	Spring	Summer	Autumn	Total
0,00	*0,20*	0,13	0,20	0,00	0,00	***0,08***	*2,80*	*3,00*	0,91	0,49	0,80	1,18	***0,85***
0,20	*0,40*	0,16	0,15	0,00	0,00	***0,08***	*3,00*	*3,20*	0,83	0,87	1,76	2,16	***1,40***
0,40	*0,60*	4,06	2,49	0,23	0,68	***1,87***	*3,20*	*3,40*	0,97	1,16	0,84	2,33	***1,32***
0,60	*0,80*	3,72	3,64	2,35	1,79	***2,87***	*3,40*	*3,60*	0,31	0,97	1,46	0,67	***0,85***
0,80	*1,00*	8,22	7,63	3,72	6,14	***6,42***	*3,60*	*3,80*	0,04	0,30	1,64	0,72	***0,68***
1,00	*1,20*	7,09	7,69	5,36	4,37	***6,13***	*3,80*	*4,00*	0,00	0,15	0,15	0,00	***0,07***
1,20	*1,40*	21,82	20,07	21,11	21,96	***21,24***	*4,00*	*4,20*	0,00	0,00	0,15	0,00	***0,04***
1,40	*1,60*	7,39	7,22	7,85	8,46	***7,73***	*4,20*	*4,40*	0,00	0,00	0,15	0,00	***0,04***

1,60	*1,80*	10,86	11,90	13,23	11,43	***11,86***	*4,40*	*4,60*	0,00	0,00	0,26	0,05	***0,08***
1,80	*2,00*	11,24	11,19	12,24	10,19	***11,22***	*4,60*	*4,80*	0,00	0,00	0,00	0,00	***0,00***
2,00	*2,20*	9,26	8,48	12,10	11,76	***10,40***	*4,80*	*5,00*	0,00	0,00	0,00	0,00	***0,00***
2,20	*2,40*	6,62	6,45	6,46	6,91	***6,61***	*5,00*	*5,20*	0,00	0,00	0,15	0,00	***0,04***
2,40	*2,60*	4,16	4,51	3,67	4,81	***4,29***	*5,20*	*5,40*	0,00	0,15	0,15	0,00	***0,08***
2,60	*2,80*	2,21	4,29	4,16	4,40	***3,77***	*5,40*	*5,60*	0,00	0,00	0,00	0,00	***0,00***

Table M-3 Seasonal wave height occurrences extracted from the Argoss database.

Height		***Winter***	***Spring***	***Summer***	***Autumn***	***Total***	***Height***		***Winter***	***Spring***	***Summer***	***Autumn***	***Total***
0,00	*0,25*	0,17	0,24	0,00	0,00	***0,10***	*3,00*	*3,25*	1,07	1,16	1,98	2,74	***1,74***
0,25	*0,50*	2,15	1,36	0,12	0,34	***0,99***	*3,25*	*3,50*	0,88	1,35	1,36	2,08	***1,42***
0,50	*0,75*	4,82	3,98	1,88	1,68	***3,09***	*3,50*	*3,75*	0,19	0,71	1,96	0,87	***0,93***
0,75	*1,00*	9,14	8,54	4,30	6,59	***7,14***	*3,75*	*4,00*	0,01	0,23	0,56	0,18	***0,24***
1,00	*1,25*	12,55	12,71	10,63	9,86	***11,44***	*4,00*	*4,25*	0,00	0,00	0,19	0,00	***0,05***
1,25	*1,50*	20,06	18,66	19,76	20,70	***19,79***	*4,25*	*4,50*	0,00	0,00	0,24	0,02	***0,07***
1,50	*1,75*	11,84	12,53	13,85	12,80	***12,76***	*4,50*	*4,75*	0,00	0,00	0,13	0,02	***0,04***
1,75	*2,00*	13,96	14,17	15,55	13,05	***14,18***	*4,75*	*5,00*	0,00	0,00	0,00	0,00	***0,00***
2,00	*2,25*	10,92	10,09	13,72	13,49	***12,05***	*5,00*	*5,25*	0,00	0,04	0,19	0,00	***0,06***
2,25	*2,50*	7,04	7,09	6,68	7,59	***7,10***	*5,25*	*5,50*	0,00	0,11	0,11	0,00	***0,06***
2,50	*2,75*	3,74	5,47	4,96	5,71	***4,97***	*5,50*	*5,75*	0,00	0,00	0,00	0,00	***0,00***
2,75	*3,00*	1,46	1,56	1,84	2,28	***1,79***							

Table M-4 Seasonal wave height occurrences extracted from the Argoss database and down scaled to the 2007 data interval.

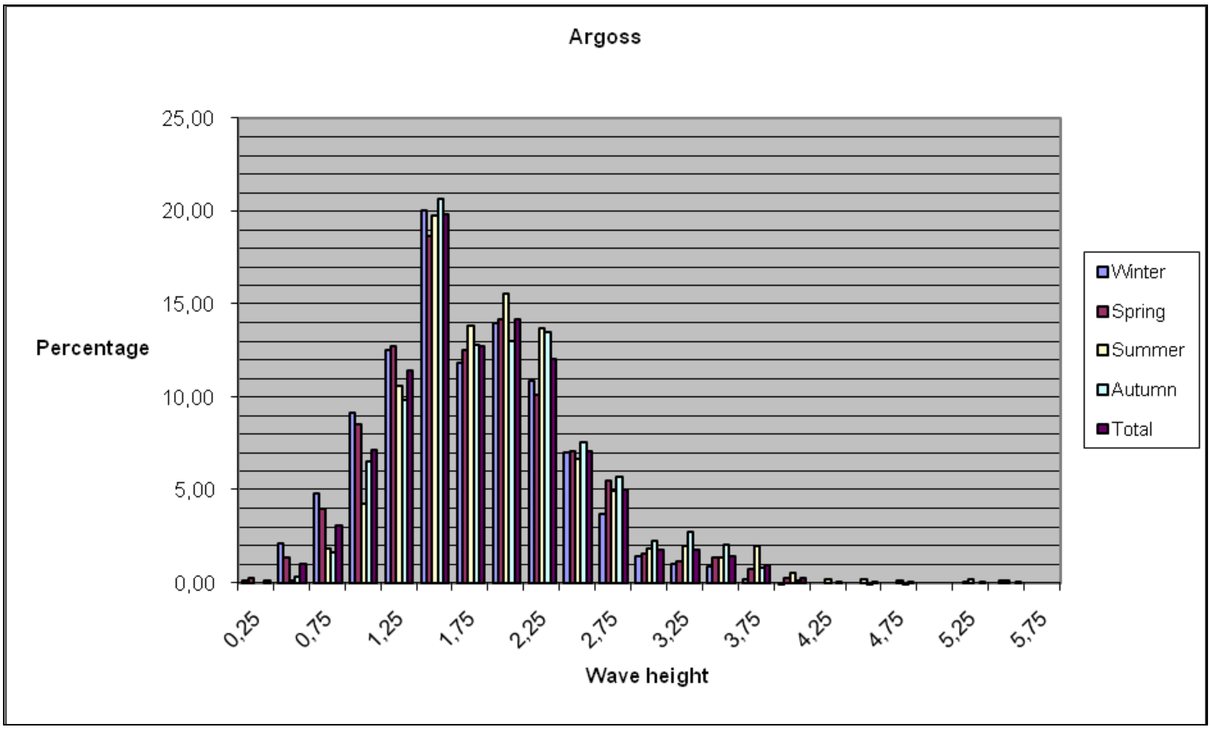


Figure M-3 Seasonal wave height occurrences extracted from the Argoss database and down scaled to the 2007 data interval.

M.3 Global Wave Statistics

The Global Wave Statistics (GWS) consists of visual estimated wave heights per season. The data is directional and divided in several, fairly large, areas. The idea is that the visual estimated wave height corresponds fairly well with the significant wave height from the other sources. There are two areas that are of interest for this project, as indicated in Figure M-4.

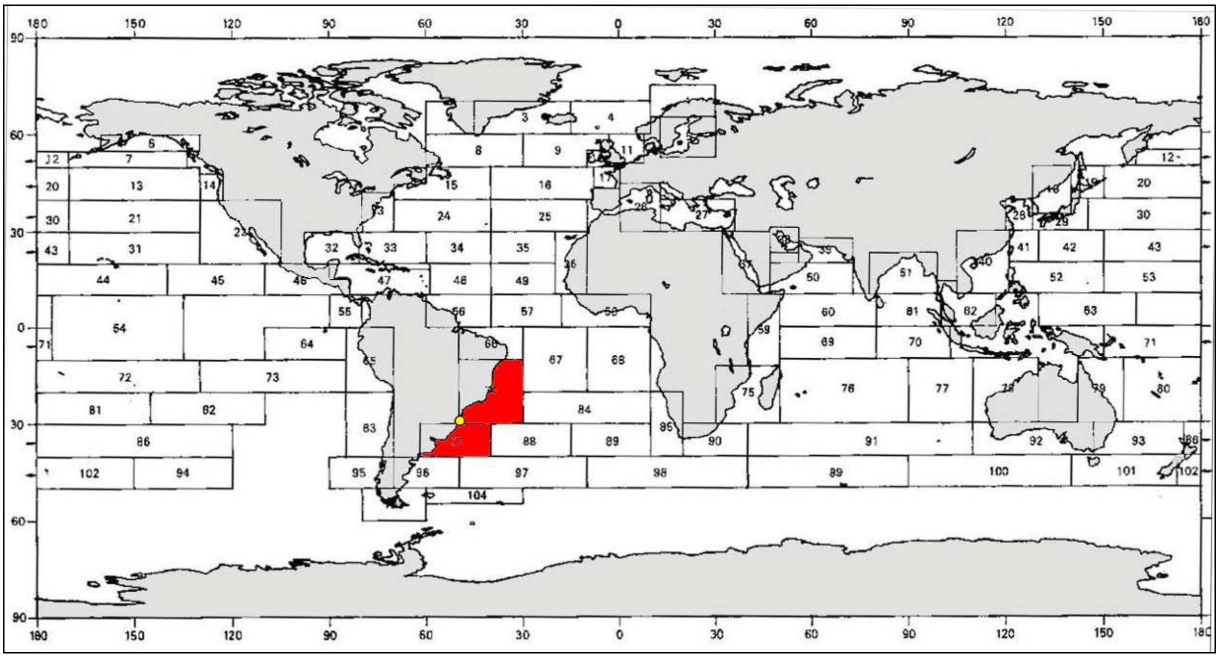


Figure M-4 Areas used to categorize the Global Wave Statistics. The areas indicated with red are used for comparison with the 2007 data. The yellow dot indicates the area of interest.

In order to be able to compare the data from the GWS, the directional information is discarded simply by adding up the values per wave height interval. Only the yearly totals are used. The result is shown in Table M-5.

Height		***Area 87***		***Area 74***		***Average***	
		Absolute	*Percentage*	*Absolute*	*Percentage*	*Absolute*	*Percentage*
0	*1*	128	12,83	118	11,84	123	12,33
1	*2*	360	36,07	422	42,33	391	39,20
2	*3*	263	26,35	289	28,99	276	27,67
3	*4*	133	13,33	115	11,53	124	12,43
4	*5*	60	6,01	37	3,71	49	4,86
5	*6*	27	2,71	11	1,10	19	1,90
6	*7*	13	1,30	3	0,30	8	0,80
7	*8*	6	0,60	1	0,10	4	0,35
8	*9*	4	0,40	1	0,10	3	0,25
9	*10*	2	0,20	0	0,00	1	0,10
10	*11*	1	0,10	0	0,00	1	0,05
11	*12*	1	0,10	0	0,00	1	0,05
12	*13*	0	0,00	0	0,00	0	0,00
13	*14*	0	0,00	0	0,00	0	0,00
14	*15*	0	0,00	0	0,00	0	0,00

Table M-5 Wave height occurrences obtained from the Global Wave Statistics.

M.4 Comparison

The data from the GWS has the lowest resolution with respect to the wave height intervals of all three sources. This resolution is, compared to the other sources, such that it is worth first comparing the 2007 data to the Argoss data only using the resolution of the 2007 data. An additional comparison will then be made with the GWS data using the resolution of the GWS data.

In the comparison of the Argoss data with respect to the 2007 data, the 2007 data resolution of the wave height intervals is used. Only the annual total wave height distributions are compared. This results in two distributions presented in Table M-6, Figure M-5, Figure M-6 and Figure M-7.

Height	***Data sources***		***Deviation***		***Height***	***Data sources***		***Deviation***	
	Data 2007	*Argoss*	*Absolute Argoss*	*Percentage Argoss*		*Data 2007*	*Argoss*	*Absolute Argoss*	*Percentage Argoss*
0,00 0,25	0,00	0,10	-0,10		*3,00 3,25*	1,00	1,74	-0,74	-73,52
0,25 0,50	0,23	0,99	-0,77	-340,60	*3,25 3,50*	0,70	1,42	-0,72	-102,59
0,50 0,75	2,43	3,09	-0,66	-27,40	*3,50 3,75*	0,35	0,93	-0,58	-166,71
0,75 1,00	12,58	7,14	5,43	43,20	*3,75 4,00*	0,15	0,24	-0,09	-62,59
1,00 1,25	21,43	11,44	9,99	46,62	*4,00 4,25*	0,10	0,05	0,05	53,07
1,25 1,50	19,28	19,79	-0,52	-2,70	*4,25 4,50*	0,00	0,07	-0,07	
1,50 1,75	14,70	12,76	1,94	13,22	*4,50 4,75*	0,00	0,04	-0,04	
1,75 2,00	10,85	14,18	-3,33	-30,71	*4,75 5,00*	0,00	0,00	0,00	
2,00 2,25	7,23	12,05	-4,83	-66,83	*5,00 5,25*	0,00	0,06	-0,06	
2,25 2,50	4,75	7,10	-2,35	-49,49	*5,25 5,50*	0,00	0,06	-0,06	
2,50 2,75	2,60	4,97	-2,37	-91,12	*5,50 5,75*	0,00	0,00	0,00	
2,75 3,00	1,65	1,79	-0,14	-8,33					

Table M-6 Difference in wave height occurrence between 2007 data and Argoss.

From the figures it can be seen that the wave height occurrence according to Argoss is shifted to the higher wave heights with respect to the 2007 wave heights. Since the measurements for the Argoss database are done over a longer period, closer to the area of interest and with more than one measurement device, the Argoss data is more reliable than the 2007 data. This means that the 2007 deep water wave heights are underestimated.

A similar comparison with the GWS data results in even a bigger shift to higher wave heights as can be seen in Figure M-8 and Figure M-9. The GWS data, however, is collected from a very big area using visual estimates which makes the data not as reliable as the Argoss data. Nevertheless, it supports the theory that the 2007 deep water wave height is underestimated.

The higher deep water wave heights do not necessarily result in higher near shore wave heights. The SWAN model of the 2007 research can be used to convert the updated deep water wave heights to an update of the near shore wave height. In order to translate the figures presented in this appendix to SWAN input data, a quite extensive analysis is needed involving wave spectra. Since the expected change in the near shore wave height is small and the intentions of this project are not to repeat the 2007 research, this analysis is not done. Instead, the figures from the 2007 research are used with the knowledge in mind that these figures are underestimated and the solutions presented should be insensitive to small differences in the near shore wave height.

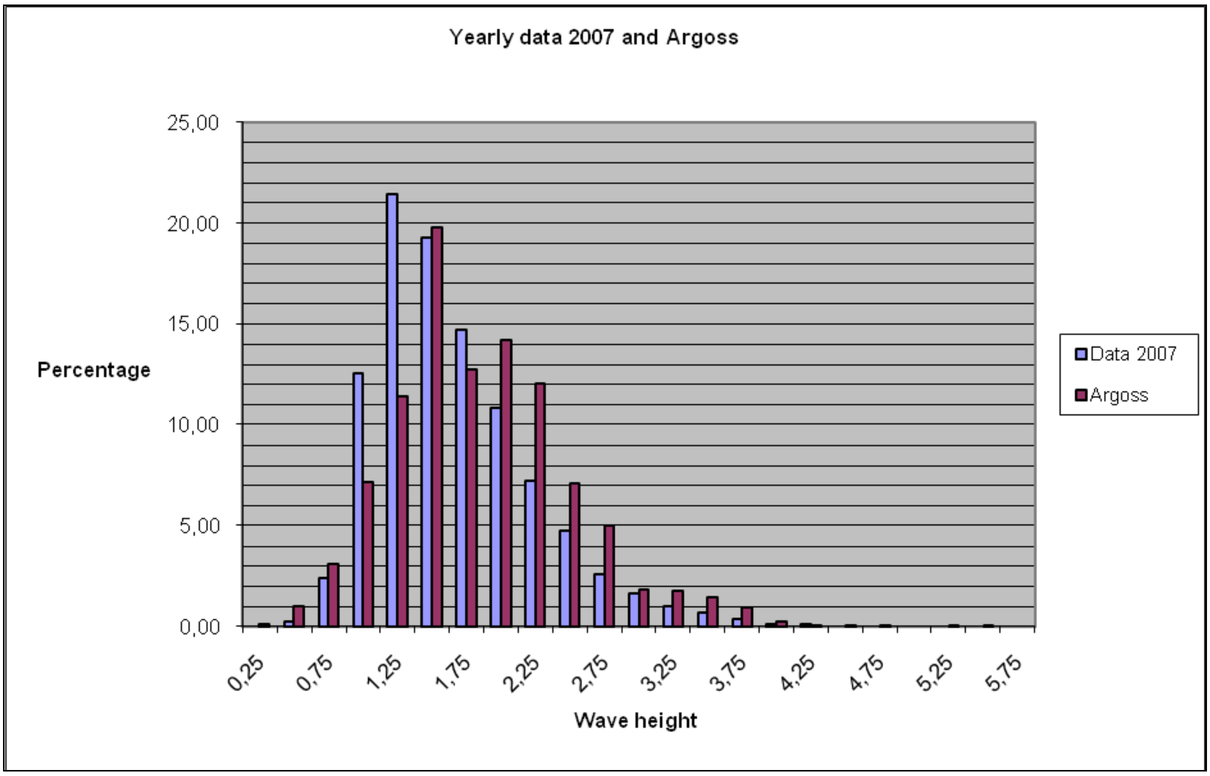


Figure M-5 Comparison between the 2007 data and the Argoss data using the 2007 data resolution.

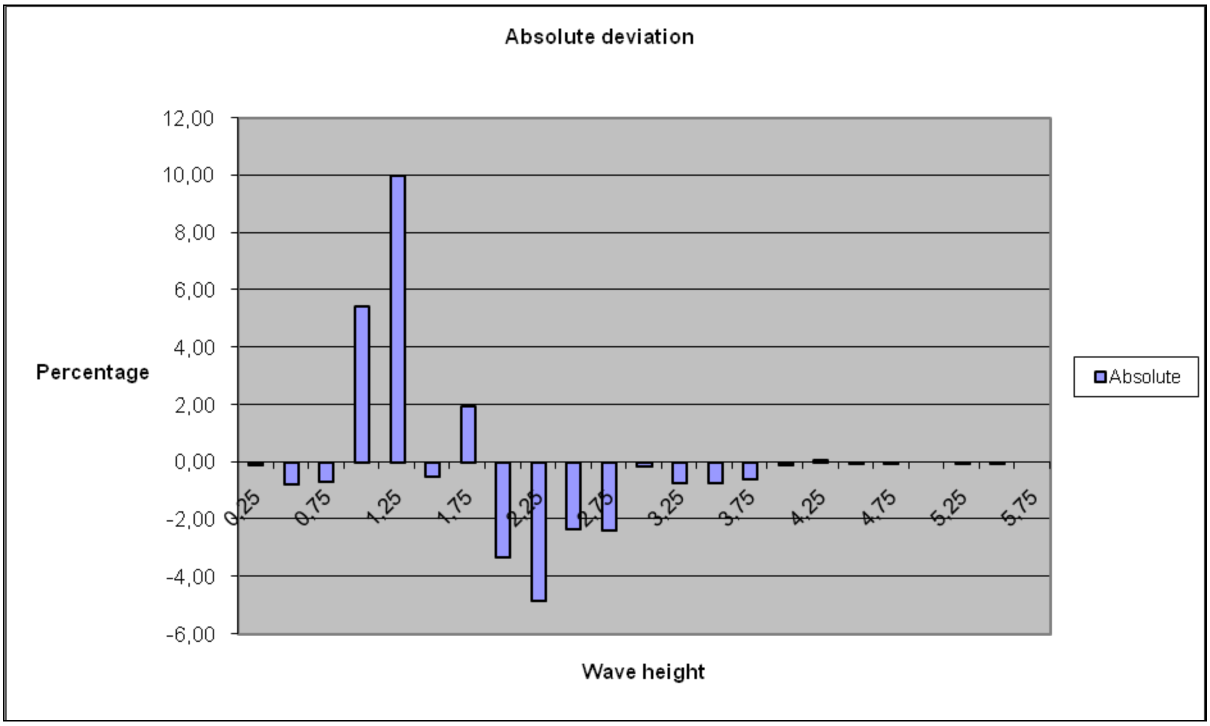


Figure M-6 Absolute difference in wave height occurrence between 2007 data and Argoss. A negative value means the 2007 data is *underestimated* compared to Argoss.

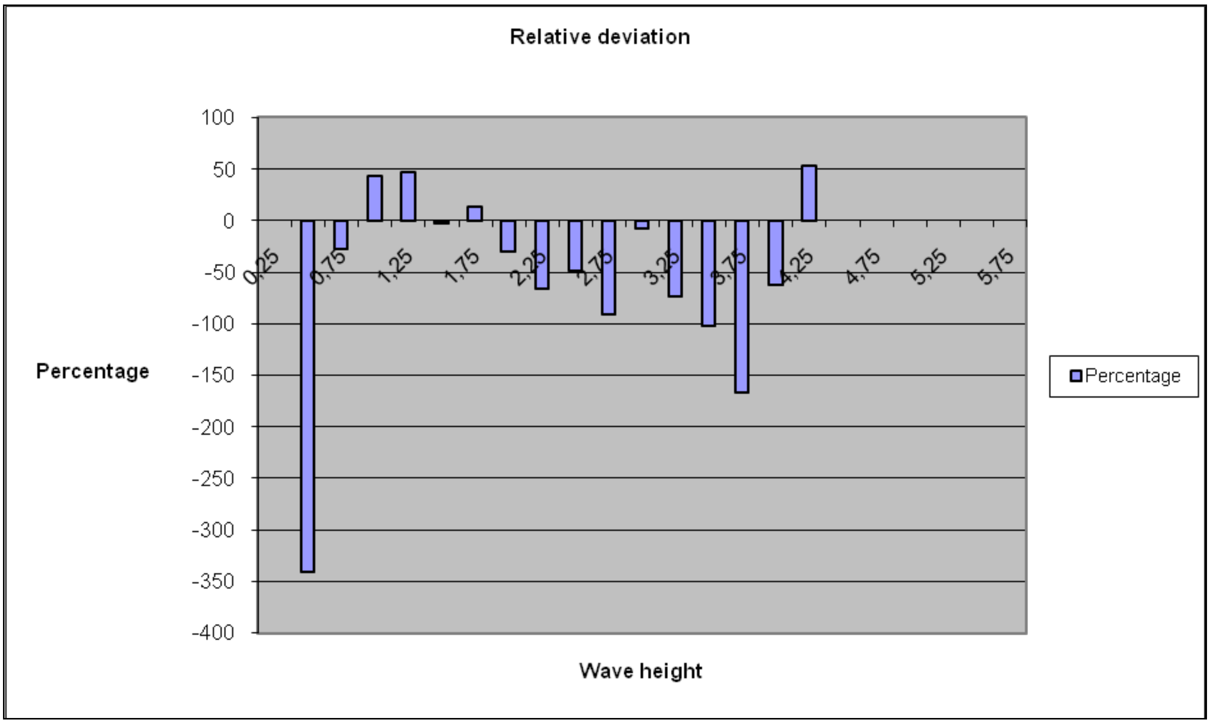


Figure M-7 Relative difference, with respect to 2007 data, in wave height occurence between 2007 data and Argoss. A negative value means the 2007 data is *underestimated* compared to Argoss.

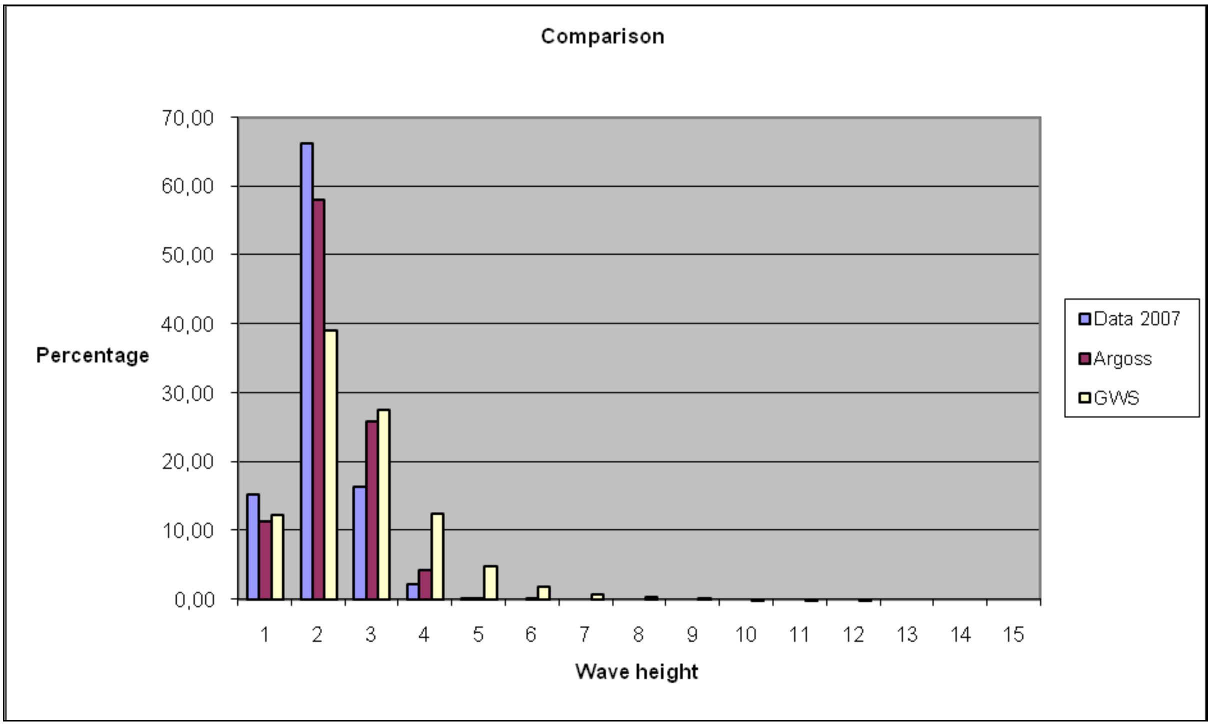


Figure M-8 Comparison between the 2007 data, the Argoss data and the GWS data using the GWS resolution.

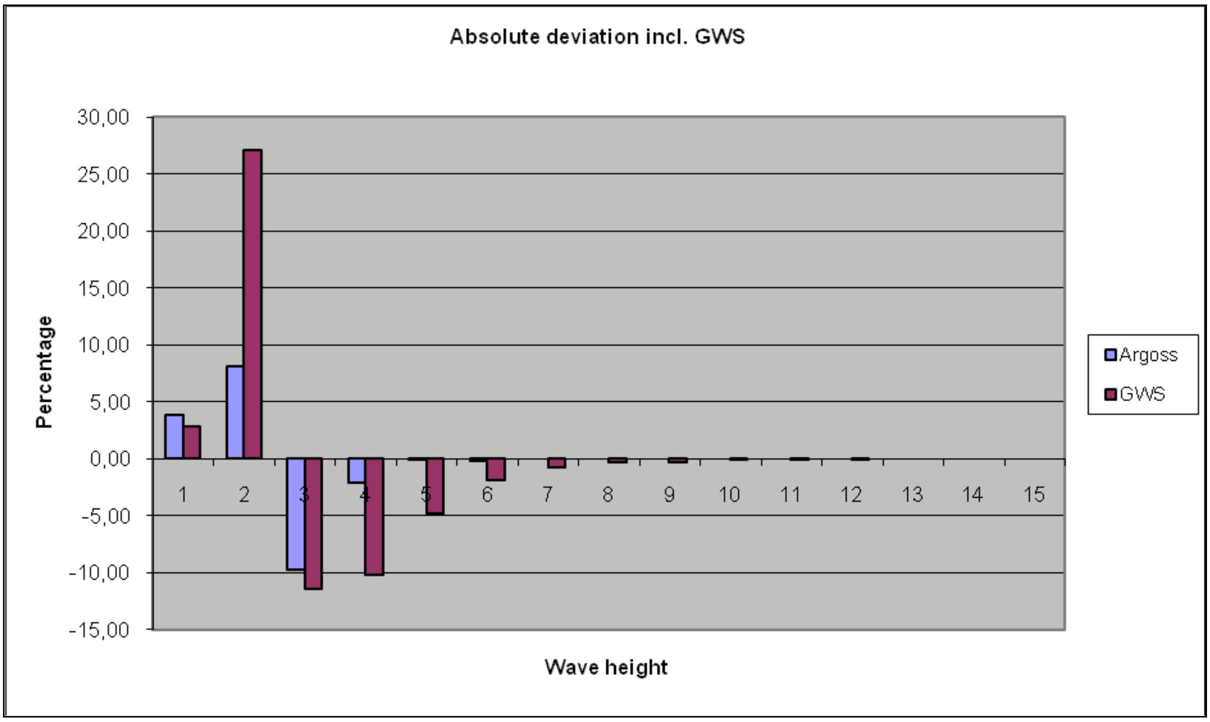


Figure M-9 Absolute difference in wave height occurrence between 2007 data and Argoss and GWS. A negative value means the 2007 data is *underestimated* compared to Argoss and / or GWS

Appendix N Numerical model

N.1 Introduction

In this appendix the simulations, which were done with UNIBEST, will be discussed. There are different simulations done to improve the model of the sand transports around Ingleses. Five different scenarios are simulated. The first two scenarios are also done by the 2007 project. The results of the simulations from 2007 are reproduced to be sure to have the same starting point.

For the other scenarios is the model adapted with improved values for different parameters. The adapted model has to reproduce the phenomena, that are observed in the photo analysis. Two historical situations are simulated, to compare the model with the results from the aerial photo analysis. The last scenario that will be simulated is the nourishment. This will be done with the model setup which reproduces the historical phenomena in the best way. With the use of this model a attempt is made to give a indication of the development of the nourishment. An overview of the simulations is given in Table N-1.

Scenario	Start year	End year	Duration (years)	Boundary North	Source
Sc1			15	No sand flux (Q = 0)	Santhino dunefield (Q = 10.000 m^3/year)
Sc2			100	No sand flux (Q = 0)	No Source
Sc3	1978	1998	20	Sandbypass (Q=71.000m^3/year)	Santhino dunefield (Q = 15.000 m^3/year)
Sc4	1938	1958	20	Sandbypass (Q=71.000m^3/year)	Santhino dunefield (Q = 15.000 m^3/year) Moçambique (56.000 m^3/year)
Sc5	2008	2018	10	Sandbypass (Q=17.000m^3/year)	Santhino dunefield (Q = 15.000 m^3/year)

Table N-1 Scenarios

N.2 Used data

N.2.1 LT modelling

N.2.1.1 Bathymetry

The bathymetry that is used for the modeling of the different scenarios is obtained during research in 2007 and is represented in their report [Project Ingleses 2007] . The bathymetry is based on two data sets, one obtained from hydrographic chart #1903 of the year 1957. The source and date of the other data set is unknown. It is not clear from which year the coastline is that is represented by the bathymetry data. But the obtained coastline is taken as starting coastline because there is no other data available. The data gives several points which represent the coastline. The distance between these points is approximately 50 meter. The different cross sections that are used in the first four scenarios are derived from the same bathymetry data and are used in the model.

For Scenario 5 is the coastline adapted. The coastline is translated over a distance equal to the nourished width of the beach in the direction of the normal on that section of the coastline. At the border of the different sections is the coastline linear interpolated over a distance of 250 meter. The cross sections are also adapted for scenario 5. The profile for the different sections can be described by the formula:

$$d = 0,115 y^{\frac{2}{3}}$$

In which *d* is the depth in meters and *y* is the distance to the coastline. The profile above mean water level is set to be equal to the profile above mean water level which is attained from the bathymetry data. To get a smooth transition of the profile at mean water level, the profile above mean water level (which is attained from the bathymetry data) is lifted over a height of 0,8 meter.

N.2.1.2 Wave data

In all scenarios the same wave data is used. This data is the same as the data that was used during the research of 2007. The wave scenarios that are used are represented in the report of Project Ingeses 2007. These wave scenarios are only based on one year of observations. More research on the wave climate is needed because the waves have a big effect on the development of the coast. For more information on the used wave data see Appendix M and the report of Project Ingleses 2007.

N.2.1.3 Wave parameters

The coefficient for wave breaking is set to 0,63. Because it is not expected that there is no bottom friction, the coefficient for bottom friction is set to 0,01. For the bottom roughness a value of 0,05m is assumed. The bottom is assumed to be not very rough. Most of the sand is quite fine and the waves that come in are mainly swell waves which don’t results in big ripples.

N.2.1.4 Transport parameters

The transport formula of *van Rijn* is used during the simulations to calculate the long shore transport.

N.2.1.5 Boundary conditions

One of the main adaptions of the model for Ingleses beach is an expected sediment bypass around the northern headland. For every scenario the sediment bypass around the southern headland is assumed to be zero. At the northern headland the sediment bypass differs for the different scenarios. For scenario 1 and 2 the bypass is zero and for the scenarios 3 and 4 the bypass is assumed to be 71.000 m^3 in northern direction. This is equal to the amount of sand that is displaced by the Moçambique Dune and the Santinho Dune together. Based on the results of scenario 3 and 4 the sediment bypass around the northern headland is adapted for scenario 5. For scenario 5, a sediment bypass of 17.000 m^3 to the north is taken.

N.2.1.6 Sources

One source of sediment for Ingleses beach is Santinho Dunefield. For the scenarios 1 and 3 untill 5 Santinho Dune is set to be a source of sediment. For scenario 1 the size of the input is roughly estimated at 10.000 m^3 sand. For the scenarios 3 till 5 a more detailed study is done to the size of the input and the size of the input is determined at about 15.000m^3. In scenario 4 (a simulation for the years 1938 until 1958) Moçambique Dune is assumed to have reached Ingleses beach too. In this situation both the Santinho and Moçambique dune were a source of sediment. The input of Moçambique dune is determined to be 56.000m^3. More about the determination of the size of the input can be found in Appendix A.

N.2.2 Results

In the next paragraphs, the development of the coastline per scenario is given. The black line in the figures represents the coastline in its starting position. The yellow line represents the coastline after the simulation. In Figure N-1 the different sections are defined.

1. River North
2. River South
3. Moçambique Dune
4. Moçambique Ridge

5. Interdune
6. Santinho Dune

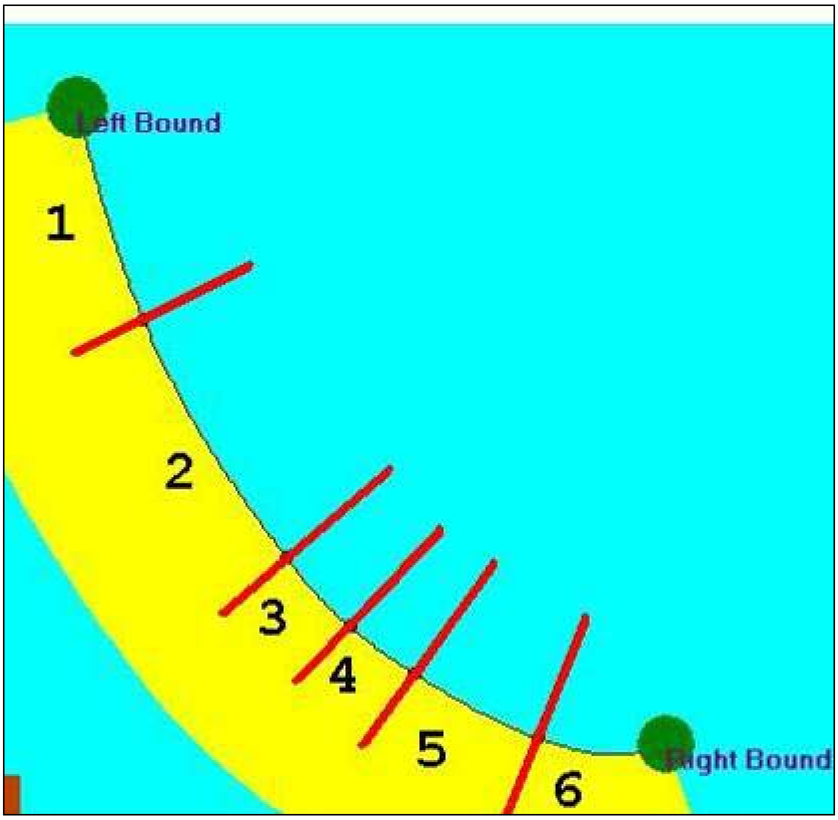


Figure N-1 Definitions of sections

N.2.2.1 Scenario 1

The results of the first scenario are represented in Figure N-2 The simulation gives approximately the same results as were obtained during the model simulations of 2007. The results show some erosion in the interdune section. In front of the Santinho Dune and more to the north of the interdune section, the beach will become wider. Near the northern boundary there is little erosion. Because of the boundary conditions (no sediment bypass around the headlands) and the input from Santinho Dune, Ingleses beach will grow over its whole length in the long term.

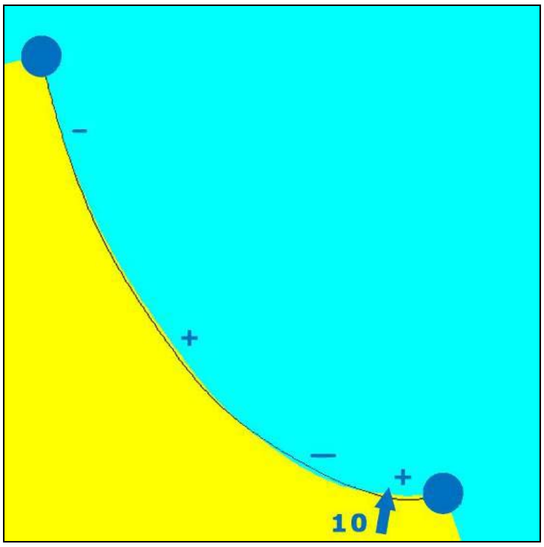


Figure N-2 UNIBEST results scenario 1

N.2.2.2 Scenario 2

The second scenario represents Ingleses beach without any inputs and outputs. With this simulation the static equilibrium of Ingleses is tried to simulate. The simulation results in erosion along the southern part of the beach and accretion in the northern part. This means that there is a net sediment transport in northern direction.

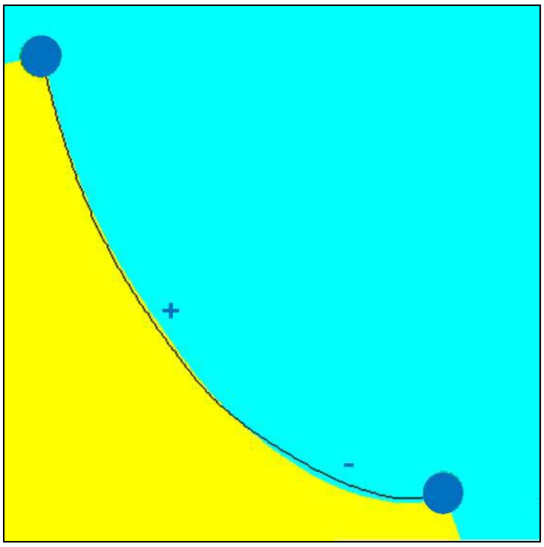


Figure N-3 UNIBEST results scenario 2

N.2.2.3 Scenario 3

In scenario 3 the northern boundary condition is a sediment bypass of 71.000 m^3. The duration is 20 years. The simulation should represent the development of the beach in the years 1978 until 1998. The results are shown in Figure N-4. The northern boundary condition has a great influence on the development of the coastline. Due to the boundary condition a very large erosion occurs in the north. In the middle part, the erosion is less and in the section ´Inter Dune´ the erosion increases again. In front of Santinho Dune there is still accretion because of the input from the Santinho Dune. If we compare the results from the photoanalyse (see Appendix A, photos of the years 1978 and 1998) with the results of the simulation it can be concluded that the simulation doesn't represent the situation of 1998. The photo analysis gives erosion along the whole coast

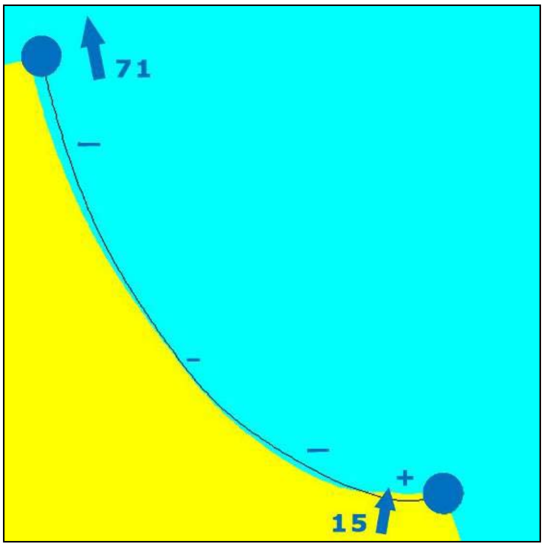


Figure N-4 UNIBEST results scenario 3

N.2.2.4 Scenario 4

A simulation of the development of the beach between the years 1938 until 1958 is done with scenario 4. This simulation should represent the case where the town Ingleses not yet is developed. The assumption is made that the Moçambique Dune reached Ingleses beach and was a sediment source for the beach. Figure N-5 gives the result of the simulation. Here the same phenomena as in scenario 3 occur. Around Santinho Dune is accretion because of the input of sediment, at the northern boundary there is strong erosion and because of the input of Moçambique Dune there is also accretion in front of this dune. In between the two dune fields there is still some erosion. It can be said that the results of the simulation don't match with the results of the photo analysis for the photos of 1938 and 1958.

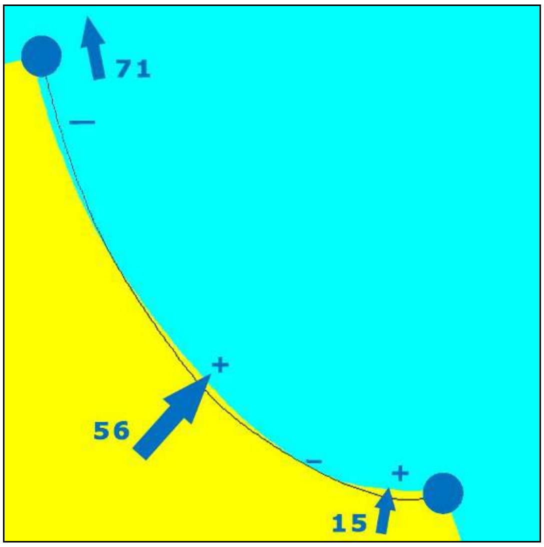


Figure N-5 UNIBEST results scenario 4

N.2.2.5 Scenario 5

In this scenario the effects of the nourishment will be simulated. From scenario 3 and 4 it seems that the sediment bypass around the northern headland is too big. In order to obtain more realistic results and maintain the idea of sediment bypass around the northern headland, the value of the sediment bypass is reduced to 17.000m^3 per year. The coastline is translated over the nourished distance for this simulation. The input from Santinho Dune is kept equal to that of scenario 3 and 4 and there is no input from Moçambique Dune to simulate the development of Ingleses. The results of the simulation are shown in Figure N-6. The sediment bypass around the northern headland causes quiet a lot of erosion in the northern part and between Santinho Dune and Moçambique Dune. In front of the dunes there is again accretion. Based on the model simulation results it seems that the nourishment in the north have to be adapted and that a nourishment in front of the dunes is not necessary because of the accretion.

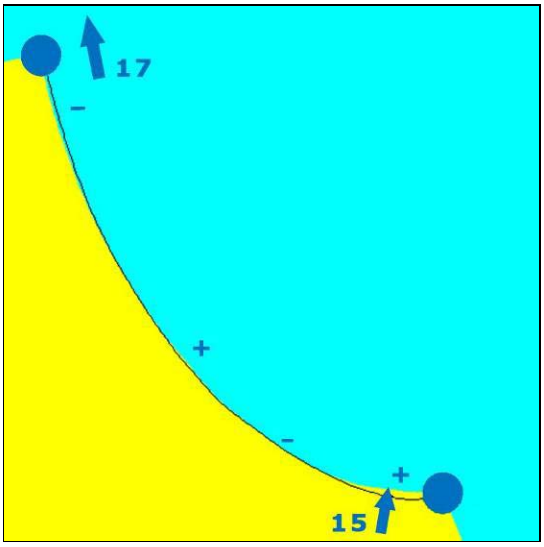


Figure N-6 UNIBEST results scenario 5

N.2.3 Comparison of simulations with photo analysis

Only the scenarios 3 and 4 will be compared with the photo analysis. These two simulations are done to reproduce a historical development of the coast for two different periods. The results of the photo analysis that are used are represented Figure N-7 below.

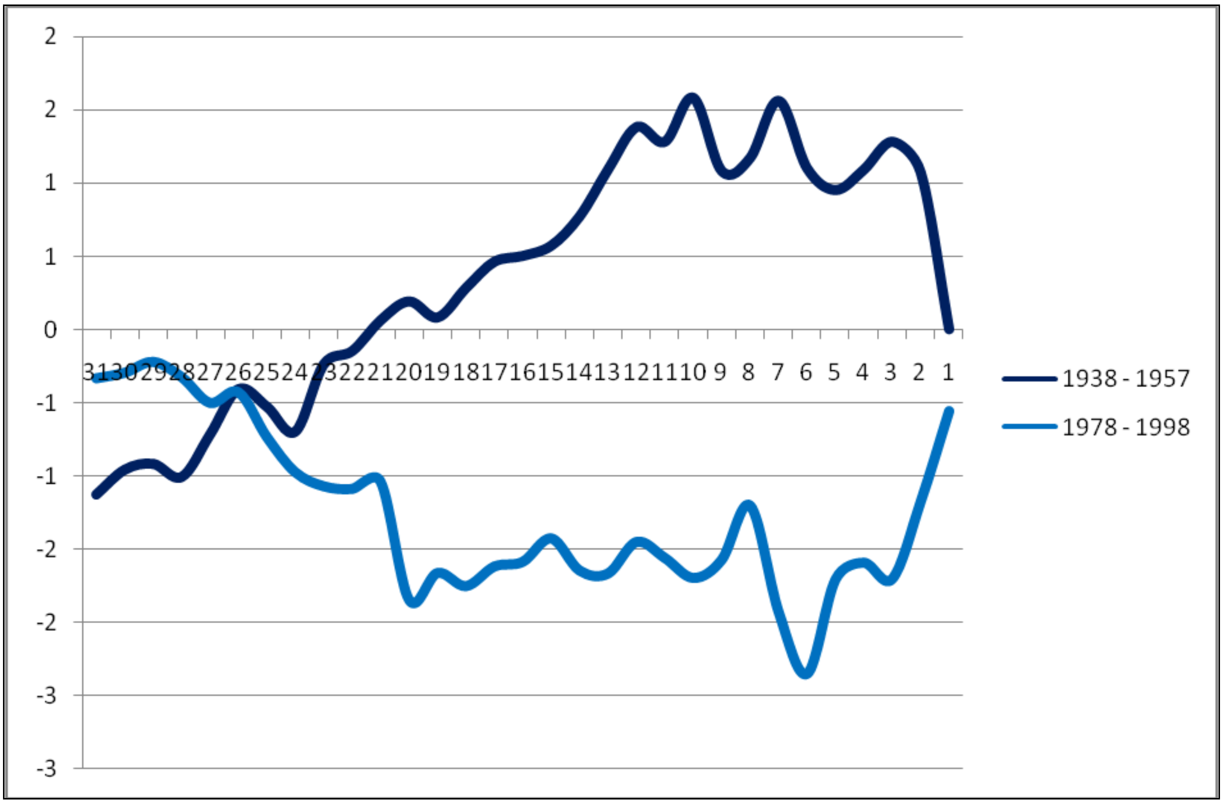


Figure N-7 Used results photo analysis

N.2.3.1 Scenario 3

The photo analysis and the simulation results of scenario 3 give both erosion in the north but the results of the photo analysis give an increase of the erosion to the south while the simulation gives a decrease of the erosion. In front of the Moçambique Dune, the erosion in the simulation decreases but the photo analysis gives an increase of erosion over there. In the interdune section the oppositeoccurs, the simulation gives an increase of the erosion while the photo analysis gives a decrease. In front of Santinho Dune the two methods give an opposite result. The model simulation results in accretion and from the photo analysis erosion appears.

N.2.3.2 Scenario 4

The results of the model simulation give qualitatively the same results as the photo analysis, erosion in the north and accretion in the southern part of Ingleses beach. There is only one difference, namely at the interdune section. The simulation gives a little erosion while the photo anlysis gives accretion.

N.2.4 Discussion and conclusion

Based on the comparison of the simulations with the results of the photo analysis, can be said that the sediment bypass at the northern boundary is a wrong assumption. There might be some sediment bypass but the volume of it is much less than is assumed in the simulated scenarios. At the other side of the northern headland there are spits that grew in the past but the source for these spits are not clear.

Regarding the input from Santinho Dune, the several scenarios lead to the same conclusion as was stated in the report of 2007 [Project Ingleses 2007]: the sediment input from Santinho Dune is an important input which results in local accretion of the beach. But this conclusion is not confirmed by the results of the photo analysis. Based on the result of the photo analysis the conclusion can be drawn that the input from Santinho Dune is much less or the coastline in front of Santinho Dune is reshaped in a more speedy way. Probably the assumed wave climate is incorrect.

All simulations give an increase of erosion just north of Santinho Dune (the interdune section). This too, is not in line with what is observed from the photographs. The photographs don’t show an increase of erosion at the interdune section. In some periods there is accretion or the rate of erosion is equal to the neighbouring sections. Possible reasons for the difference between the simulations and the photo analysis are a wrong assumed wave climate or maybe a wrong bathymetry, especially in the interdune section.

Several remarks can be made on the used input. The original coastline (starting point of simulation) is for all scenarios the same. This means that the real coastline is not represented in a right way in the model for every scenario. The data for the bathymetry came from two different sources, for more about the used bathymetry (see section N.2.1.1 and Project Ingleses 2007 pages 17 and 18 and Appendix F). This can lead to wrong simulation results, especially in cases with equilibrium states.

Coastline changes are very sensitive to wave directions because the equilibrium configuration of the coastline depends very much on the predominant wave direction. In the simulations is wave data used of only one year of observations, which is not very reliable for long term predictions especially when there is a kind of cyclic behaviour in the wave climate (El Niño and La Niña). More research on the prevailing wave climate is needed.

Comparing other beaches in the neighbourhood of Ingleses Beach can possible give more insight in the occurring phenomena of beach erosion and accretion of the Ingleses Beach.

Appendix O Software

O.1 ArcGIS

O.1.1 The program

ArcGIS is software which is special designed to view, edit and analyze GIS information. GIS is an abbreviation of *Geographic Information Systems*. The information of GIS represents data of geographical objects [Wikipedia]. In this report, ArcGIS is used to rectify and analyze photos, edit GIS information of the dune fields and to represent this information in a proper way. ArcGIS is developed by ESRI. The version that was used for this project is version 9.2. For the used files and the use of these files, see the readme files.

O.1.2 Used functions to determine the dune volume

O.1.2.1 Preparation of the contours

There are many GIS files available of Ingleses, each containing a small part of Ingleses. To analyze the dune fields, especially the files which contain the height contours are used (*ingXX_3d_dgn_Polyline* files).

The reference level of these height contours is assumed to be the Imbituba Datum (see section K.2 of Appendix K). These files are added together to the file *inglese_contour* which contains all contour lines of Ingleses. The parts of the GIS file which contains the Moçambique and Santinho dune fields are cut out of the files and added together and converted to the files *contour_dune_field1*, *contour_dune_field1_pt* for Moçambique dune field and to the file *inglese_SanthinoDunefield_FeatureVerti1* for the Santinho dune field. The several steps above are only performed once during the project.

O.1.2.2 Creating a grid

The contour files are converted in several steps to a grid, which contains height information of the dune field (files: *nngrid_field1* for Moçambique dune field, *nngrid_sdf* for Santinho dune field). The grid is made by an averaging of the height contours which lay within the borders of the grid cell. From this grid, different parts are used to calculate the volume of a dune.

To calculate the volume of a specific part of the dune field, first a closed poly line is made, by drawing (tool: *Edit*) or taking the dune limits as border of the area you want to know more about (files: *dune_pol*, *dune_pol2* and *SantDunePartNorth*).

The last conversion that has to be made is an extraction of the dune fields grid files for the area of interest. This can be done with the function *Extraction by Mask* under *Extraction* from the *Spatial Analyst Tool* and selecting the grid file and boundary file. This results in a grid file with a reduced amount of grid cells, reduced to the area of interest (files *dunefield 1* to *4*, *extract_nngr1*, *sdf1_*, *sdf2*, *sdf3* and *extr_sannorth*).

O.1.2.3 3D Analysis

After the creation of a grid, it is possible to calculate the volume of the dune with the *3D Analysis* tools, function *Area and Volume* under *Surface Analysis*. When using these tools you have to select the layer you want to analyse. This option gives also the 2D area (flat surface of the area) and the surface area (the surface of the area in 3D). The 3D Analysis tool calculates the area above a specific plane. Normally ArcGIS takes a plane through the lowest point of the area but it is possible to use a higher plane.

O.1.3 Used functions for measuring surfaces and distances

To calculate the surface of a specific area, first a closed poly line is made, by drawing (tool: *Edit*) the border of the area you want know the surface of. It is possible to use the layers which contain the GIS information of Ingleses as orientation. The line has to be drawn in a polyline shape file. The file can be made in the *ArcCatalog.* When the line is drawn and saved, the surface within the borders of this line can be calculated with the tool *Identify.*

Besides the *ArcMap* application, ArcGIS also contains the Arc Catalog. This catalog is used to manage the created files. ArcGIS creates a lot of links between the files. Moving files in the windows explorer can result in errors when opening the files again. Therefore the ArcCatalog can be used instead. In this function you can also create new shape files.

O.1.4 Used functions in photo analysis

The tool that is used for the photo rectification is the *Georeferencing* tool. When the photo is loaded in Arc GIS, 20 control points have to be found for the preferred confidence level. This is done with a tool in the *Georeferencing* toolbar. When the 20 control points are found, a table of these can be called in with the table button in the Georeferencing toolbar. In this table the coordinates, residuals and the average RMS (root mean squared, see appendix aerial photographs) error is given. Under the table a button can be found to auto adjust the photo after adding a new control point. It is advisable to use this function during the first 3 control points and after 20 control points. In this window it is also possible to save the selected control points as a *.txt* file.

The *control points* are the well defined points (see Appendix A) that are found on the photo and in the GIS file.

The photos can be saved and rectified with the use of the function *rectify* in the Georeferencing toolbar. The used format is *.tiff*. No other adaptations are made with this function.

These shape files must have the same *source*. This *source* is a reference that refers to the position on earth. It can be imported using other shape files that have the right source. Otherwise it can be selected from a list, in the area of interest *Projected Coordinate System: SAD_1969_UTM_Zone_22S* applicable.

O.1.5 Digital Shoreline Analysis System (tool for ArcGIS 9.0)

O.1.5.1 Expressions

In the chapter below several terms and expressions are explained which are used in the report and DSAS.

The *baseline* is used to draw the transects which cross two or more coastlines or dune lines. A baseline is created based on the longest coastline. After DSAS has determined the position of the transects on the baseline, it determines the distance between the two lines that are intersecting the transects and the yearly change based on entered dates of the photos.

A *transect* is a line perpendicular to the baseline and at the same time intersects two or more lines involved in a calculation. The intersections with the lines are crucial. Based on the two or more points where the transect is intersecting, DSAS calculates the distances between the intersection points and gives a *End Point Rate* (EPR) as output based on the entered dates of the pictures.

When using two lines the EPR is given as result. The EPR is calculated by dividing the distance of shoreline movement by the time elapsed between the earliest and latest measurements (the oldest and the most recent shoreline). The major advantage of the EPR is its ease of computation and minimal requirement for shoreline data (two shorelines on different dates). The major disadvantage is that in cases where more than two shorelines are available, the information about shoreline behaviour provided by additional shorelines is neglected. Thus, changes in sign or magnitude of the shoreline movement trend or cyclic behaviour may be missed. The EPR is the only output used in this research project.

Smoothing can be used when the baseline is very irregular/capricious. The orientation of the transect lines is of importance and influences you results. When using the smoothing tool, the program doesn't draw a line perpendicular at that specific place, but it draws the transect perpendicular to a line between two points on the baseline. This way the transects are not intersecting and are more likely to be perpendicular to the coastlines or vegetation lines.

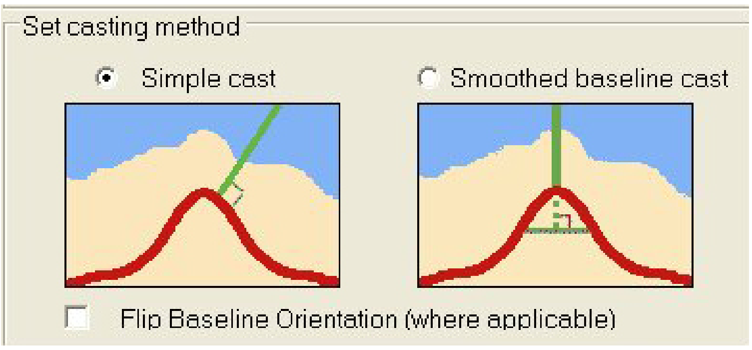


Figure O-1 Smoothing in DSAS tool

Transect length has to be such that it intersects both coastlines, dune ridges or vegetation lines in a calculation. In the case of the coastline a transect length of 250 meters is enough to intersect both lines.

The *transect spacing* is found in an iterative way such that the transects are not intersecting with each other. It is necessary to have enough points where the development in time is measured to get a good overview of de development of the shoreline. On the other hand, too much transects lead to a lot of data which might not contribute to a good overview of the development of the coastline.

Another option to correct the transects is to *edit the transects* in length and in direction. It is questionable how this will influence the output of the calculation. Editing of the transects is a subjective manner to prevent the transects from intersection and determining where DSAS has to calculate the difference between two lines. This tool is used in the first stage of the calculation of the dune migration speed.

O.1.5.2 Procedure DSAS

Creating a baseline

Creating a baseline is done with the tool buffer from ArcGIS. A buffer with a distance of 100 meter around the coastlines of 1957 is chosen. The buffer is then split so you can create a line from the buffer which can function as a baseline. Only the part of the buffer that is 100 meters set back land inward is used to create the baseline. This baseline is exported into the *Geodatabase*, that is necessary for making the calculation using DSAS. *Exporting* is done via the ArcCatalog using Export\To Geodatabase(single).

In the comparison between the different years the baseline is kept the same. This will make the comparison easier, because all the transects will be at the same positions in all the calculations, when the distances between the transects is kept the same.

In the case of the dunes, the buffer tool does not work. Here the baselines are made with the *editor* and *advanced editing*. These editor toolbars are used to edit shape files. Used tools from this toolbar are splitting, merging and drawing. Some parts of dune ridges are parabolic and intersects the transect in the analysis twice. This results in errors in the analysis. Therefore the lines have to be split and the part that intersects the transect the second time, will be removed. The splitting is done with the *split* function.

After this you need to export these files to the personal geodatabase. This file is needed by the DSAS tool. The baseline, the appending couples of lines of vegetation and the output are all in this file after running the tool.

Appending

After drawing the different lines along the coastline and dunes, the created shape-files need to be combined in sets. This can be done using the tool *append* from ArcGIS. The sets are chosen to be lines from succeeding years as showed in the Table O-1 below. At the end of this step, we have got several sets of appended sets of lines. For each set of combined set of lines from two succeeding years we investigate the development of the coastline-high water line, coastline-vegetation and dune ridges. In the case of the dunes it is not always possible to make the exact same sets because some dune ridges are not visible on all the photos.

As an overall check the lines of 1938 and 2004 are also included as a set to check the changes over the whole period where we got data from. The appending is the first step in the calculation. The files resulting from this phase are saved as A_[oldest year]_[most recent year] in case of the vegetation. The A in the beginning refers to appended.

Oldest year	Most recent year
1938	1957
1957	1978
1978	1994
1994	1998
1938	1998
1938	2004

Table O-1 Sets of succeeding years and overall check

Merge

When a line of a certain year consist of several pieces, it is necessary to merge the pieces first. This is done via the merge tool of ArcGIS. After the merging they can be appended as described above.

Reference level

One importing aspect when using ArcGIS is the reference of all the files you create. This is to make sure, when you combine the shape-files in one new project they will end up at the same location in a window of the program.

Personal Geodatabase

After appending the sets, these files are also put into the personal geodatabase. The baseline, the appending sets of lines need to be in this file before running the tool. After running the tool the output will also be gathered in this file. In total three personal geodatabases are created; for coastline-high water line, coastline-vegetation and Moçambique dune ridges. Exporting is done via the ArcCatalog, the tool to manage all the files, using Export\To Geodatabase(single).

Attributes editing

After exporting you add the appended sets of lines and the baseline to your project and start adding attributes to the table of the different files. These attributes are used by DSAS to make the calculation. A date is needed to calculate the EPR therefore the column DATE_ is added. Date should be of the type text, 10 integers long dd/mm/yyyy.

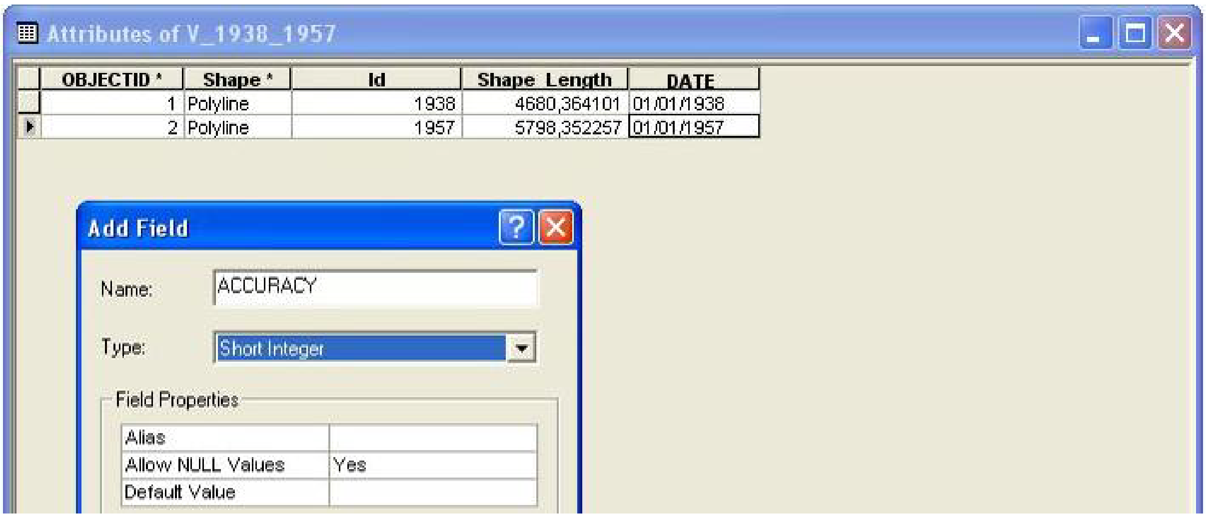


Figure O-2 Attribute table vegetation 1938 - 1957

transect length and the baseline smoothing distance are defined. A transect length of 100 meter is iteratively found as a good length. A transect length of 250 is enough to intersect all the lines in the different scenarios. In the default settings the coast is on the right hand side of the baseline seen from above, this corresponds with the situation of Ingleses.

After this u have to set your output geodatabase to the created personal geodatabase and create a new transect layer name for each appended set of lines. Now everything is

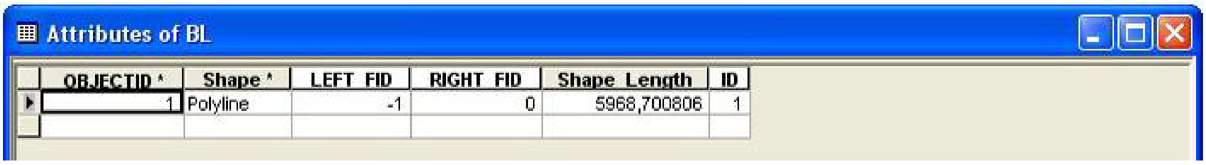


Figure O-3 Attribute table baseline vegetation

preset to run a calculation. The standard name of the output is set to T_[oldest year]_[most recent year]. T refers to transect. The last choice if you want to use a simple cast of the transect line or the smoothed baseline. In the case of the vegetation

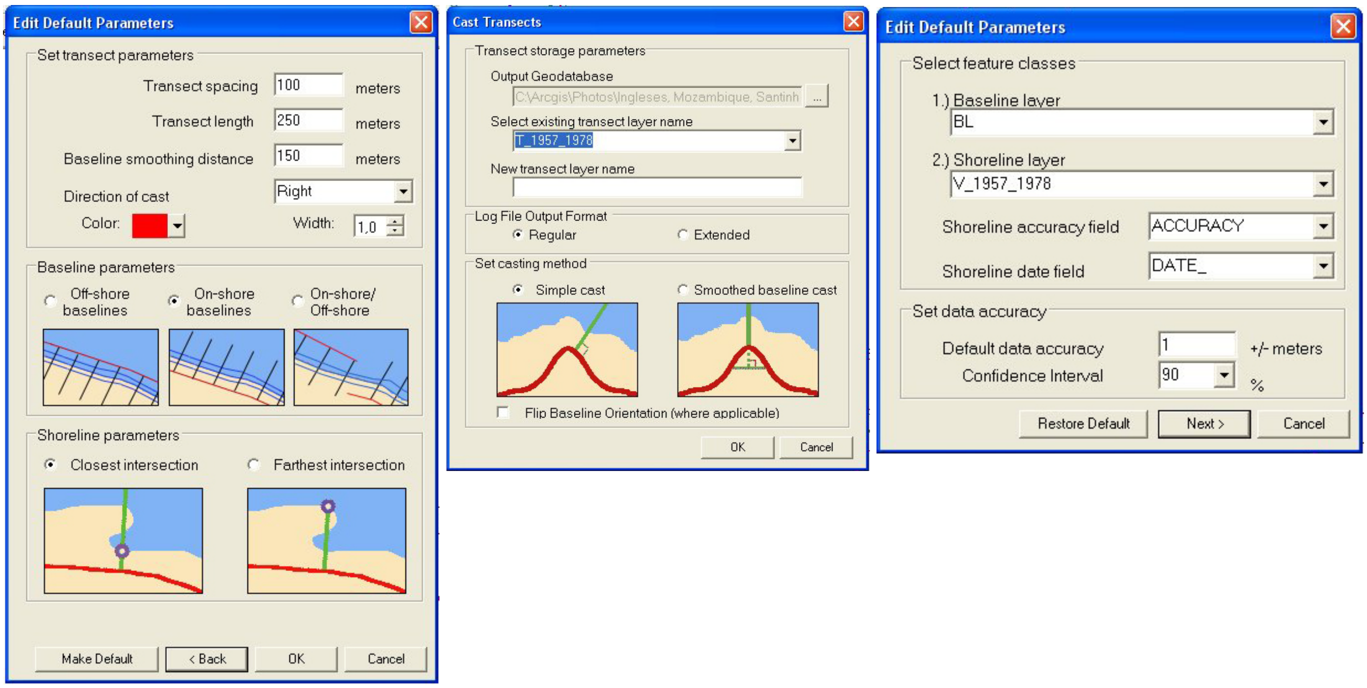


Figure O-4 Windows parameters DSAS

all the transects are drawn with the smoothed baseline cast. With a baseline smoothing distance of 150 meters.

After this the tool has calculated the EPR and other statistical information in this new shape file. There is a possibility to show the EPR on the transects and to export them to process them further. This is done in Appendix B and Appendix C.

Dunes (manually edit transects)

When applying the DSAS tool to calculate the migration of the dunes it is harder to keep the baseline the same. It is difficult to find a dune ridge on all the pictures. The total period that this dune ridge will have to be there should be in the order of 60 years. The dune migration rate is larger than the movement speed of the vegetation or coastline. Besides the larger migrations rate the shape of the dunes is more irregular than the coastline. To get a good estimation of the migration, at first it was necessary to edit the transects manually. This influences also the starting point of a transect. The starting points of the transects in the dunes are therefore not equal for all years. Later on in the photo analysis, straight baselines are used and the starting points of these transects are equal for all years.

O.2 Unibest CL+

Unibest CL+ is designed for the simulation of coastline changes due to long shore sediment transport gradients. The long shore transports are induced by tide and wave driven long shore currents. The program consists of two calculation steps. The first part is the long shore transport module (LT-module) which computes the long shore transports. The second part is the coastline module (CL-Module) which computes the coastline development based on the results of the LT computations.

O.2.1 Long shore Transport module

The parameters that are used to calculate the long shore transport are:

- Wave scenarios
- Cross sections
- Wave parameters
- Transport parameter

The wave scenarios consist of a wave part and a tide part. These scenarios represent the wave and tide climate which will be used for the calculation. To calculate the effects of the wave on the coast, one or more cross sections are needed. The cross sections consist of a dynamic and a static part. The sediment transport takes place in the dynamic part. It is assumed that the static part doesn't change. The wave parameters give more information about the breaking and other properties for the waves like bottom roughness. In the menu of the transport parameters a choice can be made for a specific transport theory with a formula. The parameters which are needed to apply the formula can be given in the pop up menu. When all input is given, the run specifications have to be made in the run specification file. Here you can define which wave scenario, wave and transport parameters belong to a cross section. The LT module will run the combinations that are specified in the run specification file. The results are given in graphs of different physical quantities.

O.2.2 Coast Line module

In the coastline module the coastline and the points where the cross sections intersect with the coastline have to be defined. The results of the LT simulation for the different cross sections are used as input for the CL module. It is also possible to give:

- Boundary conditions
- Groins
- Offshore breakwaters
- Revetments
- Sources and sinks
- Internal boundaries

Only the options ‘Boundary conditions’ and ‘Sources and sinks’ are used for the simulations done in this research. For the other options the ‘NULL’ option is used. The boundary conditions give the occurring situation at the boundaries. This can be a certain sediment transport or a pre described coastline erosion rate. In the option ‘Sources and sinks’, at a specific point a sediment source or sink can be defined.

The CL module is based on the single line theory which means that the coastline position can change but the cross sections will not change. For modelling of much curved coasts, the CL-module of Unibest is not very suitable. The coastline changes are very sensitive to wave directions because the equilibrium configuration of the coastline depends very much on the predominant wave direction, and this quantity is the most difficult to measure.

O.3 BESTFIT

BESTFIT is a computer program to analyze data sets and to execute some reliability tests like the Chi-squared test. The program gives also a histogram, the best fitting distribution and some statistics like the mean and standard deviation for a specific dataset. For this report, version 1.01a is used.

O.4 Google earth

In the real estate analysis and offshore borrow area part, pictures from Google earth are used to get a good idea about the location and infrastructure. The online maps.google.com as well as the program Google earth are used in this project.

O.5 Swan 1D

SWAN is a numerical wave model that predicts wave parameters in coastal areas, lakes and estuaries, for given wind, bottom and current conditions. SWAN (acronym for

Simulation WAves Nearshore) is being developed by Delft University of Technology, Faculty of Civil Engineering, Section of Fluid Mechanics. SWAN 1d is a Graphical User Interface designed around the 1d option of the SWAN wave model. SWAN 1D predicts wave parameters along a 1d bottom profile. The SWAN 1-d Graphical User Interface has been developed by ALKYON Hydraulic Consultancy & Research bv., The Netherlands. The work has been commissioned by the National Institute for Coastal and Marine Management in the Netherlands. [Swan User Manual]

Appendix P DVD

Almost all digitally available data used during this project has been collected on a DVD. This DVD is attached at the end of this report to the cover page. The data is structured based on the chapters and appendices in this report. Furthermore, the digital version of the report and the presentation files can be found on this DVD. Photoshop files of the explanatory pictures used in the report or presentation are also supplied. A brief description of the data that can be found in each folder is given below.

CHAPTER 2 Project description and hypothesis

This folder contains the report of the Project Ingleses 2007 and several images describing the project area.

CHAPTER 3 Aerial photographs

This folder contains all the files used for the rectification and analysis of the aerial photographs as well as the photographs of the beach and dunes self. Also, some background information about the principles of the quantification of errors can be found in the subfolders *Accuracy* and *Precision*.

CHAPTER 4 Coastline development

The detailed results for the coastline development analysis are stored in this folder. The results based on the high water line as well as the vegetation line can be found.

CHAPTER 5 Dune migration

The detailed results for the dune migration analysis are stored in this folder. Several explanatory pictures are also supplied.

CHAPTER 6 Zero-solution

This folder contains the calculations made for the zero-solution and the maps with the different classes of real estate.

CHAPTER 7 Nourishment

Calculations made for the breaker height, the overfill factor and the equilibrium profile are stored in this folder. Also, the Swan models can be found here.

CHAPTER 9 Numerical model

In this folder the different scenarios modelled with the UNIBEST model are stored. The model itself can be found as well as the input parameters, results and corresponding figures.

APPENDIX D Sediment bypass

Aerial photographs and some preliminary calculations of the two spits considered are stored in this folder.

APPENDIX E Fieldtrips

This folder contains the photos made during the three fieldtrips. The photos are divided in four series since there were four camera's.

APPENDIX G Sand sampling

This folder contains information concerning the sand samples made during the 2007 project, thereafter and during this project. Also information about offshore borrow areas can be found in this folder.

APPENDIX K Dune fields

This folder contains some basic information of the dune fields, like heights and volumes. The information is extracted from the GIS data.

APPENDIX M Wave data reliability

The source data and calculations concerning the research to the wave data reliability are stored in this folder.

APPENDIX O Software

In this folder some information, tips and tricks and binaries of the used software can be found.

Organization

This folder contains some organizational documents used during the project.

Presentation

This folder contains the entire presentation in English and Dutch. The two presentations slightly differ from each other since the English version doesn't contain the results of the research done back in the Netherlands.

References

The documents mentioned as references in this project and more are stored in this folder in case they were digitally available.