Case Study Piçarras Beach

Erosion and Nourishment of a Headland Bay Beach

Final report
MSc project CT4061
Hydraulic Engineering

Project Group CF81
November 2008

UNIVALI

TU Delft
Delft University of Technology

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.

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Department of Hydraulic Engineering
Delft University of Technology

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Preface

This report is written within the scope of the Multidisciplinary Project, CT4061. This is a part of the MSc Hydraulic Engineering at Delft University of Technology, in the Netherlands. The goal of this project is to investigate an actual and recent civil engineering problem by applying and integrating knowledge and comprehension obtained during the previous years.

We are a group of four students, with a Hydraulic Engineering background and we did a project concerning Piçarras beach, Brazil. At this specific beach, erosion is a big problem. We investigated this erosion and designed a nourishment in order to counteract the effects of the erosion. This is done in cooperation with the University of Itajaí (UNIVALI), MSc Environmental Science and Technology, and the Delft University of Technology. The project took place from April until June in the year of 2008.

We would like to thank the people at the University of Itajaí for the opportunity they gave us for this tremendous experience in this fantastic country. Especially we would like to thank our supervisor Antonio Klein. He has been a great advisor. Although he is a busy man, he was always there to answer our questions or to engage in a discussion, not seldom initiatied on his behalf to broaden our horizon. Also the students in his lab at UNIVALI, Oceanografia, were of great help. Rafael Sangoi Araujo, who wrote his master thesis about Piçarras beach, provided us with a lot of information. Also Dominicio Freitas, who studied the shoreline changes of Itapocorói bay, has been a great help. Other people we would like to thank: Lindino Benedet, Rodrigo Sperb and all Brazilian students who were interested in the project and expressed their thoughts about the aspects we dealt with during the assignment.

In the Netherlands, we would like to thank Henk Jan Verhagen and Marcel Stive. They were a great help finding a suitable project and provided the contact with Antonio Klein. Also we would like to thank the ladies of International Office at the Faculty of Civil Engineering in Delft, who helped us with all the necessary preparations.

We are grateful for all the support and love from our family and friends. Finally we would like to thank all our sponsors. Without their financial help, this project would not have been possible.

Delft, November 2008

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Summary

Piçarras is one of the touristic beaches of Santa Catarina state in Brazil. Piçarras beach is a headland bay beach. In the bay irregular features like an island, rocky outcrops and shoals are present influencing wave propagation. In the south Piçarras is bounded by Piçarras river. The river mouth has been fixated in 1970, after which erosion started. The part just a few hundred meters north of the river jetty has the most severe erosion. The erosion gradually decreases towards the north, where even some accretion has been measured. When the situation became critical a nourishment was executed in 1999, which has disappeared totally on some places. The decrease in beach width causes a devaluation of the houses and a decrease in tourism which consequently leads to a decrease of employment. It is therefore necessary to investigate the causes and the amount of the erosion and to generate measures to counteract the negative impact of the erosion. Prosul, a Brazilian engineering company, has designed a nourishment of which execution started in July 2008.

The main goal of this study is investigate erosion at Piçarras beach and to design a nourishment to counteract the effects of the current erosion. A model has been built to represent the situation at Piçarras beach. With the model the evolution of the nourishment and the evolution of the existing plan of Prosul could be evaluated.

The bathymetry has been composed of recent profile measurements and old nautical maps. They have all been related to the reference level of IBGE. To investigate the erosion at Piçarras beach the wave climate has been schematised. The available wave data was given for four direction (NE, E, SE, S) in the form of wave heights and periods. To be able to compare what the results of the incoming wave energy from these four directions were on the erosion and accretion on the beach, a schematisation has been made. A representative average wave per direction has been determined, that supplied the same energy input from that direction as did all the different waves from that direction. Headland bay beaches are historically formed in such a way that the incoming waves and thereby the wave energy, arrive perpendicular at the beach, thus absorbing the incoming wave energy in the most efficient way. This theory formed the basis of this schematisation. The mean tidal variation is 0.6m, at spring tide this is 0.9m. Storm surges lead to a set-up in water level of approximately 1.0m. Currents and wind are not taken into account. The sediment present at the beach has a D_{50} of 0.285mm. The sand used in the nourishment of 1999 was coarser than the native sand, which had a D_{50} of 0.260mm.

Erosion processes can take the sand either in cross-shore direction or in longshore direction. Without looking at the underlying process, just to get a realistic idea of the erosion and accretion patterns, the amount of eroded sediment has been calculated with shoreline changes and deduced erosion rates [2]. The erosion of the past nine years is calculated to be 395,000 m^3. To find out where the sediment is transported to at Piçarras beach a model has been build. First the nearshore wave conditions have been modelled with Delft3D (D3D) for the four wave scenarios. These conditions serve as input for Unibest (UB). This program is applied to model the shoreline changes.

To check the model, the results are compared with the manually calculated eroded volumes and another program, SMC (Sistema de Modelado Costero). This program models wave propagation and couples wave breaking to wave-induced currents and potential sediment transport. When comparing the shoreline changes of UB with the locations of potential transport in SMC, the similarities are clear. The programs are in agreement with each other, but not with the situation as observed in real life. To further check the transport indicated by the models, the wave height and direction at the breaker point have been analysed with D3D. Together with the Kamphuis formulation the longshore transport has been calculated. These calculations show the transport is in southern direction, which is a consequence of an angle of incidence towards the south. Reality however, shows these angles of incidence are in northern direction. This problem could find its origin in an overestimation of wave periods, which cause too much refraction. To compensate for this a deviation of 5 degrees in the breaker angle has been applied, which shows a large difference in amount of sediment transport and even the direction of transport changes (to the north). The modelling results that do not correspond with real life could be explained by the limited wave data, a lack of detail in the bathymetric data and by the non-uniformity and shape of the bay. This conclusion calls for further measurements of (offshore) waves and the bathymetry of the bay.

To investigate possible loss of sediment in a storm event a scenario has been used that has also been used to determine the closure depth. With SMC the erosion and accretion during such an event can be modelled quite well. The places where cross-shore transport is indicated with SMC will be used as sinks (places of sediment loss) in the UB model. When varying the sink capacity in terms of a percentage of the total eroded volume, this showed no difference between 100% and 25%. So with the current model it is not possible to define if there is any influence of cross-shore transport.

Other observations with regard to wave propagation are the large influence of diffraction and refraction, caused by the island, (rocky)shoals and headlands in the bay. At places behind these shoals wave focussing occurs. This is however north of the area where erosion occurs.

With the modelling results it is not possible to model a realistic evolution of a nourishment designed by the authors or Prosul. This called for a change in approach. The modelling was stopped and with the data analysis of the eroded volumes it was possible to design a nourishment. The Prosul plan has been evaluated qualitatively.

The nourishment volumes were calculated with the erosion rates that were used earlier on. The first nourishment is split up in two (theoretical) parts, a design fill and an advanced fill, both along the southern 2100m coastline. First a design fill will be placed which will provide a 35m wide beach planform. The second part is the advanced fill which will add another 35m. Off course these two fills will be dredged and placed simultaneously. The advanced fill has a lifetime of 10 years. After this period, the advanced fill is expected to have disappeared and needs to be placed again.

The sand is dredged by a trailing suction hopper dredger from an offshore location that was also used in 1999. Therefore the grain size will remain almost the same, thus causing no change in beach slope. The planform height will be 3.0m above IBGE, which means there is a storm buffer. The evolution of the nourishment has not been modelled since the models are not reliable.

The total costs of the first nourishment is estimated to be €4.9 million. The future nourishment are estimated at €3.1 million.

Since the situation was already critical in 2007, a nourishment plan was made by Prosul. This plan was executed in July 2008. Sand from a borrow pit in front of Alegre was used, which is the beach south of river Piçarras. The location of the borrow pit near to the coastline will possibly cause a change in wave-induced currents and an increase of erosion at Alegre beach. The sand at this location is considerably finer than the native sand of Piçarras beach. Therefore the beach slope will flatten and a wider beach will develop. This is nice for tourists, but causes higher construction costs and results in a shorter lifetime of the nourishment. The costs of the nourishment are approximately € 2 million, which is comparable to the design made in this report taking the difference in sediment volume into account. The volume dredged by Prosul is twice as small as the volume of the previously treated design. Due to the lower volume, the lifetime will be shorter thus leading to shorter renourishment intervals. This might increase the total project costs, looking at a project life time of 50 years.

A lot of work can still be done to investigate the processes at Itapocorói bay. With more accurate data the models can be adjusted so they can provide more reliable data. With realistic models the causes of erosion and the possible solutions can be modelled and optimalized. Finally the municipality of Piçarras should approach the problem using a long-term management. This means monitoring the situation and planning ahead so the situation will never be this critical again. Only then the plan with the design and advanced fill will work properly.

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1 Introduction

Piçarras beach, situated in the state Santa Catarina in the south of Brazil, is suffering erosion problems. On some spots the beach width has even decreased to several meters. For local authorities it is important to sustain the beaches in the area, since these attract tourists and consequently serve as a source of income.

This report presents the work that has been done by 'Project Group Piçarras 2008' for Piçarras beach. In the months April and May of 2008 the erosion has been investigated after which a beach nourishment has been designed in order to widen the beach. During the stay in Brazil the main goal was to collect and restore all the local available data of the study area and to learn how to create and use models. The collected data could serve as input for several modelling programs which could provide both quantitative and qualitative information of the processes that occur in the bay. In the past a nourishment has been designed and executed but seemed to be far from sustainable. Another part of the project is to evaluate a recently proposed nourishment plan by Prosul (local company) and to design a decent and sustainable nourishment based on the erosion problems which occur at the beach.

In this report the results and fundamental choices in approach will be presented. When one is interested in the process of obtaining all these results, we refer to the appendices which can be found at the end of the report. References to authors and sources are made in the form of a number in brackets, e.g. [3], which corresponds to a list at the end of the report.

In Chapter 2 the project area is described in more detail. It includes a description of the recent, local problems. Chapter 3 gives an overview of the project objectives and explains all the steps to be taken in order to fulfil these objectives; the approach. After that, Chapter 4 describes and explains the boundary conditions used for this project: the origin, the way they are obtained and what adaptations have been applied in order to make them suitable for our project. In chapter 5 a data analysis of the beach profiles, shoreline changes and eroded volumes is made to get a realistic impression of where and how much erosion occurs. The next chapter, Chapter 6, gives all the results from the modelling process. It starts with the transformation of waves from offshore to the nearshore study area. These nearshore waves serve as input for the Unibest (UB) model. This program models the shoreline changes as a result of longshore transport gradients. The results of UB are compared with the results of SMC, another software program, which also has the capability to model erosion processes along the beach, taking into account wave-induced currents. This is done to establish whether the places of erosion and accretion indicated in the two models coincide. They will also be used to investigate possible cross-shore transport. If the results of the model is in agreement with nature, a nourishment will designed and modelled.

Based on the results from the previous chapters, Chapter 7 then deals with the design of the nourishment. First, different methods to determine the amount of sand to be placed will be discussed and eventually the reasons for choosing a certain method will be explained. After that an estimation of the costs and a workplan of the beach nourishment will be presented. The Prosul plan will be evaluated in Chapter 8. Finally Chapter 9 gives recommendations for possible future steps to be taken.

2 Project description

This chapter describes the project area and its developments over time. The problems at Piçarras beach will be described with the interventions that were already taken to solve the problems. After this the environmental and economic values of Piçarras beach will be evaluated, showing that new investigations about the current situation and possible improvements are necessary. The chapter will conclude with a problem description for this project. Most of the information in this chapter comes from an investigation lead by Prof. A.H.F. Klein [23].

2.1 Project area

The location of Piçarras is visualised in Figure 2 - 1. Piçarras beach is a headland bay beach, which means it is a curved sandy beach bounded by rocky outcrops or headlands. Piçarras beach forms together with Alegre beach, Penha and Barra Velha a bay better known as the Itapocorói bay, situated in the Santa Catarina state.

Figure 2 - 1 Location project area [16]

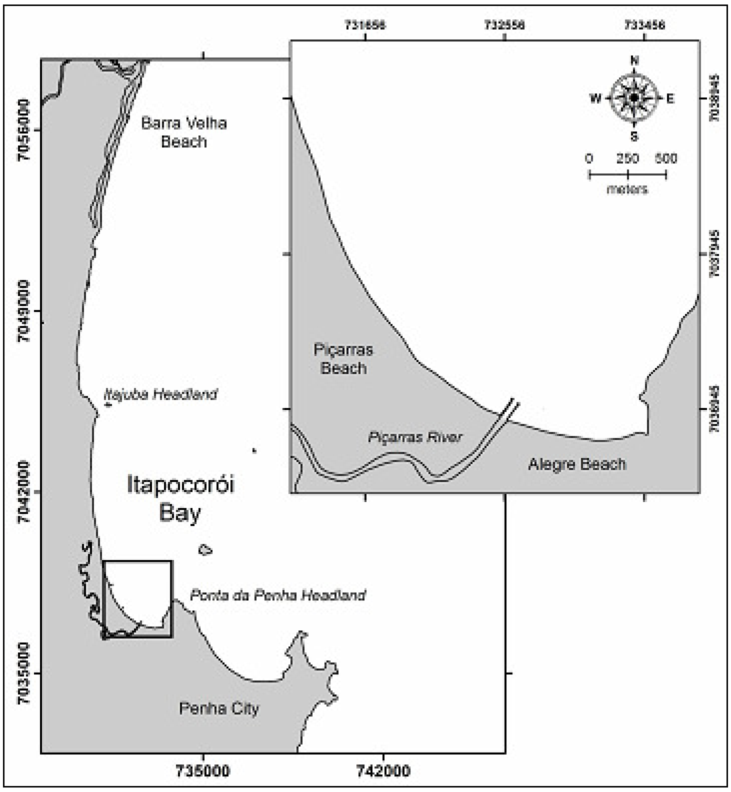


Figure 2 - 2 Location of Piçarras, Alegre, Penha, Barra Velha and the Piçarras river [23]

Figure 2 - 2 shows how river Piçarras separates Piçarras and Alegre beach. Alegre beach is also a curved sandy beach. Both beaches, Piçarras and Alegre, have adapting profiles. Their coastlines keep shifting and re-orientating towards the direction of the wave energy. This direction keeps changing per season.

In spring, sea waves (short peaky waves, also known as seas) from the east dominate over the other sea states. In summer, there is an equilibrium between seas from the east and swells (long crested, well organised waves) from the south. In autumn, swells from the south dominate, although there are scattered seas from the east and the south. In winter, swells from the south prevail over seas from the east, see Appendix II, Chapter 2.

Alegre is situated in the shadow zone of Itapocorói bay, therefore there is limited wave action and there are limited shoreline changes. The investigation of Domincio Freitas [14] supports this presumption. At Piçarras beach however, this could be different.

Currently the beach at Piçarras is rather steep and reflective, leading to plunging to surging wave breaking. The beach in the southern part, next to river Piçarras, is narrower than the beach in the northern part. The entire beach is flanked by a boulevard, which is right next to the urbanised area of Piçarras (Figure 2 - 3).

Figure 2 - 3 Left to right: Urbanisation, boulevard, tiny beach, wave run-up. [3]

Piçarras beach has been suffering erosion for decades. It is suspected that due to a change in sediment transport processes, urbanisation close to the beach and fixation of the river mouth, the coastline moves landward. Especially in the southern part of Piçarras beach the erosion is clearly visible. Some 500 meters north form the river jetty the erosion is the most severe. At some places there is no beach left. In the northern part of Piçarras the beach is stable or even accreting. On the contrary Alegre beach seems to suffer negligible erosion. The pictures below (Figure 2 - 4) illustrate the erosion at Piçarras beach.

Figure 2 - 4 Effects of erosion at Piçarras beach [2]

2.2 History of Piçarras beach

2.2.1 History

In earlier times, the river Piçarras flowed out in the sea without any regulated path. It was a river with a migrating mouth. During the 1930's the river followed such a curved path that during a time of high discharge the hydraulic gradient became too large. This caused the sand barrier between the river and the sea to breach, which resulted in a shorter path

for the river. This way the river mouth was relocated by nature to a position about 300m south of the previous position.
In the 1970's the river inlet has been fixated. At the same time the boulevard was constructed (close to the beach) and the lagoons formed by the river were filled up with sand placed by the local authorities. From this moment on Piçarras started to attract more and more people, inhabitants as well as tourists. The river mouth fixation and the urbanisation are visible in Figure 2 - 5.

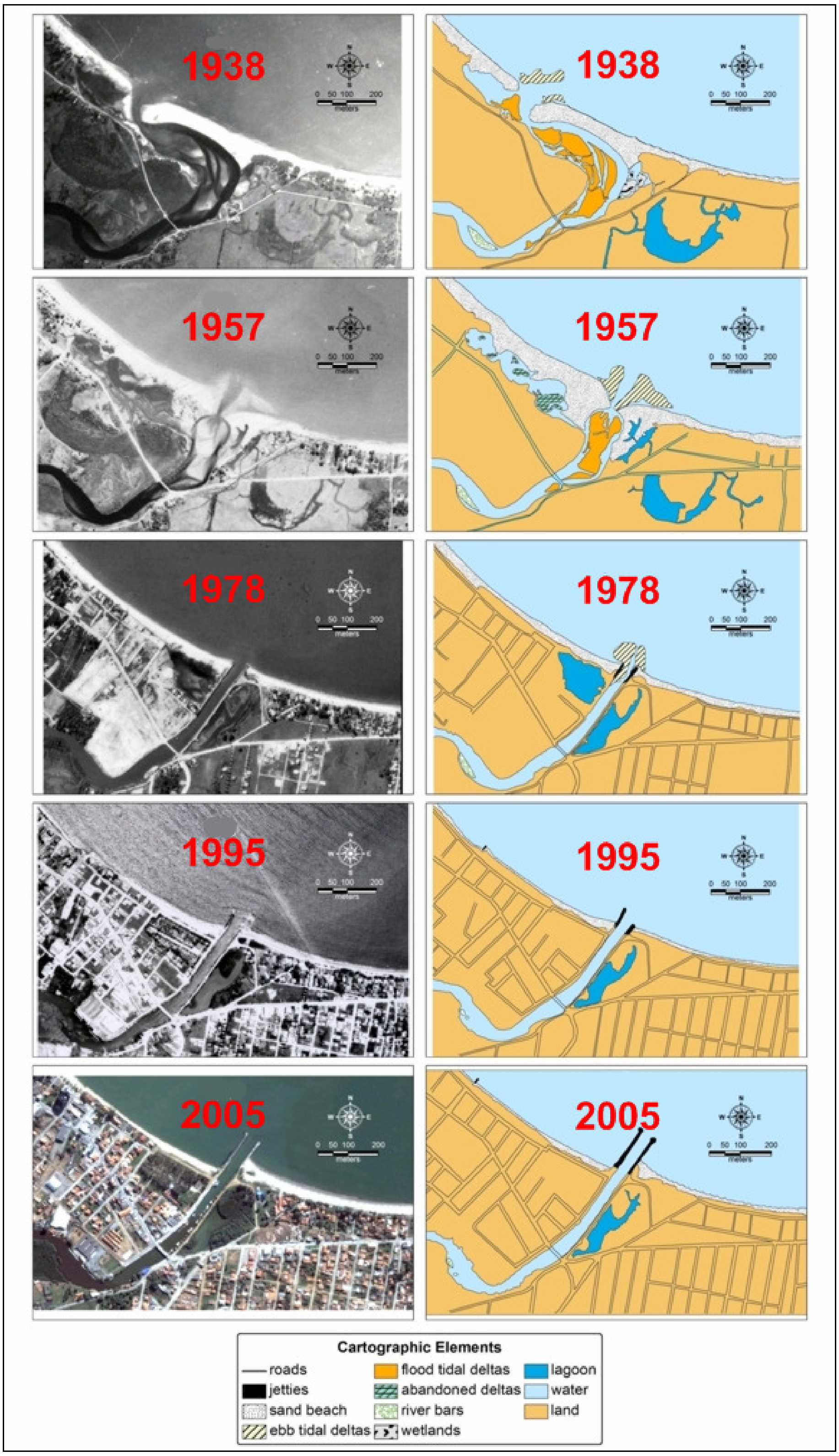


Figure 2 - 5 Evolution of river outlet throughout the years [23]

Already from 1957 on there is erosion visible in the southern part of Piçarras. The northern part starts to erode from the 80's on. This could be explained by some severe storm surges in the 80´s, the river mouth fixation and the urbanisation of the coastal area. There have been several interventions in the coastal system of Piçarras, besides the river mouth fixation.

Figure 2 - 6 Overview interventions [23]

In 1980 gabions were installed (Figure 2 - 6A) to trap sediment from longshore transport. Since this structure did not yield the desired results, a groin was build in 1995 (Figure 2 - 6B). Just like the gabions, the groin did not work as anticipated and only increased the downstream erosion. At the same time a sea wall was build next to the boulevard (Figure 2 - 6C, D). To stop the waves from destroying the restaurant a rock revetment has been placed (Figure 2 - 6F).

Since the beach only eroded further while tourism grew more and more, there was a need for interventions that would increase the beach width for sure. Therefore a beach nourishment was executed in 1999. In total 880,000m^3 sand was placed over the first 2.2 kilometres north of the river jetty. The expected lifetime of the project was 5 years. It was paid partly by the government and partly by the inhabitants of Piçarras (fifty-fifty). The total costs were US$ 3.2 million. Sand was used from a borrow pit 15 to 20 kilometres offshore, dredged at a depth of 20m. For the nourishment a hopper dredger was used with floating pipelines to the beach. The sediment in the borrow area was slightly coarser than the native sand. After the nourishment the top layer of the beach was covered with a lot of shells and gravel, which was not comfortable for the beach users.

The nourishment resulted in an increase of tourists as well as an increase in investments in Piçarras. The situation before and after the nourishment are visible in Figure 2 - 7, which are taken at the same location as Figure 2 - 4.

Figure 2 - 7 Left: before the nourishment. Right: results of the nourishment [2]

2.2.2 Recent developments

Now, almost 10 years after the first nourishment, the placed sediment has completely disappeared at some places. Therefore it is time to consider new interventions. The company Prosul has written a proposal for a new nourishment [7]. They planned a first emergency nourishment to widen the beach where the severest erosion has occurred. The second step is a nourishment over the southern 2.1km of Piçarras beach. The northern part will be 30m wide, the southern part will be 40m wide. For a short description of the plan and an evaluation see Chapter 8. In the period of writing this report, the plan has been executed.

2.3 Value of Piçarras beach

Santa Catarina state is known for its beautiful beaches. The coastal zone attracts many national and international tourists. Piçarras beach is one of these coastal zones. Over the years the tourism in Piçarras has grown, which lead to an increase in investments and inhabitants. The erosion problems in Piçarras cause a decrease in tourism which consequently leads to a decrease of employment.

Another development in Piçarras is the devaluation of the houses, hotels and restaurants, due to the decrease in safety against storm surges. As the beach narrows, there is a smaller buffer to protect against high water levels and big waves. In Figure 2 - 8 is a good example of fluctuating property values depending on the width of the beach. If a wide beach is present, the restaurant has a top value due to its distinct location. However if the beach is narrow, the restaurant is exposed to wave action and high water levels.

Besides, there will be less tourists recreating on the beach simply because there is no space.

Figure 2 - 8 Restaurant at Piçarras beach, bussiness directly affected by beach width. [3]

2.4 Field trip

On the 24th of April a field trip was planned together with the Brazilian supervisor Prof. Klein to Piçarras beach. The idea was to have a look in the neighbourhood of Piçarras, take notice of the present state of the beach and observe some processes occurring at the beach.

2.4.1 Present state of Piçarras beach

It was clearly noticeable that the southern part of the beach had been affected by erosion, because there was not much beach width left. Figure 2 - 9 visualises the southern end of the beach adjacent to the river jetty.

Figure 2 - 9 Picture of Piçarras beach adjacent to the northern jetty [3]

At some places there was even no beach width left, see Figure 2 - 10 and Figure 2 - 11. These spots are located several hundred meters northward of the river Piçarras and are suffering most from the erosion.

Figure 2 - 10 Picture of most severe eroded part of Piçarras, taken in southward direction [3]

Figure 2 - 11 Restaurant, situated at the beach stretch with the most severe erosion, gets flooded [3]

It must be remarked that about a day before the field trip, it stormed on the Atlantic Ocean. The consequence of this was an increase in water level as observed on the field trip. So the flooding of the restaurant in Figure 2 - 11 is not a daily occurring situation.

The northern part of Piçarras beach is stable or even accreting, see Figure 2 - 12. During a period of elevated water level and swell waves, there is still considerable wave run up. Scarps and cusps are formed. Since the beach is rather wide and bordered by vegetation (instead of rigid structures) this forms no problem.

Figure 2 - 12 Picture of the more stable northern part of Piçarras beach, taken in southern direction [3]

2.4.2 Observed processes at Piçarras beach

During the field trip it was clearly noticeable that waves start breaking in the southern part of the bay and subsequently break towards the north. The wave crests broke in sections, starting from the south carrying on towards the north. This is visible in Figure 2 - 13. The figure shows that waves are breaking in the southern part and hit the beach at an angle towards the north (right in the figure). Further northward waves are breaking as well but have not hit the beach yet (central in the figure), which indicates that the process of wave breaking started later.

Figure 2 - 13 Picture of wave breaking development, taken in northern direction [3]

This development of wave breaking indicates that waves arrive obliquely (from south-east direction) at the beach. These waves do not break simultaneously along the whole wave crest. This results in a wave-induced current and consequently in a longshore transport in northern direction.

This possible longshore transport was tested in practice by throwing a branch of wood in the swashzone. It was clearly observed that this branch was taken by the wave-induced current and moved in northern direction, which confirmed our previously formulated assumption.

Another image that clearly shows this development is presented in Figure 2 - 14. The waves break along their crest from south to north, inducing possible northward transport.

Figure 2 - 14 Picture of wave breaking development, taken in south-eastern direction [3]

Another observation is the presence of the dunes in the northern part of Piçarras beach. Together with the vegetation this indicates a stable beach, which is clearly observable in Figure 2 - 15. At the southern part of the beach there are no dunes or vegetation visible.

Figure 2 - 15 Presence of dunes in the northern part of Piçarras beach [3]

2.5 Problem description

Piçarras is one of the touristic beaches of Santa Catarina state, Brazil. Piçarras beach is a headland bay beach with Ilha Feia and rocky outcrops in the shallow nearshore. In the south Piçarras is bounded by Piçarras river. The river mouth was fixated in 1970, after which erosion started. A part of the beach just a few hundred meters north of the river jetty has the severest erosion. The erosion gradually decreases towards the north, where even some accretion has been measured. Due to the high economic value of the beach for Piçarras, it is important to investigate the erosion. A nourishment was executed in 1999, which on some places has disappeared totally. It is therefore important to investigate the causes and the amount of the erosion and to find possible solutions to counteract or compensate for the erosion.

3 Objective and approach

In this chapter the objectives and the approach of this project will be presented. First the objectives will be presented. Next step is the approach, which explains how these objectives will be achieved.

3.1 Objectives

Main objective:
Investigate erosion at Piçarras beach and design a nourishment to counteract the effects of the current erosion.

Sub-objectives:
- Model wave propagation with Delft3D
- Model shoreline changes with Unibest
- Evaluate nourishment and Prosul plan with the Unibest-model

3.2 Approach

To establish these objectives it is necessary to get information about the wave climate, the bathymetry and the sediment characteristics in the project area. Also the erosion rates, closure depth and boundary conditions have to be determined.

In this first modelling step Delft3D (D3D) will be used to transform offshore, deepwater wave conditions to nearshore wave conditions. These nearshore wave conditions, together with the sediment characteristics and the nearshore bathymetry will serve as input for the second modelling step. In this second step UNIBEST-CL+ (UB) will be used to design a model to simulate the shoreline changes as observed at Piçarras beach. To be able to model this shoreline change, a definition of a coastline is necessary. This will be done with 26 cross-sections for Piçarras beach and 4 cross-sections for Alegre beach that represent the bathymetry. They all have to start at the backshore of the beach, reach until beyond the closure depth and be perpendicular to the shoreline. The location of these cross-sections are presented in Figure 3 - 1. At the seaward end the wave conditions as modelled with D3D will serve as input for UB. From here on towards the beach, UB will model its own wave propagation over the bathymetry given in each cross-section.

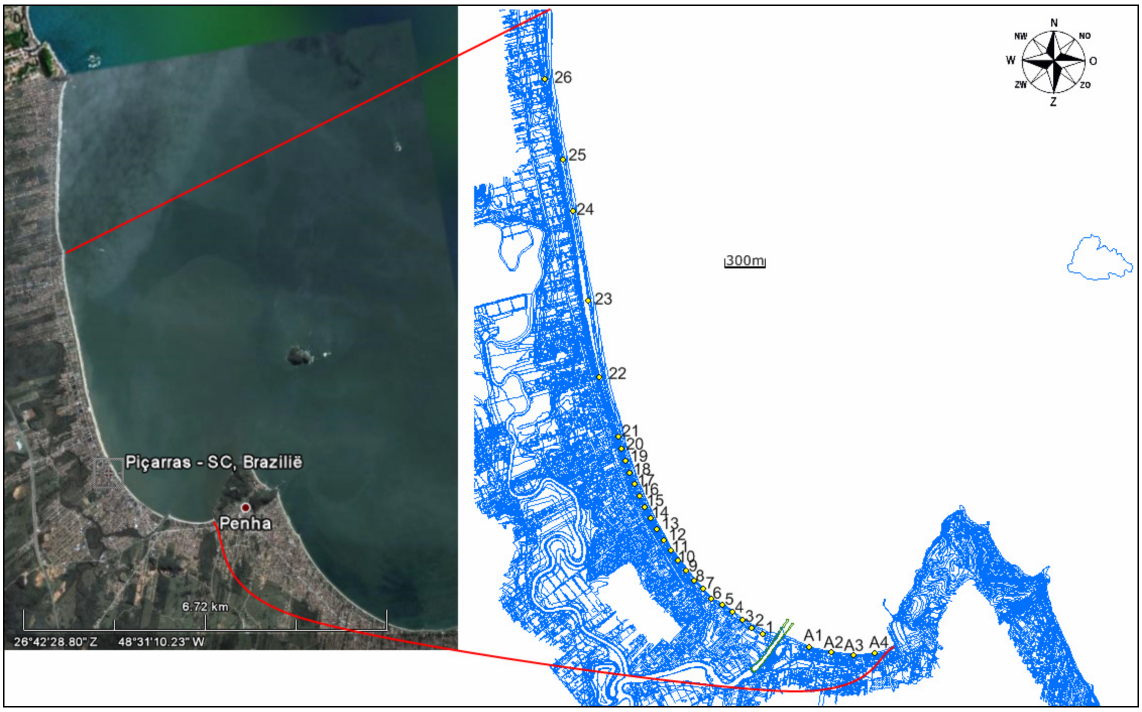


Figure 3 - 1 Locations of cross-sections. Left:[16], Right:[34].

To check whether the model is in agreement with nature, erosion rates will be determined manually and compared with the model results. As another check on UB, SMC will be used to model wave-induced currents and thereby potential sediment transport. SMC will show places of erosion and accretion that occur within 72hrs. UB will simulate a period of 9 years. Therefore, only the places of erosion and accretion will be compared, not the volumes.

The information that was mentioned in the first alinea of the approach can also be used to design a nourishment for Piçarras beach. This nourishment will be simulated in the developed UB-model, to check whether it will evolve as anticipated. New observations based on the results of this run can be used to improve the design of the nourishment. Apart from this simulation, the nourishment plan of Prosul will be evaluated using observations and results from the UB-run.

4 Boundary conditions

When dealing with a coastal engineering project such as the beach erosion at Piçarras, it is very important to have long-term, up-to-date and reliable data concerning waves, water levels and currents. Good bathymetric data is very important as well. The bathymetric data in Brazil is good around harbour areas. For Piçarras this is not the case.

In this chapter the relevant boundary conditions will be presented. How these conditions have been determined, is elaborated in Appendices I, II and V.

4.1 Bathymetry

In this project several datasets from different survey sources have been integrated in order to be able to use them for modelling and designing the nourishment of Piçarras beach, see Appendix I. The different datasets are (Table 4 - 1):

Dataset	Source	Reference level
Bathymetry	Nautical charts	DHN
Beach profiles	Univali	IBGE
Boulevard and city of Picarras	SPU	IBGE

Table 4 - 1 Datasets and their reference levels

Different reference levels have been used, depending on the purpose of the surveys. Nautical charts are made by the DHN (Diretoria Hydrografia e Navegacao), the department of the brazilian navy responsible for surveying coastal waters. The geographical surveys are usually corrected to the reference level set by IBGE, which is defined as the average annual mean sea level at the port of Imbituba averaged over a certain period of years.

Since the objective of this project is modelling wave propagation as well as modelling shoreline changes, it is necessary to couple the nearshore (nautical maps), foreshore and backshore (profile measurements [2]) of the bay. For this coupling of datasets the DHN datasets were corrected for IBGE.

The datasets listed in Table 4 - 1 left some blank spots in the bathymetry needed to model wave propagation. Moreover there were some illogically deviating points in the bathymetry that could not be detected on the nautical maps of the DHN. These points were removed from the bathymetry. Table 4 - 2 lists the features mentioned above.

Feature	Source
Jetties of Piçarras river	UNIVALI
Ilha Feia	UNIVALI
Ilha Itacolomis	Nautical map
Deviating points	Bathymetry

Table 4 - 2 Missing features edited in final bathymetry

The final integrated dataset has been interpolated with the QUICKIN-module of D3D for three different levels of detail. To be able to interpolate between the sample points a grid is needed. For each different level of detail another grid has to be made. For more details is referred to Appendix

I and III. Table 4 - 3 lists the different grids, level of detail and purpose of the grids.

Grid area	Detail	Purpose	Cell size order
Offshore	Low	Transforming waves from deep water to transitional water	250mx250m to 100mx100m.
Piçarras bay	Medium	Transforming waves from transitional water to shallow water	100mx100m to 35mx35m.
Piçarras beach and part of the bay	High	Modelling waves in shallow water including shoaling, breaking flow characteristics.	35mx35m to 10mx10m

Table 4 - 3 Grids used for generating bathymetries and modelling wave propagation

The resulting bathymetries are presented below. They have been checked with the nautical maps. Any features that could not be found on these maps or in the beach measurements were removed. Figure 4 - 1 shows the offshore bathymetry.

Already a lot of irregular shapes are visible at the 16m depth contour in front of the bay and at the 32m depth contour south of the bay.

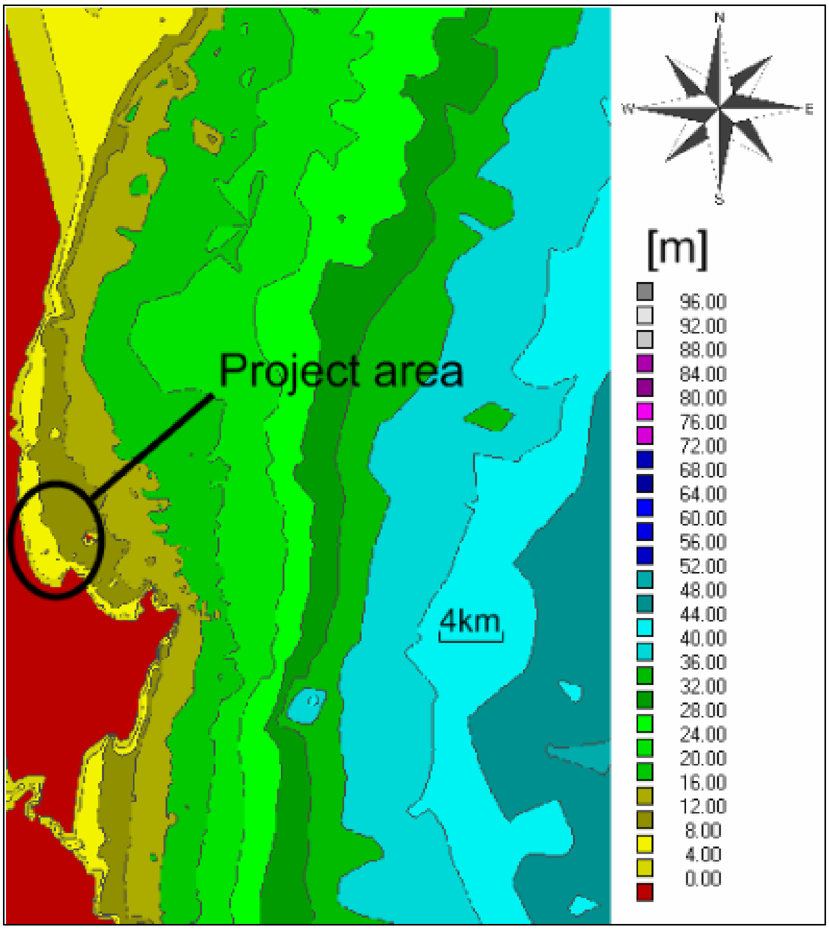


Figure 4 - 1 Offshore bathymetry

Features like beach slopes and river jetties aren't visible yet, because the grid isn't detailed enough for these features.

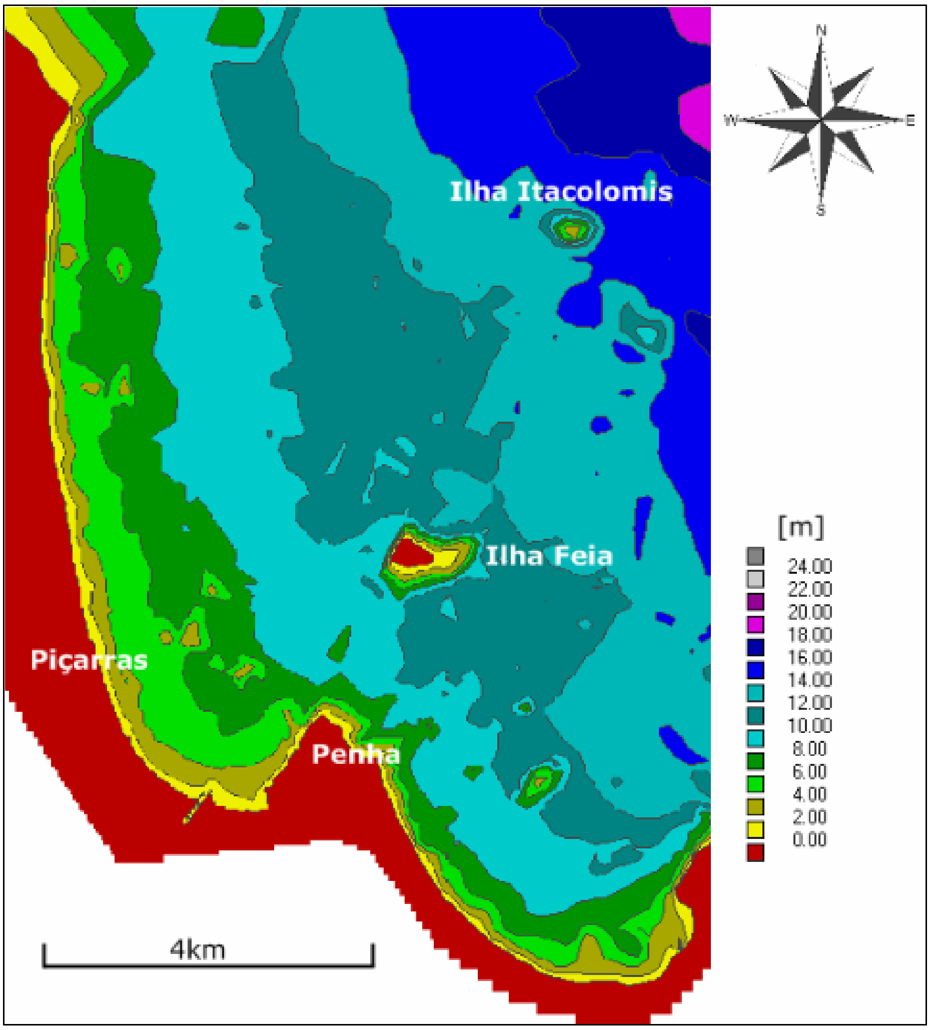


Figure 4 - 2 Bathymetry of Piçarras bay

The irregularities at the 16m depth contour become more evident in this medium grid (Figure 4 - 2). Moreover several shoals in the bay become visible. The depth contours in the bay aren't smooth and parallel and certainly not equidistant. This is characteristic for headland bay beaches. The slope of the nearshore is milder in the south than in the north of the bay. The shoals and river Piçarras can be distinguished because of the higher grid resolution.

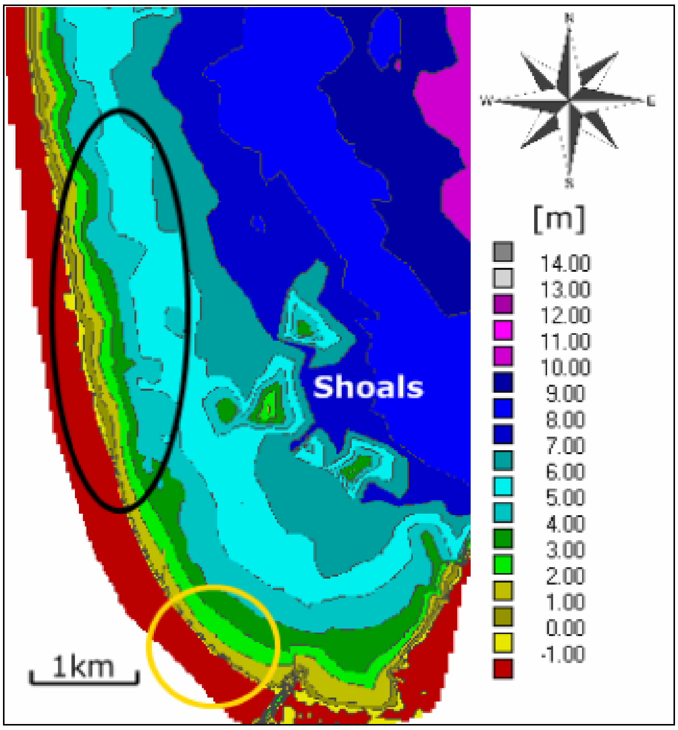


Figure 4 - 3 Bathymetry of Piçarras nearshore including beach

The finest grid, with the highest resolution has been used to compute the area directly in front of Piçarras, see Figure 4 - 3. Now it becomes clearly visible that there are several rocky shoals directly in front of the problem area. This is confirmed by the nautical charts [29]. What is also visible is the relative steep beach slope at the problem area (indicated with the yellow circle) when compared to the northern beach area (indicated with the black circle). The slope of the southern nearshore is milder than in the north, but the transition from the 1m and 2m depth contours comes very close to the urban area which borders the beach in the south almost immediately by the lack of a dry beach platform indicating erosion. The area in the black circle has a wider beach platform with a steeper foreshore, but a more gradual transition towards 5m. This indicates a more stable beach.

4.2 Water levels

The water level variation at Piçarras beach is the result of a small astronomical tide and surges caused by storms from (south)easterly directions.

4.2.1 Tides

The tidal variation at Piçarras beach is relatively small. The average tidal range is about 0.6m [21]. At springtide this can be 0.9m. In Figure 4 - 4 the tidal variation as measured by JICA in 1990 is shown. The levels are relative to IBGE (left) and mean sea level (right).

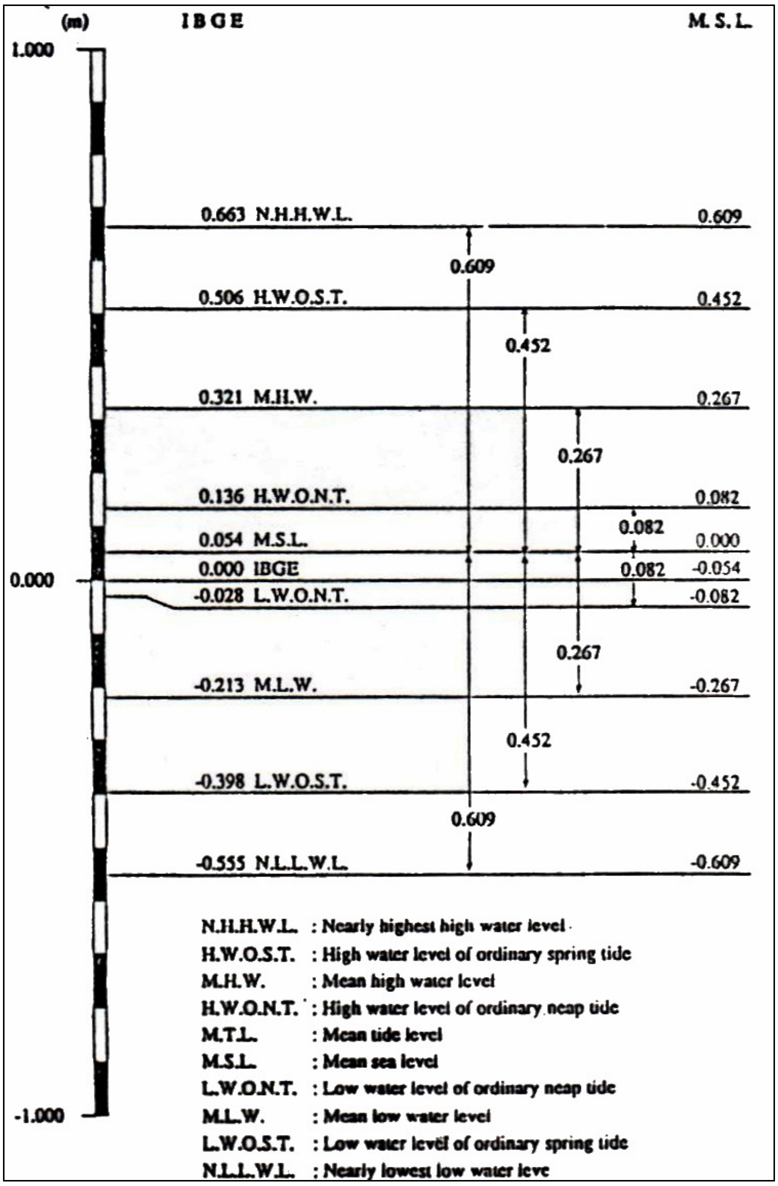


Figure 4 - 4 Water level variations caused by the tide [12]

4.2.2 Storm surges

The maximum set-up in water level is circa 0.75m. This has been determined by subtracting the astronomical tide from a year-long ('85-'86) water level measuring record [26]. By doing this, only the meteorological influence on the water level (surges) is obtained. The surges are not only the result of nearshore storms, but also of south to easterly storms far out on the ocean.

Figure 4 - 5 Extreme high water level just after storm of 1985 [12]

Further research of several storm events in the 1980's indicate an even higher possible water level (Figure 4 - 5). From the picture an estimation can be made of the storm surge level in 1985. The street level is circa 2.3m above IBGE [34] . The water level is circa. 0.75m below the street level. This level corresponds to circa 1.0m above ordinary springtide. This would suggest a storm surge level of 1.0m.

Combining these two sources it seems reasonable to account for an extra set-up in water level of 1.0m.

The surge level is relevant for the determination of the height of the beach. If there is still a substantial amount of beach above the water level during a storm, this sand can act as a buffer against storm erosion. The sand is then only redistributed over the profile and can be transported back to the beach in calmer conditions. If there is no buffer, the water and waves will wash over the entire beach and boulevard, causing more damage to the urban area. This is also negative for the perception of safety against the ocean for the inhabitants of Piçarras.

4.3 Currents

Both the vertical and horizontal tide at Piçarras beach is small. Currents are in the order of 0.1 to 0.2m/s [20][21]. There are some papers [37] on flow patterns and secondary flow effects in headland bay beach systems. However for this project no currents are taken into account.

4.4 Waves

Waves are of crucial importance for processes that take place in the coastal zone. Sediment transport, beach orientation and wave generated currents are greatly influenced by the angle of incidence, period and height of the incoming waves. Therefore, long term wave measurements (preferably several years) are very important. Especially when the aim of a project is to model these processes with software packages like UB and D3D. A non-representative wave climate can cause the models to be incapable of reproducing the real life situation. When using such models to try to make a prediction of the evolution of a coastal system, after for instance a nourishment or implementation of hydraulic structures, this can result in total nonsense. This is simply because all the input parameters, of which waves are a very important one, aren't the real life ones but a result of the analysis of a too short wave record.

Several sources for wave data are available. These have been presented and analyzed in Appendix II. It is stressed here, that the results are based on wave measurements during a period of one year. Since this is the best data available right now, it has been used for this report. The results of this analysis [1] will be presented here.

From the data analysis it follows that two main sea states are dominant, sea waves (typical periods from 4-9s) and swell (periods around 11s and more). In spring, seas (short peaky waves) from the east dominate over the other sea states. In summer, there is equilibrium between seas from the east and swells (long crested, well organised waves) from the south. In autumn, swells from the south dominate, although there are scattered seas from the east and the south. In winter, swells from the south prevail over seas from the east.

Overall, seas with a peak period of 8s from the east with a mean significant wave height of 1.25m and swells with a peak period of 12s from the south, with an increasing significant wave height from summer to winter, are the main wave regimes.

4.4.1 Wave scenarios

With a Gumbel distribution fitted through the annual significant wave height distribution wave scenarios were formulated [6] which are listed in Table 4 - 4.

	Scenario	Hs (m)	Tp (s)	Direction	Occ. (%)
Average waves	1	1.25	8	NE	5.2
	2	1.25	8	E	20.5
	3	1.25	8	SE	4.0
	4	1.60	12	SE	10.5
	5	1.25	8	S	2.0
	6	1.55	12	S	21.8
	7	1.65	14	SE	2.0
	8	1.80	14	S	2.8
Extreme storm waves	9	2.00	9	E	5.0
	10	2.50	9	E	0.5
	11	3.00	9	E	0.5
	12	3.50	9	E	0.2
	13	2.00	9	NE	1.8
Extreme swell waves	14	2.50	12	SE	4.5
	15	3.00	12	E	3.5
No waves					15.2

Table 4 - 4 Wave scenarios for modelling

One might wonder why the authors of this report didn't analyse the data as presented by Araujo et al (2008). again, since waves are of vital importance for this project. Keeping in mind the relatively short amount of time available for this project and the very short wave records at hand, it was decided not to analyse this data again. For mainly a longer wave record would influence the formulated wave scenarios, rather than analysing the same data again.

4.4.2 Further schematisation of wave scenarios

The wave scenarios have been further schematised by direction. The idea to do this came from the hypothesis that a beach will try to orientate itself perpendicular to the average incoming wave energy to dissipate this energy in such a way that no longshore sediment transport gradients occur. Since there are only four directions that are relevant for Piçarras (NE, E, SE, S), reduction to four scenarios and their respective impact on the beach could give more insight into what is happening at Piçarras. Even finding an annual mean energy direction (and corresponding wave height and period) could give more insight into the orientation of the beach desired by nature.

First the total energy per direction was calculated by using the energy flux in deep water through a vertical plane from the sea bottom until the water level with unity width. In this way it is possible to account for the wave height as well as the wave period. This is summed per scenario which results in a total energy per direction.

The second step is to calculate the average period per direction. With this period the mean wave height per direction is determined. Table 4 - 5 shows the results of the schematization.

Results	T_{mean} [s]	H_s [m]	Occ. [%]
NE	8.26	1.50	7.00
E	8.67	1.86	30.20
SE	11.43	1.81	21.00
S	11.91	1.57	26.60
No waves			15.20

Table 4 - 5 Results of the Hs, Tm for modelling.

Another wave scenario that will be used to investigate possible locations of cross-shore transport and to determine the closure depth is determined in Appendix II. The wave height H_s is 4.2m, the period T is 10s coming from the East. The determination of the closure depth is treated in Appendix IV.

4.5 Sediment characteristics

Several institution have made an analysis of the sediment present at Piçarras beach. In 1989 JICA has made measurements, followed by CTTMAR from 1994 till 1996. The sediment sizes from the latter measurements can be considered as the native sand before the nourishment in 1999. In 2007 CTTMAR has done measurements again [2]. These sediment sizes are likely to be almost equal to the sediment present in the borrow pit used. Some fines will have washed away. The data are collected in Table 4 - 6.

Comparison of grain sizes per period and location

samples	area	D50 [mm]	D90 [mm]	Dm [m]	w_s [m/s]
JICA	5-11, nourish area	0.228			0.021
JICA	12-26, north of nourish area	0.292			0.030
FACIMAR	8-11, nourish area			0.304	
FACIMAR	7, north of nourish area			0.340	
CTTMar	11-29, nourish area	0.285	0.605	0.290	0.029
CTTMar	30-37, north of the nourish area	0.298	0.566	0.313	0.030

Table 4 - 6 Sediment characteristics

It can be seen that the D_{50} has slightly coarsened after the nourishment. This means the grain size of the sediments used for the nourishment were coarser than the native sand. The fact that the sand is coarser in the north than in the south can be explained by the higher wave energy in the north. The fines have been transported elsewhere, while the coarser grains cause a steeper beach.

The sediment data of the southern 2.1km, used for the modelling and nourishment calculations, are:
$D_{50;n}$ = 0.285mm (where n stands for native, the sand currently present)
$D_{90;n}$ = 0.605mm
w_s = 0.029m/s

For the northern part of Piçarras beach the following data hold:
$D_{50;n}$ = 0.298mm
$D_{90;n}$ = 0.566mm
w_s = 0.030m/s

For the sediments in the borrow pit the following assumption has been made:
$D_{50;bp}$ = 0.260mm

5 Analysis of sediment transport

5.1 Introduction

In this chapter an analysis of the sediment transport along Piçarras beach is made. The amount of sediment that has eroded in the past decades is analysed using historical data. The analysis will give an impression of the evolution of Piçarras beach and the actual situation. The erosion of the last nine years, since the nourishment in 1999, will be quantified. This amount has been calculated in several ways, see Appendix V.

5.2 Quantification of the erosion

To get a first impression of the eroded volumes, the sub-aerial volumes have been calculated, Appendix V Chapter 3. This is only the volume above the waterline and gives therefore no indication of the sand present under the waterline.

To get a better estimate, the shoreline changes of several time periods between 1957 and 2007 are interpreted using aerial photos [2], resulting in Figure 5 - 2. With these shoreline changes an erosion rate can be calculated with which an eroded volume can be calculated using the height of the active profile, being the berm height and the closure depth (Figure 5 - 1):

$$EV = ER \times \left(B + d^*\right)$$

Where

EV = Eroded volume
ER = erosion rate
B = berm height
d^* = closure depth

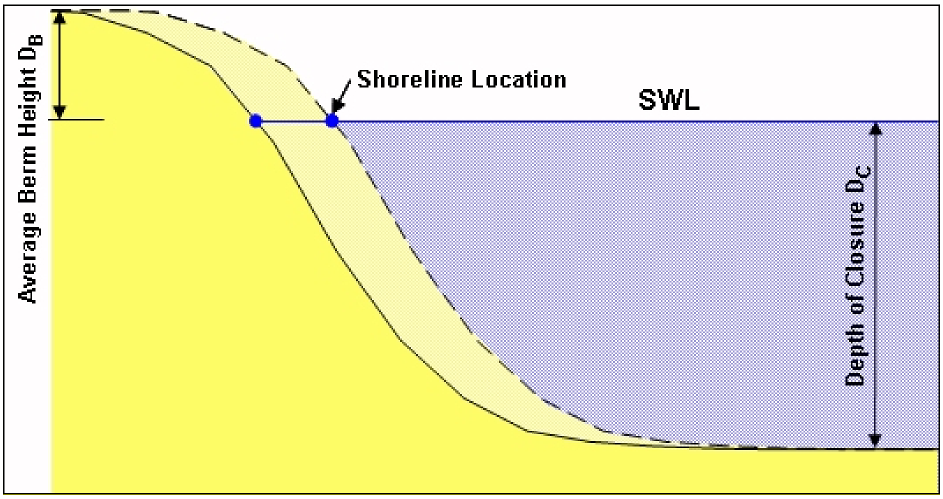


Figure 5 - 1 Definition of closure depth and berm height in a cross-section

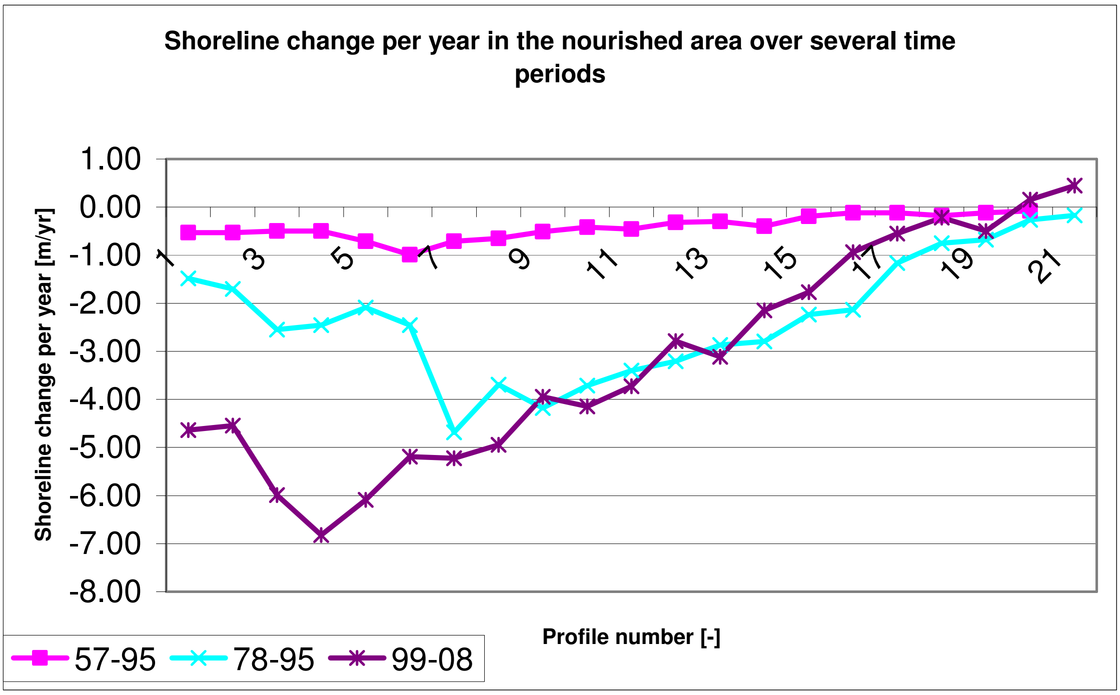


Figure 5 - 2 Shoreline changes per year in the nourished area

The erosion rates of the compared time intervals are given in Table 5 - 1, to get an indication of the growth in erosion over the decades. A positive value of shoreline change indicates a seaward growth of the beach, which is due to the nourishment of 1999.

Shoreline changes over first stretch of Piçarras beach

year	shoreline change per year [m/yr]
57-78 photo	-0.24
57-95 photo	-0.42
57-07 photo	-0.23
78-95 photo	-0.97
95-05 photo	0.38
98-99 profile	31.40
99-08 profile	-3.17

Table 5 - 1 Shoreline changes of nourished area

Another way to calculate the eroded volumes is determining the surface beneath the cross-section of each profile (Appendix IX) An example of the cross-sections for profile 1 is visible in Figure 5 - 3. This has been done for the profiles of 2007 and 1999. The difference then is the volume eroded after the nourishment.

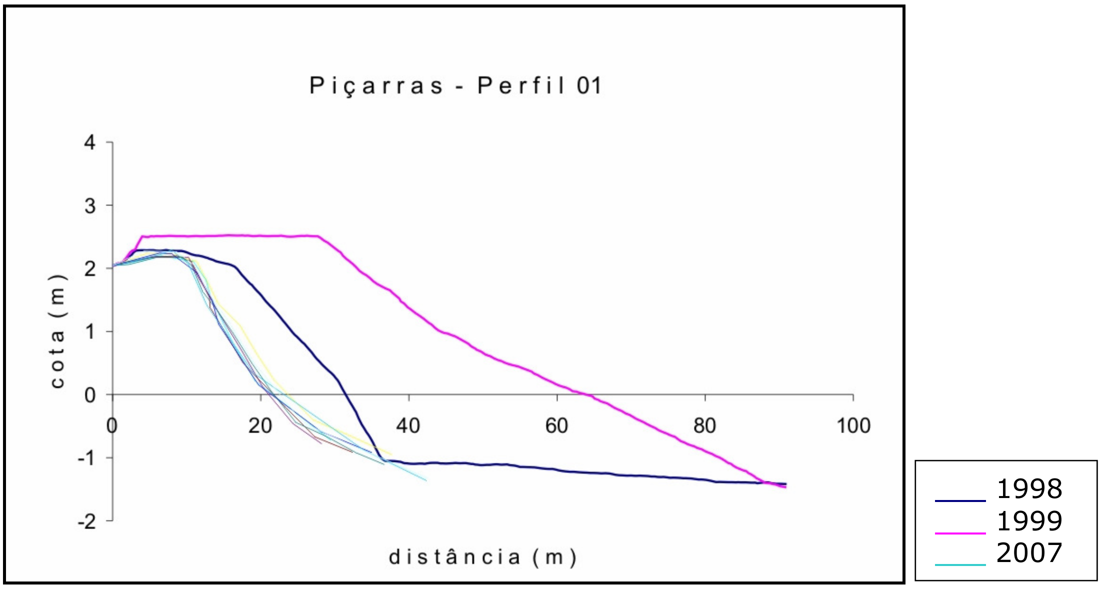


Figure 5 - 3 Cross-sections of profile 1 over time [2]

In Table 5 - 2 the results of the different methods are given.

Eroded volume per method

method	eroded volume [m3]
sub-aereal volumes	204,323
shoreline changes	394,047
profile changes	366,626

Table 5 - 2 Eroded volume per calculation method for cross-sections 1 - 21

As said before the sub-aerial volumes only give an indication of the eroded volumes. Therefore only the results from the shoreline changes and the profile changes can be compared. It is clear that these results are in the same range. To design a save solution later on, the most severe erosion is chosen to compare with future calculations and with the results of the different models later on. Therefore the erosion of the past nine years is set to 395,000m^3.

6 Modelling

6.1 Introduction

The offshore wave conditions formulated in Chapter 4 have to be translated to nearshore wave conditions that govern the sediment transport processes at Piçarras beach. As stated in the approach D3D will be used to model wave propagation. The output will serve as input for UB. Because Piçarras beach has been split up in 26 cross-sections and Alegre beach in 4 cross-section the use of UB is justified, see Appendix VI. Each cross-section represents a small 'uniform' beach which gets its input (from D3D) at the seaward end of the cross-section and its boundary conditions from the neighbouring cross-sections. It has already been stated in this report that the wave data is limited. Consequently the four wave scenarios used here could cause the models to give erroneous non-representative coastline changes. It has also been stressed that the authors are fully aware of this, but that this is the data available right now and will thus be used. The next paragraph will shortly state the overall observations regarding wave propagation and processes governing it. In paragraph 6.3 the wave modelling is coupled to an investigation into longshore transport at Piçarras using the Kamphuis expression. In paragraph 6.4 the wave modelling and shoreline analysis are linked, discussed and compared with the results of SMC. The results of UB and SMC can be found more elaborately in respectively Appendix VI and VII. To investigate possible cross-shore transport the extreme wave scenario of H_s = 4.2m from the East is modelled. Finally, paragraph 6.5 presents conclusion with respect to the modeling activities and the consequences for the project.

6.2 Waves

For the modelling of wave propagation three different grids have been made, which will be nested when running the model. This is explained quite elaborately in Appendix III. The main reason is to speed up computations. Inside the bay, around the island and shoals, grids with cell sizes of circa 25mx25m are needed to model refraction, diffraction and shoaling. But offshore these cell sizes are far too small. To capture wave breaking and shoaling in the breaker zone, which varies in width from 10m to 40m depending on the conditions, an even finer grid is needed. All the grids need boundary conditions before they can compute anything. By nesting the different grids only the offshore wave conditions (see Chapter 4) have to be applied on the biggest grid. When convergence is reached for this grid, it imposes its results on the underlying grid (the finer and smaller grid) without having to formulate the boundary conditions for this grid manually. In this way the nearshore wave conditions can be modelled quick and with the desired level of detail.

After running the scenarios as formulated in Chapter 4, there are several important observations regarding wave propagation that will be discussed:
- Diffraction
- Refraction
- Wave focussing

6.2.1 Diffraction

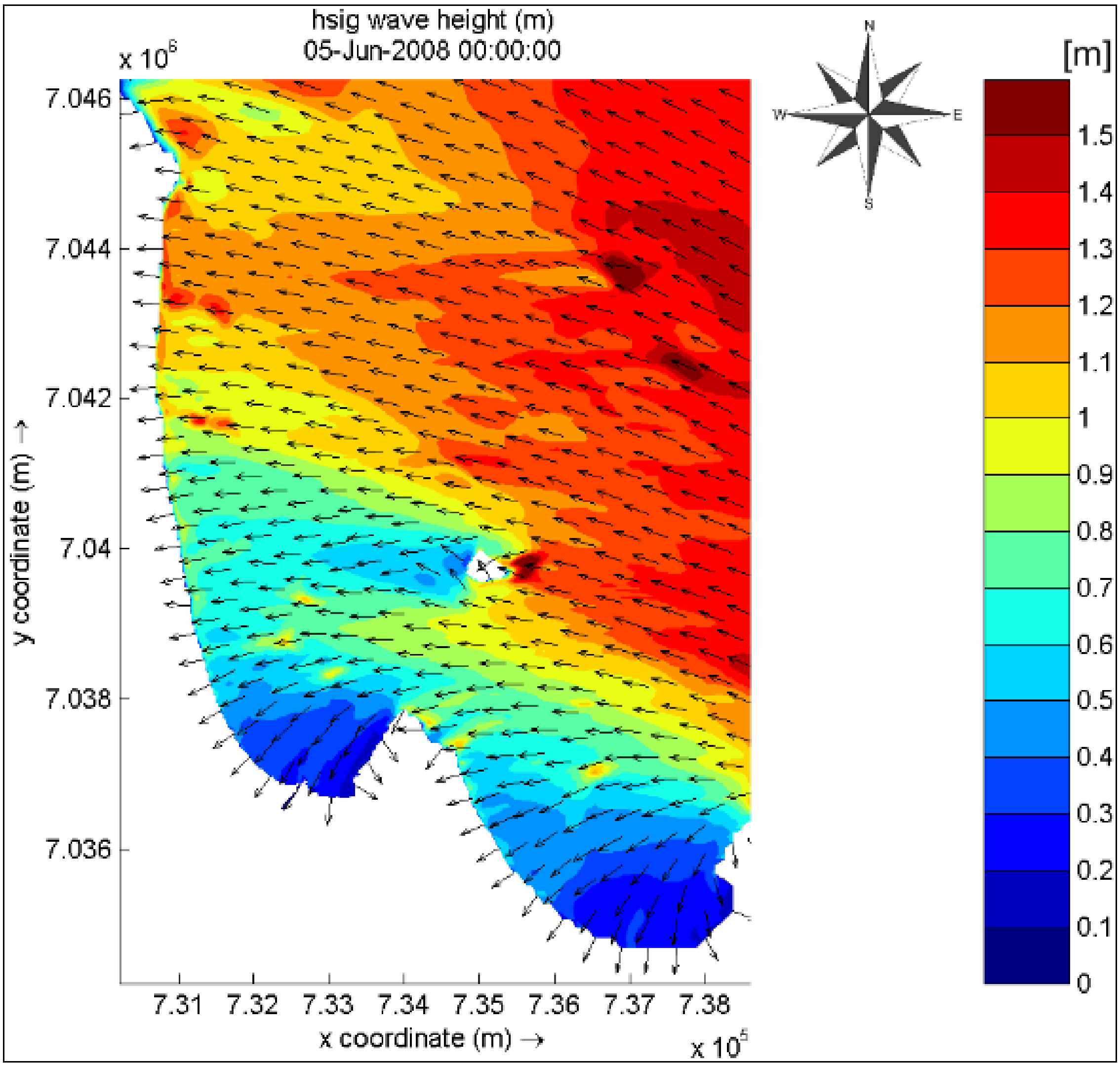


Figure 6 - 1 Diffraction

In Figure 6 - 1 it is clearly visible that the wave heights behind the island and the headlands (south) are a lot smaller than in the rest of the bay. This is due to the turning of waves towards areas with lower amplitudes (and thus wave heights) due to amplitude changes along the wave crest; diffraction. Diffraction is particularly strong along the geometric shadow line of obstacles such as islands and headlands. Behind the island this only causes a slight reduction in wave height. The effect however is noticeable at the beach of Piçarras in the form of decreased wave attack. The beach of Alegre and the south of Piçarras can be classified as protected as a result of diffraction. It is the diffraction that causes the bay to have its characteristic shape.

6.2.2 Refraction

Another thing that became quite clear during the modelling was the angle of the waves that arrived at the beach. At Piçarras beach the difference between the angles of incidence of offshore waves from the south and offshore waves from the east don't vary more than 2°. This is shown more clearly in Table 6 - 1. It can be concluded that refraction plays a major role in headland bay beaches.

	Angles [°]			
profile	NE	E	SE	S
1	13.6	**11.8**	**12.1**	**12.3**
2	4.1	**2.0**	**2.4**	**2.6**
3	4.8	**2.2**	**2.6**	**1.8**
4	7.6	**4.6**	**3.6**	**3.7**
5	7.4	**4.3**	**4.5**	**4.6**
6	9.1	**6.0**	**6.0**	**5.3**
7	10.6	**7.3**	**6.0**	**6.0**
8	10.2	**6.7**	**6.7**	**6.6**
9	8.1	**4.7**	**4.9**	**5.2**
10	5.9	**2.8**	**3.1**	**3.4**
11	6.9	**3.7**	**4.2**	**4.5**
12	8.6	**4.0**	**4.1**	**4.9**
13	10.8	**-0.7**	**6.0**	**6.1**
14	11.6	**6.6**	**7.1**	**7.9**
15	16.3	**11.5**	**11.1**	**11.2**
16	16.0	**9.8**	**9.8**	**10.3**
17	11.6	**5.8**	**5.5**	**5.8**
18	13.4	**8.4**	**8.2**	**8.6**
19	15.3	**11.1**	**10.7**	**11.3**
20	12.2	7.5	5.8	6.4
21	10.0	5.3	4.5	6.8
22	13.6	7.4	1.3	5.1
23	16.1	6.9	1.5	1.4
24	4.8	-3.9	-8.6	-6.8
25	15.6	8.2	5.0	3.4
26	14.9	6.7	4.0	1.8

Table 6 - 1 Angles of incidence at wave breaking point for 4 scenarios.

6.2.3 Wave focussing

Refraction on a more local scale is observed behind the shoals as indicated in Figure 6 - 2. The bathymetry causes the waves to refract in such a way that they are focused on certain areas at the beach. This causes more energy per meter along the beach to arrive at these spots resulting in increased breaker heights. This more local refraction process is also called focussing of waves. The stretch of beach next to the area of focussing is subject to less energy per meter along the beach and which results in smaller breaker heights. Subsequently wave induced set-up and wave-induced currents are triggered which may cause sediment transport. In some cases the shoals even cause wave breaking and thus initiate currents as well. This can be seen in the results of SMC. For instance for the scenario for waves from the southeast which is shown in Figure 6 - 2.

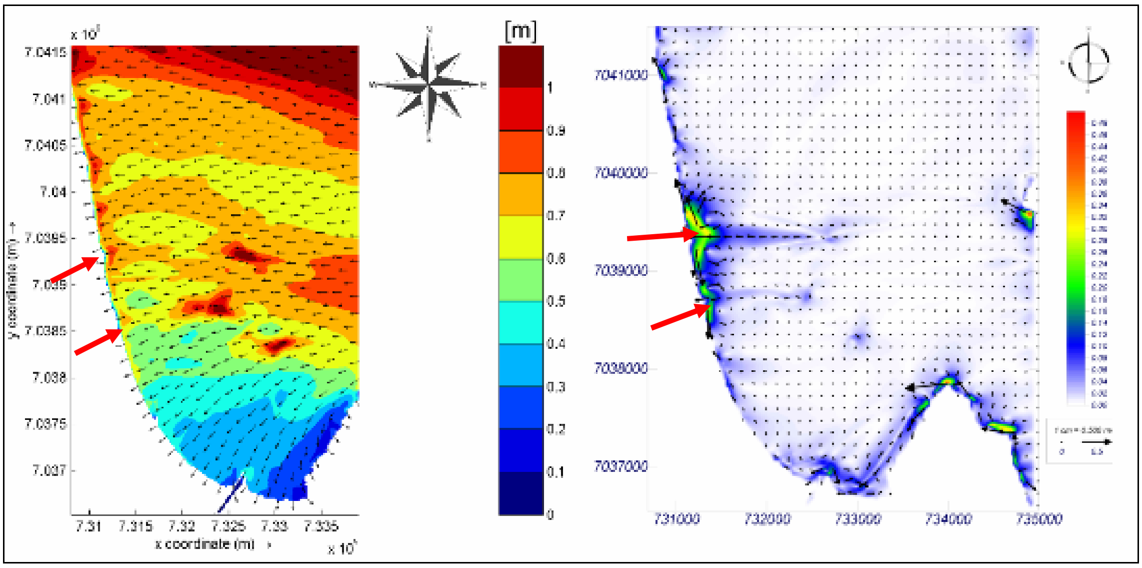


Figure 6 - 2 Output from D3D and SMC for waves from southeast H=1.81m, T=11.43s

6.3 Lonshore transport with Kamphuis Expression

In this paragraph the output from D3D wave will be used to calculate longshore transport with the Kamphuis expression. The reason why the CEM formula hasn't been used lies in the fact that this formula can not be applied when there are longshore gradients in wave heights and strong curving depth contours. In agreement with ir. Verhagen [19] the Kamphuis expression has been used for this project.

To be able to calculate longshore transport several parameters are needed:

- Wave height at breakpoint
- Angle of incidence at breakpoint
- Deep water wave period (peak)
- Grain size of the sediment
- Slope of the beach

These have been determined in Appendix III with the help of D3D. the Kamphuis expression takes into account the wave steepness, beach slope (which is a important parameter for Piçarras beach) and grain size. Per scenario and per profile the sediment transport has been calculated. Table 6 - 2 presents a summary of the total results per scenario. It is clearly visible that these rates are far too high since the total eroded volume during 9 years should be in the order of 395.000m^3, see Chapter 5. The direction doesn't seem to match real nature either. A minus sine means transport to the north. These results suggest net transport to the south, whereas there is erosion in the south and no sign of accretion near the northern jetty.

	Transport [m3/yr]	Transport with 3° south [m3/yr]	Transport with 5° south [m3/yr]
NE	17,747,775.84	14,477,737.85	11,384,321.64
E	59,657,335.03	34,336,423.64	11,888,001.29
SE	235,575.15	104,471.26	-19,423.45
S	5,628,769.60	2,356,449.04	-358,493.19
Total	**83,269,455.63**	**51,275,081.79**	**22,894,406.29**

Table 6 - 2 Results of longshore transport calculations.

6.3.1 Remarks

There are a few things that strongly influence the results. Most important is the angle of the incoming waves, which determines the direction of the transport. From the D3D wave modeling it can be seen that the waves arrive at the coast almost perpendicular, but with a small angle towards the south. This could mean there is something wrong with the refraction computations in the model. To counteract this the breaker angle has been varied from the original one to 3 and 5 degrees more south. This resulted in a significant decrease in the transport south, but still not sufficient.

The second source of errors could be the overestimation of the wave period. For the southern scenarios the result would be more serious because waves with a longer period refract stronger, resulting in a smaller or even positive angle causing southern transport. Moreover the wave period counts to the power 1.5 in the Kamphuis expression.

For all scenarios the breaker height seems reasonable. During a field visit similar breaking waves were observed, though, at all profiles along the beach, with a breaker angle towards the north.

The grain sizes could be too small. UNIVALI has taken samples at the backshore and the foreshore. A bigger grain size means less transport than a smaller grain size. But looking at the sizes used for the calculations this seems to be alright. The last source of errors could be the measured slope of the beach profile. Since for the Kamphuis expression the slope in the breaker zone should be used. The slope used for these calculations is the average slope of the profile, simply because there are no measurements of the slope in the breaker zone. This average slope would in general be milder than the slope in the breaker zone, causing less transport. So this doesn’t clarify the huge amount of calculated transport either.

Normally, the alongshore sediment transport in headland bay beaches is not very big. Simply because these coastal systems have evolved over many thousands of years. The amount of transport calculated here is definitely wrong. What this calculation does show, is the sensitivity of the outcome with regard to changing the angle of incidence with 5 degrees. The waves are apparently almost perpendicular to the shore, which suggests an equilibrium shape of the bay. The plan shape of the bay will shift a bit landwards and then seawards again, depending on the storminess of the years. This would cause no trouble if housing or other hard structures wouldn’t be too close to the beach, as is the case now. Nevertheless there is erosion in the south of the bay, slopes are steeper here than anywhere else along the beach, while wave attack is very mild. Also the sediment is coarser here than in the neighboring sections of the beach.

6.4 Shoreline analysis

Shoreline analysis can be made in several ways. In this project UB and Mepbay are used. The results of Mepbay are not useful due to all the irregularities in the bay of Piçarras. The theory uses one diffraction point which determines the shape of the headland bay beach, whereas in the bay of Piçarras there are several. For results of the Mepbay analysis is referred to Appendix VIII. Shoreline analysis with UB is better applicable to the bay of Piçarras. In this paragraph D3D-, UB- and SMC-output will be coupled.

The UB-models contain closed boundaries. In this way it is possible to quickly see where erosion and accretion takes place and it is possible to compare the results of SMC and UB in a qualitative way. It is emphasized that the models simulate different time periods (UB years, SMC days). The places of potential transport and erosion/accretion can be compared, to see whether the predictions of the models are in agreement with each other. If they are, and they are in agreement with real life as well, the UB model can be used to simulate the evolution of a designed nourishment. In the next section the results for the following wave scenarios will be presented (Table 6 - 3)

Results	T_{mean} [s]	H_s [m]	Occ. [%]
NE	8.26	1.50	7.00
E	8.67	1.86	30.20
SE	11.43	1.81	21.00
S	11.91	1.57	26.60
No waves			15.20

Table 6 - 3 Wave scenarios for modelling

The first simulation has been made using waves from the northeast. These waves are present 7% of the time, with a significant wave height of 1.50m and a mean period of 8.26s.

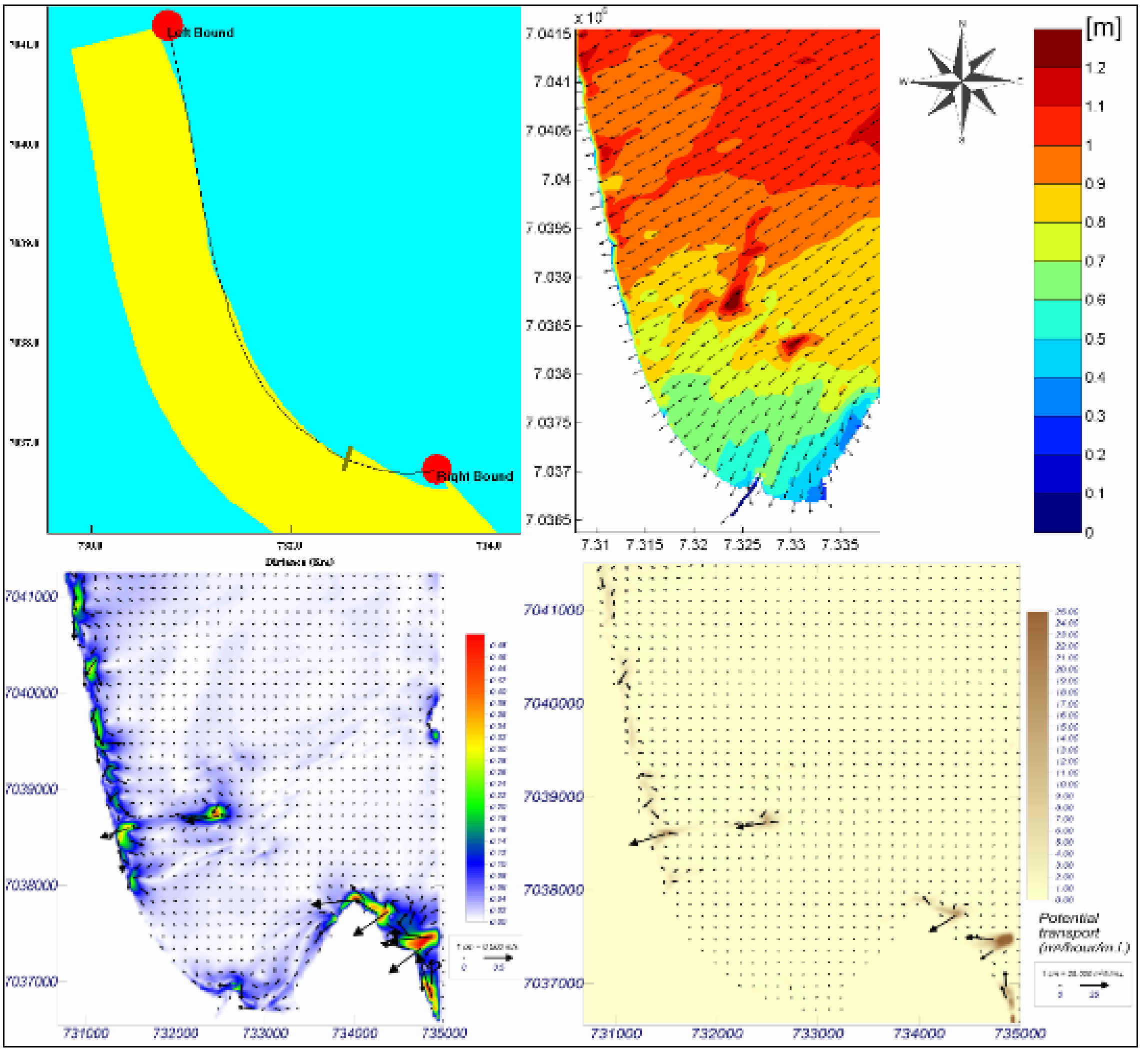


Figure 6 - 3 Results modelling, waves from northeast

The outcome of UB is shown in the upper left corner of Figure 6 - 3. When it is compared to the SMC output both programs show transport from north to south. Between the jetty and y=7038666 SMC shows very little transport. As a result of the transport to the south and the lack of transport in the south, accretion occurs on a stretch of beach from 500m to 2000m north of the jetty. Apart from the results at Alegre beach, both model results are in line with each other.

The second simulation has been made using waves from the east. These waves are present are present 30.2% of the time, with a significant wave height of 1.86m and a mean period of 8.67s. Below the modelling results are presented.

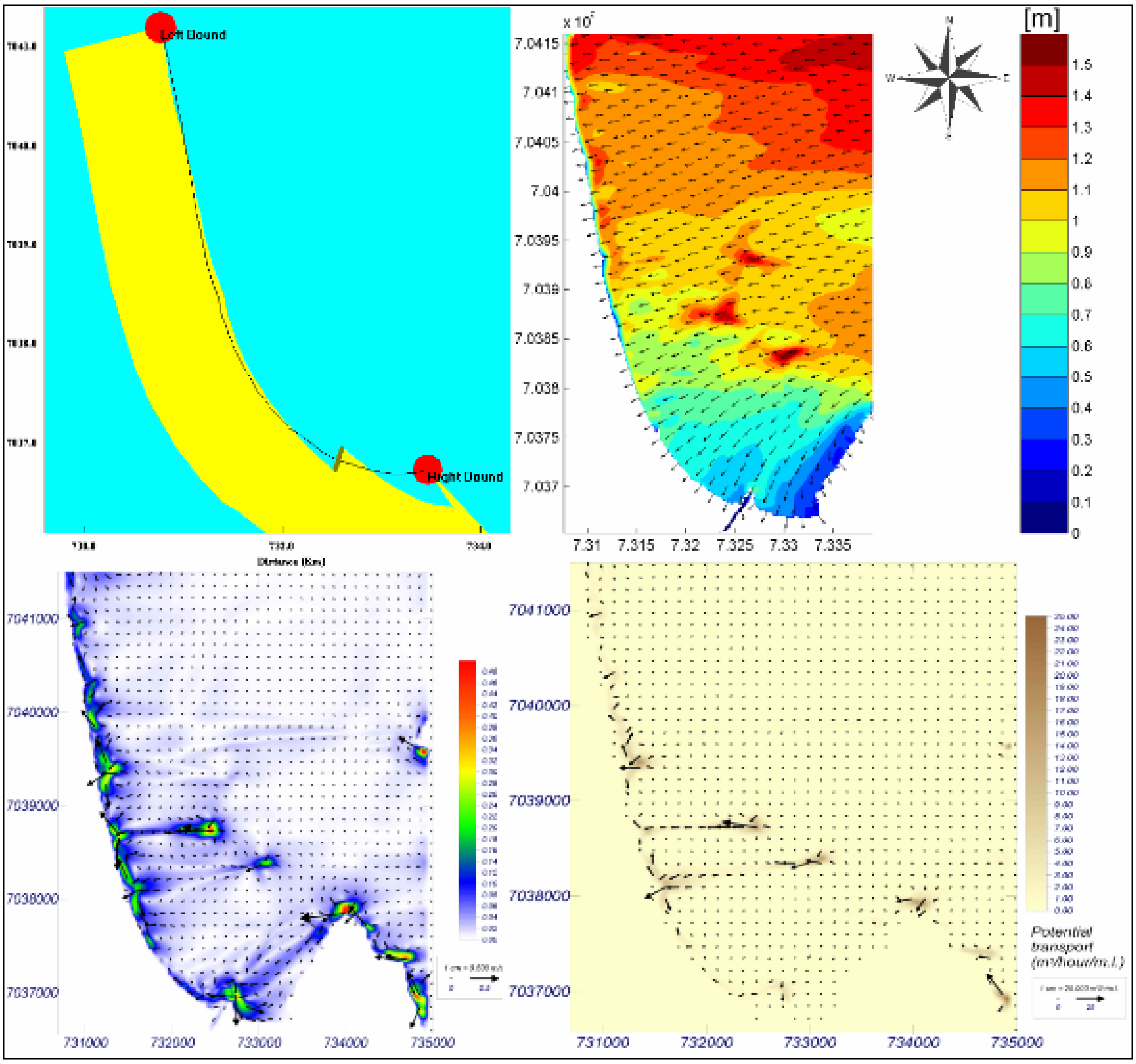


Figure 6 - 4 Results modelling, waves from east

SMC shows transport in different directions between y=7037500 and y=7040000. Transport occurs in both northern and southern direction. The net transport however is not that big at this stretch of the beach.

The transport computed in UB seems larger than predicted with SMC. The latter only gives potential transport in the stretch mentioned above and very little transport on the northern and southern side towards this stretch. The results for this case are a bit doubtful and not straightforward.

Now the modelling results for waves from the southeast will be compared.

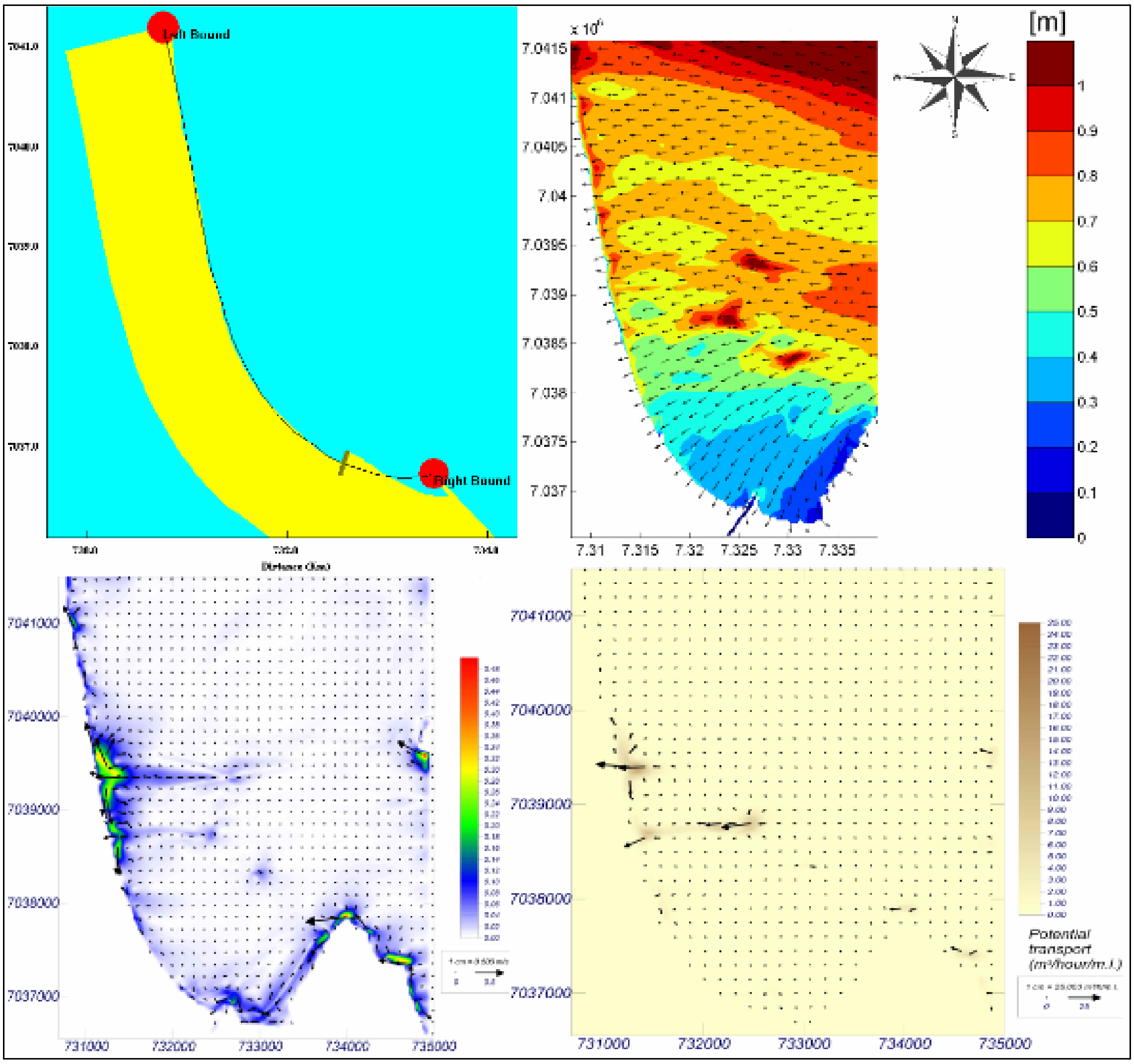


Figure 6 - 5 Results modelling, waves from southeast

Waves from the southeast are present 21% of the time, and have a significant wave height of 1.81m and a mean period of 11.43s. SMC shows very little transport, apart from the area surrounding y=7039333. This transport is not visible in UB as erosion. This point is probably the result of shoals in front of the coast. These shoals are not present in the cross-sections that form the bathymetry in UB, simply because these shoals are located outside or between these cross-sections. The next step is to compare the results when waves come from the south.

These waves from the south are present are present 26.60% of the time, with a significant wave height of 1.57m and a mean period of 11.91s. Below the modelling results are presented.

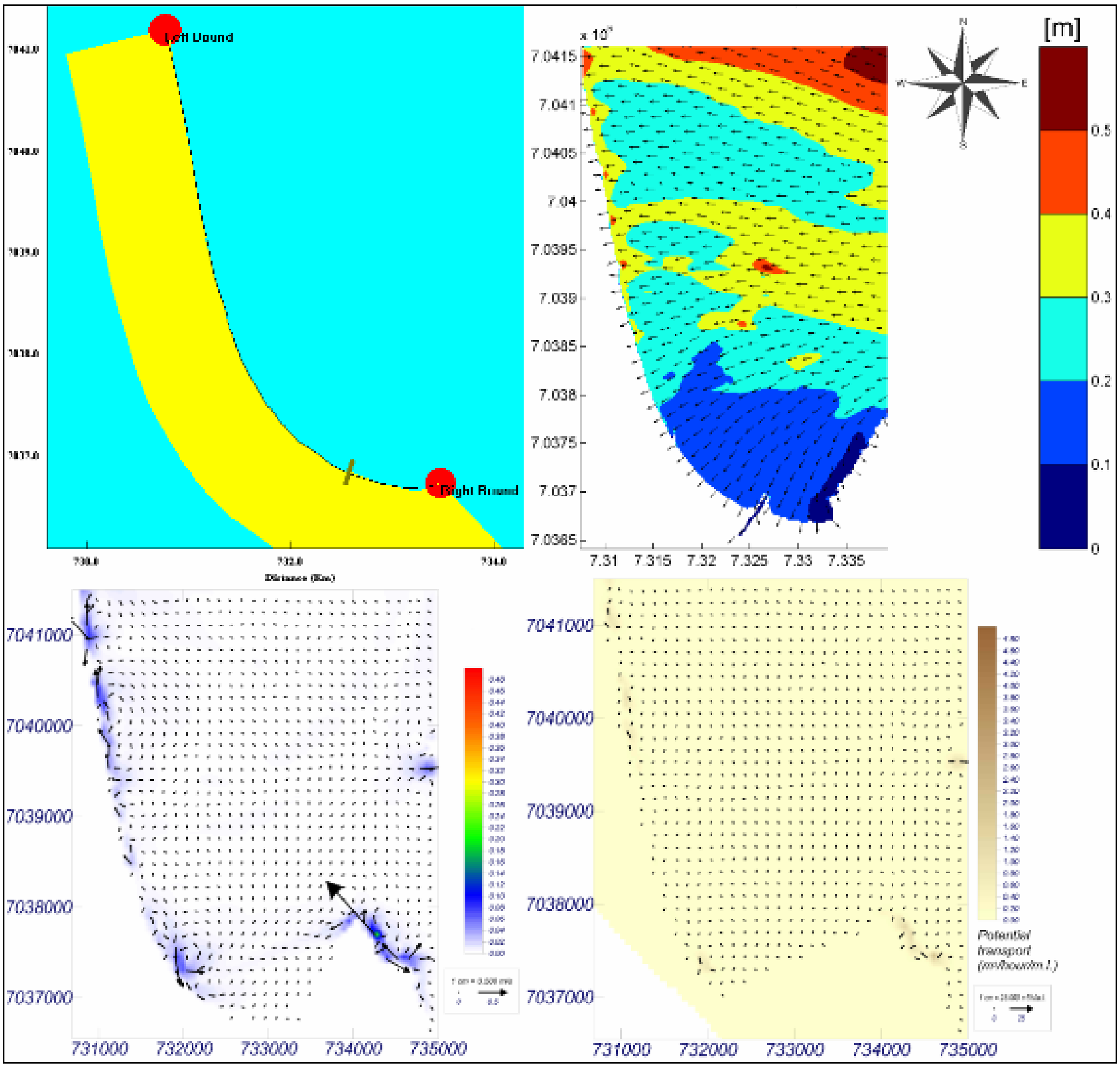


Figure 6 - 6 Results modelling, waves from south

SMC shows low currents and low potential transport when waves come from southern direction. As a result of these low capacities, almost no transport occurs. This is also visible in UB, because there is almost no coastline movement noticeable.

The model runs for all wave directions show results that correspond with each other most of the time. Only Alegre beach shows very different behaviour in the programs. This is because UB does not take the diffraction zone behind the Penha headland into account but SMC does. At Piçarras beach most results are in agreement. Nevertheless there are some small differences. This can be clarified by the difference in simulation time which is in the order of years in UB, while SMC only simulates 72 hours.

Another explanation is the absence of shoals in UB. Moreover, SMC models its own wave propagation from offshore to nearshore, thus including all bathymetrical features like shoals and headlands and their influence on wave characteristics. UB however, only gets its input (output from D3D) at the end of the cross-sections as defined in Chapter 3. Overall it can be concluded that both models are build correctly, or contain the same error(s).

The final step is to see if UB will show the same erosion/accretion pattern as in real life, using a simulation period of 9 years and a wave climate existing of the 4 wave scenarios simultaneously. This simulation has an open boundary condition in the north, which has the property to maintain the coastline at the same position for the entire simulation period. UB will import or export as many sediment as necessary to achieve this. For more information about the open boundary, see Appendix VI.

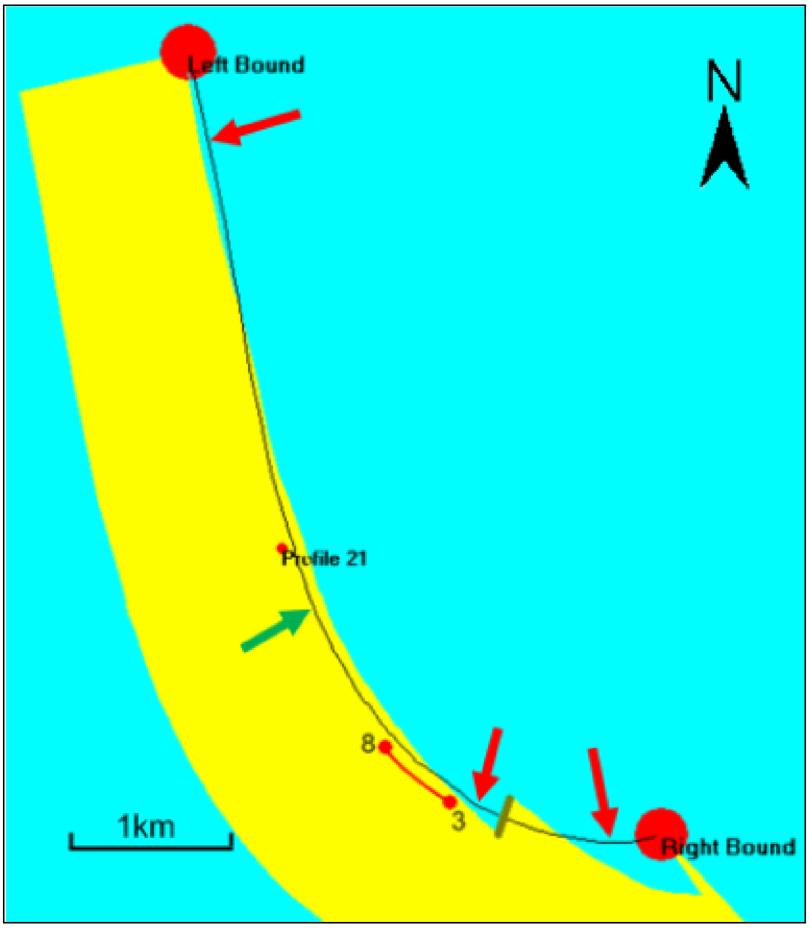


Figure 6 - 7 Results UB, waves from all directions

Looking at Figure 6 - 7, the result is not satisfying at all. The model does not only show a non-representative situation at Alegre beach, but also at Piçarras beach. It shows accretion along almost the entire nourished area (2100m), where erosion should dominate. There is severe erosion visible next to the jetty, but in the critical area (between profile 3 and 8, see Figure 6 - 7) the erosion is not that strong. The erosion in the north at profile 26 (left bound in Figure 6 - 7) is not in agreement with real life either.

So far, only longshore sediment transport has been modelled. May be, cross-shore transport has an influence on the erosion/accretion patterns. This will be investigated by simulating a storm event. Cross-shore transport will only take place during storm surges. When a storm scenario is modelled in SMC, the program shows the erosion and accretion locations. These spots will be used in UB to model the location of sinks that simulate the effects of cross-shore transport on the movement of the coastline.

A run in D3D and SMC is made using storm conditions (Hs = 4.2m, T = 10s). These conditions were used to define the closure depth along the project area, see Appendix IV, and are thus the most severe conditions that can be expected. The result is shown in Figure 6 - 8. This figure shows six possible cross-shore locations along the coastline of Piçarras.

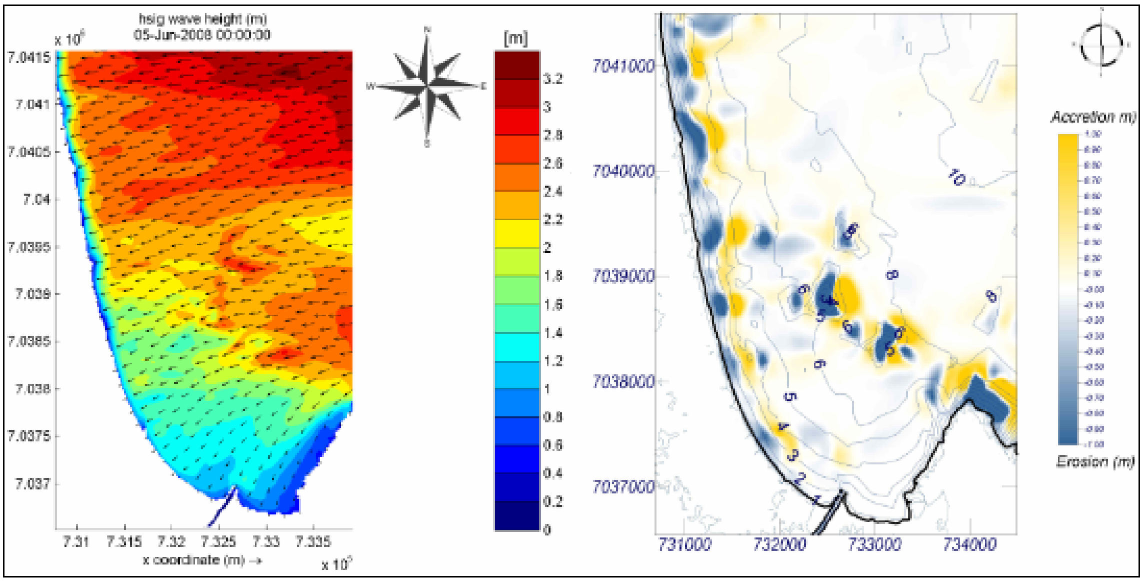


Figure 6 - 8 D3D output wave propagation and SMC output of storm event Hs = 4.2m, T = 10s

There are two uncertainties in modelling cross-shore transport. First, it is not known how many sediment is lost by cross-shore transport. Second, each location that has been pointed out by SMC has a different influence in the amount of cross-shore transport. The first problem will be solved by making three runs in UB, in which the amount of lost sediment due to cross-shore transport will be 100%, 50% and 25% of the total amount of eroded volume. In this way it may be possible to give an estimation about the influence of cross-shore transport. The second problem will be solved by giving an estimation of the influence per location, based on Figure 6 - 8. The tables below indicate the capacity of the sinks. This means that the volumes in the tables will be extracted from the beach.

Percentage lost in sinks [%]	Lost sediment in 9 years [m3]	Lost sediment in 1 year [m3]
100	395.000	43.889
50	197.500	21.944
25	98.750	10.972

Table 6 - 4 Amount of lost sediment due to cross-shore transport

X	Y	Lost sediment [%]	Lost sediment [m3/yr] (100%)	Lost sediment [m3/yr] (50%)	Lost sediment [m3/yr] (25%)
731770	7037400	10	4.389	2.194	1.097
731404	7038100	10	4.389	2.194	1.097
731251	7038700	15	6.583	3.292	1.646
731100	7039400	25	10.972	5.486	2.743
730940	7040333	25	10.972	5.486	2.743
730816	7041000	15	6.583	3.292	1.646

Table 6 - 5 Amount of lost sediment per sink

The northern boundary condition will be such that the coastline will stay on its position.

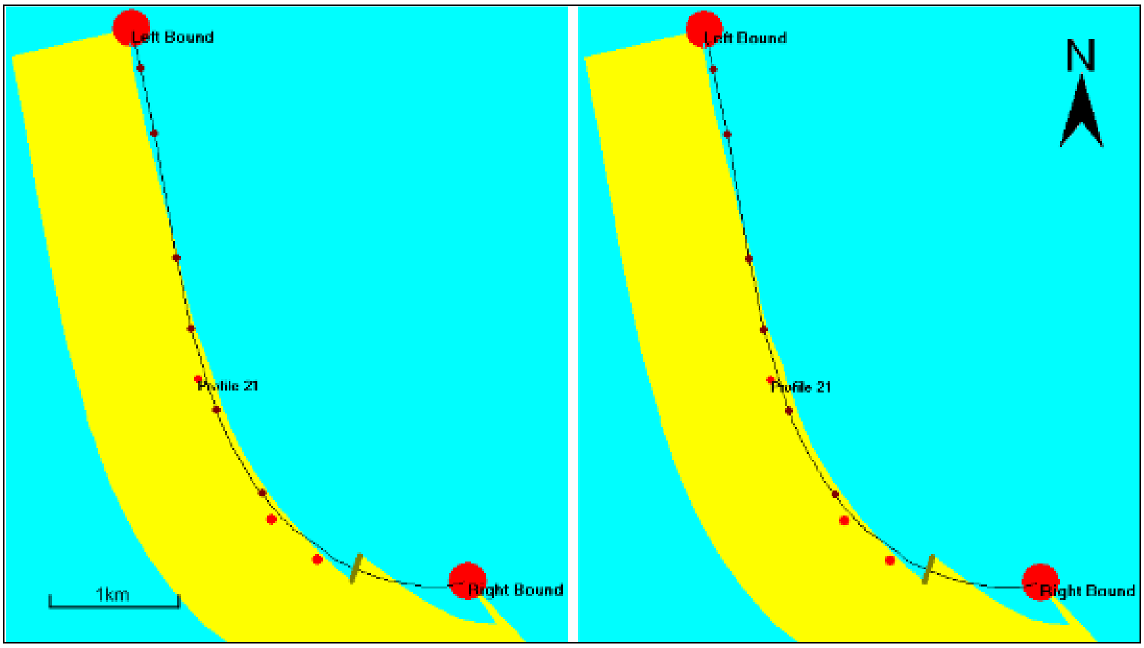


Figure 6 - 9 Total sink capacity 100% of total eroded volume (left) and total sink capacity 50% of total eroded volume (right)

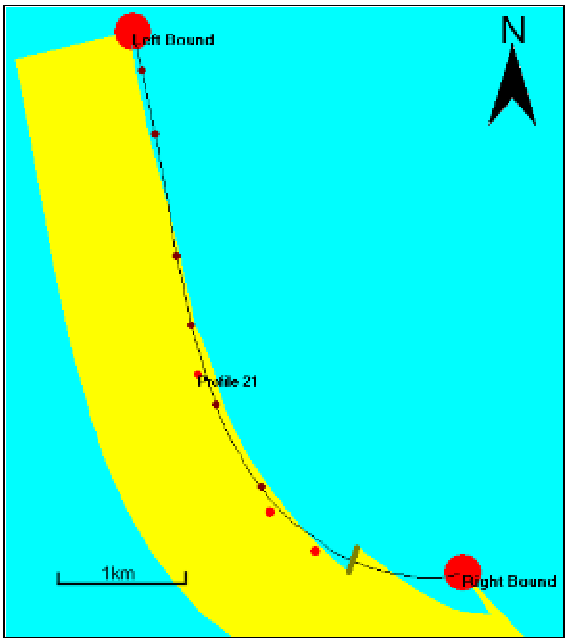


Figure 6 - 10 Total sink capacity 25% of total eroded volume

The results in Figure 6 - 9 and Figure 6 - 10 show that there is not noticeable more accretion when the sink-capacity is reduced from 100% to 25% of the total eroded volume. When the sink-capacity is 100% of the total eroded volume no accretion is expected in the model, but the result does not match this expectation.

It can be concluded that if the total eroded volume is calculated correctly, the UB model not only shows a wrong erosion/accretion pattern, but also the transported volumes are way too large. As a consequence of this, it is not possible to define if there is any influence of cross-shore transport on the coastline movement with the current UB model.

6.5 Conclusions

The used models (UB and SMC) are more or less in agreement with each other when leaving cross-shore processes out of consideration. They indicate the same trends such as direction and location of sediment transport. However they are not in agreement with the actual erosion/accretion patterns as observed in reality. This could be caused by several aspects, treated below.

6.5.1 Wave data

There are very limited wave data available to do a decent analysis of the wave climate of the southern Brazilian coast. If wave periods are overestimated, consequently refraction will be as well, causing the waves to curve towards the coast so much that they break towards the south (model results) instead of to the north (real life observations). The schematisation made in this report could have resulted in a wave period that is to high. The directional aspect however, has not been simplified by this schematisation. The raw data were measured in directional bins of 45°. So waves that have a direction between 65° and 110° are registered as coming from the East. This is a very rough way of measuring. One could argue that by using the schematisation of one wave scenario per direction the influence of smaller and bigger wave periods and -heights isn't represented well. It is emphasized here that the authors are fully aware of this. However, the time available for this project had long been exceeded at this point, so further modelling was not an option.

6.5.2 Bathymetry

The bathymetry has been composed of several data sets. For the deep water part the accuracy is of minor importance when compared to the shallow part inside the bay. The latter is a result partly of digitalisation of a nautical chart and partly of beach measurements. The nautical chart however hasn't been made to model wave propagation or morpho-dynamics in the bay, but just for navigation. Consequently this map isn't detailed enough. The beach measurements are a good start to get better data, however they are only measured until a depth of 1.5m. Because of this underwater slopes (nearshore and foreshore) are not known, making it hard to model or calculate accurate wave breaking angels, heights and types, and thus sediment transport.

6.5.3 Shape of the bay

A third aspect that complicates modelling of the shoreline changes and sediment transport at Piçarras beach is the combination of the shape of the bay and the software packages used for modelling. The longshore non-uniformity, strong curvature and heterogeneity of the bay call for simplifications that could be too crude to represent real nature with the models used.
Examples of this are:
- the irregular depth contours in combination with the use of UB. An attempt has been made to compensate for this by using 30 cross-sections, each of which represents a uniform beach section with its own orientation. However the (rocky) shoals are not captured within these cross-sections, resulting in a smoother nearshore.
- the rocky headlands that interact with the longshore sediment transport from one bay to another. Since there are no measurements of transport around these headlands they have been schematised as closed (south) and varied (north). This has caused strange model results, as presented in Appendix VI, clearly not in agreement with real nature.
- the shadow zone behind the headland. Looking at the drastic evolution of Alegre beach it is clear that UB models the waves at Alegre beach erroneous. SMC does take the shadow zone into account which is caused by the shape of the bat. Therefore SMC is in better agreement with the situation in real life.

6.6 Recommendations

In this paragraph the some recommendations will be given which are an immediate result of the modelling activities. These recommendations hold for the aspects discussed in this chapter. They will be presented in recommendations for modelling and monitoring of Piçarras beach.

Recommendations for modelling:
- Have a closer look at the refraction calculations. Waves from the east-south-east to south (offshore) should result in breaker angles to the north (as observed in the field visit).
- Find a better way of determining the wave breaker height.
- Couple wave breaking and wave set-up to flow calculations and secondary flow effects that possibly carry the sediment away, thus not enabling it to be transported back to the beach in calmer periods.
- Use better wave data. Use longer measurement records.
- Use more detailed bathymetric data.
- Use one software package in which, wave propagation, flow, sediment transport and morphology are integrated.

Recommendations for monitoring:
- Measure the foreshore and nearshore, for instance with a GPS and echosounder, to get a better picture of the beach profiles. Do this on a regular basis for a long time and certainly after storm events to monitor the sediment in the profiles.

6.7 Further approach

After concluding that with the data, knowhow and models up until now the real life situation can not be reproduced, a change in approach has to be made. Although the modelling has provided insight into wave propagation and sediment transport processes in the bay of Piçarras the resulting UB-model can not be used to evaluate the nourishment of Prosul nor a nourishment designed by the authors.

However, with the previously acquired knowledge and data it is perfectly possible to design a nourishment. The next chapter will present the designed nourishment. How the design has been made has been elaborately documented in Appendix IX. The Prosul nourishment will be evaluated in Chapter 8 in a more qualitative way than initially anticipated.

7 Nourishment Design

In this chapter the results of the nourishment design will be presented and briefly explained. These are the area to be nourished, the location of the borrow pit, the required beach width and slope, the volume of sand that needs to be dredged, a cost estimate and finally a workplan of the execution.

7.1 Area to be nourished

In 1999 a nourishment has been executed on Piçarras beach over a total length of 2100m starting from the jetty at the north side of the Piçarras river northward, see Figure 7 - 1.

Figure 7 - 1 Image of the Piçarras bay with nourishment zone of 1999 [16]

Recent measurements of cross shore profiles show that the beach is still suffering significant erosion from the jetty until 2100m northward. That is until profile 21, see Figure 7 - 2.

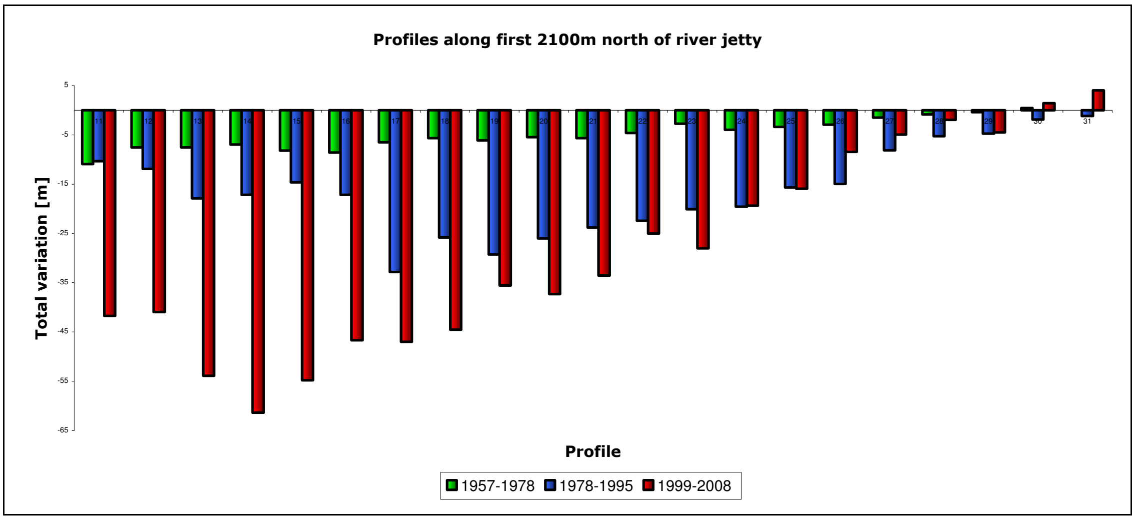


Figure 7 - 2 Beach width variation per cross-sections over several time periods

From profile 22 on, the measurements show that the beach has sufficient width, therefore the nourishment will be designed for the same area as defined for the nourishment of 1999.

7.2 Location of the borrow pit

A few alternatives for the location of the borrow pit have been assessed. The first possibility is locating the borrow pit near the coastline of Alegre beach. In Figure 7 - 3 this location is indicated with '2007 Borrow Site', because this location is defined as the location for the borrow pit in the Prosul plan.

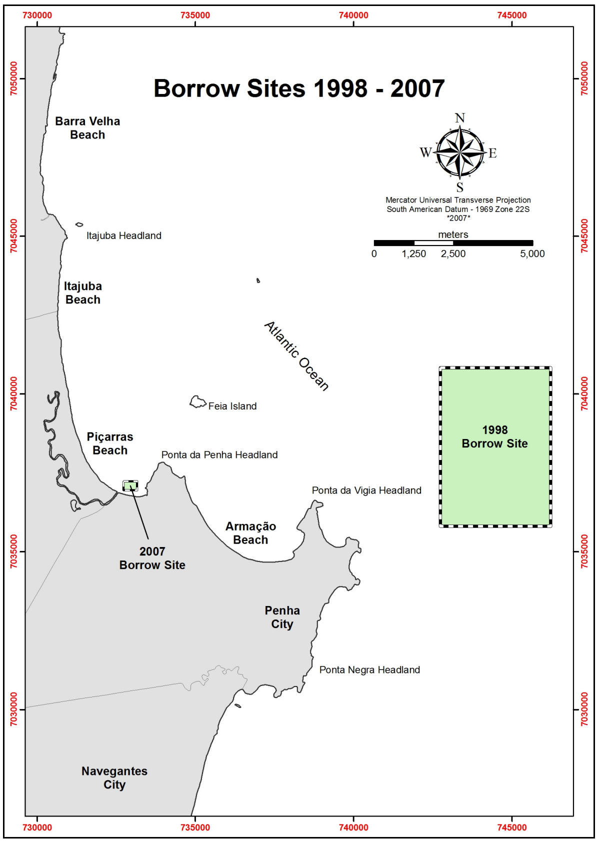


Figure 7 - 3 Map with possible locations of the borrow pits [2]

Since this borrow pit is located close to the mouth of the river Piçarras, the borrow pit supplies a lot of fine sediment. Dredging this fine sediment and dumping it on Piçarras beach will initially result in a very muddy beach. Besides, the fine sediments will erode relatively quick which will reduce the lifetime. Furthermore, using this location can also have consequences for Alegre beach. Deepening this nearshore location can significantly influence the local wave conditions. The same consequence counts for a borrow pit allocated in the nearshore of Piçarras beach.

An alternative location could be the borrow pit used for the nourishment in 1999 indicated with '1998 Borrow Site' in Figure 7 - 3. As this spot is located in deeper water, this will have significantly less effect on wave propagation and flow patterns and consequently sediment transport. No measurements were performed to collect data about the sediment present at this location. It is however determined that the sediment size present in this borrow pit is somewhat finer than the native sand at Piçarras beach now, but coarser than the sediment present in the previously mentioned alternative borrow pits close to the shore [23]. The determined value of sediment size present in the '1998 Borrow Site' is d_{n50} = 0.260mm, see also Appendix 5. The location of the borrow pit is assigned the same location as the borrow pit used in 1999.

7.3 Beach width and slope

A few factors play an important role in the determination of the beach width. Basically this is the erosion rate at the most endangered place and the recreation on the beach. To a lesser extent this is also the availability of a buffer of sediment during a storm, from an engineering point of view.

With a limited availability of data from the nourishment of 1999 and with the support of stories from local people it is concluded that after the nourishment of 1999 the dry beach had an average width of circa 65m and the beach platform a width of 40m. This added width has disappeared in 9 years. Conclusion is that a planform width of 40m is minimal. This design will therefore have a minimal beach width of 35m, called the design fill. This width is desired to create enough area for recreation and to have a buffer of sediment during severe storm conditions. To ensure that the design fill will sustain after the nourishment, an additional amount of sediment needs to be supplied, to compensate for the loss of sediment due to spreading out and ongoing erosion. The size of this advanced fill is based on its lifetime combined with the erosion rates from the past. The average erosion rate is in the order of 3.5m per year, see Appendix V. With a set lifetime of the advanced fill of 10 years, this will result in a width of another 35m. Adding the advanced fill to the design fill will result in a total beach planform of 70m wide. after the nourishment. The advanced fill needs to be repeated after a set time interval. Using erosion rates the advanced fill has a lifetime of 10 years. Every ten years a new nourishment has to be executed. This way the amount of sand placed as design fill will not decline.

In Figure 7 - 4 several cross-section in the nourishment period are shown. The brown volume is the current profile. First a profile as the red line will be placed, the design fill. Immediately after the advanced fill will be placed, leading to a cross-section as shown by the orange line.

The slope is very steep, 1:3. Wave action will reshape the beach and a flatter slope will be shaped. Therefore the beach width will initially decrease after the nourishment to a total beach planform width of 70m, as can be deducted from the volume indicated by "Advanced post-nourishment". This is the equilibrium profile very shortly after the nourishment. The slope will in time change due to seasonal changes in wave action and ongoing erosion. As said before the advanced fill has to be repeated each 10 years. So the white plane will erode in 10 years and replenished as the orange line every 10 years.

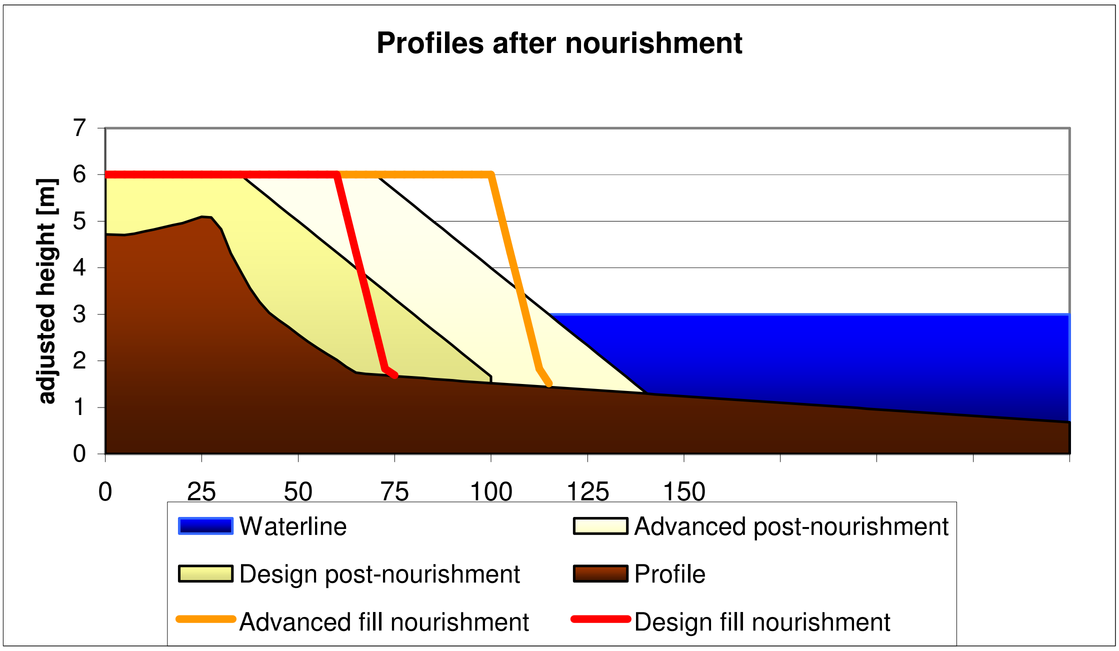


Figure 7 - 4 Cross-section in different phases pré- and post-nourishment

From a recreational point of view it is important to reduce both the berm height of the beach and the steepness of the slope. A berm that is elevated too much can induce scarping and a relatively steep beach slope will reflect the incoming waves. Both these processes can cause dangerous situations for swimmers. For these reasons, the berm of the beach will have a height of IBGE + 3.0m. This height is approximately the height of the natural level without being flooded during a severe storm. The slope of the beach will mainly be determined based on the sediments size available. The sediment shouldn't be to coarse in order to prevent the beach slope being too steep and thereby dangerous for swimmers. A sediment size as discussed in the previous paragraph will give a bit milder slope than currently present, sufficiently mild for recreation.

7.4 Volume calculation

In the past a few different methods have been proposed to calculate for the volumes to be placed for a beach nourishment. The methods used in this study are:

- The method of translating profiles
- Dean's method of intersecting and non-intersecting profiles
- The Dutch method

All these methods are applied in this study to make sure that the most optimum result will be obtained for the design. For the detailed elaboration of all these methods will be referred to Appendix V. In this paragraph only the results are presented. Table 7 - 1 gives an overview of the calculated volumes.

Comparison of calculation methods

method	volume first nourishment [m3]	volume repeated nourishments [m3]
translating profiles	817,029	440,333
equilibrium profiles	910,424	491,093
dutch method	1,039,186	519,593

Table 7 - 1 Comparison of volume calculation methods

The results for the different methods presented in the table are within the same range. The calculated amounts of sediment are based on actual observed numbers, the erosion rates of the past 9 years. The first two theories in the table assume the existence of equilibrium profiles which in theory are not depending on hydraulic boundary conditions. For this study the results of the Dutch method will be used, because the results can be considered as most reliable.

For the first nourishment an amount of 1 040 000m³ will be placed, the beach width will then be 70m. Since the lifetime of the advanced fill is set to 10 years it is necessary to repeat the nourishment with an interval of 10 years. A lifetime shorter than 10 years will lead to higher costs. For the repeated nourishments an amount of sediment of 520 000m³ needs to be placed; the second advanced fill. In ten years time, the advanced fill will have been eroded away almost completely. This still leaves a beach width of 35m, which has been nourished primarily; the design fill. The authorities should realise that the system of design and advanced fill has to be respected in order to have successful coastal zone management. If however the advanced fill is not placed with the prescribed intervals of approximately ten years, the first nourishment will sustain for 20 years leading to the present emergency situation as described in the Project Description.

7.5 Retaining structures

In Appendix IX the possiblity of constructing a retaining structure was evaluated. For intervening with the cross-shore current, constructing a perched beach would be a solution. A groyne would retain the sand, preventing it from longshore spreading. An offshore breakwater would reduce the wave action at the beach. But both structures would only shift the erosion problems downstream. Therefore it is decided to design no construction. Repeated nourishments are the best solution to intervene in the retreating coastline.

7.6 Workplan & costs

7.6.1 Workplan

The sediment will be dredged from the borrow pit with a trailing suction hopper dredger (TSHD), see Figure 7 - 5.

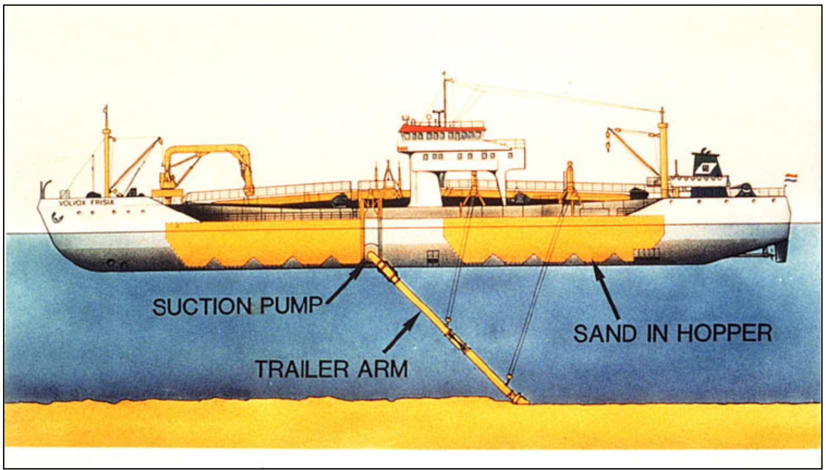


Figure 7 - 5 Image of Trailing suction hopper dredger

The reason why the TSHD will be deployed for this project is that it has a high level of seaworthiness. The vessel is equipped with several swell compensating parts allowing work to proceed during bumpy wave conditions. Moreover this type of vessel can sail (self propelled) to almost any location in the world. This was also a decisive factor because in this proposal it is assumed that a vessel has to be mobilised from Europe. After the sediment has been dredged, the vessel will sail to a nearshore location, approximately 10km from the borrow pit. From this point on, the sediment will be transported further to the beach with pipelines. It is not possible for the vessel to dump the sediment directly onto the beach since the required depth for the vessel is not sufficient. For further details regarding the execution is referred to Appendix IX.

For optimal use the vessel will be deployed full time, that means 168 hours per week (24 hours per day). A few limiting factors have to be taken into account which prevent the vessel from operating, like extreme wave and wind conditions and mechanical and operational downtime. In one week the vessel can dredge and place an amount of 296 000m^3 per week. A total amount of 1 040 000m^3 needs to be placed for the first nourishment. This means that the entire operation will take about 3.6 weeks. For future nourishments an amount of 520 000m^3 needs to be dredged. This will take almost 2 weeks. Both calculated periods are excluding the mobilisation and demobilisation of the vessel which takes approximately a week each.

7.6.2 Costs

Based on the execution time and some standard costs for an operating vessel, an estimation of the project costs has been made. The operational costs for the vessel cover the depreciation, interest, maintenance, repair, crew on board, fuel and lubricants and insurance expenses. Another extra 10% of the total is included for unforeseen costs. The costs for an operating vessel are € 651,750 per week. Regardless of the costs for the vessel some other costs need to be included to calculate the price for the whole project. This includes the rent of pipelines to transport the sediment ashore and the staff on site. The costs are estimated on € 75,000 per week. These extra costs only apply for the 3.6 weeks while the nourishment is being executed. For a detailed calculation of these costs is referred to Appendix IX. The results are summarised in Table 7 - 2.

Summary total project costs first nourishment

cost	period	amount
mobilisation	1 week	€681,175
execution nourishment (1,040,000m³)		
production costs vessel	3.6 weeks	*€ 2,452,230*
other expenses	3.6 weeks	*€ 270,000*
total		€ 2,722,230
profit/risk/general overhead (20% of total)		€ 544,446
demobilisation	1 week	€ 681,175
TOTAL		€ 4,629,026

Table 7 - 2 Summary total project costs first nourishments

The total costs concern the cost for the first nourishment. For future nourishment the execution time will decrease, because the amount of sediment to be placed is only 520,000m³. This results in an execution time of 1.8 weeks as calculated in the previous paragraph. The costs for mobilising and demobilising the vessel remain the same. An new overview is given for costs concerning the future nourishments in Table 7 - 3.

Summary total project costs future nourishments

cost	period	Amount
mobilisation	1 week	€ 681,175
execution nourishment (520,000m³)		
production costs vessel	1.8 weeks	*€ 1,226,115*
other expenses (rent of tugs, pipes etc.)	1.8 weeks	*€ 135,000*
total		€ 1,361,115
profit/risk/general overhead (20% of total)		€ 272,223
demobilisation	1 week	€ 681,175
TOTAL		€ 2,995,688

Table 7 - 3 Summary total project costs future nourishments

8 Evaluation Prosul

In 2007 the company Prosul designed a beach nourishment for the community of Piçarras, as mentioned in Chapter 2. In this chapter this plan will be evaluated. While making this report, the plan has been executed. For now it is only possible to evaluate the plan and observe the current situation. For the actual evolution of the nourishment, the nourished area needs to be studied for the coming years. Then the real effects can be judged.

First the boundary conditions as formulated by Prosul will be presented and evaluated. Secondly the location and characteristics of the borrow pit will be discussed. The last part of the design to consider is the execution. Besides the technical content of the plan, the costs will be compared.

8.1 Boundary conditions

8.1.1 Description

Data from wave measurements done by JICA from December 1988 till November 1989 were analysed to obtain the significant wave height and wave period. It appeared that the highest measured significant wave was 3.0m high with a corresponding period of 8.0s. The dominant wave direction was SE.

The measured wave heights have been plotted and several candidate distribution function have been fitted. A Gumbel distribution had the best fit. With this distribution a design wave height of 3.75m with a return period of 30 years has been defined. For the wave period several cases were taken corresponding to the directions relevant for Piçarras: E, ESE, SE. Then the wave height in the bay was calculated, see Table 8 - 1.

Transformation of offshore to nearshore waves

Offshore direction	Period T [s]	Offshore wave height [m]	Refraction coefficient	Shoaling coefficient	Nearshore wave height [m]
E	6.0	3.75	0.445	1.092	1.82
E	8.0	3.75	0.318	1.226	1.46
ESE	6.0	3.75	0.242	1.092	0.99
ESE	8.0	3.75	0.345	1.226	1.58
SE	8.0	3.75	0.255	1.226	1.17

Table 8 - 1 Offshore wave height with a return period of 30 years, transformed to nearshore wave height [7]

The first three columns give offshore wave conditions. The 4th and 5th columns represent the refraction- and shoaling coefficients which determine the wave conditions in the bay. With these wave heights the breaker height at the 1m, 2m and 3m depth contour have been computed, see Table 8 - 2.

Breaker heights

depth [m]	breaker height [m]
-1.0	1.05
-1.5	1.40
-2.0	1.80

Table 8 - 2 Breaker heights according to Prosul

The dominant wind direction is SSE, with a maximum speed of 15m/s. These data are also taken from the JICA measurement in the period December 1988 till November 1989.

The tide data and current data are also based on the measurements of JICA, leading to an average tidal range of 0.60m and an average current speed of 0.19m/s.

Also for the native sand analysis data from JICA were used. These data have been analysed in this report, see Appendix V. It shows an average grain size of 0.20 to 0.45mm. In the area with the most severe erosion the sediment is coarser, with an average grain size of 0.52mm.

8.1.2 Evaluation

When looking at the reasoning of Prosul, it becomes clear that they are interested in a wave height to design a structure. The design wave height is important for the design of the groynes that they would like to build, since these should stay intact during a severe storm. For the design of a nourishment a wave height with a return period of 30 years isn't relevant. To design a proper beach nourishment, the significant wave height during stormconditions that is only being exceeded 0.137% of the time has to be determined. With this wave height the closuredepth can be determined, and thus the volumes to be nourished. Determination of the closure depth has been done for this project in Appendix IV.
Modelling of this scenario, to invest the cross-shore transport during this storm condition has been done in Chapter 6. From the provided information it is not clear whether Prosul has determined a closure depth, let alone modelled the evolution of their nourishment.

Moreover it seems strange to calculate such an extreme wave height from measurements obtained in 10m water depth. Additionally it is remarkable that a very basic theory, only taking refraction and shoaling into account, is used to transform waves from offshore to nearshore. This theory is based on coasts with straight and parallel depth contours which is obviously not the case in the Piçarras bay. Also no diffraction has been taken into account which appeared to have a large influence, see Chapter 6. Modelling could improve the wave information for the design of the nourishment.

Because no further explanation of the Prosul plan has been given to the authors of this report, only these superficial remarks can be made regarding the formulation of the boundary conditions.

To conclude this part of the evaluation it is emphasized that no closure depth has been determined, the beach nourishment design is not subjected to modelling and no further investigation into long-term wave conditions has been performed.
The tide and currents are the same as used for this report. However there is no sign that the water level set up due to storms has been taken into account by Prosul.

The native sediment size adopted by Prosul is almost the same range as assumed earlier in this report. As can be seen in Graph V – 1, Appendix V, the diameters lay in the range of 0.10 till 0.35mm, which is slightly finer than assumed by Prosul.

8.2 *Location of the borrow pit*

8.2.1 Description

The plan is to use sediment with the same size as has been used for the nourishment of Alegre beach in 1999. This sediment is present right in front of the coastline of Alegre beach. Additional probing has been executed to get better information about the grain sizes and the local depth.

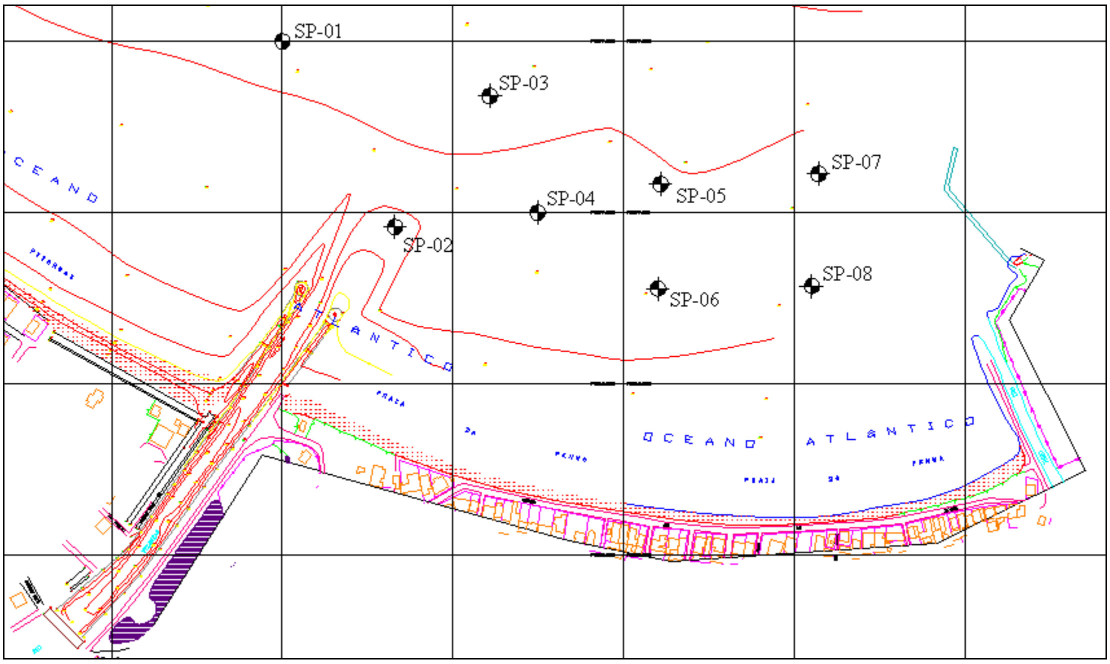


Figure 8 - 1 Location of probing points investigated by Prosul [7]

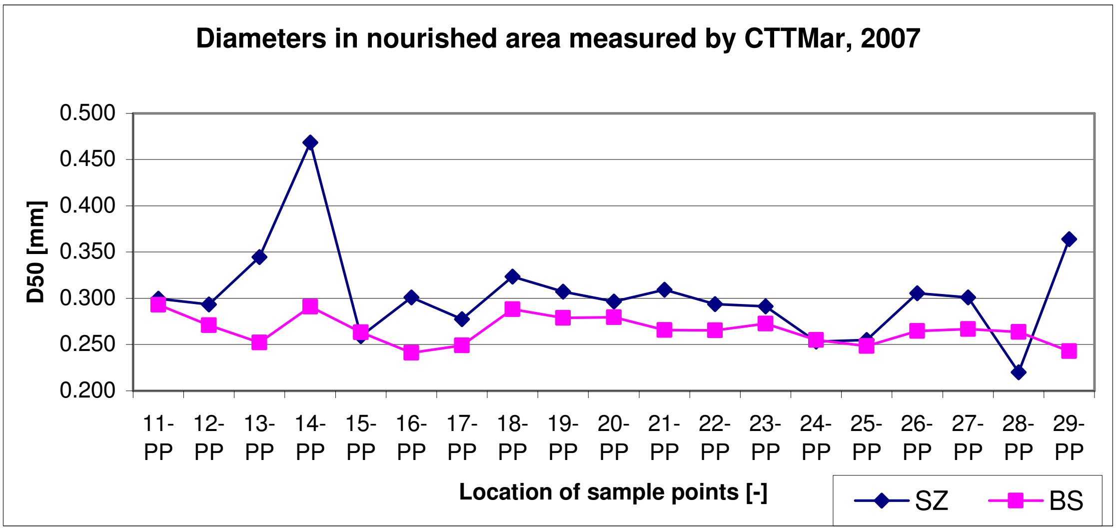
8.2.2 Evaluation

The borrow location is choosen in front of Alegre beach. This has two consequences. First, the excavation will cause a sudden increase in depth which will alter the wave-induced currents. This may lead to more erosion of Alegre beach, since sand taken by cross-shore currents may leave the active profile this way, see Chapter 5. The second consequence of using this location in front of Alegre is nourishing with fine sediments, compared to the native sand at Piçarras beach.

In Table V – 6, Appendix V, the diameters of sand present at Alegre beach are presented. These numbers are repeated here, in
Table 8 - 3 Diameters of Alegre beach by CTTMar and UNIVALI, 2007
. If these are compared to the grain sizes along Piçarras beach, visualised in Graph 8 - 1, it is obvious that Alegre beach accommodates finer sands than Piçarras beach. Assuming the under water situation is similar, the borrow pit will contain finer sand than present at Piçarras beach.

Diameters of Alegre beach by CTTMar and UNIVALI, 2007							
name sample	cross-section	x-coordinate	y-coordinate	D50 [mm]	D90 [mm]	Dm [mm]	ws [m/s]
02-FP	A1	733368	7036687	0.174	0.267	0.174	0.014
02-PP	A1	733372	7036669	0.184	0.606	0.184	0.015
04-FP	A2	733151	7036668	0.153	0.342	0.164	0.012
04-PP	A2	733156	7036642	0.212	0.904	0.224	0.019
05-FP	A3	732988	7036680	0.156	0.363	0.170	0.012
05-PP	A3	732977	7036675	0.198	0.381	0.200	0.017
07-FP	A4	732800	7036730	0.206	0.460	0.216	0.018
07-PP	A4	732793	7036709	0.168	0.265	0.167	0.014
Mean				0.182	0.448	0.187	0.015

Table 8 - 3 Diameters of Alegre beach by CTTMar and UNIVALI, 2007



Graph 8 - 1 Diameters of Piçarras beach by CTTMar and UNIVALI, 2007

In itself finer sediment should not be a problem. Finer sand causes a flatter beach, which means more sediment is needed to get the same platform width. Due to the flatter slope, the beach will be more attractive to tourists since the wave action reduces. There is another side however, which is the fact that finer sediment is brought quicker into suspension. Therefore the sand will erode faster, resulting in a shorter lifetime of the nourishment and therefore shorter renourishment intervals. More nourishments together with more sediments needed for the same planform width will lead to higher costs for a design period of several decades. Multiple nourishments also lead to bigger discomfort, since it will happen more often that the beach has a minimal width, like nowadays. Besides that, the nourishment process also causes discomfort.

8.3 Execution

8.3.1 Description

The plan exists of two phases. The first phase is the nourishment of the stretch of beach which is in the worst condition. An amount of 100 000m^3 sand will be dredged to make a 20m wide planform. After this planform the slope will be 1:20 until the current seabottom. The length of the area nourished in the first phase is approximately 600m.

The second phase will be executed subsequently. The entire beach will be nourished over a length of 2.1km. An amount of 430 000m^3 sand will be placed. Two riprap groynes will keep the sand from sideward spreading. The groynes will be made until a waterdepth of 2m.

The stone sizes were determined using Hudson, but all that will not be evaluated here. The northern 200m beach of the nourished area will become 30m wide, with a seaward slope of 1:20. South of this stretch the beach will receive a 40m wide planform with a seaward slope of 1:20. There will be a small transition zone between these two sections.

The sand will be dredged from a borrow pit in front of Alegre and transported towards the project area by pipelines.

8.3.2 Evaluation

First widen the stretch of beach with the severest erosion is a good consideration. This way the beach width will be more equalised. Besides this, the erosion will maintain more severe at certain stretches, so at those places more sand is needed to level the nourishment lifetime.

The construction of the two groynes in the Prosul plan is remarkable. It is common knowledge that the sand nourished will spread in longshore direction. The jump in coastline will dissapear. This can be prevented by constructing groynes. It will however also influence the longshore current. If this current cannot pass the groyne, sand will be trapped. This leads to increased erosion at the downstream side of the groyne. The result will be a slightly wider beach in the nourished area, but increased erosion north of this area.

8.4 Costs

8.4.1 Description

An overview of the costs of the Prosul plan is given in Table 8 - 4. To calculate the amount in euro’s a currency rate of €1 = R$2.80657 has been used.

Costs of beach nourishment by Prosul

item	description	unit	quantity	unit price	total (R$)	total (€)
1	*Mobilisation*					
1.1	Equipment	-	1	-	300,000	106,762
1.2	Employees	-	1	-	40,000	14,235
	Total item 1				**340,000**	**120,996**
2	*Groynes*					
2.1	Rocks 50 a 250 kg	t	12,489	50	624,435	222,219
2.2	Rocks 250 a 650 kg	t	1,368	51	69,744	24,820
2.3	Rocks 450 a 750 kg	t	2,234	52	116,169	41,341
2.4	Rocks 900 a 1500 kg	t	2,723	56	152,490	54,267
	Total item 2				**962,838**	**342,647**
3	*Dredging and dumping*					
3.1	Dredging of beach sand	m3	429,886	14	6,018,410	2,141,783
3.2	Dredging of groyne core	m3	1,847	7	12,930	4,602
	Total of item 3				**6,031,341**	**2,146,385**
4	*Demobilisation*					
4.1	Equipment	-	1	-	300,000	106,762
4.2	Employees	-	1	-	40,000	14,235
	Total of item 4				**340,000**	**120,996**
	Total of plan				7,674,178	2,731,024

Table 8 - 4 Prices of Prosul plan

8.4.2 Evaluation

The first major difference in the price shows up in the (de)mobilisation costs. For the design in this report it is assumed that the vessel needs to be mobilised from and to Europe, the calculated costs are € 650,000.- per phase. In the Prosul design the vessel is already mobilised in an area close by since the costs are remarkably lower; €121,000.-. These cost aspects will therefore not be taken into account for the comparison.

Secondly, in the Prosul calculation the price for the construction of the groynes is included. These costs are not comparable, because for the nourishment design in this report no groins are included. Therefore these costs will be substracted from the total price as well.

The remaining costs of the Prosul plan to be compared are a little over R$ 6 million, which is approximately € 2.1 million. The costs of the design in this project are approximately € 3.5 million, this is excluding the costs for (de)mobilisation.

One way of explaining the difference is the amount of sediment needed. For the nourishment designed in this project more than twice the amount of sand is needed. It will provide a planform of 35m width at minimum, which is almost equal to the Prosul plan. However, most of the time the beach will be wider with a maximum of 70m.

Moreover, the nourishment designed will have a longer lifetime due to the coarser sediment and the bigger amount. Taking this differences in designs into account, the costs of the different nourishment designs are in the same order of magnitude.

8.5 Current situation

In July 2008 the execution of the Prosul plan started. In Figure 8 - 2 the execution and the results are displayed. The first row shows the dredging vessel and the pipelines over the beach. On the photo right also the equipment to flatten the beach is present. The second row shows the result of the nourishment. This is the same restaurant as shown in Figure 2 - 8, which suffered from some severe wave attack during storms. The last row shows the variability of the sediment placed. Some stretches are covered with shells while other stretches are covered with clay. The consequences of the clay are visible in the right picture at the second row. Here a student of UNIVALI, measuring the beach profiles, subsides in the clay and gets stuck.

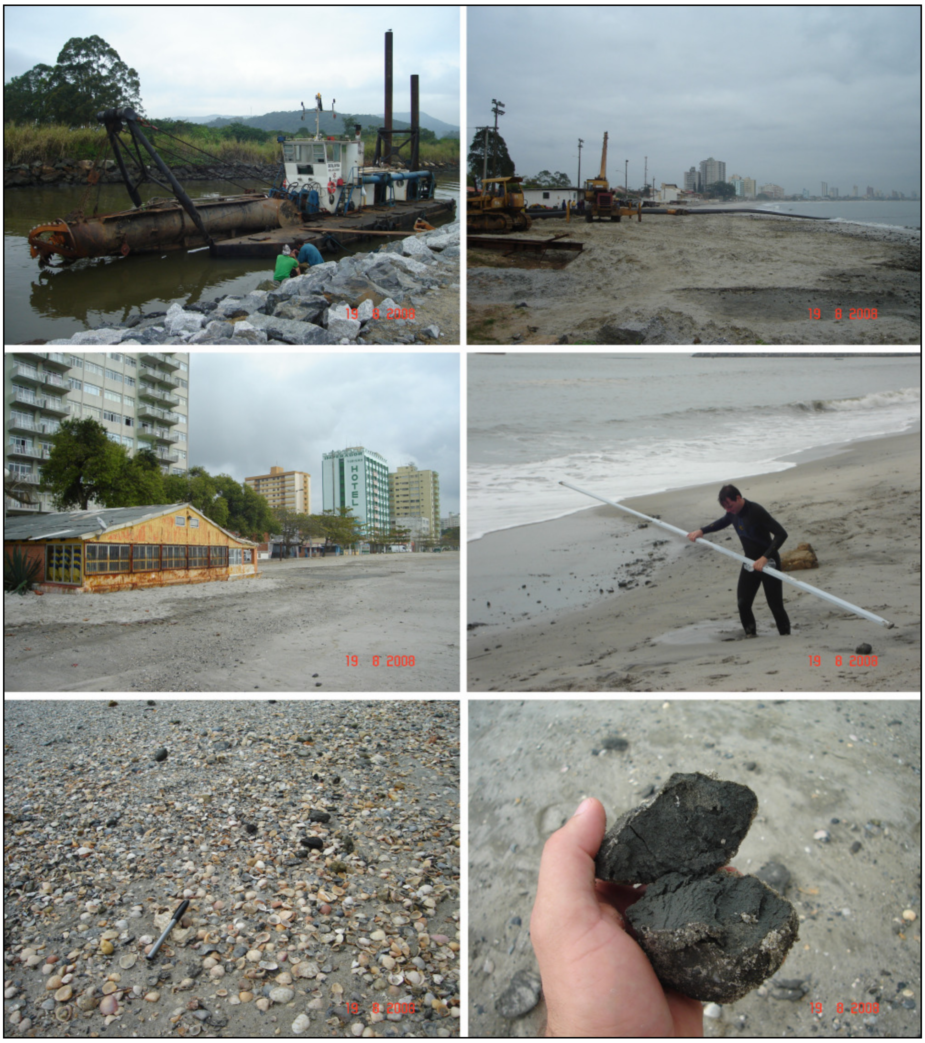


Figure 8 - 2 Results of the execution of the Prosul plan in July and August 2008 [25]

9 Recommendations

In Chapter 6 it has been concluded that the modelling results are not in agreement with the real life situation. With the current data and model it is therefore not possible to simulate the evolution of the designed nourishment nor the Prosul plan. A few steps have to be made in order to improve the output of the modelling programs for the project area. In this chapter some recommendations will be made for future progress of the models. Also some general advice will be given.

Modelling results will only improve with better long-term, up-to-date and reliable wave data. The first recommendation is to make sure this is collected. This is not possible on a short term, so a quick development of modelling results should not be expected. If improvement is required more rapidly, hindcasting can be an option too.

Apart from the wave data, the bathymetric data are also not reliable enough. The bathymetric data used for this project had different sources, all collected for another purpose and in a different time period. Especially nearshore data is of importance because of the significant influence of refraction and diffraction on the wave propagation in the Itapocorói bay. Therefore the second recommendation is to improve the (nearshore) bathymetric data. This can easily be done with a small boat, a gps-device and an echo sounder. To model what happens after a storm it is suggested to measure beach profiles and the bathymetry before and after the storm. In this way sediment can be traced which will give insight into the processes governing the erosion.

With better wave and bathymetric data a big step can be made in the modelling of Piçarras beach, but it is doubtful if Unibest (UB) will show realistic output anyway. With the conversion from Delft3D (D3D) to UB a lot of information is lost. Apart from this, UB does not account for important wave transformation processes that play a significant role in bay of Piçarras, like the diffraction behind the Penha headland. The third recommendation is to use only D3D, because it is anticipated that UB will not show major improvements in its output. To further clarify this it is suggested that D3D-wave, flow and morphology modules are used to minimise the loss in data transfer.

Currently a nourishment, designed by Prosul, is executed. Although there are some doubtful aspects about this nourishment design, monitoring the evolution of the nourished area is important. By monitoring, more accurate erosion rates can be determined, which can be used for future nourishment designs and better understanding of the causes of the erosion processes that occur.

Further investigation into the causes of the erosion are crucial to design effective solutions. With improved models and more accurate data it is possible to get a better insight in the processes in Piçarras bay. It will then be possible to define the causes of erosion. With this information a good intervention can be designed to solve the erosion problems and maybe even the causes.

The last recommendation that can be made is to inform local people and authorities about the importance of repetitive nourishments. The design presented in this report will only be (cost-)effective when new nourishments will be applied when the advanced fill is eroded. Furthermore, critical situations like in June 2008 will only be prevented if action is taken in time. It is emphasized here again, that a nourishment is always a good intervention in case of erosion, because every sediment grain is useful and never lost.

Recapitulating a lot of work can still be done to investigate the processes at Itapocorói bay. With more accurate data the models can be adjusted so they can provide more reliable results. With realistic models the causes of erosion and the possible solutions can be modelled and optimized. Finally the municipality of Piçarras should approach the problem using a long-term management vision. This means monitoring the situation and planning ahead so the situation will never be this critical again. Only then the plan with the design- and advanced fill will work properly.

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Appendices

Content of appendices

I. Bathymetry

I.1 Introduction

For a coastal engineering problem good bathymetric data is very important. Bathymetric data are measurements (a.k.a. samples) of the sea bottom. The data available for this project is not very good. It is old, has a low resolution and questionable reference levels.

This appendix deals with the collection, processing and verification of bathymetric data. Important factors such as reference level of the different data sources and parties executing the measurements will be discussed as well. The last paragraph presents the bathymetry files that will be used for modelling of the wave propagation.

First a figure is presented of some terms that will be used quite often in the appendices (Figure I - 1)

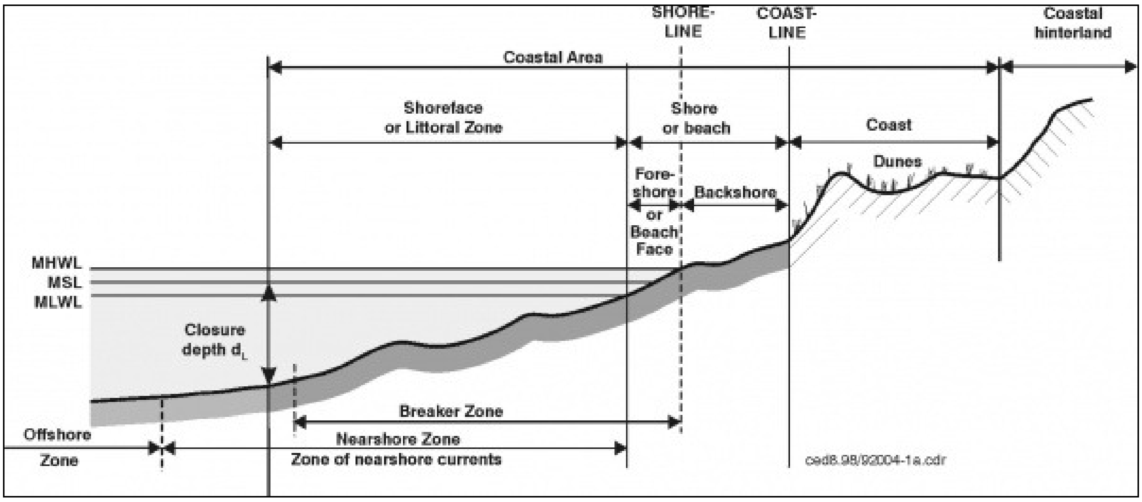


Figure I - 1 Definition of the terms used in the appendices regarding to coastal zones. [10]

I.2 The collection of data

The hydrographical department of the Brazilian Navy has made hydrographical charts for the purpose of navigation. These maps have been digitalized [25]. The maps do not include the nearshore and beach since the vessels couldn't reach these areas because of their draughts and the relative irrelevance of these data for navigation. Also islands and very shallow rocky outcrops left blank spots on the digitalized nautical maps.

For this project it was necessary to have data of the breaker zone, the position of the shoreline and backshore as well as to be able to model or calculate amongst others height of the breaking waves, breaker angles, beach slopes, sediment transport and volumes in the beach profiles. Unfortunately there was very limited data of the backshore available, whereas there was a lot of data of the urban area bordering the beach.

So on the one hand there were bathymetric data and on the other hand there were data of the urban areas with in the middle a 'gap'. This is very characterizing for a coastal engineering project and is important and sometimes difficult to deal with.

One part of this 'gap' has been taken away by monthly measurements of the beach profiles of Piçarras beach by UNIVALI [25]. These measurements were made from the seaward side of the boulevard and houses until the -1.5m depth contour. This is due to limitations in measuring equipment. This only left a 'gap' of +/- 1.5m between the hydrographical data of the Navy and the data of UNIVALI (Figure I - 2). All data-files were provided by UNIVALI [2].

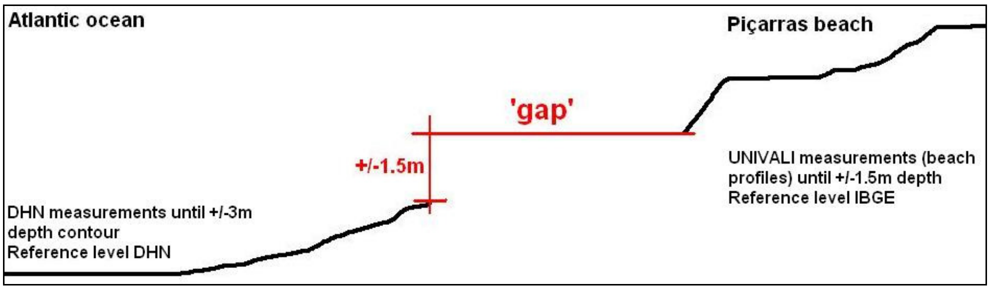


Figure I - 2 Showing the 'gap' in data between hydrographical and geographical surveys [3]

I.3 Reference levels

There are different reference levels for hydrographical and geographical maps in Brazil. The hydrographical surveys are carried out for the purpose of navigation. Therefore all the samples are corrected to the reference level set by the Diretoria Hidrografía e Navegaçao, in short DHN. The definition of this reference level is [30] 'the average of the spring low waters'.

The results of the geographic surveys were provided by the SPU (Secretaria do Patrimônio da Unão). The reference level for these maps is '*the average annual mean sea level at the port of Imbituba'*, Santa Catarina, Brazil. This is determined by the Instituto Brasileiro de Geografía e Estatística (IBGE). The measurements of UNIVALI are all related to IBGE. For Piçarras the difference between DHN and IBGE is 0.398m.

DHN= IBGE – 0.398m

I.4 Processing of data

In order to be able to link all the different samples together, the bathymetric data was corrected to IBGE by adding 0.398m to every sample:

'DHN sample' + 0.398m

The next step was to add Ilha Feia, Ilha Itacolomis, the jetties of the mouth of Rio Piçarras and the shallow rocky outcrops that were mentioned before. This has all been done manually [2][3]. Figure I - 3 has been added to clarify the position of the features mentioned above.

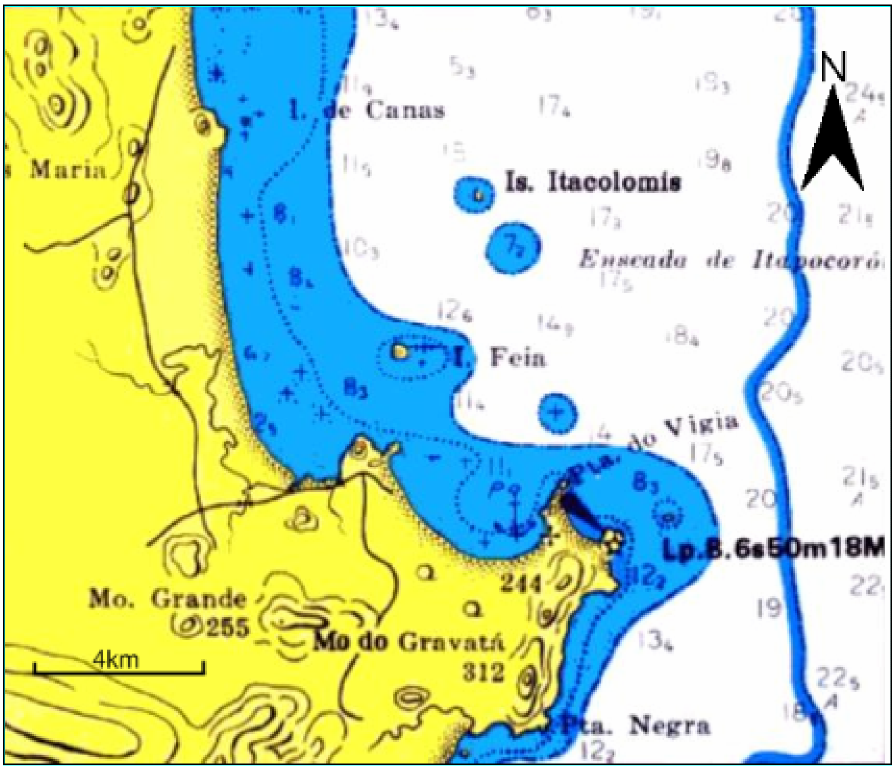


Figure I - 3 Location of islands Itacolomis, Feia, mouth of Rio Piçarras etc. [13]

The data-files provided were ArcGis files. By transforming these files into so called xyz-files they were easy to edit in Excel. With this program the correction of the bathymetric data was carried out.

Another tool that was used to process the data was the RGFGRID/QUICKIN-module of the software package Delft3D (D3D). With this program the .xyz-files could be imported and visualized. By doing this, all the different parts (shoreline, beach profiles, jetties, islands etc.) could be added separately. In this way missing parts of the bay could be added. This resulted in a 'complete' basis for the bathymetry of the Piçarras area including the beach and backshore with one and the same reference level.

This was the first time a link between the wet part and the dry part of this area was made. By no means this is a perfect representation of the bay as it is in real nature, simply because the hydrographical surveys are relatively old, the beach was nourished 9 years ago without any systematic monitoring afterwards and the beach profiles are only being measured since August 2007 and until a depth of 1.5m. Because of this, there can only be speculated about the amount of sand still left in the profile at greater depths. But this data is what is available, so this is what will be used as final samples points for the interpolation to get a digital bathymetry needed to model wave propagation. The sample points and physical setting of Piçarras are visualized in Figure I - 4.

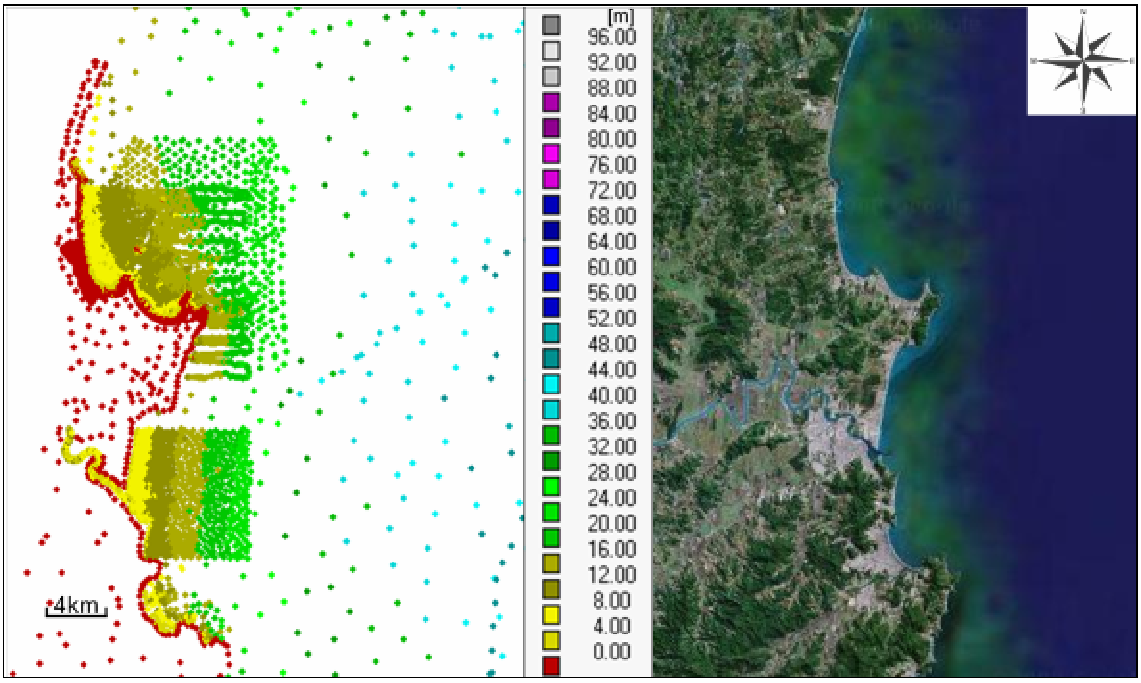


Figure I - 4 Sample points (left), legend in [m] (middle), physical settings of the bay (right) [16]

I.5 Interpolation

To interpolate between the sample points a grid is needed. How a grid is made and which aspects to bear in mind while doing this, is described in Appendix III.

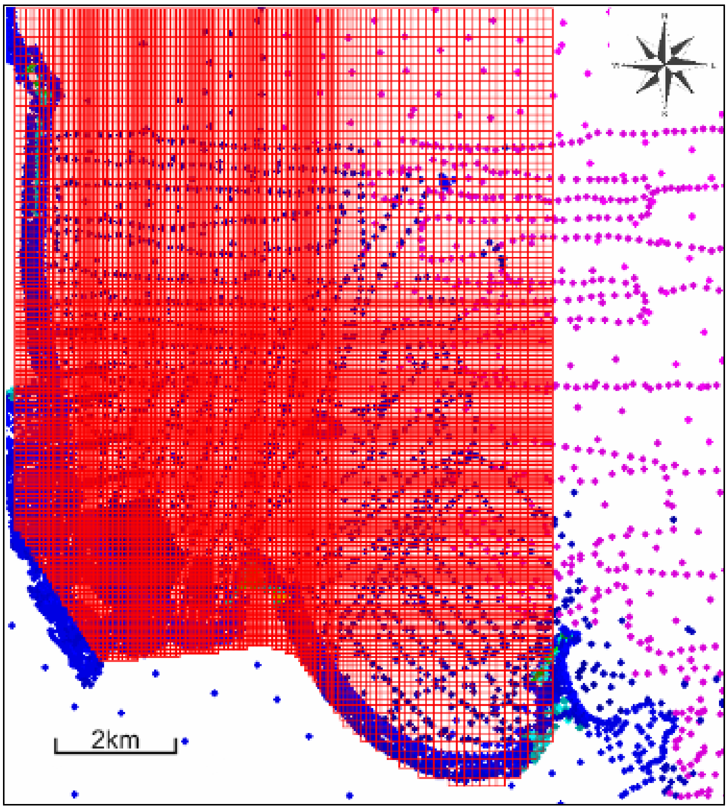


Figure I - 5 Grid resolution versus data resolution

In this paragraph the focus is on the generation of a bathymetry. The interpolation of the sample points is done with the same module from D3D that was used to process and edit the different samples: RGFGRID/QUICKIN. The method of interpolation used is called triangular interpolation. This method is best suited for data sets that have a resolution that is about equal to or smaller than the grid resolution, see Figure I - 5. The sample points are first organized into a so-called Delaunay network, next grid values are interpolated [38]. To make sure that the depth gradients are not too large, which could cause non-smooth numerical results in the hydrodynamic or wave programs, the next step is 'smoothing'. The smoothing factor should be less than 0.2 and is by default set to 0.05.

The last step in obtaining a bathymetry for wave modelling is to make sure that all the grid points have a depth. For this purpose the 'internal diffusion' function is implemented. Grid points that don't have a depth value (especially on the border) are assigned a depth of the neighbouring grid points.

I.6 Verification

The bathymetric map obtained by interpolation can be visualized with Delft3D. This bathymetry has been compared with the nautical charts of DHN. Any strange results (as a result of the interpolation or deviating sample points) were visually and manually removed, after which the interpolation, internal diffusion and smoothing were executed again. These actions were repeated until plausible and satisfactory results in the project area were obtained.

An example of this were strange very shallow spikes offshore that became visible after interpolation. It concerned a sample point offshore with a depth value of +/-10m in a surrounding water depth of 50m. The nautical charts gave no indication of rocky outcrops in that area. Therefore this point was removed. The resulting bathymetries are treated in the next paragraph.

I.7 Resulting bathymetries used for modelling

Three different grids have been made for this project, see Appendix III. For each grid a separate bathymetry file has been made. The first grid covers an extensive offshore area. The northern boundary lies 27km north of the project area (indicated with a circle in Figure I - 6). The eastern boundary lies approximately 35km offshore. The southern boundary lies 16km south of the project area. The resulting bathymetry is shown in Figure I - 6.

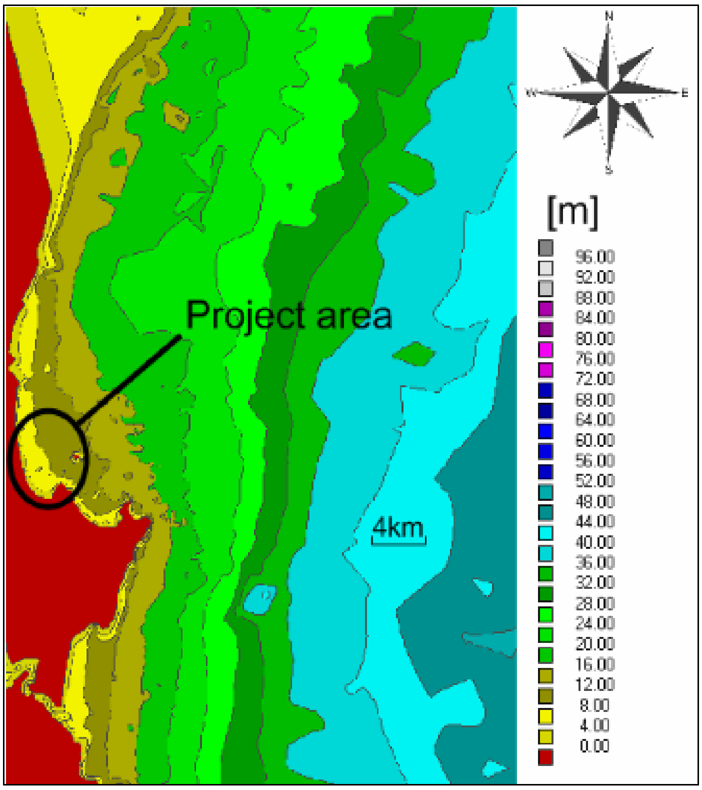


Figure I - 6 Bathymetry after interpolation with biggest grid.

The next bathymetry has been computed with a smaller grid using a higher resolution. The result is shown in Figure I - 7.

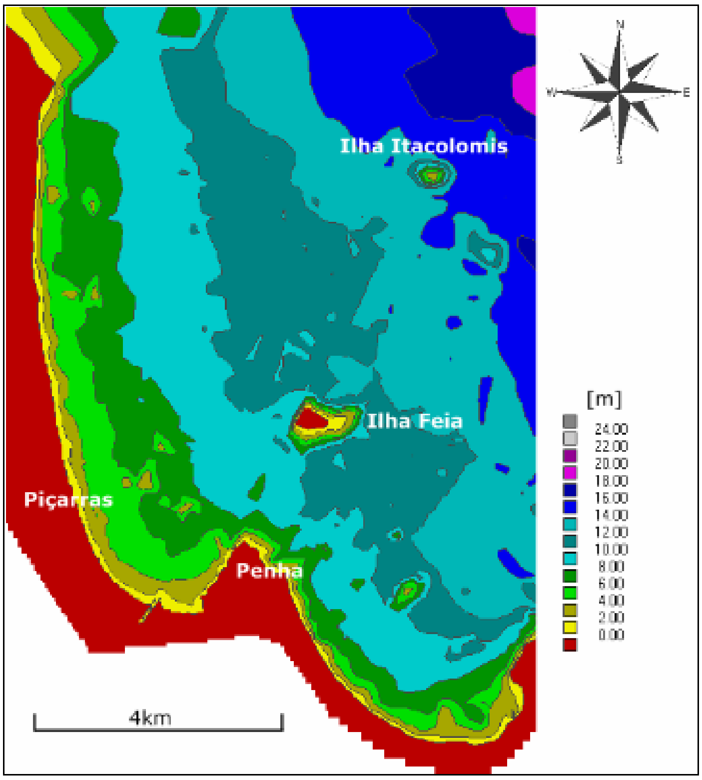


Figure I - 7 Bathymetry of Piçarras and Penha, medium grid.

The finest grid, with the highest resolution has been used to compute the area directly in front of Piçarras, see Figure I - 8. Now it becomes clearly visible that there are several shoals directly in front of the problem area.

What is also visible is the relative steep beach slope at the problem area (indicated with yellow circle) when compared to the northern beach area (indicated with black circle).

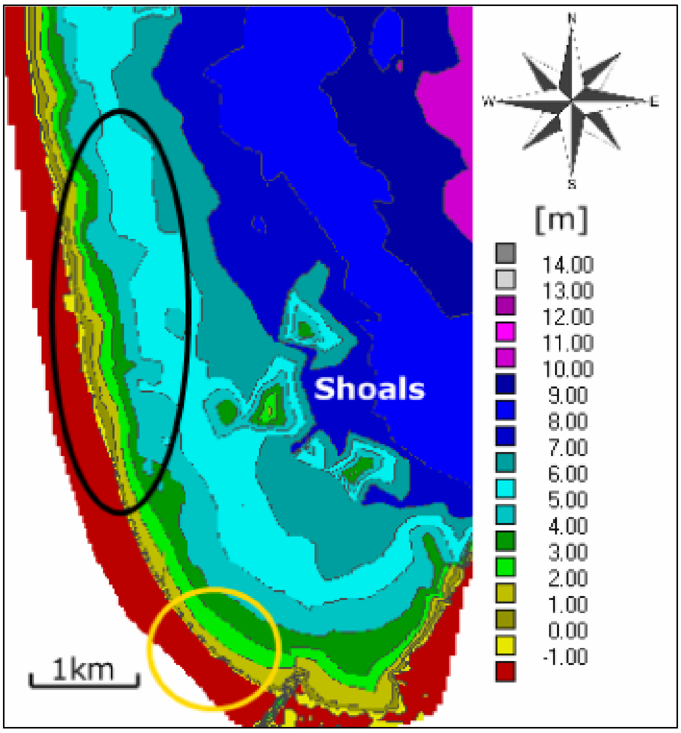


Figure I - 8 Bathymetry of Piçarras with the finest and smallest grid.

II. Hydraulic Boundary Conditions

II.1 Introduction

When dealing with a coastal engineering project such as the beach erosion at Piçarras, it is very important to have long-term, up to date and reliable data concerning waves, water levels and currents; the hydraulic boundary conditions. This appendix deals with the description of these hydraulic boundary conditions. First the prevailing offshore wave conditions will be described. Water level variations caused by tides and surges will be presented next, followed by a short description of the currents in the near shore area of Piçarras. In the different paragraphs there will be elaborations and clarifications of the choices made regarding the simplification and schematisation of the various parameters in order to be able to use them for the modelling done with Delft3D (D3D), Unibest (UB) and SMC.

II.2 Waves

Waves are of crucial importance for processes that take place in the coastal zone. Sediment transport, beach orientation and wave generated currents are greatly influenced by the angle of incidence, period and height of the incoming waves. Therefore, long-term wave measurements (preferably several years) are very important. Especially when the aim of a project is to model these processes with software packages as mentioned above. A non-representative wave climate can cause the models to be incapable of reproducing the real-life situation. When using such a model to try to make a prediction of the evolution of a coastal system, after for instance a nourishment or implementation of hydraulic structures, this can result in total nonsense. This is simply because all the input parameters, of which waves are a very important one, aren't the real life ones but a result of the analysis of a too short wave record.

II.2.1. Available wave data

A Datawell wave rider buoy deployed 35km east of the Island of Santa Catarina at a depth of approximately 80m recorded wave height, period and direction for the duration of one year (December 2001 – January 2003) [1]. These records have been analysed [1]. A summary of this analysis has been made [6], which is presented in this paragraph.

First a conventional data analysis has been performed, after which the wave regime has been characterized by the following three parameters: the significant wave height (H_s), the peak period (T_p) and the dominant mean direction (θ_p). The results are seasonal statistics, consisting of H_s histograms and bivariate distributions of θ_p versus T_p, θ_p versus H_s and T_p versus H_s, which are shown here below in Figure II - 1, Figure II - 2, Figure II - 3 and Figure II - 4.

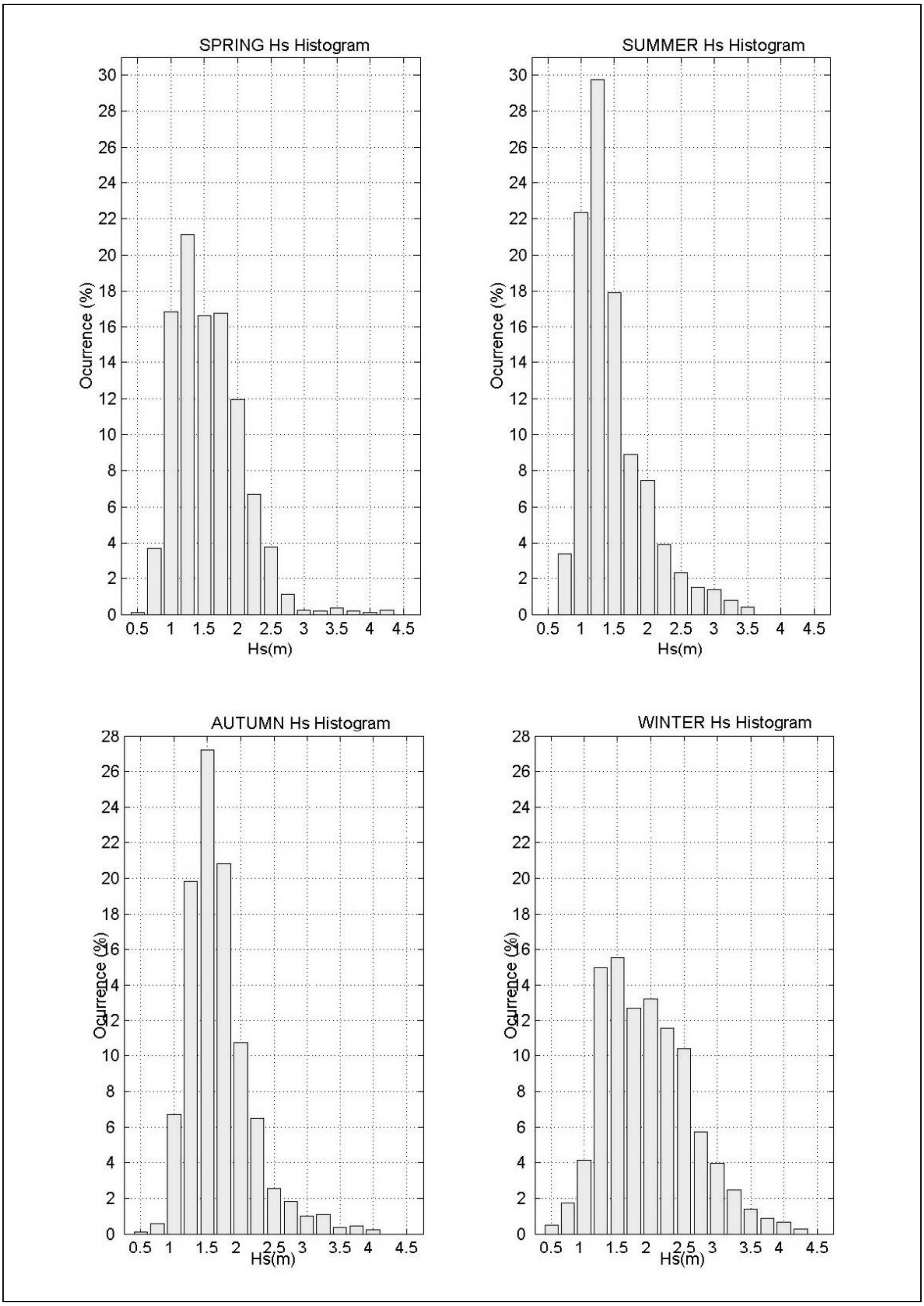


Figure II - 1 Seasonal H_s histograms [1]

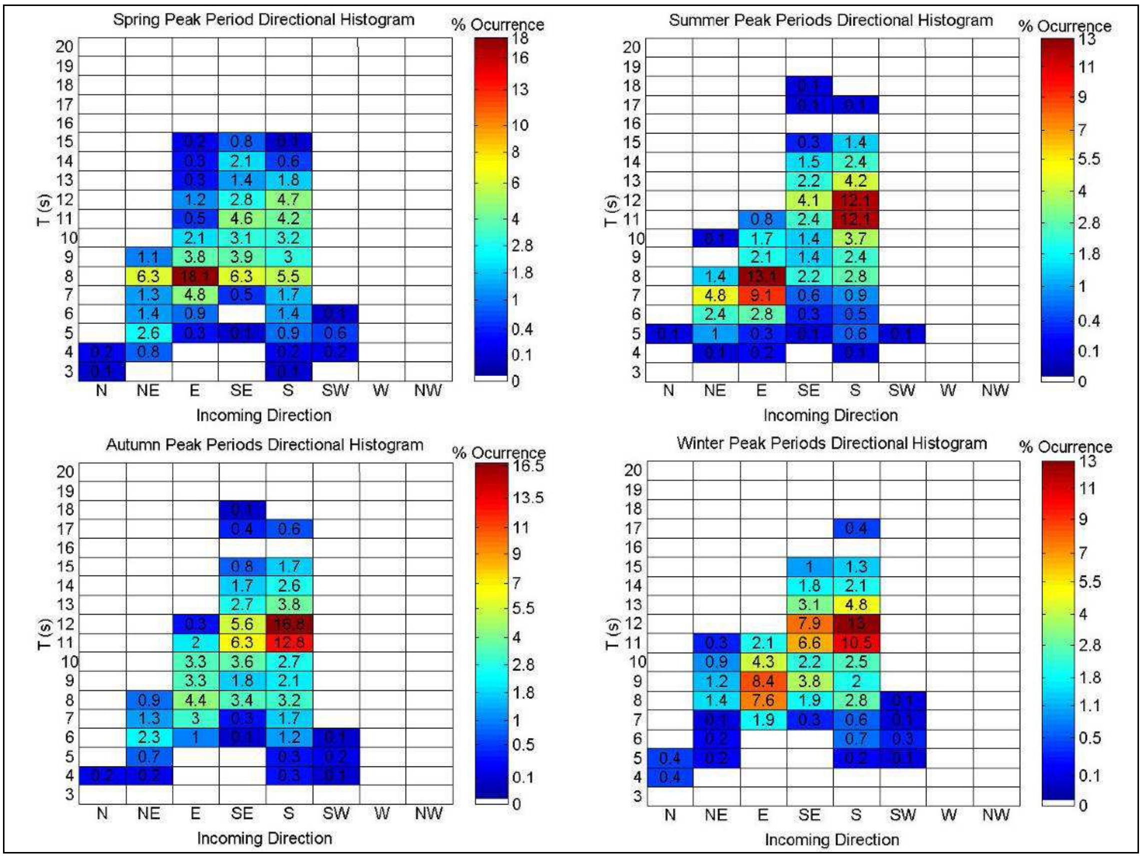


Figure II - 2 Seasonal T_p x θ_p bivariate histograms based on single-peaked spectra hypothesis [1]

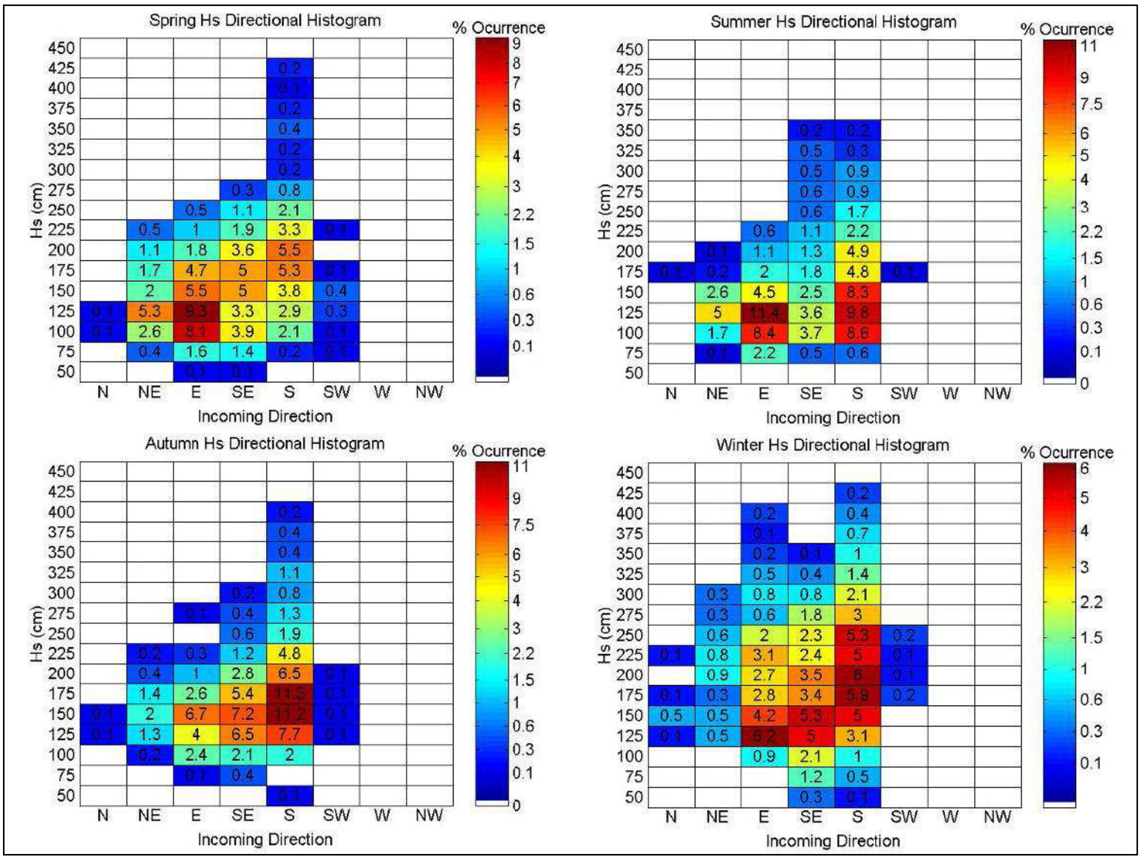


Figure II - 3 H_s x θ_p bivariate histograms based on single-peaked spectra hypothesis [1]

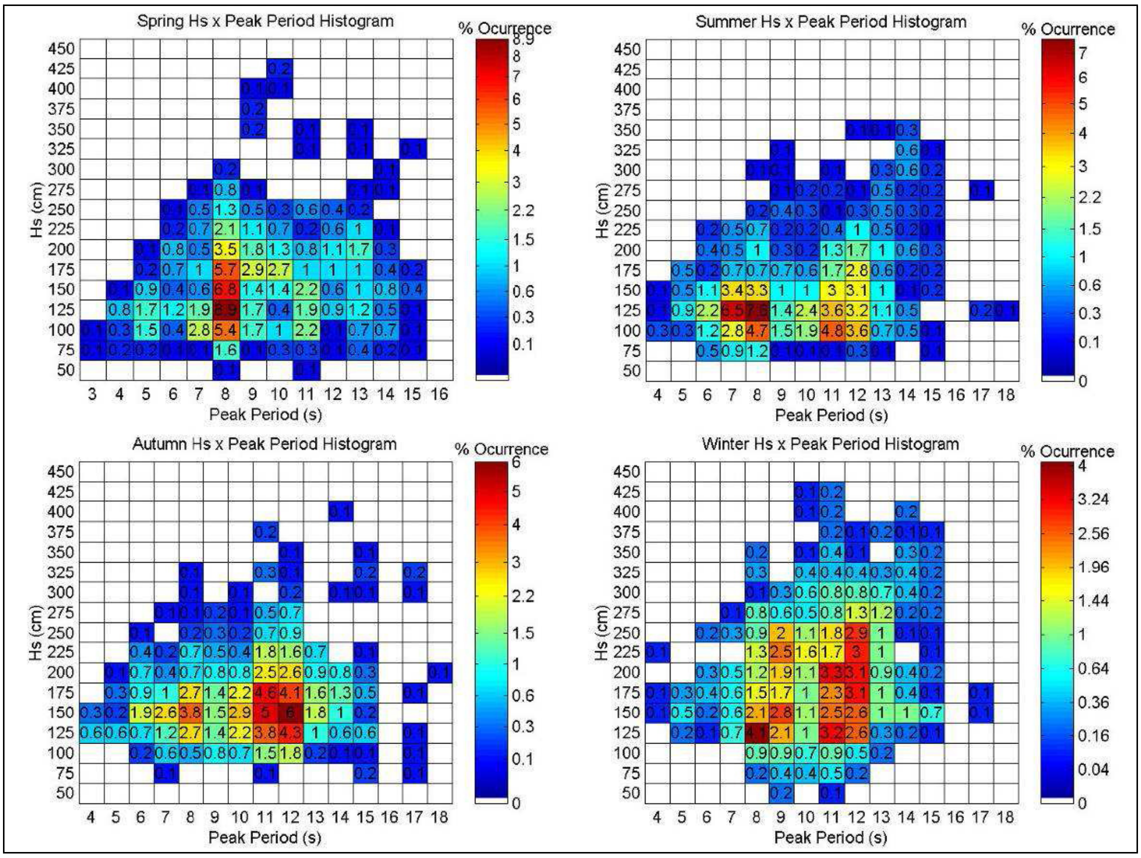


Figure II - 4 T_p x H_s bivariate histograms based on single-peaked spectra hypothesis [1]

In this single-peaked spectra hypothesis approach multimodal sea states (double or more peaked spectra) are not taken into account: every sea state is supposed to have only a single-peaked spectrum.

With a procedure to identify multimodal spectra, it was revealed that on average over 32% of the spectra are multi-peaked (2 or 3 peaks), indicating the simultaneous occurrence of sea waves and swell. These multi-peaked spectra occur mostly in the summer (43%) and least in the winter (24%). Bivariate distributions of θ_p versus T_p for all season have been recalculated, but unfortunately no new H_s data, belonging to the multimodal spectra, was available in 2007 neither now, in 2008 [6]. The analyzed data acquired from the single-peaked spectra approach has been used in a similar coastal engineering project in Santa Catarina. They determined the offshore wave climate near Santa Catarina Island. A summary of their findings is given below.

From the data analysis it follows that two main sea states are dominant, sea waves (typical periods from 4-9s) and swell (periods around 11s and more). In spring, seas (sea waves) from the east dominate over the other sea states. In summer, there is equilibrium between seas from the east and swells from the south. In autumn, swells from the south dominate, although there are scattered seas from the east and the south. In winter, swells from the south prevail over seas from the east.

Overall, seas with a peak period of 8s from the east, with a mean significant wave height of 1.25m and swells with a peak period of 12s from the south, with an increasing significant wave height from summer to winter are the main wave regimes. In order to be able to calculate average and extreme waves, the distribution of the offshore waves has been analyzed. It is not necessary to use seasonal distributions, so a yearly distribution has been created and plotted as a histogram (Figure II - 5).

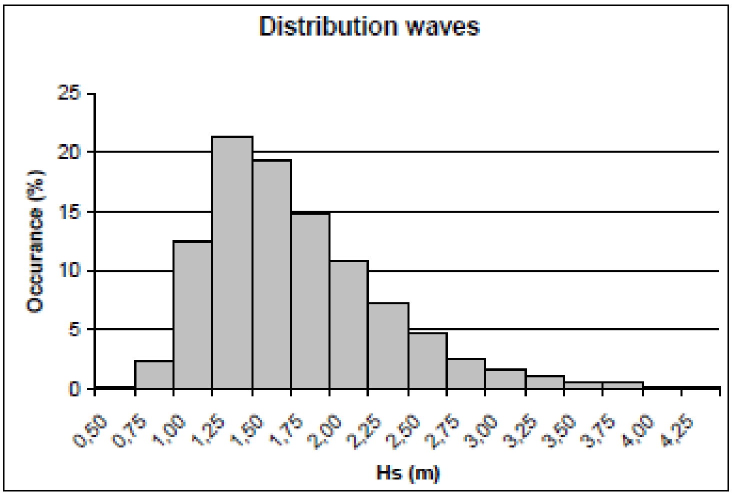


Figure II - 5 Histogram of the significant wave height December 2001-January 2003 for the Datawell buoy [6]

After fitting several candidate distributions through the data it turned out that a Gumbel-distribution had the best fit [6]. The probability function and parameters are given below:

$$f(x) = \frac{1}{\beta} e^{-\frac{x-\alpha}{\beta}} e^{-e^{-\frac{x-\alpha}{\beta}}}$$

Location parameter (α) = 1.31
Scale parameter (β) = 0.4366

II.2.2. Wave scenarios

Now that this is known, average and extreme wave conditions can be determined. With this distribution fifteen wave scenarios were formulated [6] which are listed in Table II - 1.

	Scenario	Hs (m)	Tp (s)	Direction	Occ. (%)
Average waves	1	1.25	8	NE	5.2
	2	1.25	8	E	20.5
	3	1.25	8	SE	4.0
	4	1.60	12	SE	10.5
	5	1.25	8	S	2.0
	6	1.55	12	S	21.8
	7	1.65	14	SE	2.0
	8	1.80	14	S	2.8
Extreme storm waves	9	2.00	9	E	5.0
	10	2.50	9	E	0.5
	11	3.00	9	E	0.5
	12	3.50	9	E	0.2
	13	2.00	9	NE	1.8
Extreme swell waves	14	2.50	12	SE	4.5
	15	3.00	12	E	3.5
No waves					15.2

Table II - 1 Wave scenarios for modeling

II.2.3. JICA measurements

Another source of wave data are measurements done by JICA [1]. A wave buoy in 10m water depth just offshore of Piçarras measured wave height and period but no direction. The buoy operated from December 1988 to October 1989. Table II - 2 gives the wave data.

Wave measurements Piçarras December 1988 - October 1989

wave height [m]	number of observations (2608)								
3.0-3.5				0	0	0			0
2.5-3.0		2	0	0	0	0	0		2
2.0-2.5		7	6	1	0	0	0	4	18
1.5-2.0	0	17	28	8	8	5	17	7	90
1.0-1.5	23	104	181	96	75	22	31	15	547
0.5-1.0	39	332	463	345	265	124	61	55	1684
0-0.5	0	21	46	63	88	28	18	3	267
	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	2608
	wave period [s]								

Table II - 2 Wave measurements from JICA 12/1988 – 10/1989

From Table II - 2 it can be observed that a substantial quantity of swell was present. The wave height is relatively low, with an average wave height of 1.2m. The average wave period is 8.26s. The highest measured wave height equals 2.5 to 3m but looking at the corresponding wave period this as to be a lonely wave in a short storm. Another possibility is that the buoy stopped measuring in this storm after recording these two waves. It certainly isn’t swell.

Compared to the wave measurements in front of Santa Catarina Island, the buoy in Piçarras was relatively sheltered from waves from the east-south-east to south directions. This could cause the Hs to be too low. The limited depth also causes a reduction in wave height. This makes these measurements less applicable to determine the offshore wave climate than the observations in front of Santa Catarina as described above. Therefore the results of Araujo et al (2003) and the Ingleses group will be used in this report.

One might wonder why the authors of this report didn't analyse the data as presented by Araujo et al. (2003) again, since waves are of vital importance for this project. Keeping in mind the relatively short amount of time available for this project and the very short wave records at hand, it was decided not to analyse this data again. For mainly a longer wave record would influence the formulated wave scenarios, rather than analysing the same data again.

II.3 Further schematisation of wave scenarios

The wave scenarios have been further schematised by direction. The idea to do this came from the hypothesis that a beach will try to orientate itself perpendicular to the incoming wave energy to dissipate this energy in such a way that no alongshore sediment transport gradients occur. Since there are only four directions (NE, E, SE, S) reduction to four scenarios and their respective impact on the beach could give more insight into what is happening at Piçarras. Even finding an annual mean energy direction (and corresponding wave height and period) could give more insight into the orientation of the beach orientation desired by nature.

First the total energy per direction was calculated by using the energy flux in deep water through a vertical plane from the sea bottom until the water level with unity width. In this way it is possible to account for the wave height as well as the wave period:

$$P = E \times c_g = \frac{1}{8}\rho g H^2 \times \frac{gT}{4\pi} = \frac{\rho g^2 H^2 T}{32\pi}$$

This is summed per scenario which results in a total energy per direction.
The second step is to calculate the average period per direction in the following way:

$$\%_1 T_1 + ... + \%_n T_n = T_{mean}$$

With this period the mean wave height per direction is determined:

$$H_s = \sqrt{\frac{32\pi P_{tot}}{\rho g^2 T_{mean}}}$$

Table II - 3 shows the results of the schematization.

Direction	H [m]	T [s]	%	cum [-]	Energyflux P [W/m]		Tmean [s]	Hs [m]
NE	1,25	8,00	5,20	0,74	9111,24			
	2,00	9,00	1,80	0,26	9083,20			
		Total	**7,00**	**1,00**	**18194,44**	**P-total-NE**	**8,26**	**1,50**
E	1,25	8,00	20,50	0,68	8325,67			
	2,00	9,00	5,00	0,17	5848,27			
	2,50	9,00	0,50	0,02	913,79			
	3,00	9,00	0,50	0,02	1315,86			
	3,50	9,00	0,20	0,01	716,41			
	3,00	12,00	3,50	0,12	12281,37			
		Total	**30,20**	**1,00**	**29401,38**	**P-total-E**	**8,67**	**1,86**
SE	1,25	8,00	4,00	0,19	2336,21			
	1,60	12,00	10,50	0,50	15071,39			
	1,65	14,00	2,00	0,10	3561,79			
	2,50	12,00	4,50	0,21	15769,45			
		Total	**21,00**	**1,00**	**36738,84**	**P-total-SE**	**11,43**	**1,81**
S	1,25	8,00	2,00	0,08	922,19			
	1,55	12,00	21,80	0,82	23183,63			
	1,80	14,00	2,80	0,11	4685,02			
		Total	**26,60**	**1,00**	**28790,85**	**P-total-S**	**11,91**	**1,57**
No waves			15,20		0,00		0,00	0,00
Total scenarios			**100,00**					

Table II - 3 Calculation of annual mean scenarios per direction

To give a clearer overview Table II - 4 (left) has been added.

Results	Tmean [s]	Hs [m]	Occ [%]
NE	8,26	1,50	7,00
E	8,67	1,86	30,20
SE	11,43	1,81	21,00
S	11,91	1,57	26,60
No waves			15,20
Total			100,00

Table II - 4 Results of the Hs, Tm for modeling.

II.4 Water levels

The nautical maps use DHN as Chart Datum which lies 0.398m below the chart datum for land surveys (IBGE). The water level variation at Piçarras is caused by a semi diurnal astronomical tide and the occurrence of storm surges.

II.4.1. Tides

JICA has measured the tidal variation in the bay of Piçarras in 1990.

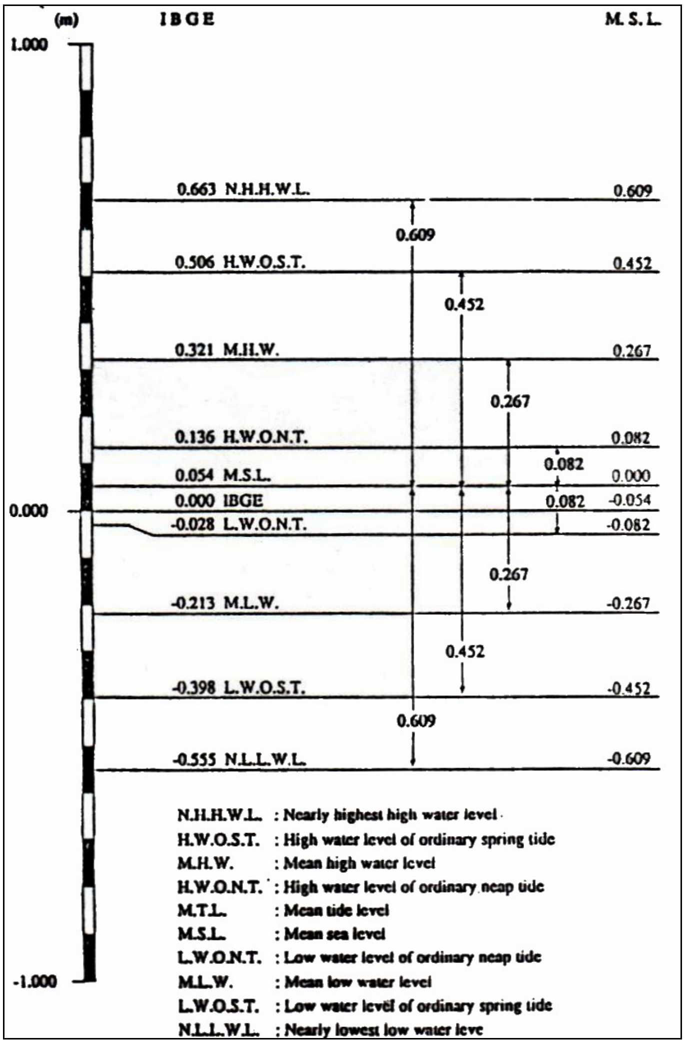


Figure II - 6 Water level variation at Piçarras as a result of the tide. [12]

Figure II - 6 shows the different water levels caused by the tide. Mean sea level lies 0.054m above IBGE. The average tidal range is about 0.6m. At springtide this can be 0.9m.

II.4.2. Storm surges

UNIVALI [26] has recorded the water level variation at Piçarras from the 6th of October 1995 to 31th of December 1996, with the purpose of identifying the storm surges. By subtracting the astronomical components from the time series of the measurements, only the meteorological influence on the water level (surges) remained. This showed a maximum set-up in water level of 0.75m. The surges are not only the result of near shore storms, but also of south to easterly storms far out on the ocean.

In several (near shore) storm events, such as 1983 and 1985 there must have been considerable storm surge levels as the picture in Figure II - 7 suggests.

Figure II - 7 Extreme high water level during storm in 1985 [12]

Unfortunately there are no recordings of such extreme storm events. From the picture an estimation can be made of the storm surge level. The street level is circa 2.3m above IBGE [34]. The water level is ca. 0.75m below the street level. This level corresponds to circa 1.0m above ordinary springtide. This would suggest a storm surge level of 1.0m. The pictures combined with the information from UNIVALI means that to account for an extra set-up in water level an increase of 1.0m seems reasonable.

The surge level is relevant for the determination of the height of the beach. If there is still a substantial amount of beach above the water level during a storm, this sand can act as a buffer against storm erosion. The sand is then only redistributed over the profile and can be transported back to the beach in calmer conditions. If there is no buffer, the water and waves will wash over the entire beach and boulevard, causing more damage to the urban area. This is also negative for the perception of safety against the ocean for the inhabitants of Piçarras.

II.4.3. Currents

Available current measurement data were collected with a current meter installed [20][21] at three distinct locations near Penha's Headland, Ilha Feia and at approximately the 10m depth contour south of Ilha Feia and east of Penha's Headland.

Measurements were carried out at the months December 1988 and February 1989 for a period of approximately 15 days with continuous observations.
Velocity of tidal currents proved to be low; lower than 30 cm/s at 2 meters from the bottom, with direction SSE.

INPH, the National Institute for Hydrographical Research, has also carried out current measurements from 21/09/1985 till 02/11/1985, with floaters deposited beyond the breaking zone. The results indicate that:
Observed currents were basically directed to the north (59.5%) with most frequent velocities between 0.10 and 0.24 m/s and east (38.2%) with an average velocity of 0.19 m/s.

It needs to be pointed out that the measurements using floaters have also suffered the influence of wind and waves.

Overall it can be concluded that current velocities are very small, with a maximum of 0.3m/s. Because of this, no currents will be taken into account for this project.

III. Modelling Wave Propagation

III.1 Introduction

With the hydraulic boundary conditions, as stated in Appendix II, the nearshore wave conditions can be modelled. In headland bay beaches diffraction and refraction play a very big role (Figure III - 1). Diffraction is the turning of waves towards areas with lower amplitudes due to amplitude changes along the wave crest. As a result the wave height behind the geometric shadow line (starting from the headland or island in the bay) diminishes.

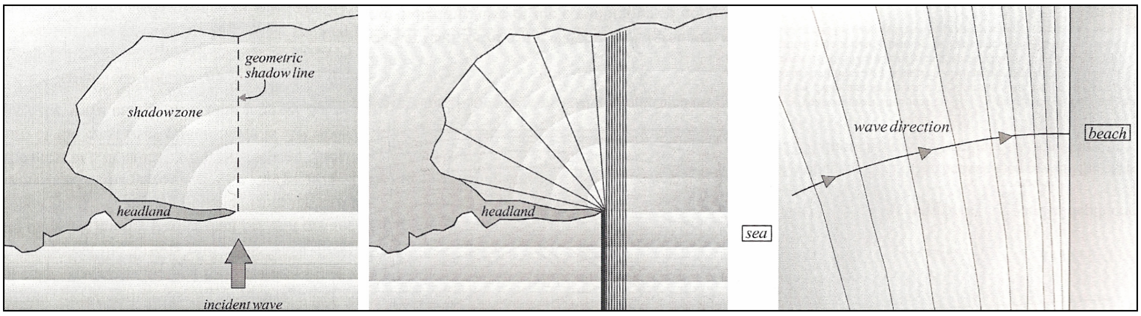


Figure III - 1 Headland bay beaches, diffraction(left, middle) and refraction(right). [18]

Refraction is the turning of waves towards shallower water due to depth or current induced changes of the phase speed along the wave crest. Depending on the direction of the offshore waves the headlands will cause a shadow zone on the lee side. This also holds for islands and other obstacles in the waves' path. The half-moon or comma shape of the headland bay beaches cause the depth contours to be curved as well. When a wave train approaches this near shore area the waves will refract stronger where the depth contours are curved stronger, and less where the depth contours are straighter. This also causes spreading of energy in the rounder part of the bay, resulting in locally calmer conditions. In real life, depth contours are never straight and parallel. Shallow, rocky outcrops, gullies or river mouths cause irregularities in the near shore bathymetry, influencing wave propagation, triggering secondary flow effects or wave(de)focusing. This appendix describes how the wave propagation model is made, which choices have been made concerning the processes involved and the interpretation of the output. It will have a highly describing character, which will show the process of modelling itself and the changes in approach to gain more insight in specific aspects of this project.

III.2 Which software and why?

Before setting off to Brazil a decision had to be made which software would be used for the project. To be more precise software to model wave propagation (including diffraction and refraction), sediment transport and shoreline changes was required. Since there was no experience with any program, it was decided that SWAN, Unibest CL+ (UB) and SMC would be used. With SWAN deep water wave conditions could be modelled to near shore wave conditions which would serve as input for UB. UB would then be used to evaluate shoreline changes, thus erosion and accretion areas, see Appendix VI.

SMC is a software package where wave propagation is modelled and where wave-induced currents as well as erosion and accretion areas are computed, see Appendix VII. So it could serve as a comparison with the UB output.

Since D3D has a stand-alone wave module, with a user friendly GUI, this module has been chosen for the wave propagation instead of the raw SWAN. In Brazil an attempt has been made to use D3D-wave coupled with D3D-flow and D3D-mor, to set up a model that would eliminate manual (simplified) transfer of output from one program (SWAN) as input for the other program (UB), including tides and secondary flow effects which couldn't be modelled with SMC. As it turned out, this was well beyond the scope of this project. So it was decided, in agreement with Prof. Klein, to use only the wave module of D3D in combination with UB. SMC will still serve as a comparison for the UB output. It is also very useful to simulate erosion during storm events.

III.3 Grids and bathymetry

To be able to compute anything or even to generate a digital depth from the given bathymetric sample points, a grid is needed. There are a few things to keep in mind when making a grid.

A grid is composed of grid cells. These grid cells are to be given a dimension in both x- and y-direction. How big these cells should be, depends on the processes to be modelled. For instance in deep water, where waves don't feel the bottom, the cell size should be in the order of the wave length. Towards shallower areas where processes like refraction and diffraction start playing a role, a smaller cell size is needed, for more detailed modelling of the propagation. And in the breaker zone, that can vary from 10m to 50m, a cell size in the order of 10m x 10m should be chosen. This becomes even more relevant when flow characteristics and sediment transport will be modelled.

The second point of attention is the boundaries of the grid. These should be chosen far away from the area of interest to make sure that non-physical behaviour of the model doesn't reach the area of interest. The seaward boundaries should be chosen in similar depth as where the wave measurements have been obtained to get a more realistic model. Another fact is the typical geography of the coast of Santa Catarina. Swell from the south is by refraction directed to this SSE facing coast, providing a shadow zone for the more northern laying project area. This will cause the scenarios from the south to be slightly overestimated.

In order to facilitate these requirements, three grids have been generated [38]. To speed up computations and decrease the difference in cell size between the overlapping grids, the grids have varying cell size itself as well.

First an overview of a part of the Santa Catarina coastline (visualized with sample points) is given in Figure III - 2. The biggest grid (left), medium grid (middle) and smallest grid (right) are the red areas in Figure III - 2. These look like solid planes, but consist of numerous lines in x and y direction.

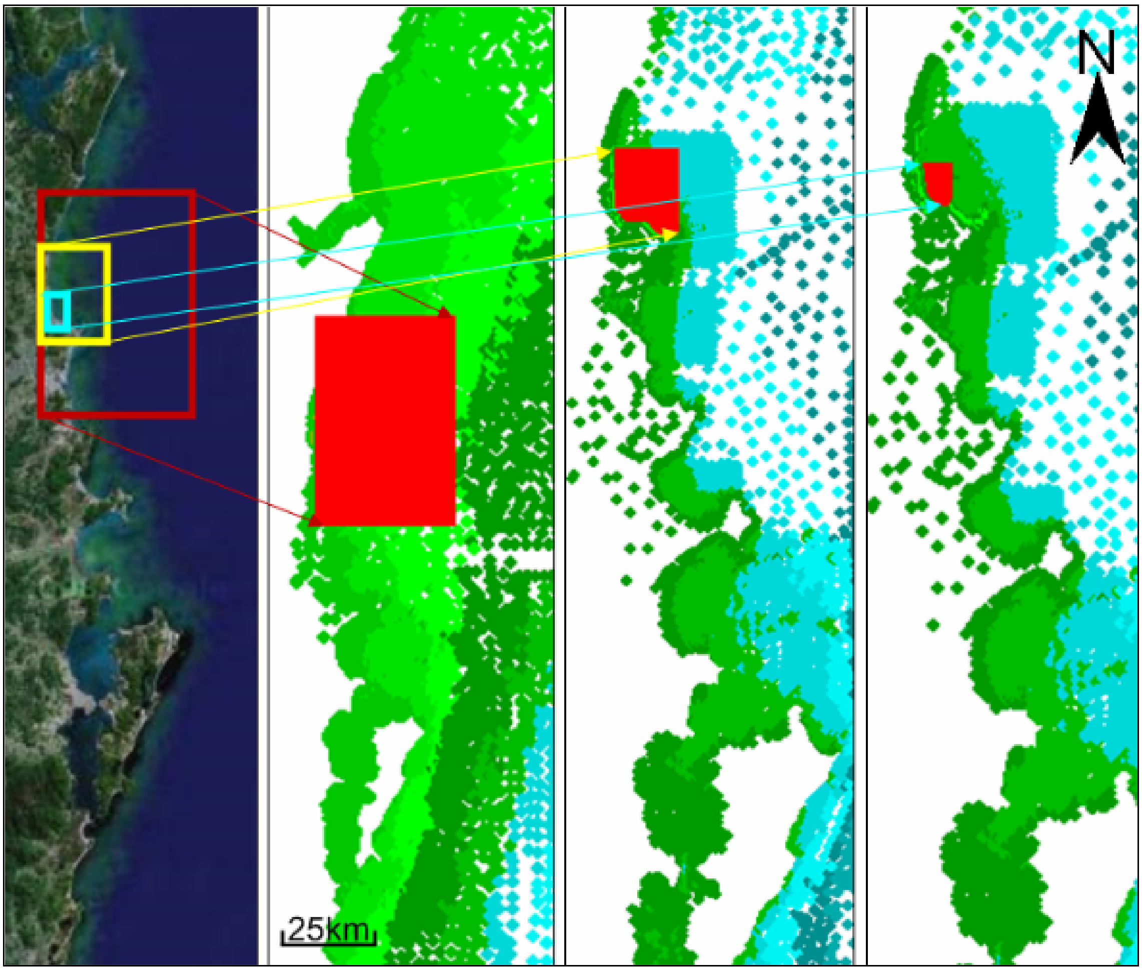


Figure III - 2 Overview of the Santa Catarina coast with three different grids used for modelling.

The biggest grid has on the eastern side cell sizes of approximately 250mx250m, gradually reducing to 100mx100m towards the coast. This grid (Figure III - 3) mainly serves to transform the offshore waves to the near shore area.

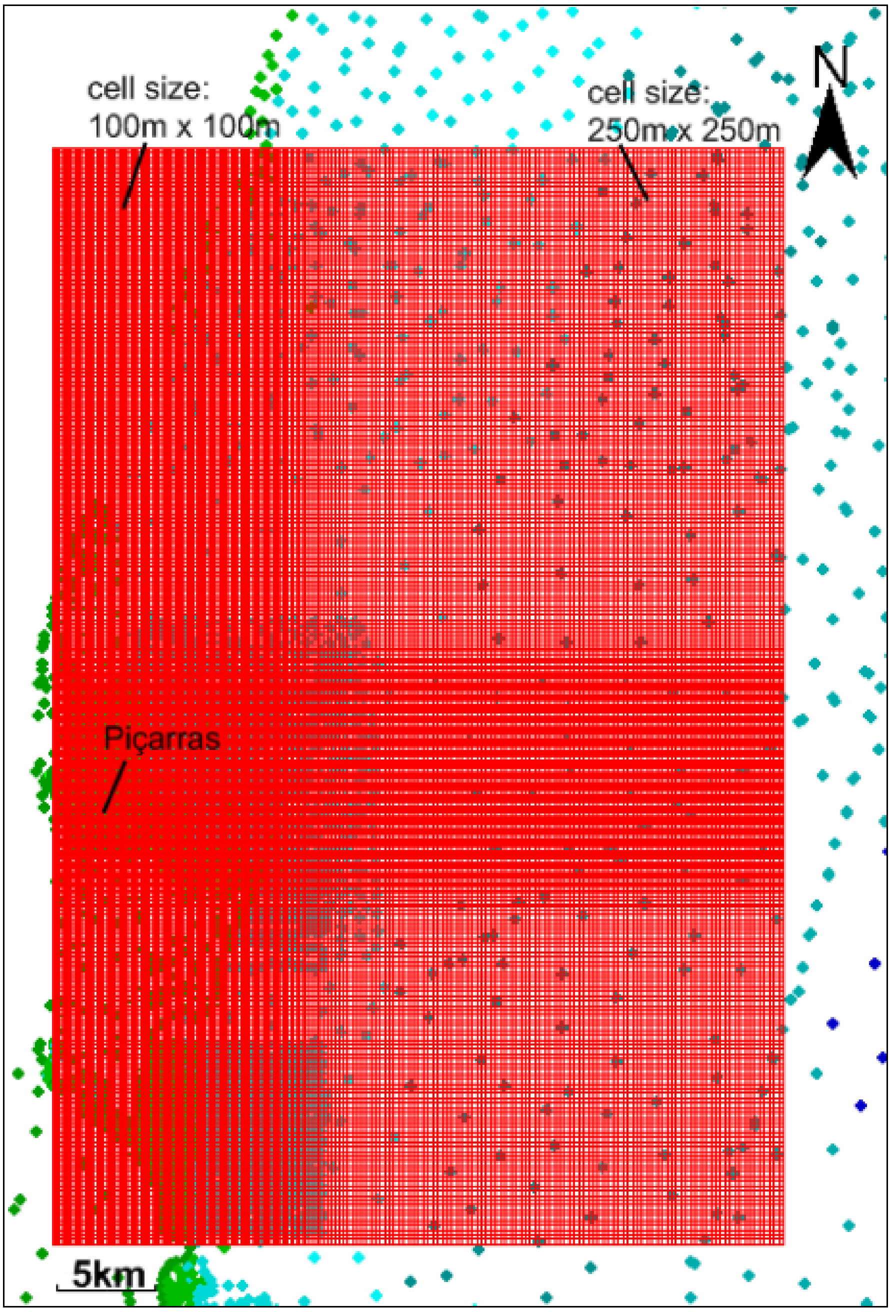


Figure III - 3 Biggest, coarsest grid used for modelling

Around the islands and shallow parts in front of the headland of Penha a more detailed grid is required in order to calculate wave transformation. Therefore a grid is generated with boundaries well inside the biggest grid, but encompassing the islands and shallow parts. The jump between the cell size of this second grid with respect to the underlying bigger grid, should be (on the borders) as small as possible, to have better computational results. This second grid (Figure III - 4) has cell sizes in the order of 100mx100m on the eastern boundary, decreasing to 30mx30m in front of the breaker zone.

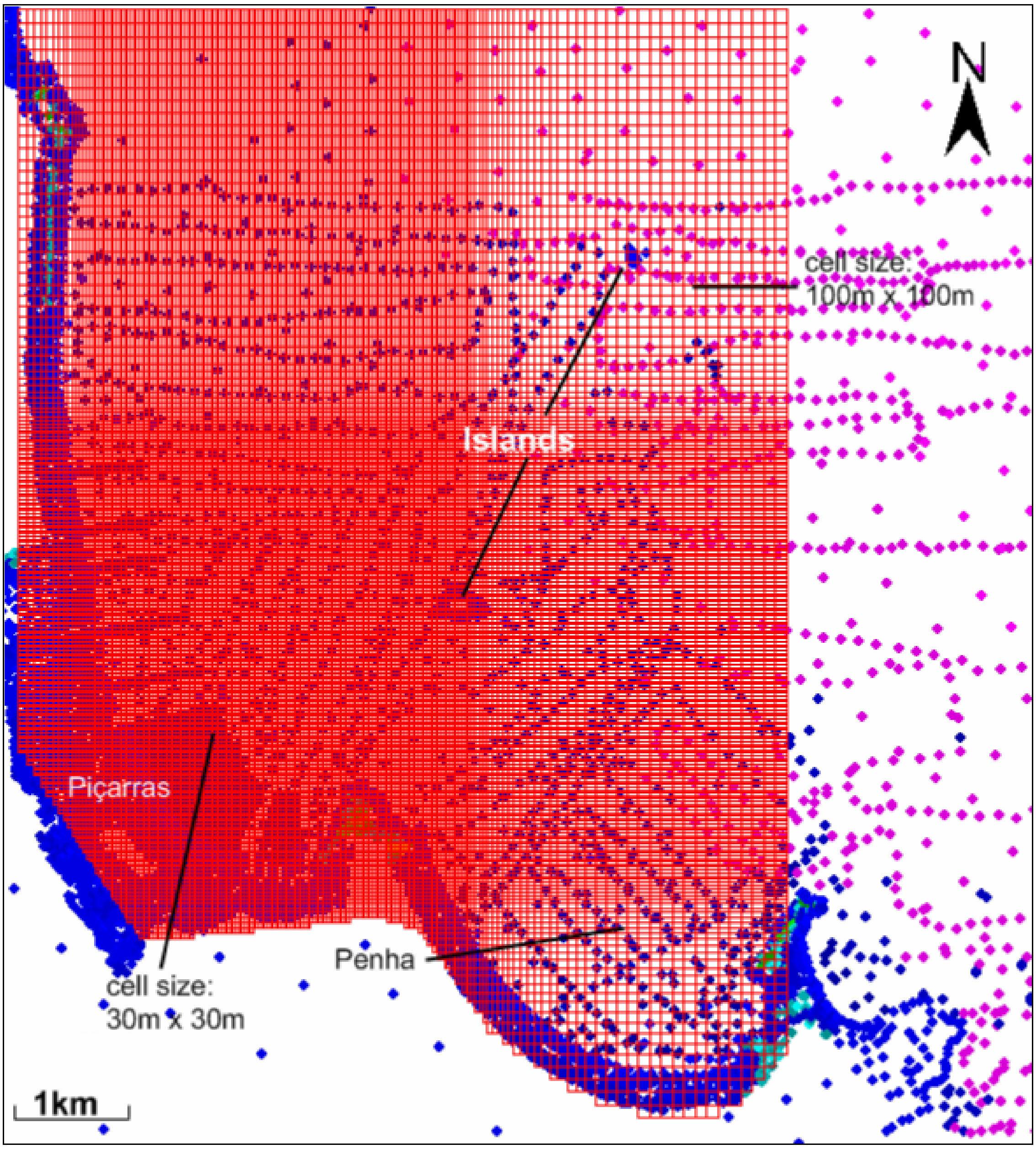


Figure III - 4 Medium grid used for modelling.

For the third grid (Figure III - 5), the same requirements hold. The area covered is even smaller, just encompassing Alegre beach and the beach of Piçarras itself until ca. 4500m north of the jetty. To be able to use this grid for flow calculations as well, the cell size is in the order of 30mx30m with the finest cells being 15mx15m.

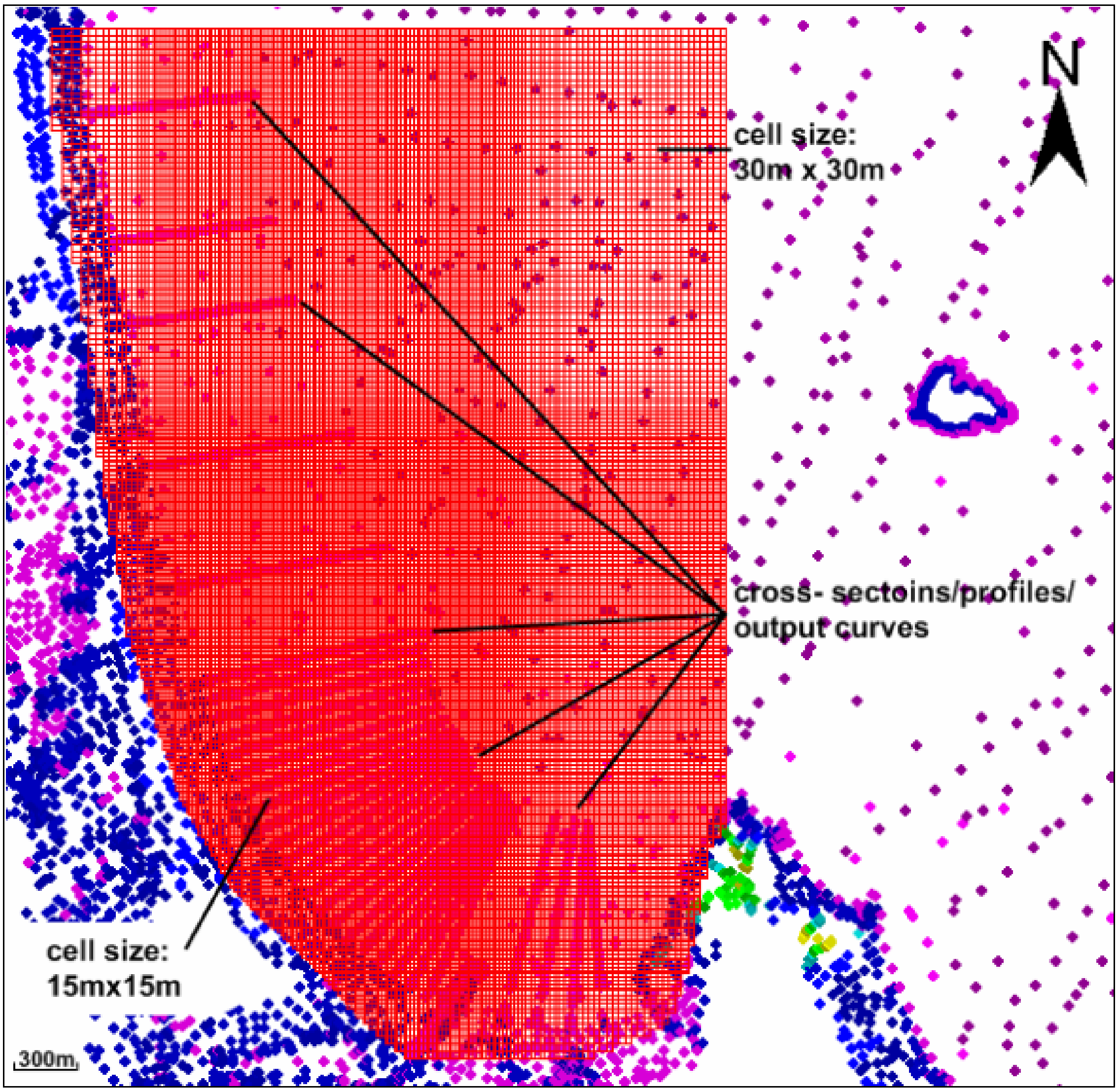


Figure III - 5 Smallest and finest grid used for modelling.

In this figure the 26 cross sections (Piçarras) and 4 cross section for Alegre are also distinguishable.

III.3.1. Generation of a grid

With the RGFGRID-module of D3D, generating a grid can be done visually [38]. It is a process of trial and error until a satisfying grid has been generated. Starting off with a rectangular grid with even cell sizes is the easiest thing to do. By locally refining and de-refining certain rows and columns one can obtain a better resolution where needed. The transition in cell sizes within a grid should be smooth. This smoothing step should be no bigger than 0.2. By repeating the process of refining and smoothing a so called cross-grid is obtained. This is also visible in the grids shown in the previous paragraph (Figure III - 3/Figure III - 4/Figure III - 5).

When the right resolution is obtained, a check on the orthogonality has to be done. A built-in function takes care of this when margins are set by the user. The last step is to cut away cells that are irrelevant, for instance ones that cover inland areas.

III.3.2. Generation of a bathymetry

For each different grid a separate bathymetric file has to be made, so that with a higher resolution grid, more detailed depths and thereby more detailed calculations of wave propagation can be made, see Appendix I. In this paragraph is explained quickly how this can be done.

Making a bathymetry with the RGFGRID/QUICKIN-module of D3D is straight forward [38]. First a grid has to be loaded in the QUICKIN-module. Next, a file with sample points (x-, y-, z-coordinates) is loaded and visualized. With the built-in triangular interpolation all the grid points are assigned a depth value. The triangular interpolation is chosen because this method is better than the cell-averaging method when the resolution of the sample points is equal to or smaller than the resolution of the grid. Now a digital bottom has been generated, a so called depth. The depth is visualized straight after computation. There is a possibility that large depth gradients occur. Therefore smoothing of these gradients is the next step to be done. This function is also built into QUICKIN. The last step is to take care of empty grid points (grid points that haven't been assigned a value). This is done by internal diffusion. Grid points that don't have a depth value (especially on the border) are assigned a depth of the neighbouring grid points.

III.4 Modelling goals

The goal of the D3D modelling is to transform offshore wave conditions to near shore wave conditions. The output will, hopefully, give an idea about the diffraction and refraction processes in the bay. The most important goal is to generate input for UB (H_s, T_p and direction), in order to model coastline changes. For the manual calculation of alongshore transport, wave breaker heights and angles are needed. UB also needs a closure depth as input. The closure depth is a measure for the active depth in a beach profile. Wave height, -period and water depth form the three parameters that determine the closure depth. The closure depth is also needed to make a nourishment design.

III.5 Model approach

To generate the required output, 26 cross sections (output curves in D3D) have been drawn through the area of interest. Figure III - 6 shows the cross-sections. The cross-sections are perpendicular to the coast with a known orientation with respect to the north. At the seaward end of every cross-section output tables generated by D3D, list amongst others the wave height, wave period and wave direction. These parameters will be the input for UB.

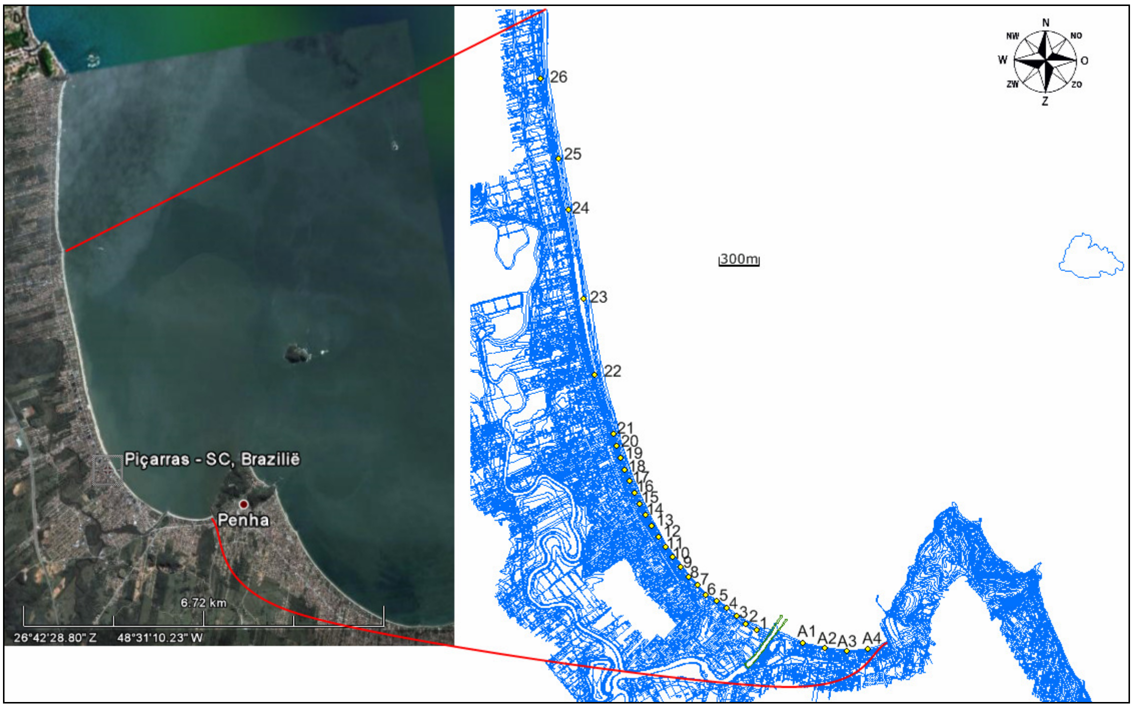


Figure III - 6 Locations of the 26 cross-sections along Piçarras and 4 along Alegre beach. [16][34]

Along these cross-sections, on regular intervals of circa 4.25m, the wave height H_s, wave period T_p, wave direction, directional spreading, dissipation and wave length are registered and given as output in so called 'output curve tables'. Moving towards the coast, these parameters will vary. Of course, these cross-sections are no wave rays. Direct plotting of the parameters along the cross-sections will in most cases not show the transformation of a single wave. But near the breaker zone it is assumed that the wave ray and cross-section will be almost parallel. This enables the evaluation of the wave transformation in this area. Processes like shoaling and increasing dissipation will indicate a breaking wave. The corresponding angle with respect to the north can be read at the same location in the output table. Since the angle of the cross-section with respect to the north is known, the approximate breaker angle of the waves can be determined.

The closure depth is treated in a separate appendix IV. Again, the 'output curves' form the basis for the calculations.

III.6 Model parameters

III.6.1. Physical parameters

Constants to be determined before running the model:

Gravitation	: 9.81m/s^2
Water density	: 1025kg/m^3
North w.r.t. x-axis	: 90°
Minimum depth for computation	: 0.05m
Convention	: nautical (such that waves from the North have direction 0º)
Wave set up	: none (chosen after no convergence was obtained in the model runs)
Forces	: Wave energy dissipation rate

Wind
Type of wind :uniform 0m/s (chosen because purely wave propagation should be modelled without sink or source terms for wind)

Processes
depth induced breaking with : α=1, γ=1
bottom friction : JONSWAP type coefficient 0.067
diffraction : smoothing coefficient 0.2
: 5 smoothing steps

Various
Wind growth : de-activated
White-capping : de-activated
Quadruplets : de-activated

Wave propagation in spectral space
Refraction : activated
Frequency shift : activated

III.6.2. Numerical parameters

Spectral space
Directional space CDD : 0.5
Spectral space CSS : 0.5

Accuracy criteria (to terminate the iterative computations)
Relative change H_s-T_{m01} : 0.2
Percentage of wet grid points : 98%

Relative change with respect to mean value
H_s : 0.02
T_{m01} : 0.02
Maximum number of iterations : 15

III.6.3. Output curves

The output curves are numbered 1 through 30. Table III - 1 shows which curve is along which cross-section. P stands for Piçarras and A for Alegre.

Output curve	Cross section	Output curve	Cross section	Output curve	Cross section
#1	P1	#11	P11	#21	P21
#2	P2	#12	P12	#22	P22
#3	P3	#13	P13	#23	P23
#4	P4	#14	P14	#24	P24
#5	P5	#15	P15	#25	P25
#6	P6	#16	P16	#26	P26
#7	P7	#17	P17	#27	A1
#8	P8	#18	P18	#28	A2
#9	P9	#19	P19	#29	A3
#10	P10	#20	P20	#30	A4

Table III - 1 Output curves and profiles/cross-sections

III.6.4. Output parameters

The three grids have to generate output. These files can be further processed in any processing tool. In this report the QUICKPLOT-module will be used to visualize the results. When more precise values at predefined locations are needed the coordinates can be loaded, for which D3D gives an output table.

III.7 First modelling attempt

The first modelling attempt was to run 15 successive scenarios. The boundary conditions are as stated in Table III - 2. The generated output however was such a lot that comparison between the 15 plots and several parameters became difficult. Therefore it was decided not to use either of these scenarios here in this report.

	Scenario	Hs (m)	Tp (s)	Direction	Occ. (%)
Average waves	1	1.25	8	NE	5.2
	2	1.25	8	E	20.5
	3	1.25	8	SE	4.0
	4	1.60	12	SE	10.5
	5	1.25	8	S	2.0
	6	1.55	12	S	21.8
	7	1.65	14	SE	2.0
	8	1.80	14	S	2.8
Extreme storm waves	9	2.00	9	E	5.0
	10	2.50	9	E	0.5
	11	3.00	9	E	0.5
	12	3.50	9	E	0.2
	13	2.00	9	NE	1.8
Extreme swell waves	14	2.50	12	SE	4.5
	15	3.00	12	E	3.5
No waves					15.2

Table III - 2 Wave scenarios

III.8 Second modelling attempt

Since the 15 wave scenarios didn't provide a good basis to get insight into the refraction and diffraction processes in the bay another approach was needed.

Sediment transport and the net shoreline changes are a result of incoming waves stirring up sediment, initiating currents and thereby carrying the sediment to other places alongshore. Whenever there are gradients in the alongshore transport erosion or accretion will occur. This changes the orientation of the coast with respect to the incoming waves. This process will terminate when the waves are coming in perpendicular to the coast. Another way of looking at this process is in terms of energy. The beach will orientate itself in such a way that it dissipates the energy of the incoming waves without having to transport sediment. In other words it will orientate itself perpendicular to the direction of the average incoming energy.

Since there are only four different directions, the idea was to find an average annual wave height and period per direction. How this has been done is described in Appendix II.

Now only four scenarios had to be run with the model. This provided a better basis for comparison of wave propagation from different directions as well as their respective impact on sediment transport. The latter through analyzing the initiated alongshore transport over 26 cross sections. This will be done later on in this appendix.

III.9 Output

To begin, an overview will be presented (Figure III - 7) of the significant wave height and mean direction per scenario for the biggest grid. Notice the legend on the right side of every figure with the significant wave height in meters.

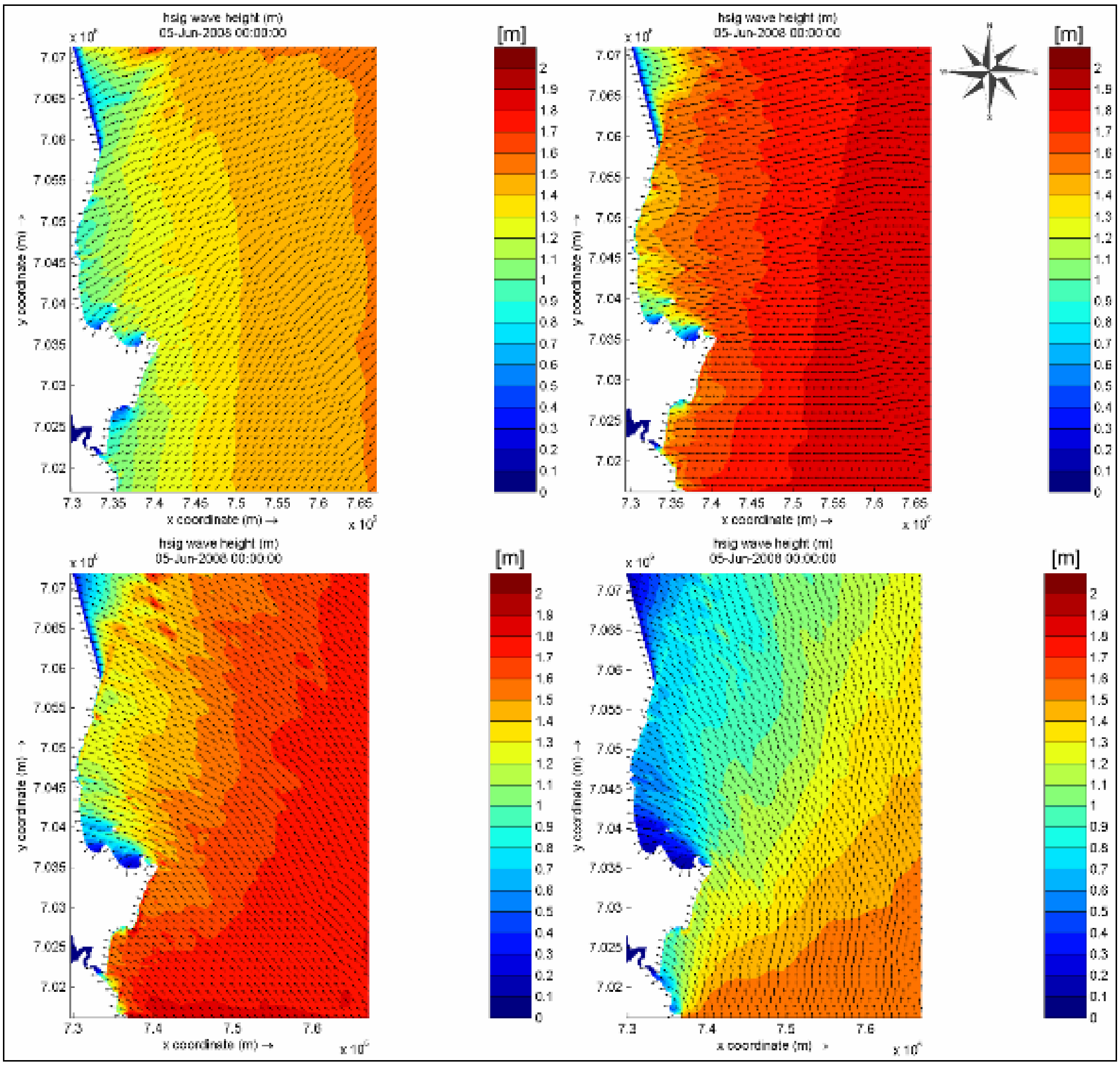


Figure III - 7 Biggest grid. H_s and propagation direction for 4 scenarios: top left NE, top right E, left SE, right S.

In all of the figures it is clear to see that the headlands cause a shadow zone, being more evident when waves are coming from more southern direction. The second thing to be noticed is the decrease in wave height from deep water towards the near shore. This is mainly caused by bottom friction and in case of the south scenario by refraction towards the southern headlands before reaching the near shore area of Piçarras.

Another remarkable observation is that the angle of incidence of the waves that reach Piçarras does not differ a lot, while the offshore wave angle differs more than 90º. This will be further examined with the more detailed grids.

The grid that is one step finer, covers the near shore area. For the four different scenarios, again the wave height and mean direction is shown in Figure III - 8.

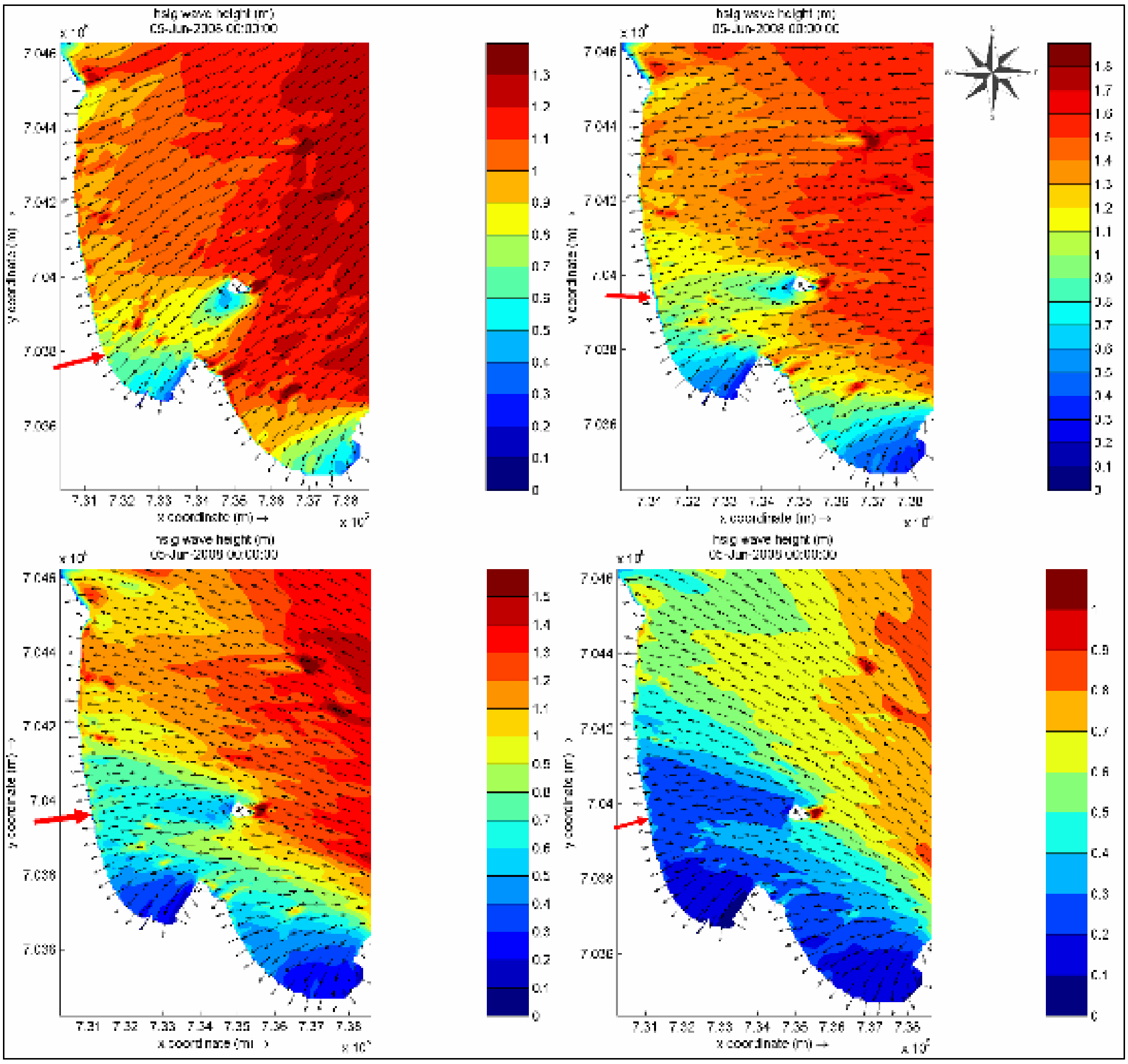


Figure III - 8 Medium grid. H_s and propagation direction for 4 scenarios: top left NE, top right E, left SE, right S.

For all four scenarios the wave heights grow from the southern end of the bay towards the northern end. Ilha Feia causes in all cases a considerable shadow zone. It also causes some serious diffraction, as is indicated by the arrows behind the island. When the waves are coming from the east to south-east Ilha Feia blocks a lot of energy. The direction of the waves that pass the island changes in a way that they cause some wave focusing near the 7039500 y-coordinate (indicated with red arrows). These more detailed grids also show that refraction plays a major role in the bay.

For the south-east and south scenario the wave direction in (the southern part of) the bay is nearly identical, though the wave height is considerably smaller for the latter.

Furthermore, several places show shoaling and some wave breaking between the island and the beach. These shoals also influence the direction of the waves causing focusing around the 7038000 y-coordinate.

The last grids, covering a smaller area with greater detail, confirm the remarks made earlier in this paragraph. Figure III - 9 shows considerable shoaling at three places marked with arrows. This is caused by shallow parts in the bathymetry which also influence the direction of the incoming waves. The features could trigger wave focussing (places at the beach with concentrated wave attack).

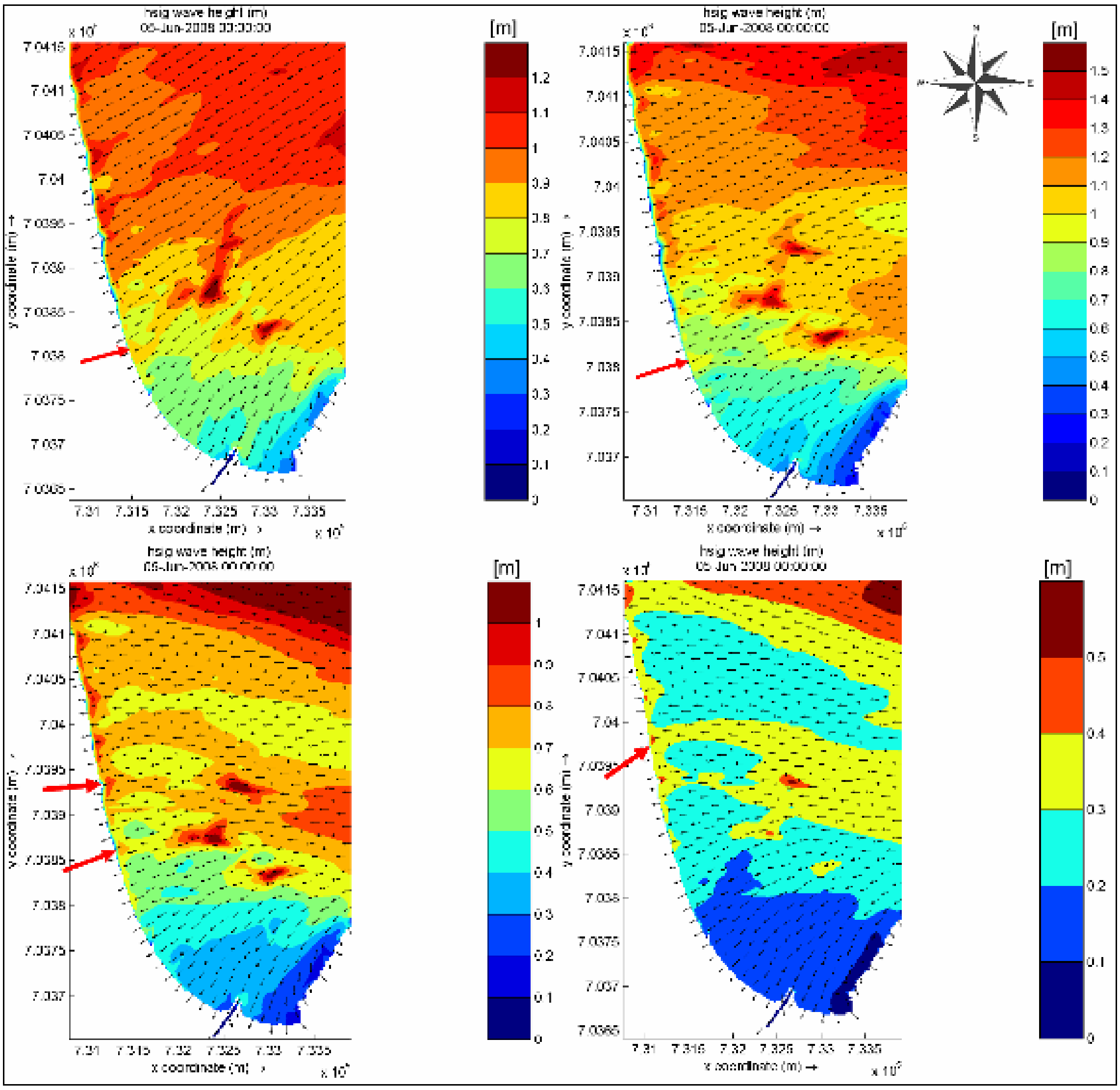


Figure III - 9 Smallest grid. H_s and propagation direction for 4 scenarios: top left NE, top right E, left SE, right S.

III.10 Interpretation

For the erosion at Piçarras one would expect increased wave attack at the hot spot stirring up sediment and thus making it transportable by any given current. This can be a wave generated current or a water level gradient caused by varying wave set up. However the waves in the north are always bigger than in the south of the bay thus, by a water level gradient, generating a current towards the south while no accretion is found in the south.

The angles of the incident waves are in most cases almost perpendicular to the coast. The southern scenarios seem to give angles at the beach that could initiate a current or at least transport in the swash zone, towards the north. Strangely the part of the bay where the severe erosion is taking place is for all scenarios relatively protected and the angles of incidence are almost always the same; nearly perpendicular to the beach. To verify this observation the output curves can give a more detailed picture. The angles at the breaker point have been analyzed in Appendix V. Table III - 3 shows these angles for the profiles 1 to 26.

Angles [°]				
	Wave scenarios			
profile	NE	E	SE	S
1	13,6	11,8	**12,1**	**12,3**
2	4,1	2,0	**2,4**	**2,6**
3	4,8	2,2	**2,6**	**1,8**
4	7,6	4,6	**3,6**	**3,7**
5	7,4	4,3	**4,5**	**4,6**
6	9,1	6,0	**6,0**	**5,3**
7	10,6	7,3	**6,0**	**6,0**
8	10,2	6,7	**6,7**	**6,6**
9	8,1	4,7	**4,9**	**5,2**
10	5,9	2,8	**3,1**	**3,4**
11	6,9	3,7	**4,2**	**4,5**
12	8,6	4,0	**4,1**	**4,9**
13	10,8	-0,7	**6,0**	**6,1**
14	11,6	6,6	**7,1**	**7,9**
15	16,3	11,5	**11,1**	**11,2**
16	16,0	9,8	**9,8**	**10,3**
17	11,6	5,8	**5,5**	**5,8**
18	13,4	8,4	**8,2**	**8,6**
19	15,3	11,1	**10,7**	**11,3**
20	12,2	7,5	5,8	6,4
21	10,0	5,3	4,5	6,8
22	13,6	7,4	1,3	5,1
23	16,1	6,9	1,5	1,4
24	4,8	-3,9	-8,6	-6,8
25	15,6	8,2	5,0	3,4
26	14,9	6,7	4,0	1,8

Table III - 3 Wave angles at breaker point for profile 1-26 for 4 scenarios.

It can be seen clearly now that for the SE and S scenario and to a lesser extend for the E scenario that the angles at the breaker point vary within 1º until profile 19. Profile 15 and 16 are the locations where wave focusing was observed. This clarifies the sudden jump in breaker angles for the E, SE and S scenarios.

During extreme storm events cross-shore transport takes place. In Appendix IV an extreme storm event will be modelled and used to determine the closure depth. The output of this wave scenario will be used in UB and SMC to investigate cross-shore transport.

Further investigation into longshore transport due to the four modelled wave scenarios will be done in the following paragraph.

III.11 Longshore Transport with the Kamphuis expression

The angles of incidence as presented in the previous paragraph call for investigation into longshore transport. The CERC-formula can not be applied at Piçarras beach, because there is to much variation in the shoreline regarding wave breaker heights and non-uniform depth contours. In agreement with Ir. Verhagen [19] the Kamphuis expression has been used for this project.

First an outline of how this will be done is given, followed by the results. Finally some remarks and conclusions will be formulated regarding the results and further steps to be taken.

III.11.1. Set up

To be able to calculate alongshore transport several parameters are needed:

- Wave height at breakpoint
- Angle of incidence at breakpoint
- Deep water wave period (peak)
- Grain size of the sediment
- Slope of the beach

With the help of D3D the near shore wave conditions have been modelled. There have been determined 26 output curves. Along these curves several wave parameters (height, period, direction, dissipation, length) and water depth are recorded. In order to find the breaker height and breaker angle of the waves the following has been done.

Along the curves the wave height and dissipation have been monitored. Just before breaking there is an increase in wave height and dissipation. Where the wave height reaches its maximum is classified as the breaker height (H_{sb}). At this same location the breaker angle (α_b) is determined. This results, per scenario (NE, E, SE and S) in a table with 26 H_{sb}'s and α_b's.

Because the α_b is with respect to the North and not with respect to the beach normal, it has to be corrected first. The beach normal is determined quite accurately with ArcGis, although it has to be mentioned that this has been done after manually subtracting the shoreline from an image. Meaning that the beach normal will be normal to this shoreline, but maybe not as accurately normal to the one in nature.

Because the foreshore of Piçarras isn't very regular and certainly not alongshore uniform with constant parallel depth contours, not every sediment transport formula can be used. The Kamphuis expression for sediment transport has been used here:

$$Q_k = 6.4 \cdot 10^4 H_{sb}^2 T_{op}^{1.5} m_b^{0.75} D^{-0.25} \sin^{0.6} 2\alpha_b$$

Where

Q_k = total sediment transport in [m^3/yr]
H_{sb} = breaking height of the significant wave
T_{op} = peak wave period in deep water
m_b = beach slope at breaker point
D = D_{50} of the sediment in the breaker zone
α_b = angle of incidence at breaker point

This expression takes into account the wave steepness, beach slope (which is a important parameter for Piçarras beach) and grain size.

Per scenario and per profile the sediment transport has been calculated. The tables below give the results.

Profile	Breaker height [m]	Breaker angle [°]	3° south	5° south	Slope [-]	Transport [m3/yr]	Transport with 3° south [m3/yr]	Transport with 5° south [m3/yr]
1	0,46	13,57	10,57	8,57	0,09	6886076,49	5981038,72	5298960,30
2	0,54	4,14	1,14	-0,86	0,08	2915497,73	1349398,55	-1134101,71
3	0,59	4,77	1,77	-0,23	0,15	6006011,09	3323436,87	-968261,78
4	0,61	7,58	4,58	2,58	0,13	7249089,19	5381688,12	3820254,16
5	0,61	7,42	4,42	2,42	0,14	6896193,91	5074705,69	3539801,25
6	0,65	9,07	6,07	4,07	0,12	9174702,71	7249611,63	5717063,57
7	0,65	10,57	7,57	5,57	0,14	11196174,17	9225376,01	7699065,87
8	0,66	10,19	7,19	5,19	0,13	10450547,24	8531254,62	7036301,12
9	0,65	8,09	5,09	3,09	0,10	7392242,77	5625793,08	4179018,26
10	0,69	5,88	2,88	0,88	0,09	6102630,92	3988665,42	1958273,52
11	0,70	6,95	3,95	1,95	0,10	7745671,54	5540360,66	3632206,06
12	0,67	8,58	5,58	3,58	0,08	6844805,84	5315829,77	4083127,76
13	0,64	10,79	7,79	5,79	0,08	6821808,45	5649719,32	4744728,53
14	0,75	11,63	8,63	6,63	0,07	9271736,11	7809724,50	6691569,10
15	0,76	16,29	13,29	11,29	0,06	10551467,29	9442021,21	8614049,07
16	0,80	15,98	12,98	10,98	0,06	11597767,99	10348703,40	9415902,76
17	0,84	11,58	8,58	6,58	0,06	10526503,04	8858752,57	7582637,38
18	0,86	13,38	10,38	8,38	0,06	11019563,58	9546162,33	8434511,50
19	0,80	15,34	12,34	10,34	0,06	10520212,92	9327488,86	8435210,00
20	0,80	12,15	9,15	7,15	0,06	9472136,16	8053633,42	6974024,48
21	0,79	9,98	6,98	4,98	0,04	6194910,09	5030483,77	4120448,81
22	0,90	13,61	10,61	8,61	0,04	8875521,55	7712086,26	6835412,09
23	1,00	16,09	13,09	11,09	0,08	19779378,75	17667600,73	16090929,11
24	1,09	4,78	1,78	-0,22	0,07	10636684,35	5892915,71	-1687854,18
25	0,98	15,57	12,57	10,57	0,08	19495917,36	17327069,17	15705669,00
26	1,13	14,87	11,87	9,87	0,05	19916403,66	17571305,99	15814220,26
					Totaal Transport [m3/yr]	253539654,9	206824826,4	162633166,3
					Transport 7% of time [m3/yr]	17747775,84	14477737,85	11384321,64

Table III - 4 Results of transport calculation for North east scenario.

Profile	Breaker height [m]	Breaker angle [°]	3° south	5° south	Slope [-]	Transport [m3/yr]	Transport with 3° south [m3/yr]	Transport with 5° south [m3/yr]
1	0,45	11,81	8,81	6,81	0,09	6370322,04	5384413,55	4631765,81
2	0,53	1,95	-1,05	-3,05	0,08	1927120,60	-1325119,84	-2513764,69
3	0,58	2,24	-0,76	-2,76	0,15	3952793,75	-2060854,32	-4472068,75
4	0,60	4,61	1,61	-0,39	0,13	5606517,25	2988596,50	-1278909,59
5	0,61	4,33	1,33	-0,67	0,14	5342989,70	2633699,82	-1754945,54
6	0,65	6,05	3,05	1,05	0,12	7831418,62	5208263,59	2746605,89
7	0,66	7,30	4,30	2,30	0,14	9919336,67	7251407,15	4989860,36
8	0,68	6,70	3,70	1,70	0,13	9385082,75	6595775,38	4139199,08
9	0,68	4,70	1,70	-0,30	0,10	6283710,62	3423549,89	-1202804,21
10	0,71	2,84	-0,16	-2,16	0,09	4619594,87	-829625,87	-3925390,12
11	0,75	3,75	0,75	-1,25	0,10	6614279,14	2521098,50	-3428437,91
12	0,73	3,95	0,95	-1,05	0,08	5565933,60	2375721,85	-2511013,89
13	0,76	-0,73	-3,73	-5,73	0,08	-2056687,34	-5481401,48	-7077428,04
14	0,82	6,61	3,61	1,61	0,07	8554607,40	5971662,64	3680679,67
15	0,77	11,53	8,53	6,53	0,06	9672475,20	8132729,63	6953988,90
16	0,85	9,77	6,77	4,77	0,06	10732415,66	8665561,72	7044263,53
17	0,95	5,77	2,77	0,77	0,06	9582146,00	6188190,40	2871763,88
18	0,97	8,38	5,38	3,38	0,06	11582690,81	8923488,62	6766415,03
19	0,90	11,13	8,13	6,13	0,06	11849135,94	9882975,38	8371060,19
20	0,90	7,51	4,51	2,51	0,06	9813538,65	7259992,24	5118293,30
21	0,89	5,34	2,34	0,34	0,04	5888311,79	3600686,12	1137049,54
22	0,97	7,40	4,40	2,40	0,04	7718771,77	5673331,15	3947897,02
23	1,11	6,89	3,89	1,89	0,08	16168711,13	11523118,91	7489080,20
24	1,25	-3,90	-6,90	-8,90	0,07	-13368321,81	-18749618,29	-21758320,72
25	1,15	8,20	5,20	3,20	0,08	20044044,85	15327985,71	11480184,17
26	1,30	6,70	3,70	1,70	0,05	17939904,83	12611138,10	7919219,57
					Totaal Transport [m3/yr]	197540844,5	113696767	39364242,69
					Transport 30.2% of time [m3/yr]	59657335,03	34336423,64	11888001,29

Table III - 5 Results of transport calculation for East scenario.

Profile	Breaker height [m]	Breaker angle [°]	3° south	5° south	Slope [-]	Transport [m3/yr]	Transport with 3° south [m3/yr]	Transport with 5° south [m3/yr]
1	0,28	12,08	9,08	7,08	0,09	3771376,74	3202866,59	2769924,58
2	0,33	2,36	-0,64	-2,64	0,08	1246538,74	-567436,63	-1330556,04
3	0,36	2,58	-0,42	-2,42	0,15	2496709,32	-836441,73	-2399271,48
4	0,40	3,60	0,60	-1,40	0,13	3340190,34	1140883,84	-1898745,72
5	0,41	4,46	1,46	-0,54	0,14	3791855,45	1942358,83	-1076072,97
6	0,42	6,02	3,02	1,02	0,12	4838436,56	3208232,09	1672502,09
7	0,46	5,98	2,98	0,98	0,14	6572351,83	4341744,74	2230116,55
8	0,43	6,75	3,75	1,75	0,13	5592048,07	3944364,93	2498648,02
9	0,42	4,91	1,91	-0,09	0,10	3705888,79	2109336,62	-331875,58
10	0,45	3,06	0,06	-1,94	0,09	2853817,06	264752,50	-2174715,33
11	0,49	4,24	1,24	-0,76	0,10	4708014,18	2255387,58	-1683273,74
12	0,46	4,09	1,09	-0,91	0,08	3405193,66	1545479,22	-1380458,53
13	0,48	5,95	2,95	0,95	0,08	4508983,95	2970944,56	1509902,02
14	0,54	7,13	4,13	2,13	0,07	6020530,67	4355626,48	2930661,36
15	0,49	11,13	8,13	6,13	0,06	5698505,26	4753530,26	4026925,88
16	0,58	9,84	6,84	4,84	0,06	7582767,38	6134356,53	4999622,29
17	0,65	5,52	2,52	0,52	0,06	6635056,30	4156755,01	1612569,55
18	0,66	8,20	5,20	3,20	0,06	8140527,94	6224596,69	4661284,14
19	0,62	10,71	7,71	5,71	0,06	8363997,83	6913164,19	5791631,86
20	0,64	5,78	2,78	0,78	0,06	6415255,41	4149549,23	1940754,97
21	0,59	4,48	1,48	-0,52	0,04	3561529,74	1837769,59	-977272,69
22	0,61	1,27	-1,73	-3,73	0,04	1628194,41	-1967680,19	-3112937,76
23	0,70	1,47	-1,53	-3,53	0,08	3886601,57	-3965761,14	-6547923,11
24	0,84	-8,57	-11,57	-13,57	0,07	-14476843,08	-17204843,56	-18814754,06
25	0,79	5,02	2,02	0,02	0,08	10743151,12	6240923,87	422325,06
26	0,84	4,00	1,00	-1,00	0,05	8405090,63	3665382,58	-3664964,92
					Totaal Transport [m3/yr]	113435769,8	50815842,65	-8325953,564
					Transport 21.0% of time [m3/yr]	23821511,67	10671326,96	-1748450,25

Table III - 6 Results of transport calculation for South east scenario.

Profile	Breaker height [m]	Breaker angle [°]	3° south	5° south	Slope [-]	Transport [m3/yr]	Transport with 3° south [m3/yr]	Transport with 5° south [m3/yr]
1	0,11	12,25	9,25	7,25	0,09	669758,92	570431,99	494899,72
2	0,13	2,58	-0,42	-2,42	0,08	230116,18	-76991,69	-221052,22
3	0,15	1,81	-1,19	-3,19	0,15	347755,42	-269751,22	-487388,09
4	0,17	3,67	0,67	-1,33	0,13	613982,17	221524,32	-334588,91
5	0,17	4,59	1,59	-0,41	0,14	690229,81	365850,47	-163451,73
6	0,19	5,27	2,27	0,27	0,12	968453,16	585624,71	162426,58
7	0,19	5,99	2,99	0,99	0,14	1227992,97	812044,97	418810,42
8	0,18	6,60	3,60	1,60	0,13	1011305,91	705428,30	433909,87
9	0,17	5,21	2,21	0,21	0,10	648779,62	389019,36	95405,52
10	0,18	3,44	0,44	-1,56	0,09	504098,09	146637,93	-314361,93
11	0,20	4,54	1,54	-0,46	0,10	866952,71	454098,01	-220293,39
12	0,18	4,85	1,85	-0,15	0,08	621967,26	349967,20	-76247,24
13	0,19	6,09	3,09	1,09	0,08	774280,29	517327,92	277612,43
14	0,22	7,90	4,90	2,90	0,07	1076730,72	812113,48	593795,37
15	0,21	11,22	8,22	6,22	0,06	1173217,97	980467,28	832412,25
16	0,24	10,26	7,26	5,26	0,06	1366667,77	1117823,21	924229,27
17	0,25	5,78	2,78	0,78	0,06	1052868,62	680716,48	317672,75
18	0,28	8,61	5,61	3,61	0,06	1528390,90	1188189,91	914120,00
19	0,25	11,33	8,33	6,33	0,06	1495157,33	1252120,86	1065657,29
20	0,26	6,36	3,36	1,36	0,06	1219445,41	834747,74	486113,42
21	0,28	6,78	3,78	1,78	0,04	1058232,96	748344,99	477151,27
22	0,28	5,13	2,13	0,13	0,04	838845,81	495945,64	90660,19
23	0,33	1,41	-1,59	-3,59	0,08	928003,23	-993491,59	-1619093,89
24	0,35	-6,83	-9,83	-11,83	0,07	-2355534,93	-2912689,11	-3237668,26
25	0,35	3,44	0,44	-1,56	0,08	1777554,75	519962,42	-1105613,48
26	0,32	1,82	-1,18	-3,18	0,05	825534,93	-636632,63	-1152835,98
					Totaal Transport [m3/yr]	21160787,97	8858830,968	-1347718,761
					Transport 26.6% of time [m3/yr]	5628769,60	2356449,04	-358493,19

Table III - 7 Results of transport calculation for South scenario.

Table III - 8 presents a summary of the total results per scenario. It is clearly visible that these rates are far too high since the erosion rate as determined in Appendix V should be in the order of 395.000m^3/yr. The direction doesn't seem to match real nature either. A minus sine means transport to the north. These results suggest net transport to the south, whereas there is erosion in the south and no sign of accretion near the northern jetty.

	Transport [m3/yr]	Transport with 3° south [m3/yr]	Transport with 5° south [m3/yr]
NE	17.747.775,84	14.477.737,85	11.384.321,64
E	59.657.335,03	34.336.423,64	11.888.001,29
SE	235.575,15	104.471,26	-19.423,45
S	5.628.769,60	2.356.449,04	-358.493,19
Total	83.269.455,63	51.275.081,79	22.894.406,29

Table III - 8 Results of transport per scenario

III.11.2. Remarks

There are a few things that strongly influence the results. Most important is the angle of the incoming waves, which determines the direction of the transport. From the D3D wave modeling it can be seen that the waves arrive at the coast almost perpendicular, but with a small angle towards the south. This could mean there is something wrong with the refraction computations in the model. To counteract this the breaker angle has been varied from the original one to 3° and 5° more south. This resulted in a significant decrease in the transport south, but still not sufficient.

The second source of errors could be the overestimation of the wave period. For the southern scenarios the result would be more serious because waves with a longer period refract stronger, resulting in a smaller or even positive angle causing southern transport. Moreover the wave period counts to the power 1.5 in the Kamphuis expression.

For all scenarios the breaker height seems reasonable. During a field visit similar breaking waves were observed, though, at all profiles along the beach, with a breaker angle towards the north.

The grain sizes could be too small. UNIVALI has taken samples at the backshore and the foreshore. A bigger grain size means less transport than a smaller grain size. But looking at the sizes used for the calculations this seems to be alright. The last source of errors could be the measured slope of the beach profile. Since for the Kamphuis expression the slope in the breaker zone should be used. The slope used for these calculations is the average slope of the profile, simply because there are no measurements of the slope in the breaker zone. This average slope would in general be milder than the slope in the breaker zone, causing less transport. So this doesn't clarify the huge amount of calculated transport either.

Normally, the alongshore sediment transport in headland bay beaches is not very big. Simply because these coastal systems have evolved over many thousands of years. The amount of transport calculated here is definitely wrong. What this calculation does show, is the sensitivity of the outcome with regard to changing the angle of incidence with 5°. The waves are apparently almost perpendicular to the shore, which suggests an equilibrium shape of the bay. The plan shape of the bay will shift a bit landwards and then seawards again, depending on the storminess of the years. This would cause no trouble if housing or other hard structures wouldn't be too close to the beach, as is the case now. Nevertheless there is erosion in the south of the bay, slopes are steeper here than anywhere else along the beach, while wave attack is very mild. Also the sediment is coarser here than in the neighboring sections of the beach. In the next section some recommendations will be given to get a better idea of where the sediment is going and thus determining how much is leaving the beach and in what direction.

Recommendations for modeling:
- Have a closer look at the refraction calculations. Waves from the east-south- east to south (offshore) should result in breaker angles to the north (as observed in the field visit).
- Find a better way of determining the wave breaker height
- Couple wave breaking and wave set-up to flow calculations and secondary flow effects that possibly carry the sediment away, thus not enabling it to be transported back to the beach in calmer periods.

Recommendations for monitoring:
- Measure the foreshore and near shore, for instance with a GPS and echosounder, to get a better picture of the beach profiles. Do this on a regular basis for a long time and certainly after storm events to monitor the sediment in the profiles.

III.12 Conclusions

After the definition of four scenarios from an energy point of view a good analysis of the wave propagation can be made. Observations so far indicated that:

- the headlands cause a considerable shadow zone
- refraction causes wave concentration at certain locations at the beach. However, these is not at the location with the most severe erosion, but approximately 2000m north of the river jetty.
- Ilha Feia and shoals dissipate wave energy
- diffraction decreases wave heights behind Ilha Feia and the headland of Penha
- a 90° change in offshore wave direction (east to south) only causes a change in the order of 1° for the angle of incidence at the breaker point (profile 1-19)
- wave conditions at the problem area are relatively mild

IV. Determination of the Closure Depth

IV.1 Introduction

The closure depth is a measure for the depth at the seaward end of the active profile (Figure IV - 1).

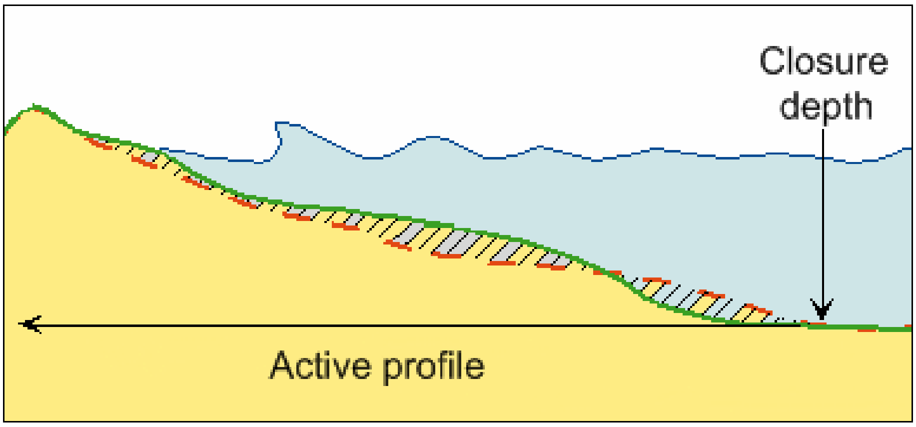


Figure IV - 1 Active profile, with closure depth as seaward boundary of littoral transport zone.

This means that beyond this depth, the waves are unable to influence the sediment on the bottom for transport. Sediment outside this active profile can be regarded as lost. During storm conditions sand from the beach or dunes is being eroded by the heavy waves. Usually this sand isn't lost permanently, but simply redistributed over the active profile. During milder conditions the sand that stayed in the active profile is transported back to the beach. If also the upper limit of the active profile is known it enables engineers to calculate volumes and as such enables them to account for erosion and accretion. The closure depth is also an important parameter for instance for a beach nourishment. If one would place an amount of sand beyond the closure depth, this sand will not be redistributed over the profile. This appendix deals with the determination of the closure depth of Alegre beach and Piçarras beach. This will be done in the following way:
- Determination of the design wave height for the closure depth
- Modelling the wave conditions at the nearshore of Piçarras
- Formulating an equation for the closure depth according to Dean [11].
- Making a spreadsheet in which actual water depth, wave height and period and calculated closure depth are linked.
- Determining the closure depth for all 26 profiles, by comparing actual depth and closure depth along the profiles. The location where the actual water depth is not smaller anymore than the closure depth is the seaward end of the active profile. The corresponding water depth is the closure depth.

At the end the results will be presented in graphs with accompanying comments.

IV.2 Determination of the design wave height

According to Deans theory a good measure to determine the wave conditions that are governing for the closure depth is the significant wave height that is exceeded with a probability of 0.137% per year. This corresponds with a storm condition that occurs 12hr/yr.

With the probability function and Gumbel distribution for the offshore wave heights, as stated in Appendix II the governing wave scenario for the determination of the closure depth is [6]: H_s = 4.2m, T = 10s

This wave has only been recorded from the east. These parameters will be used as input to model wave conditions nearshore.

IV.3 Modelling the wave conditions at the nearshore of Piçarras

With the boundary conditions as stated in the previous paragraph the model can be run. The model parameters are the same as mentioned in Appendix III. The first figure (Figure IV - 2) shows the result for the biggest grid. This shows that waves are depth limited at the nearshore of Piçarras. The wave height decreases rapidly inside the bay. The next figures (Figure IV - 2/ Figure IV - 3/ Figure IV - 4) will make this clearer.

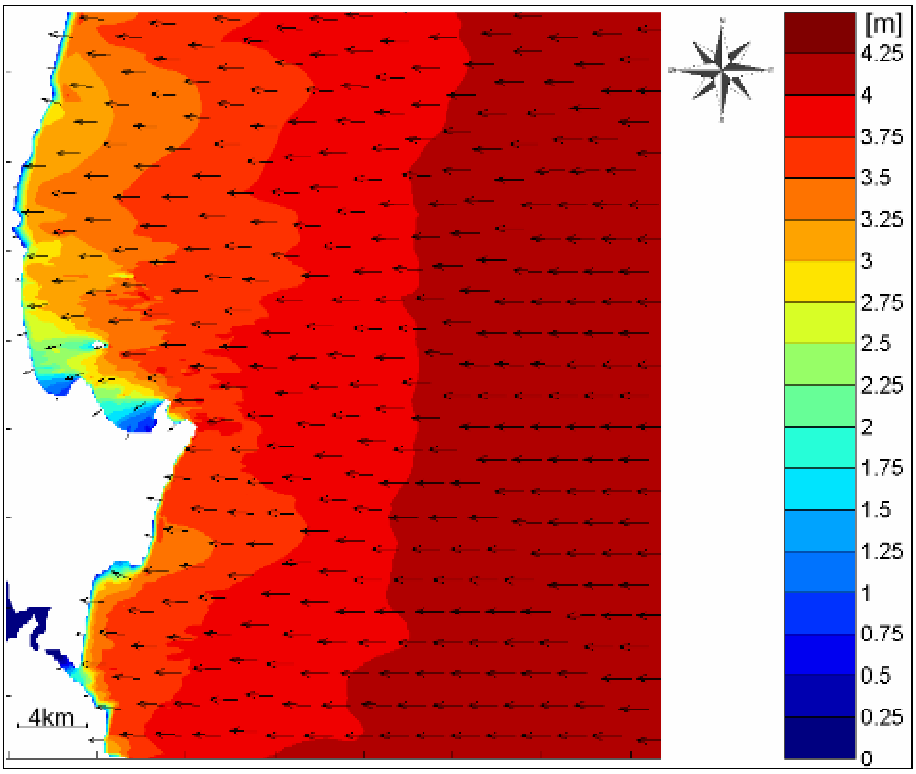


Figure IV - 2 Extreme wave scenario: H=4.2m T=10s east (biggest grid)

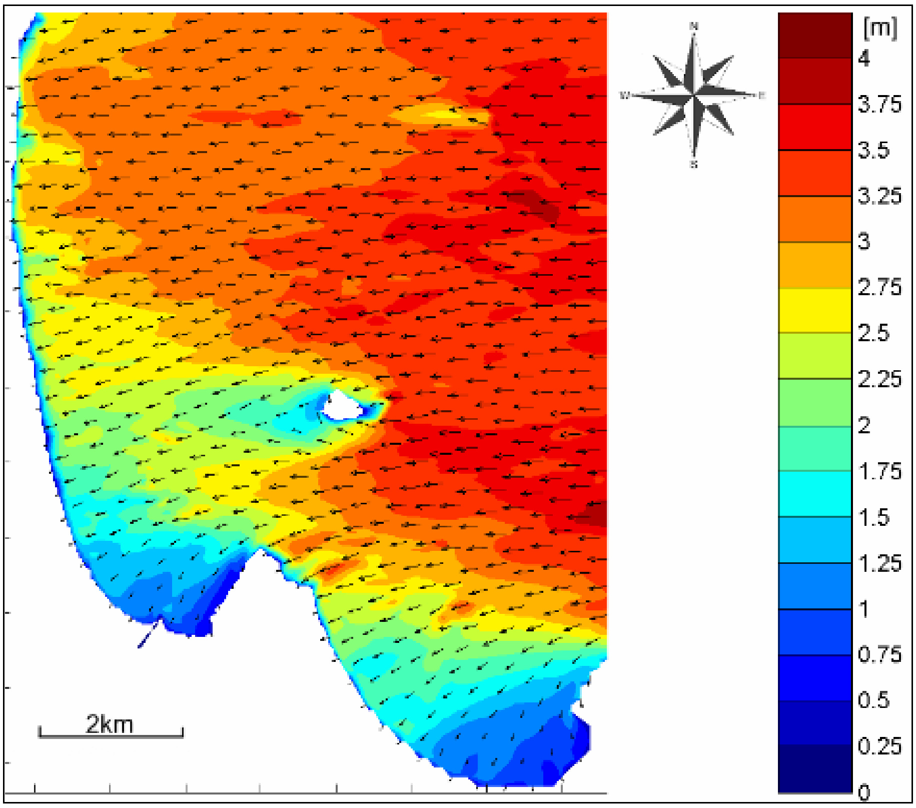


Figure IV - 3 Wave height entering the bay of Piçarras (already decreased height)

From Figure IV - 3 it can be observed that waves during a severe storm from the east will reach the problem area with a height of 1.5 to 2m. In the northern part of the bay this is much higher; between 2.5 to 3m. Because of the steep slope of the beach at the problem area [2] these big waves will break as collapsing waves whereas in the northern part they'll be more plunging-collapsing. Another observation is the influence of Ilha Feia on the storm waves. A lot of energy is caught by the island as well as by Penha headland. This allows the energy that passes through (between Ilha Feia and Penha) to spread which causes a decrease is wave height. However it also influences the direction of the waves, maybe even in such a way that the problems at Piçarras get worse. This seems unlikely since only in the last decades there is a severe erosion problem, while Ilha Feia has been there forever.

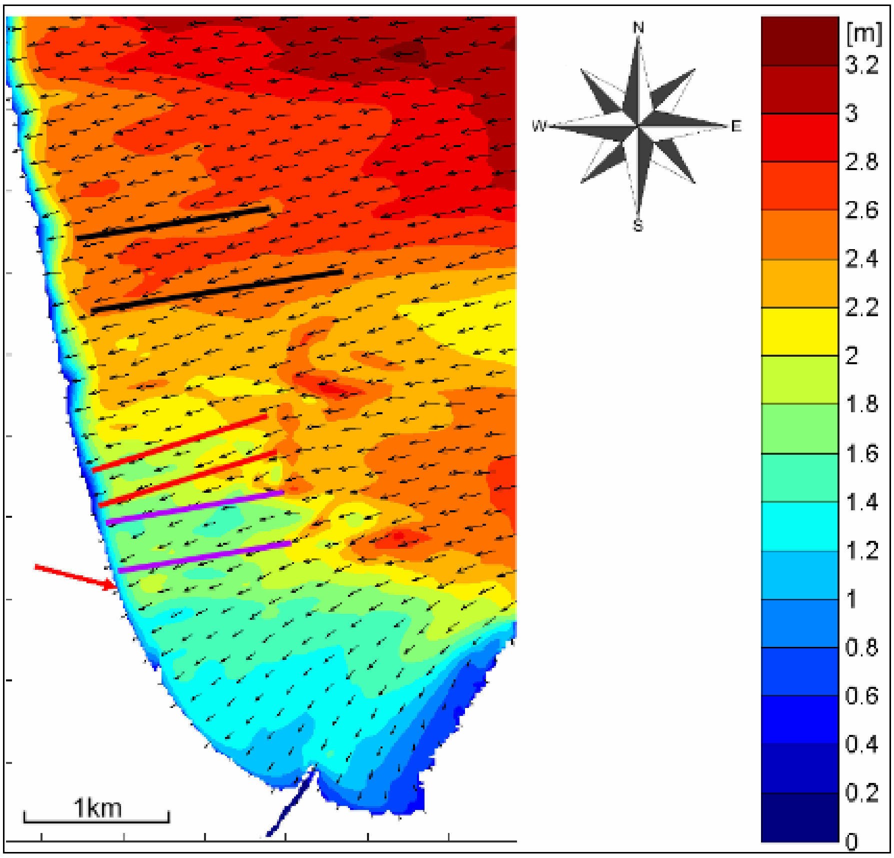


Figure IV - 4 Wave heights determining the closure depth inside the bay of Piçarras

Figure IV - 4 is the result of the storm scenario simulation with the finest grid. It seems to suggest wave focussing at profile 15 (red arrow). Secondly, between the black lines bigger wave heights penetrate closer to the coast than at the surrounding area, whereas between the red and purple lines smaller waves arrive at the beach. This will most likely be the result of refraction and dissipation over the shoals. What this means for the closure depth will be discussed later.

IV.4 Closure depth

The equation used to calculate the closure depth is based on Deans theory [11]. The formula is:

$$d^* = 2.28H_e - 68.5\left(\frac{H_e^2}{gT_e^2}\right)$$

where:
d^* = the closure depth
H_e = effective significant wave height, only exceeded 12 hours per year or 0.137% of the time.
T_e = the wave period associated with H_e

In the next paragraph the spreadsheet that has been made to calculate the closure depth will be shown and explained for one profile. In essence it is the same for the other profiles.

IV.5 The spreadsheet

The output curves coincide with the profiles of the beach measurements (figure IV-5) and UB cross-section for computing the shoreline changes.

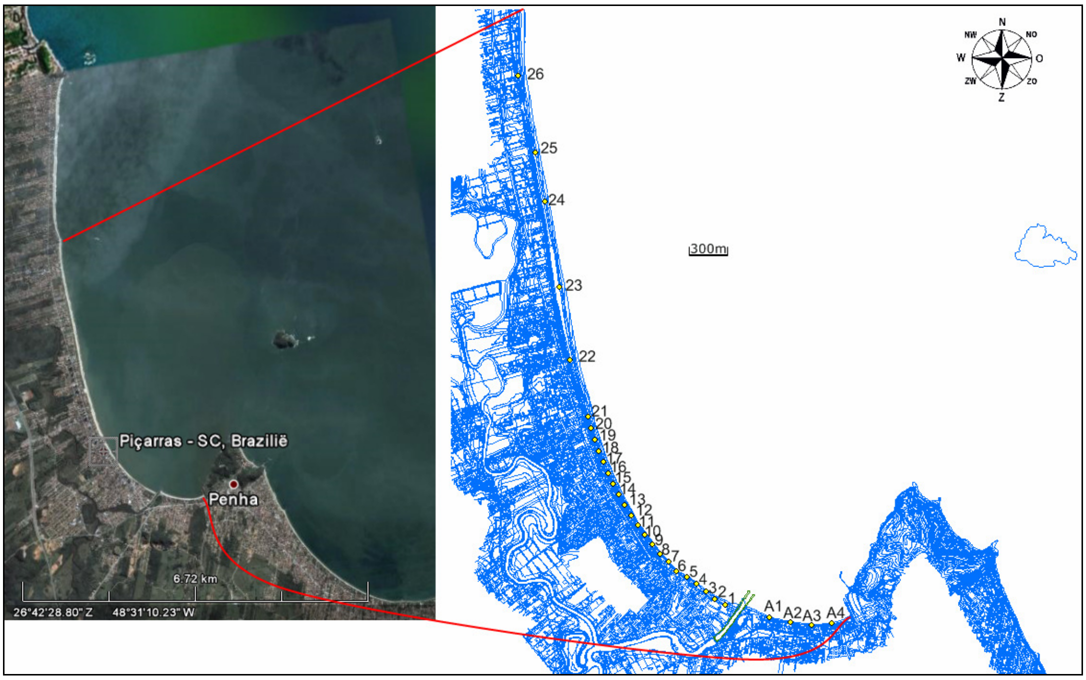


Figure IV - 5 Locations of the start of the cross sections at the beach. Piçarras (1-26) and Alegre (A1-4) [16][34]

Along these output curves with an interval of circa 4.25m the following parameters are registered:
- x-, y- coordinate
- distance from start of calculations
- water depth
- significant wave height
- period associated with the significant wave
- direction of wave propagation
- energy dissipation
- directional spreading
- wave length

For presentation purposes only the first 200m of the output curve table is shown in Table IV - 1.

x	y	Dist [m]	Depth [m]	Hs [m]	Per [s]	Dir [°]	Diss []	Dspr []	Wavelength [m]	d* [m]
732700.00	7038000.00	0.00	6.05	1.58	8.07	56.54	20.87	1.34	53.61	3.33
732700.00	7038000.00	4.17	6.03	1.58	8.07	56.41	20.88	1.34	53.58	3.33
732700.00	7038000.00	8.34	6.02	1.58	8.07	56.29	20.89	1.34	53.55	3.33
732700.00	7038000.00	12.50	6.01	1.57	8.07	56.16	20.91	1.34	53.52	3.32
732700.00	7038000.00	16.67	6.00	1.57	8.07	56.03	20.92	1.34	53.49	3.32
732700.00	7038000.00	20.84	5.99	1.57	8.07	55.90	20.93	1.34	53.46	3.32
732700.00	7038000.00	25.00	5.98	1.57	8.07	55.78	20.95	1.34	53.44	3.31
732700.00	7038000.00	29.17	5.97	1.57	8.07	55.65	20.96	1.34	53.42	3.31
732700.00	7038000.00	33.34	5.96	1.56	8.07	55.53	20.98	1.34	53.40	3.30
732700.00	7038000.00	37.51	5.96	1.56	8.07	55.42	20.99	1.34	53.38	3.30
732600.00	7038000.00	41.67	5.95	1.56	8.07	55.30	20.99	1.34	53.36	3.29
732600.00	7038000.00	45.84	5.94	1.56	8.07	55.20	21.00	1.33	53.34	3.29
732600.00	7038000.00	50.01	5.94	1.55	8.07	55.09	21.01	1.33	53.32	3.28
732600.00	7038000.00	54.18	5.93	1.55	8.07	54.98	21.01	1.33	53.30	3.28
732600.00	7038000.00	58.34	5.93	1.55	8.07	54.89	21.01	1.32	53.29	3.27
732600.00	7038000.00	62.51	5.93	1.55	8.07	54.81	21.00	1.32	53.28	3.27
732600.00	7038000.00	66.68	5.93	1.54	8.07	54.72	21.00	1.32	53.27	3.26
732600.00	7038000.00	70.85	5.92	1.54	8.07	54.63	21.00	1.31	53.27	3.26
732600.00	7038000.00	75.01	5.93	1.54	8.07	54.56	20.99	1.31	53.26	3.25
732600.00	7038000.00	79.18	5.93	1.54	8.07	54.49	20.97	1.30	53.26	3.25
732600.00	7038000.00	83.35	5.93	1.53	8.07	54.42	20.95	1.30	53.25	3.24
732600.00	7038000.00	87.52	5.93	1.53	8.07	54.36	20.94	1.29	53.26	3.24
732600.00	7038000.00	91.68	5.93	1.53	8.07	54.30	20.91	1.29	53.25	3.23
732600.00	7038000.00	95.85	5.93	1.53	8.07	54.25	20.88	1.28	53.25	3.23
732600.00	7038000.00	100.00	5.93	1.52	8.06	54.20	20.85	1.28	53.25	3.22
732600.00	7038000.00	104.20	5.93	1.52	8.06	54.14	20.82	1.27	53.24	3.22
732600.00	7038000.00	108.40	5.93	1.52	8.06	54.09	20.79	1.27	53.23	3.21
732600.00	7038000.00	112.50	5.92	1.51	8.06	54.06	20.74	1.27	53.22	3.21
732600.00	7038000.00	116.70	5.92	1.51	8.06	54.05	20.69	1.26	53.20	3.20
732600.00	7038000.00	120.90	5.91	1.51	8.06	54.03	20.63	1.26	53.19	3.20
732600.00	7038000.00	125.00	5.91	1.51	8.06	54.01	20.57	1.26	53.17	3.19
732600.00	7038000.00	129.20	5.90	1.50	8.06	53.99	20.52	1.25	53.16	3.19
732600.00	7038000.00	133.40	5.90	1.50	8.06	53.97	20.46	1.25	53.14	3.18
732600.00	7038000.00	137.50	5.89	1.50	8.06	53.95	20.40	1.25	53.13	3.18
732600.00	7038000.00	141.70	5.89	1.50	8.06	53.94	20.34	1.25	53.11	3.17
732600.00	7038000.00	145.90	5.88	1.50	8.06	53.94	20.27	1.24	53.10	3.17
732600.00	7038000.00	150.00	5.88	1.49	8.06	53.92	20.21	1.24	53.09	3.17
732600.00	7038000.00	154.20	5.87	1.49	8.06	53.91	20.14	1.24	53.08	3.16
732600.00	7038000.00	158.40	5.86	1.49	8.06	53.89	20.08	1.24	53.06	3.16
732500.00	7038000.00	162.50	5.86	1.49	8.06	53.88	20.01	1.24	53.04	3.15
732500.00	7038000.00	166.70	5.85	1.49	8.06	53.87	19.94	1.24	53.03	3.15
732500.00	7038000.00	170.90	5.84	1.48	8.06	53.86	19.89	1.24	53.02	3.15
732500.00	7038000.00	175.00	5.84	1.48	8.06	53.84	19.83	1.24	53.02	3.14
732500.00	7038000.00	179.20	5.83	1.48	8.06	53.83	19.77	1.23	53.01	3.14
732500.00	7038000.00	183.40	5.82	1.48	8.06	53.82	19.72	1.23	52.99	3.14
732500.00	7038000.00	187.50	5.81	1.48	8.07	53.79	19.67	1.23	52.98	3.14
732500.00	7038000.00	191.70	5.81	1.48	8.07	53.76	19.63	1.23	52.97	3.13
732500.00	7038000.00	195.90	5.80	1.48	8.07	53.73	19.60	1.23	52.96	3.13
732500.00	7038000.00	200.00	5.79	1.48	8.07	53.70	19.56	1.24	52.95	3.13

Table IV - 1 The output along an output curve. Last column: calculated closure depth.

Per interval the corresponding closure depth according to Deans formula is calculated (last column of the table). Table IV - 1 shows the result for profile 6. For the convenience of reading only the columns with distance, depth, wave height, period and the calculated closure depth are listed.

Starting from the seaward end the actual depth is greater than the calculated closure depth (d*). This is indicated with the blue arrow pointing in landward direction. From the landward end going seaward the calculated closure depth is bigger than the actual depth. This is indicated with the red arrow pointing in seaward direction. For a certain location this changes the other way around. This is where the actual depth and the closure depth are the same. This depth is the closure depth for that profile. Because the distance of this point from the begin coordinates of the profile is known, the x- and y- coordinates of the location can be determined.

	dist	depth	Hs	T	d*		dist	depth	Hs	T	d*		dist	depth	Hs	T	d*	
	0,00	6,09	1,48	8,04	3,14		356,20	5,27	1,34	8,17	2,88		712,50	3,63	1,27	8,34	2,72	
	4,24	6,08	1,48	8,05	3,13		360,50	5,26	1,34	8,18	2,87		716,70	3,60	1,27	8,34	2,73	
	8,48	6,07	1,47	8,05	3,13		364,70	5,24	1,34	8,18	2,87		721,00	3,58	1,27	8,35	2,73	
	12,72	6,06	1,47	8,05	3,12		369,00	5,23	1,34	8,18	2,87		725,20	3,55	1,27	8,35	2,73	
	16,96	6,05	1,47	8,05	3,12		373,20	5,22	1,34	8,18	2,87		729,40	3,52	1,27	8,35	2,73	
	21,20	6,04	1,47	8,05	3,11		377,40	5,21	1,34	8,18	2,86		733,70	3,50	1,27	8,36	2,73	
	25,45	6,03	1,47	8,06	3,11		381,70	5,19	1,34	8,18	2,86		737,90	3,47	1,27	8,36	2,73	
	29,69	6,02	1,46	8,06	3,11		385,90	5,18	1,34	8,19	2,86		742,20	3,45	1,27	8,36	2,73	
	33,93	6,02	1,46	8,06	3,10		390,20	5,17	1,33	8,19	2,86		746,40	3,42	1,27	8,36	2,73	
	38,17	6,01	1,46	8,06	3,10		394,40	5,16	1,33	8,19	2,85		750,60	3,39	1,27	8,37	2,73	
	42,41	6,00	1,46	8,06	3,09		398,60	5,14	1,33	8,19	2,85		754,90	3,36	1,27	8,37	2,74	
	46,65	6,00	1,46	8,07	3,09		402,90	5,11	1,33	8,20	2,85		759,10	3,33	1,27	8,37	2,74	
	50,89	5,99	1,45	8,07	3,09		407,10	5,09	1,33	8,20	2,85		763,40	3,31	1,27	8,38	2,74	
	55,13	5,98	1,45	8,07	3,08		411,40	5,07	1,33	8,20	2,85		767,60	3,28	1,27	8,38	2,74	
	59,37	5,98	1,45	8,07	3,08		415,60	5,06	1,33	8,20	2,84		771,80	3,26	1,27	8,38	2,74	
	63,61	5,97	1,45	8,07	3,07		419,80	5,04	1,33	8,20	2,84		776,10	3,23	1,27	8,39	2,74	
	67,85	5,97	1,45	8,07	3,07		424,10	5,02	1,33	8,21	2,84		780,30	3,20	1,28	8,39	2,75	
	72,10	5,96	1,44	8,08	3,07		428,30	4,99	1,33	8,21	2,84		784,60	3,18	1,28	8,39	2,75	
	76,34	5,95	1,44	8,08	3,06		432,60	4,97	1,32	8,21	2,84		788,80	3,15	1,28	8,39	2,75	
	80,58	5,95	1,44	8,08	3,06		436,80	4,95	1,32	8,21	2,84		793,00	3,12	1,28	8,40	2,75	
	84,82	5,94	1,44	8,08	3,05		441,10	4,93	1,32	8,22	2,83		797,30	3,09	1,28	8,40	2,75	
	89,06	5,94	1,43	8,08	3,05		445,30	4,91	1,32	8,22	2,83		801,50	3,06	1,28	8,40	2,75	
	93,30	5,93	1,43	8,08	3,05		449,50	4,89	1,32	8,22	2,83		805,80	3,03	1,28	8,41	2,75	
	97,54	5,93	1,43	8,08	3,04		453,80	4,87	1,32	8,22	2,83		810,00	3,00	1,28	8,41	2,75	
	101,80	5,92	1,43	8,08	3,04		458,00	4,85	1,32	8,23	2,83		814,30	2,98	1,28	8,41	2,76	
	106,00	5,91	1,43	8,08	3,03		462,30	4,83	1,32	8,23	2,83		818,50	2,95	1,28	8,42	2,76	
	110,30	5,91	1,42	8,08	3,03		466,50	4,81	1,32	8,23	2,83		822,70	2,92	1,28	8,42	2,76	
	114,50	5,90	1,42	8,08	3,02		470,70	4,79	1,32	8,23	2,82		827,00	2,89	1,28	8,42	2,76	
	118,70	5,90	1,42	8,09	3,02		475,00	4,77	1,32	8,24	2,82		831,20	2,86	1,28	8,43	2,76	
	123,00	5,89	1,42	8,09	3,01		479,20	4,75	1,32	8,24	2,82		835,50	2,83	1,28	8,43	2,76	
	127,20	5,89	1,41	8,09	3,01		483,50	4,73	1,32	8,24	2,82		839,70	2,80	1,28	8,43	2,76	
	131,50	5,88	1,41	8,09	3,01		487,70	4,71	1,31	8,24	2,82		843,90	2,77	1,28	8,44	2,77	Closure depth < Actual depth
	135,70	5,87	1,41	8,09	3,00		491,90	4,69	1,31	8,24	2,82		848,20	2,74	1,28	8,44	2,77	
	139,90	5,87	1,41	8,09	3,00		496,20	4,67	1,31	8,25	2,81		852,40	2,72	1,28	8,44	2,77	
	144,20	5,86	1,41	8,09	2,99		500,40	4,65	1,31	8,25	2,81		856,70	2,69	1,28	8,45	2,77	
	148,40	5,85	1,40	8,09	2,99		504,70	4,63	1,31	8,25	2,81		860,90	2,66	1,28	8,45	2,77	
	152,70	5,85	1,40	8,09	2,99		508,90	4,61	1,31	8,25	2,81		865,10	2,63	1,29	8,46	2,77	
	156,90	5,84	1,40	8,09	2,98		513,10	4,59	1,31	8,26	2,80	Landward	869,40	2,60	1,29	8,46	2,77	
	161,20	5,83	1,40	8,09	2,98		517,40	4,57	1,31	8,26	2,80		873,60	2,57	1,29	8,46	2,77	
	165,40	5,83	1,40	8,09	2,98		521,60	4,54	1,30	8,26	2,80		877,90	2,54	1,29	8,47	2,77	
	169,60	5,82	1,40	8,09	2,97		525,90	4,52	1,30	8,26	2,80		882,10	2,51	1,29	8,47	2,77	
	173,90	5,81	1,39	8,09	2,97		530,10	4,50	1,30	8,26	2,79		886,30	2,48	1,29	8,48	2,77	
	178,10	5,80	1,39	8,10	2,97		534,40	4,48	1,30	8,27	2,79		890,60	2,45	1,28	8,48	2,77	
	182,40	5,80	1,39	8,10	2,97		538,60	4,47	1,30	8,27	2,79		894,80	2,42	1,28	8,48	2,77	
	186,60	5,79	1,39	8,10	2,96		542,80	4,45	1,30	8,27	2,78		899,10	2,39	1,28	8,49	2,77	
	190,80	5,78	1,39	8,10	2,96		547,10	4,43	1,30	8,27	2,78		903,30	2,36	1,28	8,49	2,76	
	195,10	5,77	1,39	8,10	2,96		551,30	4,41	1,29	8,27	2,78		907,60	2,33	1,28	8,50	2,76	
	199,30	5,76	1,39	8,10	2,96		555,60	4,39	1,29	8,27	2,78		911,80	2,30	1,28	8,50	2,76	
	203,60	5,75	1,39	8,10	2,95		559,80	4,38	1,29	8,27	2,77		916,00	2,27	1,28	8,51	2,76	
	207,80	5,74	1,38	8,11	2,95		564,00	4,36	1,29	8,28	2,77		920,30	2,24	1,28	8,51	2,75	
	212,00	5,74	1,38	8,11	2,95		568,30	4,34	1,29	8,28	2,77		924,50	2,21	1,28	8,52	2,75	
	216,30	5,73	1,38	8,11	2,95		572,50	4,32	1,29	8,28	2,76		928,80	2,18	1,27	8,52	2,75	
	220,50	5,72	1,38	8,11	2,95		576,80	4,31	1,28	8,28	2,76		933,00	2,14	1,27	8,53	2,74	
	224,80	5,71	1,38	8,11	2,94		581,00	4,29	1,28	8,28	2,75		937,20	2,11	1,27	8,53	2,73	
	229,00	5,70	1,38	8,11	2,94		585,20	4,27	1,28	8,28	2,75		941,50	2,08	1,26	8,54	2,73	
	233,20	5,69	1,38	8,12	2,94		589,50	4,26	1,28	8,28	2,75		945,70	2,06	1,26	8,54	2,72	
	237,50	5,68	1,38	8,12	2,94		593,70	4,24	1,28	8,28	2,74		950,00	2,03	1,26	8,55	2,71	
	241,70	5,67	1,38	8,12	2,93		598,00	4,22	1,28	8,28	2,74		954,20	1,99	1,25	8,55	2,70	
	246,00	5,65	1,37	8,12	2,93		602,20	4,20	1,27	8,29	2,74		958,40	1,95	1,25	8,56	2,69	
	250,20	5,64	1,37	8,12	2,93		606,40	4,18	1,27	8,29	2,74		962,70	1,92	1,24	8,57	2,68	
	254,50	5,63	1,37	8,13	2,93		610,70	4,16	1,27	8,29	2,73		966,90	1,89	1,24	8,57	2,67	
	258,70	5,62	1,37	8,13	2,93		614,90	4,14	1,27	8,29	2,73		971,20	1,86	1,23	8,58	2,66	
	262,90	5,61	1,37	8,13	2,93		619,20	4,12	1,27	8,29	2,73		975,40	1,83	1,22	8,58	2,65	
	267,20	5,60	1,37	8,13	2,92		623,40	4,11	1,27	8,29	2,73		979,60	1,79	1,22	8,59	2,63	
	271,40	5,58	1,37	8,13	2,92		627,70	4,09	1,27	8,29	2,72		983,90	1,76	1,21	8,60	2,61	
	275,70	5,57	1,37	8,14	2,92		631,90	4,06	1,27	8,30	2,72		988,10	1,73	1,20	8,61	2,60	
	279,90	5,55	1,37	8,14	2,92		636,10	4,04	1,26	8,30	2,72		992,40	1,69	1,19	8,61	2,58	
	284,10	5,54	1,37	8,14	2,92		640,40	4,02	1,26	8,30	2,72		996,60	1,64	1,18	8,62	2,55	
	288,40	5,52	1,36	8,14	2,91		644,60	4,00	1,26	8,30	2,72		1001,00	1,59	1,17	8,63	2,53	
	292,60	5,51	1,36	8,14	2,91		648,90	3,98	1,26	8,30	2,72		1005,00	1,53	1,15	8,64	2,50	
	296,90	5,49	1,36	8,15	2,91		653,10	3,96	1,26	8,31	2,72		1009,00	1,47	1,14	8,65	2,47	
	301,10	5,48	1,36	8,15	2,91		657,30	3,94	1,26	8,31	2,72		1014,00	1,40	1,12	8,66	2,43	
	305,30	5,46	1,36	8,15	2,90		661,60	3,91	1,26	8,31	2,72		1018,00	1,25	1,08	8,68	2,36	
	309,60	5,44	1,36	8,15	2,90		665,80	3,89	1,26	8,31	2,72		1022,00	1,07	1,03	8,70	2,25	
	313,80	5,42	1,36	8,15	2,90		670,10	3,87	1,26	8,32	2,72		1026,00	0,87	0,96	8,71	2,11	Sea
	318,10	5,41	1,36	8,16	2,90		674,30	3,85	1,26	8,32	2,72		1031,00	0,67	0,88	8,73	1,95	
	322,30	5,39	1,35	8,16	2,89		678,50	3,82	1,26	8,32	2,72		1035,00	0,00	0,00	0,00	0,00	
	326,50	5,37	1,35	8,16	2,89		682,80	3,80	1,26	8,32	2,72		1039,00	0,00	0,00	0,00	0,00	Land
	330,80	5,36	1,35	8,16	2,89		687,00	3,77	1,26	8,33	2,72		1043,00	0,00	0,00	0,00	0,00	
	335,00	5,34	1,35	8,16	2,89		691,30	3,75	1,26	8,33	2,72		1048,00	0,00	0,00	0,00	0,00	
	339,30	5,33	1,35	8,17	2,89		695,50	3,72	1,26	8,33	2,72		1052,00	0,00	0,00	0,00	0,00	
	343,50	5,31	1,35	8,17	2,88		699,70	3,70	1,26	8,33	2,72		1056,00	0,00	0,00	0,00	0,00	
	347,80	5,30	1,35	8,17	2,88		704,00	3,68	1,26	8,34	2,72		1060,00	0,00	0,00	0,00	0,00	
Landward	352,00	5,28	1,35	8,17	2,88	Landward	708,20	3,65	1,27	8,34	2,72							

Figure IV - 6 Determining the closure depth of profile 6

This has been done for all 26 profiles.

IV.6 Resulting closure depth of Piçarras bay

To give an idea about the longshore variation of the closure depth, Figure IV - 7 Longshore variation of the closure depth at Piçarras has been made. Table IV - 2 gives the values of the closure depth per profile. The northern jetty coincides with the 0 (=zero) coordinate of the horizontal axis. The rest of the distances are relative to that jetty. The vertical axis gives the closure depth. This figure will be presented later on in this appendix on a larger scale (Figure IV - 9, Figure IV - 10).

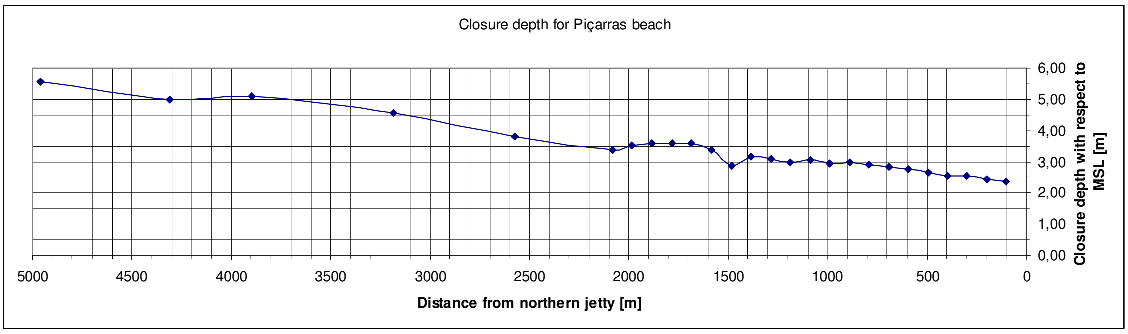


Figure IV - 7 Longshore variation of the closure depth at Piçarras

A gradual increase in closure depth is visible. This is in agreement with the wave action in the bay. The wave conditions in the south of the bay are milder than in the north. Beyond profile 21 there is a more rapid increase of the closure depth, because the end of the shadow zone from the headlands and island is reached. Wave heights are bigger in this area. At profile 15 a smaller closure depth is the result of a smaller wave height. This fits with the observations made regarding the results of the finest grid (Figure IV - 4). There are some areas with smaller waves than the surrounding area because of dissipation over shoals, which are common presence in the bay of Piçarras.

For Alegre beach the same has been done as for Piçarras. The graph with the values and locations of the closure depth along Alegre beach is shown in Figure IV - 8.

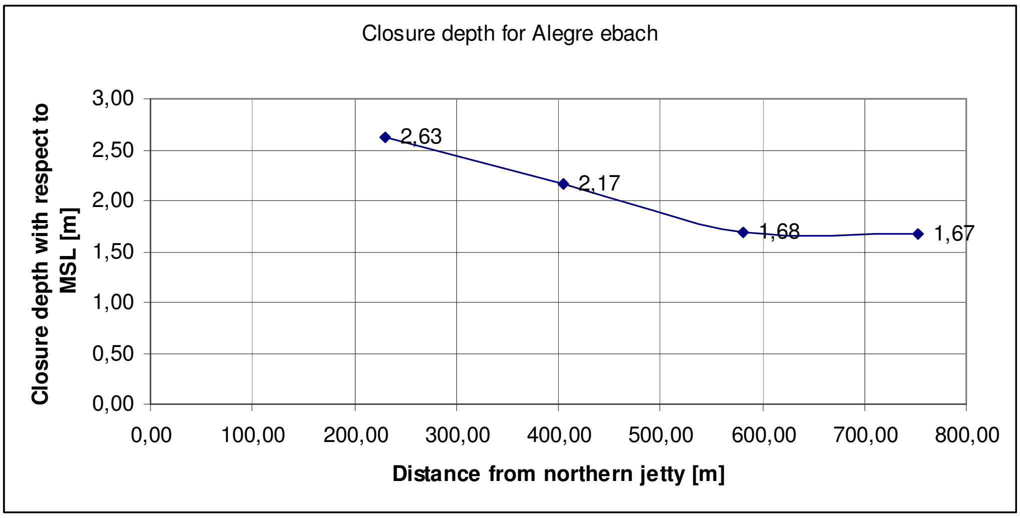


Figure IV - 8 Longshore variation of the closure depth at Alegre beach

Profile	Distance from northern jetty in northern direction [m]	Actual depth [m]	Hs [m]	T [s]	Direction [°]	Closure depth [m]
P1	100.58	2.35	1.09	8.64	27.19	2.36
P2	199.58	2.46	1.13	8.60	30.88	2.46
P3	296.96	2.56	1.17	8.56	35.07	2.54
P4	393.61	2.58	1.19	8.52	38.09	2.57
P5	494.06	2.67	1.24	8.49	40.70	2.67
P6	592.81	2.77	1.28	8.44	42.19	2.77
P7	691.55	2.84	1.31	8.40	44.56	2.82
P8	789.34	2.92	1.36	8.39	46.49	2.91
P9	889.36	2.97	1.39	8.36	48.83	2.97
P10	988.16	2.94	1.38	8.30	52.44	2.94
P11	1087.23	3.08	1.43	8.25	54.51	3.05
P12	1185.77	3.01	1.40	8.23	57.40	2.99
P13	1285.51	3.08	1.45	8.25	62.23	3.09
P14	1384.44	3.20	1.50	8.21	61.79	3.18
P15	1484.33	2.86	1.34	8.04	61.05	2.86
P16	1584.16	3.38	1.59	8.22	68.35	3.37
P17	1684.21	3.60	1.71	8.24	72.17	3.59
P18	1783.45	3.63	1.71	8.30	65.00	3.59
P19	1883.38	3.59	1.71	8.34	62.52	3.60
P20	1983.03	3.52	1.68	8.19	66.40	3.54
P21	2082.19	3.38	1.60	8.16	65.41	3.38
P22	2571.11	3.87	1.83	8.13	73.35	3.82
P23	3182.74	4.59	2.24	8.12	76.12	4.58
P24	3895.89	5.09	2.52	8.24	78.98	5.09
P25	4310.54	5.01	2.48	8.16	76.76	5.01
P26	4961.14	5.58	2.80	8.30	86.07	5.58
	Southern direction					
A1	230.01	2.63	1.21	8.90	27.29	2.63
A2	405.16	2.17	0.99	9.02	16.91	2.17
A3	580.51	1.71	0.76	9.09	3.59	1.68
A4	752.51	1.67	0.75	9.12	351.20	1.67

Table IV - 2 Values of the closure depth for profile P1-P26 and A1-A4, with Hs and T

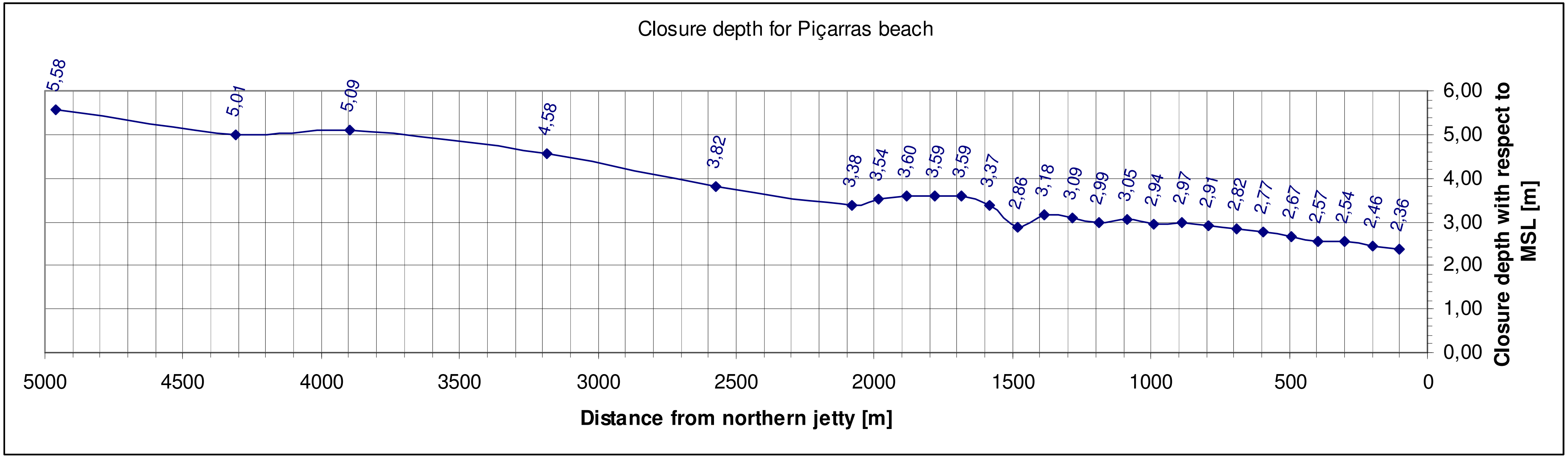


Figure IV - 9 Closure depth along Piçarras beach

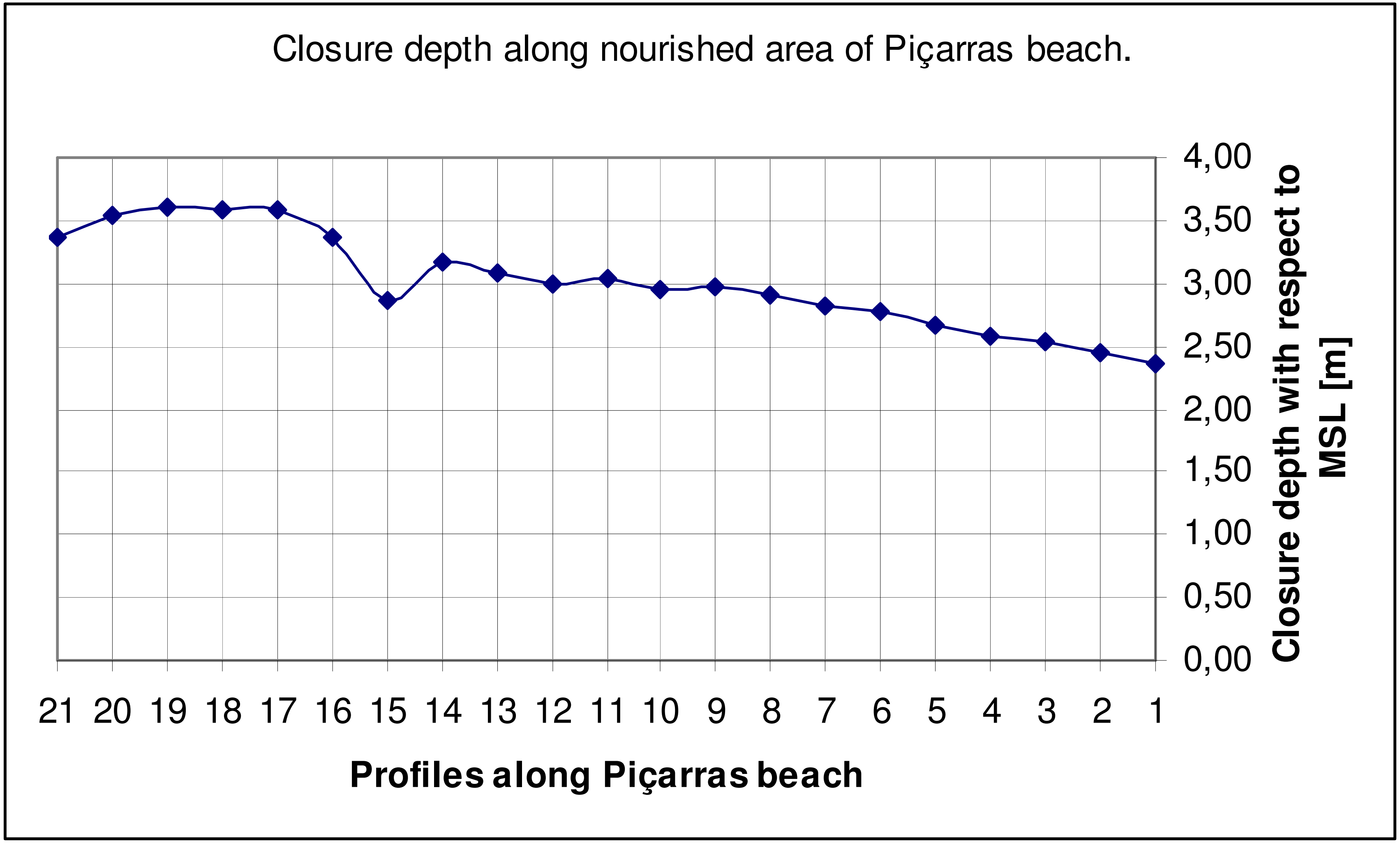


Figure IV - 10 Closure depth along nourished area of Piçarras beach.

V. Sediment Transport

V.1 Introduction

This appendix will treat several aspects of the sediment transport processes in the Piçarras bay. First the sediment present on the beach will be analysed using different measurements. The most representative data will be established, which will be used in the models of Unibest (UB, Appendix VI) and SMC (Appendix VII) and for the design of the nourishment (Appendix IV).

Secondly the eroded volumes will be analysed. Using different data sources and different methods, an erosion rate will be established. This is useful to verificate the output of UB and will be a tool in the design of the nourishment.

The actual sediment transport processes present in the Piçarras bay will not be treated in this appendix. The physical processes are too complex to be described in a numerical way without the aid of a computational method. Therefore the qualitative descriptions will be treated in other appendices, like Appendix VI and Appendix VII.

V.2 Sediment

For the models in UB and the design of the nourishment the grain sizes of the beach in different time periods are important. The analysis of the sediment will be explained here in chronological order.

V.2.1.Pré-nourishment

To determine the sediment sizes present in the period before the nourishment, the data of JICA (Japan International Coorperation Agency) are used. There are also data available of 1985 by INPH (Instituto Nacional de Pesquisas Hidroviárias) but these have only six sample locations, see Table V - 1. The locations of the samples are either backshore (BS) or swash zone (SZ).

Diameters by INPH, September 1985

name sample	location sample	D50 [mm]	D50 [φ]
INPH # 04	BS	0.29	1.79
INPH # 04	SZ	0.22	2.22
INPH # 11	BS	0.32	1.64
INPH # 11	SZ	0.34	1.56
INPH # 18	BS	0.44	1.18
INPH # 18	SZ	0.35	1.51

Table V - 1 Diameters by INPH, September 1985

Other sediment data are collected by FACIMAR in 1994 until 1996, see Table V - 2. The positions of the required samples are visualised in Figure V - 1.

Diameters by FACIMAR, 1994 - 1996			
name sample	location sample	Dm [mm]	Dm [φ]
FACIMAR # 07	BS	0.340	1.56
FACIMAR # 08	BS	0.321	1.59
FACIMAR # 09	BS	0.313	1.65
FACIMAR # 10	BS	0.293	1.76
FACIMAR # 11	BS	0.288	1.96

Table V - 2 Diameters by FACIMAR, 1994 - 1996

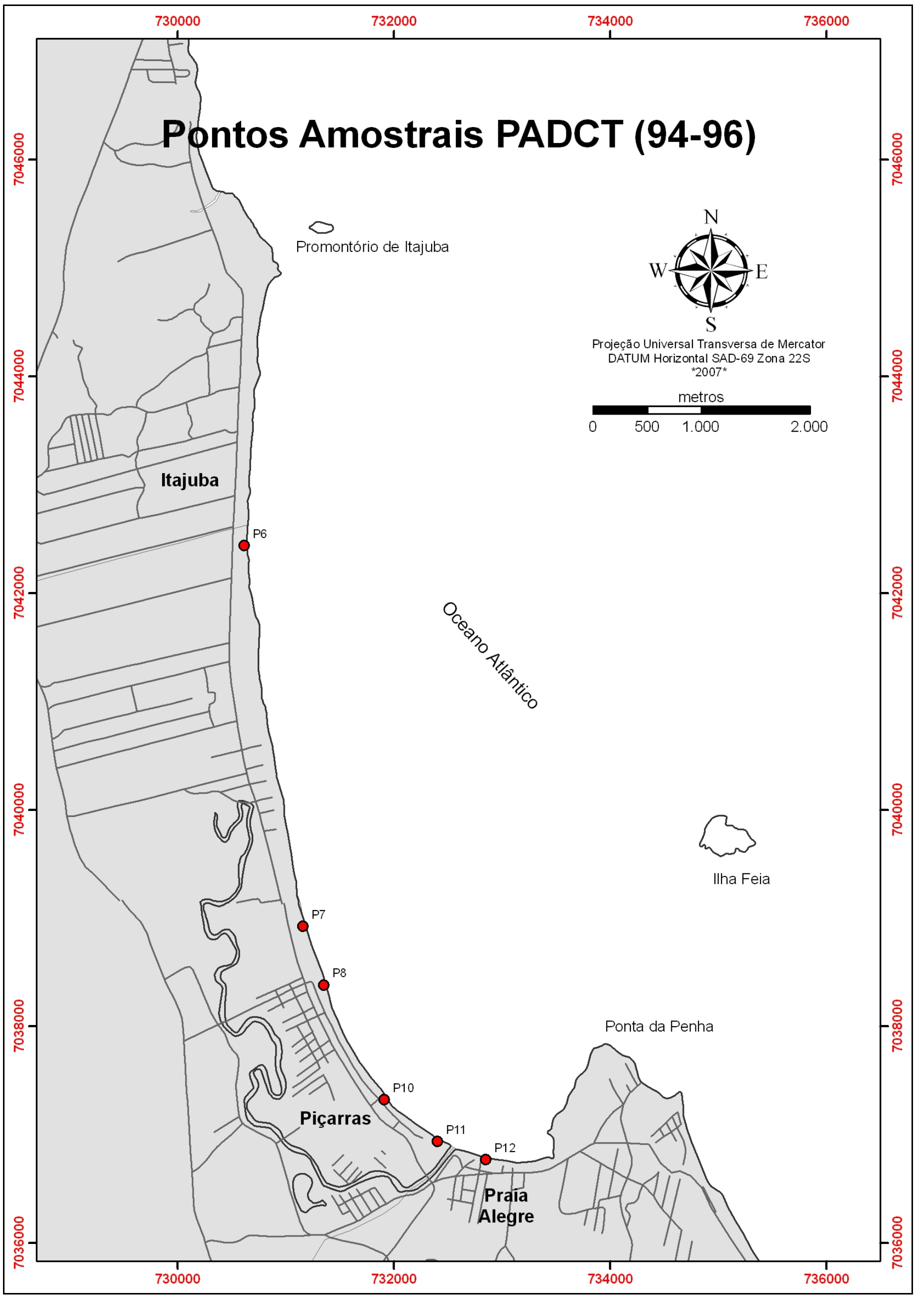


Figure V - 1 Location sample points by FACIMAR, 1994 – 1996 [2]

But the most thrustworthy results for an easy application are the data from JICA, sampled in May 1989. Because all these samples are from the swash zone, they are most suitable for the calculations. Besides that, the locations of the data are known. The sediment data from JICA are collected in Table V - 3.

Diameters by JICA, May 1989			
name sample	location sample	Dm [mm]	Dm [φ]
JICA # 01	SZ	0.12	3.06
JICA # 02	SZ	0.45	1.15
JICA # 03	SZ	0.12	3.06
JICA # 04	SZ	0.16	2.64
JICA # 05	SZ	0.17	2.56
JICA # 06	SZ	0.30	1.74
JICA # 07	SZ	0.27	1.89
JICA # 08	SZ	0.27	1.89
JICA # 09	SZ	0.23	1.12
JICA # 10	SZ	0.22	2.18
JICA # 11	SZ	0.20	2.32
JICA # 12	SZ	0.20	2.32
JICA # 13	SZ	0.22	2.18
JICA # 14	SZ	0.20	2.32
JICA # 15	SZ	0.25	1.99
JICA # 16	SZ	0.52	0.94
JICA # 17	SZ	0.35	1.51
JICA # 18	SZ	0.40	1.32
JICA # 19	SZ	0.20	2.32
JICA # 20	SZ	0.21	2.25
JICA # 21	SZ	0.32	1.64
JICA # 22	SZ	0.26	1.94
JICA # 23	SZ	0.33	1.60
JICA # 24	SZ	0.42	1.25
JICA # 25	SZ	0.25	1.99
JICA # 26	SZ	0.25	1.99

Table V - 3 Diameters by JICA, May 1989

In Figure V - 2, the location of the sample points are clearly indicated. In a small overview of the sample diameters is given from south Piçarras (left) to north Piçarras (right).

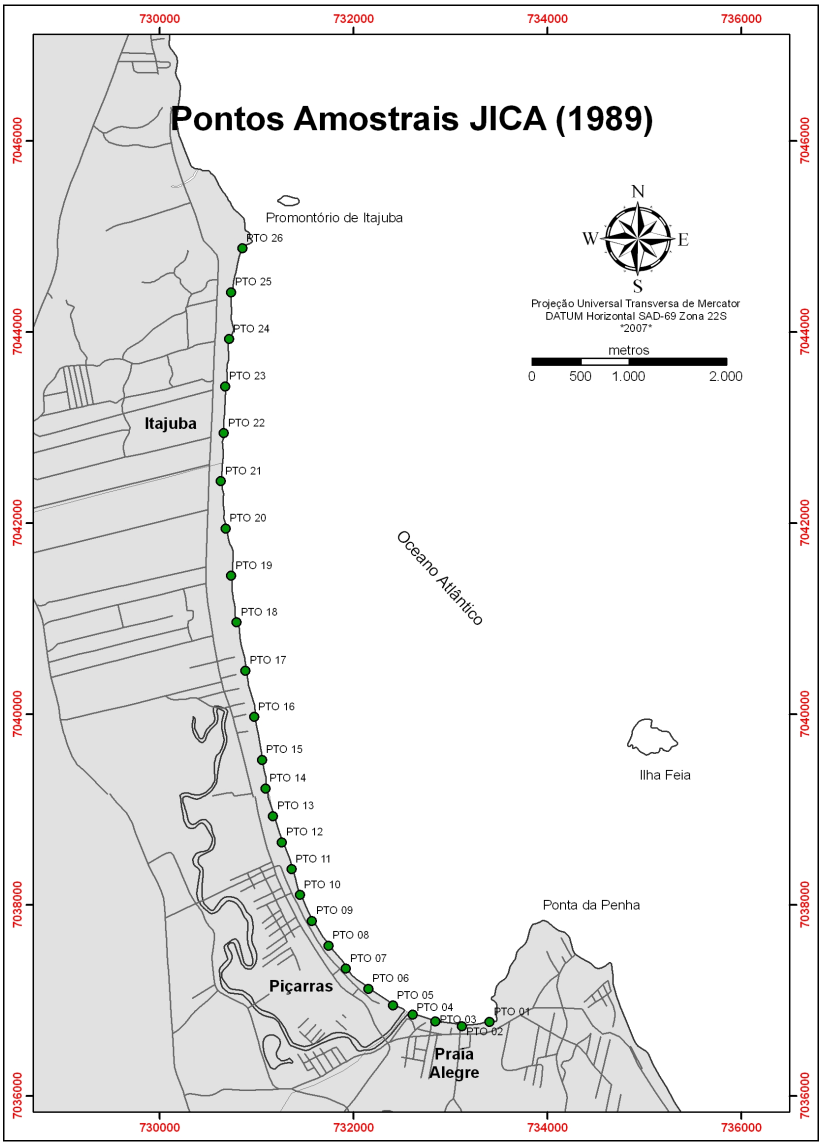


Figure V - 2 Location sample point JICA, May 1989 [2]

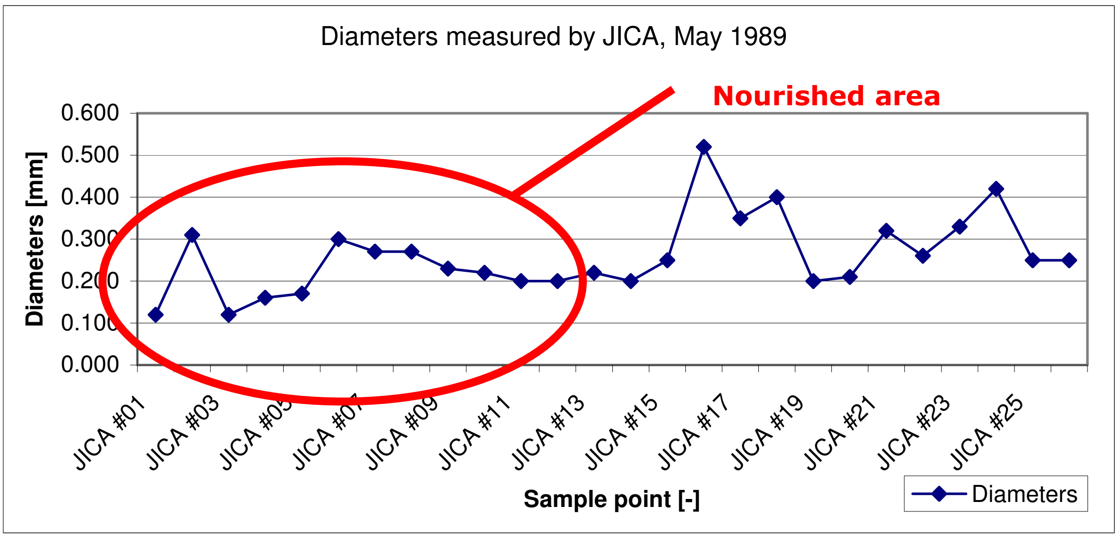


Figure V - 3 Diameters of sample points measured by JICA, May 1989

The samples of JICA were averaged to be able to make a comparison later on. The previous nourishment, in 1999, was executed from profile 1 until 21. To be able to analyse the evolution of the grain sizes the beach of Piçarras is divided in two sectors; first the nourished area and second the area north of the nourishment. Point 11 is the last point of JICA in the area nourished in 1999. In Table V - 4 the characterizing grain sizes in 1989 are given.

Characterizing grain sizes, JICA

sector	sample points	mean diameter [mm]
1	5 - 11	0.228
2	12 - 26	0.292

Table V - 4 Characterizing grain sizes, JICA

V.2.2.Post-nourishment

In 2007 CTTMar and UNIVALI have taken samples of Piçarras beach. The sampling was done every 100 meters, coinciding with the locations of the profile measurements by UNIVALI, Figure V - 4 and Figure V - 5.

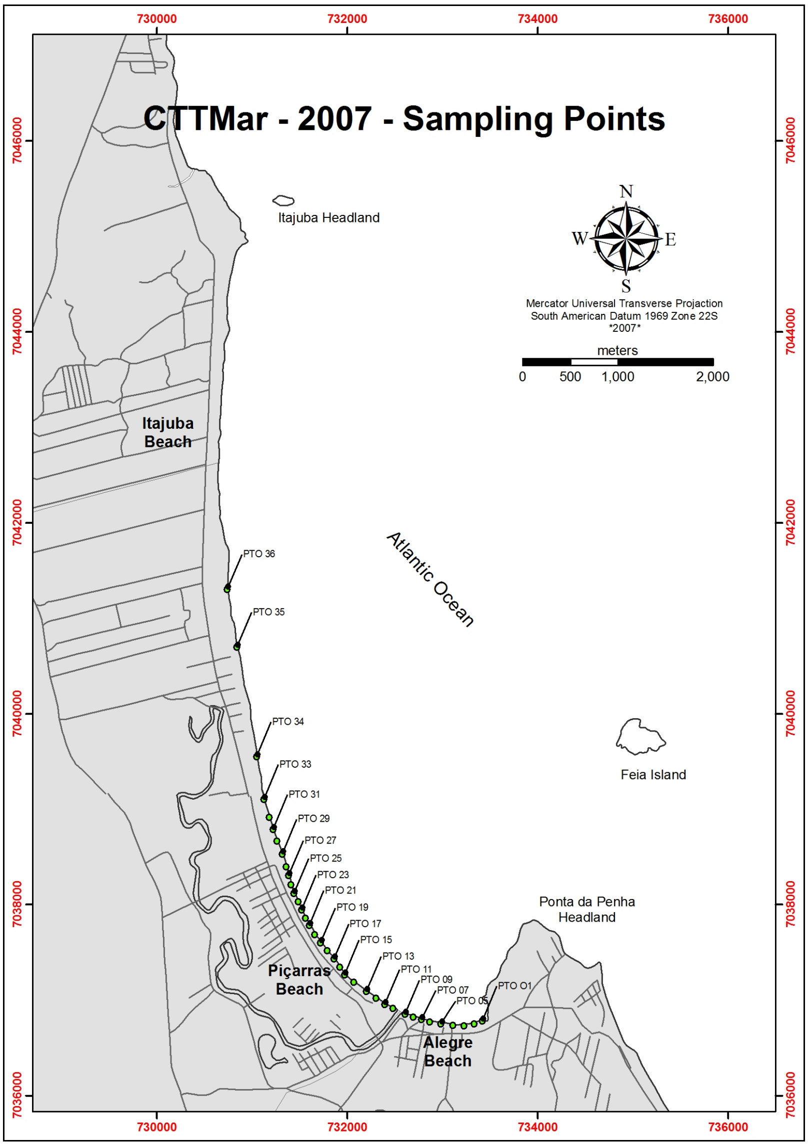


Figure V - 4 Sampling points CTTMar, 2007 [2]

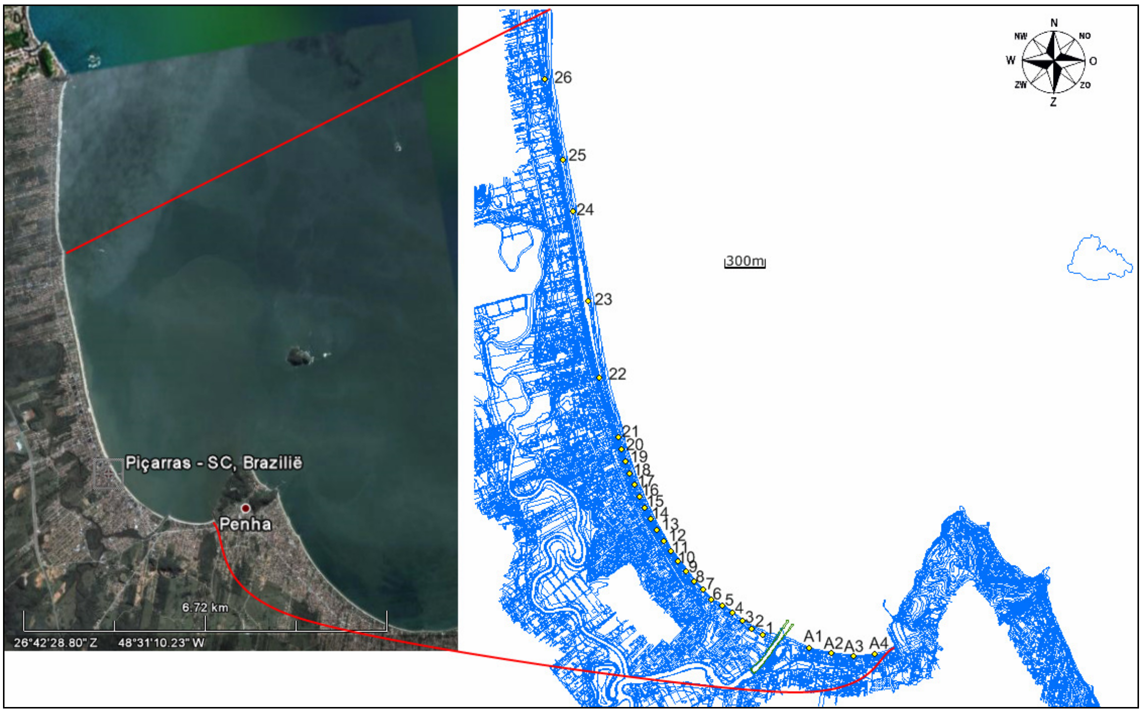


Figure V - 5 Location profile measurements UNIVALI, 2007 & 2008 [16][34]

At every cross-section two samples were taken: one from the backshore (BS) and one from the swash zone (SZ). For every sample position the Krumbein phi (φ) (Krumbein & Sloss, 1963) was determined. Using the next formulas the diameters were calculated.

$$D_{50} = 2^{-\varphi_{50}} \qquad D_{90} = 2^{-\varphi_{10}} \qquad D_m = 2^{-\varphi_m}$$

After the first analysis of the sediment sizes, the samples of 13-BS and 14-BS seemed odd. They had a large deviation from samples of neighbouring cross-sections. This can be explained in two ways: it could be due to the location of the cross-sections in the area of the erosional hotspot (profile 4 and 5), or due to shells in the sample. To determine the best explanation, the samples were analysed again and there proved to be a lot of shells, which were extracted for the new analysis. Table V - 5 shows the old and new sediment samples. The results do not show a lot of difference but since the new results are slightly lower and therefore more compatible, the sediment size of samples 13-SZ and 14-SZ were altered from the first measurements.

Comparison of first and second analysis on samples 13-SZ and 14-SZ

name sample	number of cross-section	x-coordinate	y-coordinate	D50 [mm]	D90 [mm]
13-SZ old	4	732218	7036954	0.346	0.635
13-SZ new	4	732218	7036954	0.345	0.493
14-SZ old	5	732083	7037050	0.474	0.872
14-SZ new	5	732083	7037050	0.468	0.836

Table V - 5 Comparison of first and second analysis on samples 13-SZ and 14-SZ

In Table V - 6 the measured data are presented, with the new 13-SZ and 14-SZ. In the second column the location of the sediment sampling is coupled to the location of the measured profiles by UNIVALI, as mentioned before. Here 'A' indicates Alegre beach.

The fall velocity was calculated using the next formulas:

$$w_{s;uncorrected} = \frac{-3\mu + \sqrt{9\mu^2 + gr^2\rho(\rho_s - \rho)(0.015476 + 0.19841r)}}{\rho(0.011607 + 0.14881r)} \quad [15]$$

and $w_s = 0.761 w_{s;uncorrected}$ [4]

Where

$w_{s;uncorrected}$ = fall velocity uncorrected for irregular carbonate grain shapes [cm/s]

μ = dynamic viscosity, 0.010250 g/(cm.s)

g = gravitational acceleration, 981 cm/s^2

r = grain radius, [cm]

ρ = water density, 1.025 g/cm^3

ρ_s = sediment density, 2.650 g/cm^3

w_s = fall velocity

Diameters of Alegre beach and Piçarras beach by CTTMar and UNIVALI, 2007							
name sample	cross-section	x-coordinate	y-coordinate	D50 [mm]	D90 [mm]	Dm [mm]	ws [m/s]
01-FP		733442	7036726	0.167	0.249	0.168	0.0133
01-PP		733447	7036707	0.196	1.084	0.231	0.0171
02-FP	A1	733368	7036687	0.174	0.267	0.174	0.0142
02-PP	A1	733372	7036669	0.184	0.606	0.184	0.0155
03-FP		733257	7036669	0.192	0.390	0.199	0.0165
03-PP		733252	7036650	0.374	4.282	0.491	0.0405
04-FP	A2	733151	7036668	0.153	0.342	0.164	0.0117
04-PP	A2	733156	7036642	0.212	0.904	0.224	0.0190
05-FP	A3	732988	7036680	0.156	0.363	0.170	0.0120
05-PP	A3	732977	7036675	0.198	0.381	0.200	0.0173
06-FP		732880	7036710	0.170	0.472	0.193	0.0137
06-PP		732870	7036694	0.166	0.279	0.171	0.0133
07-FP	A4	732800	7036730	0.206	0.460	0.216	0.0182
07-PP	A4	732793	7036709	0.168	0.265	0.167	0.0135
08-FP		732726	7036762	0.158	0.301	0.164	0.0123
08-PP		732720	7036740	0.226	0.363	0.220	0.0209
09-FP		732637	7036815	0.159	0.282	0.162	0.0123
09-PP		732618	7036799	0.175	0.283	0.178	0.0143
10-FP		732509	7036790	0.259	0.478	0.252	0.0252
10-PP		732505	7036779	0.192	0.311	0.192	0.0165
11-FP	1	732429	7036830	0.300	0.518	0.298	0.0306
11-PP	1	732422	7036818	0.293	0.613	0.297	0.0298
12-FP	2, 3	732330	7036882	0.294	0.527	0.295	0.0298
12-PP	2, 3	732320	7036875	0.271	0.798	0.298	0.0268
13-FP	4	732223	7036959	0.345	0.493	0.358	0.0366
13-PP	4	732218	7036954	0.252	0.389	0.242	0.0243
14-FP	5	732087	7037059	0.468	0.836	0.437	0.0526
14-PP	5	732083	7037050	0.291	0.551	0.297	0.0295
15-FP	6, 7	732004	7037139	0.259	0.515	0.267	0.0253
15-PP	6, 7	731990	7037131	0.263	0.671	0.274	0.0258
16-FP	8	731938	7037209	0.301	0.571	0.305	0.0308
16-PP	8	731923	7037194	0.241	0.462	0.240	0.0229
17-FP	9	731870	7037280	0.277	0.703	0.291	0.0277
17-PP	9	731856	7037269	0.249	0.359	0.255	0.0239
18-FP	10	731795	7037385	0.324	0.906	0.340	0.0338
18-PP	10	731779	7037366	0.288	0.601	0.301	0.0291
19-FP	11	731736	7037467	0.307	0.562	0.313	0.0316
19-PP	11	731721	7037456	0.279	0.717	0.297	0.0279
20-FP	12	731682	7037557	0.297	0.542	0.302	0.0302
20-PP	12	731659	7037545	0.280	1.002	0.300	0.0280
21-FP	13	731624	7037652	0.309	0.596	0.319	0.0319
21-PP	13	731598	7037637	0.266	0.491	0.264	0.0261
22-FP	14	731583	7037735	0.294	0.576	0.303	0.0299
22-PP	14	731561	7037718	0.265	0.942	0.275	0.0261
23-FP	15	731547	7037805	0.291	0.557	0.298	0.0295
23-PP	15	731521	7037791	0.273	1.439	0.280	0.0270
24-FP	16	731501	7037898	0.253	0.398	0.250	0.0245
24-PP	16	731470	7037886	0.255	0.402	0.250	0.0247
25-FP	17	731465	7037981	0.255	0.556	0.281	0.0247
25-PP	17	731428	7037970	0.248	0.447	0.243	0.0238
26-FP	18	731425	7038086	0.305	0.536	0.304	0.0314
26-PP	18	731395	7038067	0.265	0.431	0.257	0.0260
27-FP	19	731393	7038181	0.301	0.580	0.309	0.0308
27-PP	19	731360	7038166	0.267	0.499	0.268	0.0262
28-FP	20	731365	7038261	0.220	0.384	0.223	0.0201
28-PP	20	731332	7038250	0.264	0.490	0.260	0.0258
29-FP	21	731330	7038371	0.364	0.915	0.387	0.0391
29-PP	21	731301	7038359	0.243	0.400	0.242	0.0231
30-FP		731310	7038479	0.230	0.517	0.256	0.0214
30-PP		731287	7038467	0.317	0.559	0.323	0.0330
31-FP		731269	7038567	0.326	0.889	0.355	0.0341
31-PP		731244	7038559	0.287	0.469	0.286	0.0290
32-FP		731238	7038642	0.262	0.411	0.258	0.0257
32-PP		731231	7038633	0.304	0.530	0.308	0.0311
33-FP	22	731208	7038771	0.307	0.547	0.311	0.0317
33-PP	22	731178	7038766	0.313	0.575	0.320	0.0324
34-FP		731167	7038956	0.263	0.517	0.282	0.0257
34-PP		731154	7038952	0.328	0.555	0.328	0.0343
35-FP	23, 24	731069	7039452	0.349	0.689	0.371	0.0371
35-PP	23, 24	731054	7039451	0.265	0.506	0.282	0.0260
36-FP	25	730879	7040570	0.267	0.445	0.266	0.0264
36-PP	25	730856	7040564	0.309	0.581	0.318	0.0318
37-FP	26	730773	7041182	0.267	0.634	0.324	0.0264
37-PP	26	730738	7041178	0.304	0.553	0.310	0.0312

Table V - 6 Diameters of Alegre beach and Piçarras beach by CTTMar and UNIVALI, 2007

In Figure V - 6 the sediment sizes in the nourished area of 1999 are shown. It is obvious that the sediment is courser in the swash zone, due to the increase in wave action.

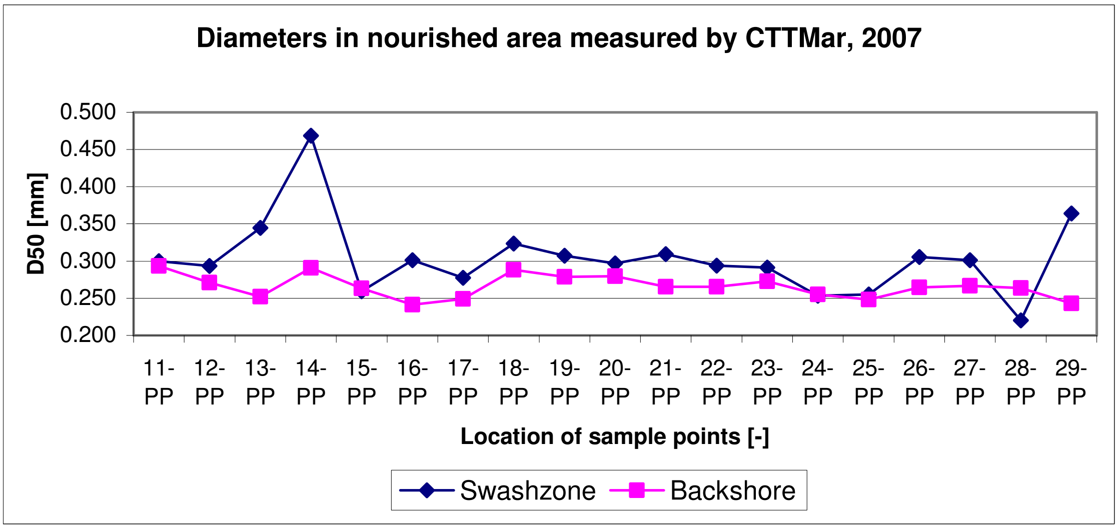


Figure V - 6 Diameters in nourished area measured by CTTMar, 2007

To determine characteristic grain sizes for several areas, the diameters of the backshore and the swash zone are averaged per sample location. This leads to Figure V - 7.

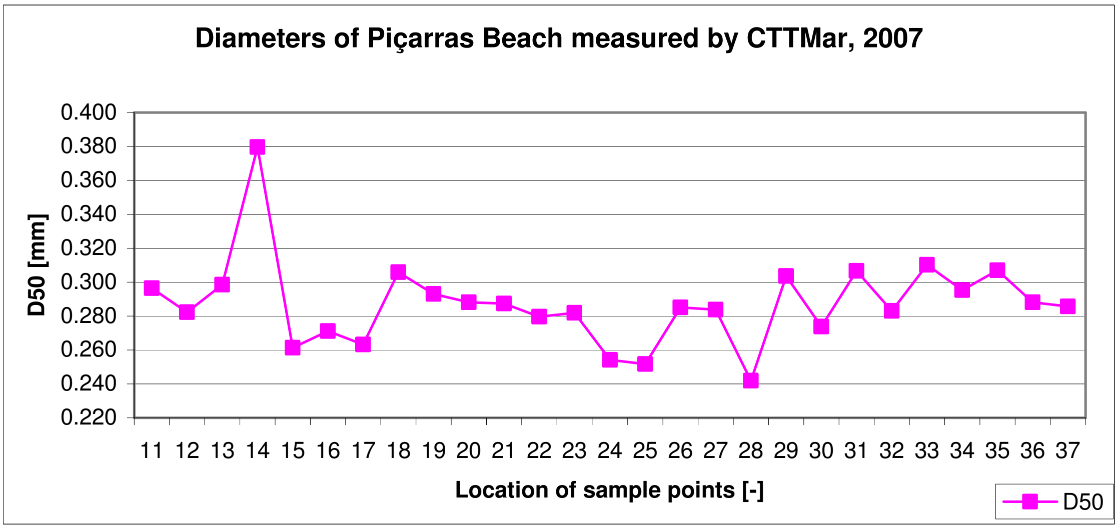


Figure V - 7 Characteristic diameters of Piçarras beach measured by CTTMar, 2007

Like the data from JICA, all the diameters were averaged, after dividing them into two sectors. This leads to an average D_{50} of 0.285mm for the nourished area, which is sample location 11 till 29. The averaging for the section north of the nourished area, using sample location 30 till 37, results in an average D_{50} of 0.298mm.

V.2.3.Comparison of grain sizes

The comparison of grain sizes will be done in two steps. First of all, the grain sizes will be compared per position along the beach. For this the data of JICA, FACIMAR and CTTMar will be used. The second step is comparison of the average diameters. Here also three sources of data are compared.

Table V - 7 until Table V - 10 show the grain sizes in 4 locations. The first location on Alegre beach will not be considered since there is no relevance.

Median diameters of coincident sampling point no. 2

sampling institution	sampling year	sample number	Dm [mm]
JICA	1989	5	0.17
FACIMAR	1994-1996	11	0.29
CTTMar	2007	11	0.30

Table V - 7 Median diameters of coincident sampling point no. 2

Median diameters of coincident sampling point no. 3

sampling institution	sampling year	sample number	Dm [mm]
JICA	1989	7	0.27
FACIMAR	1994-1996	10	0.29
CTTMar	2007	16	0.31

Table V - 8 Median diameters of coincident sampling point no. 3

Median diameters of coincident sampling point no. 4

sampling institution	sampling year	sample number	Dm [mm]
JICA	1989	11	0.20
FACIMAR	1994-1996	8	0.32
CTTMar	2007	28	0.22

Table V - 9 Median diameters of coincident sampling point no. 4

Median diameters of coincident sampling point no. 5

sampling institution	sampling year	sample number	Dm [mm]
JICA	1989	13	0.22
FACIMAR	1994-1996	7	0.34
CTTMar	2007	32	0.26

Table V - 10 Median diameters of coincident sampling point no. 5

Figure V - 8 indicates the location of the coincident sampling points. Coincident sampling point no. 4 is on the border between the area nourished and the area north of the nourishment. Location 5 is north of the nourishment of 1999.

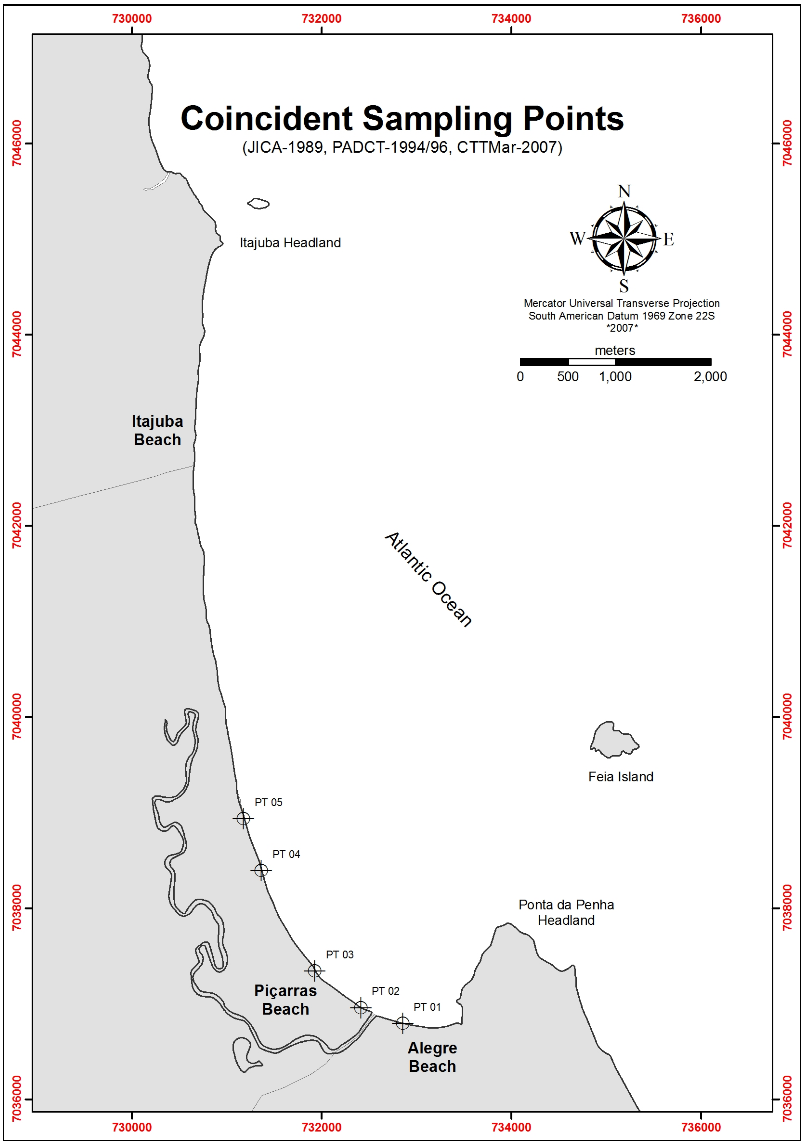


Figure V - 8 Location of coincident sampling points [2]

In Table V - 11 the average sediment sizes previously calculated are collected.

Comparison of grain sizes per period and location

samples	area	D50 [mm]	D90 [mm]	Dm [m]	ws [m/s]
JICA	5-11, nourish area	0.228			0.021
JICA	12-26, north of nourish area	0.292			0.030
FACIMAR	8-11, nourish area			0.304	
FACIMAR	7, north of nourish area			0.340	
CTTMar	11-29, nourish area	0.285	0.605	0.290	0.029
CTTMar	30-37, north of the nourish area	0.298	0.566	0.313	0.030

Table V - 11 Comparison of grain sizes per period and location

Comparing the data from CTTMar with the data from JICA and FACIMAR, it could be concluded that the sand in the nourished area became coarser after the nourishment. This means the grain size of the sediment used for the previous nourishment was coarser than the native sand. In the last nine years probably some fines are washed out by wave action.

It can therefore be concluded that the sediment in the borrow pit a slightly finer than the sediment now present at Piçarras, say D_{50} = 0.260mm [23]

The fact that the sand is coarser in the north than in the south can be explained by the higher wave energy in the north. The fines have been transported elsewhere, while the coarser grains cause a steeper beach.

V.3 Eroded volumes

V.3.1.Introduction

There are several ways to calculate the volumes sand that eroded throughout the years. The methods applied in this chapter use historical data. With nourishment data, and data from before this nourishment, shoreline changes were calculated. Also volumes from before and after the nourishment will be analysed using the cross-sections from 21 profiles. Finally, the calculated volumes will be compared to find a governing erosion rate, which will be used for validation of the computermodels and the design of the nourishment.

V.3.2.Sub-aereal volumes

One way of getting a first feeling with the eroded volumes is the use of dry volumes. This means that the sand volume above mean sea level is calculated and compared. The results are shown in Figure V - 9.

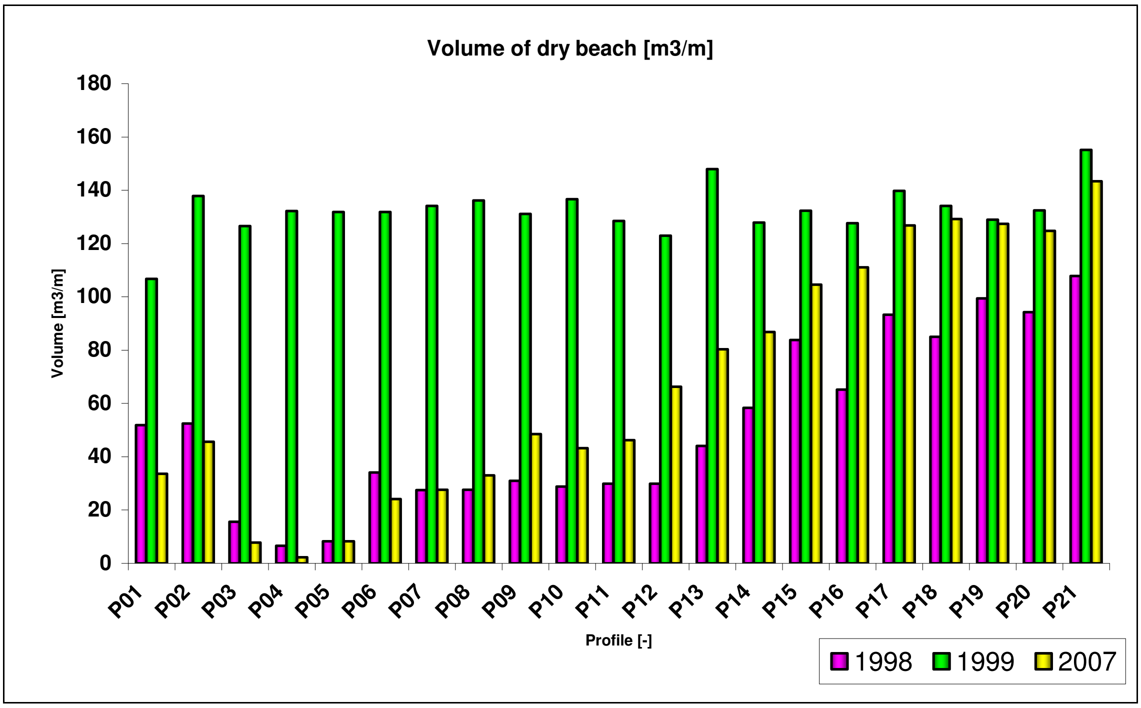


Figure V - 9 Volumes of sand present in the area above mean sea level per measured profile

It is visible that the total volume of 2007 is larger than the volume present in 1998. About half of the volume placed in 1999 is gone in 2007.

It should be noted that this is just for a first indication, since the method has its shortcomings. The volume present above the waterline gives no indication for the spreading under the water.

For example, there could have been a berm in 1998, which was leveled out by the nourishment and is not (yet) restored. This means the difference in sand volume present in 1998 and 2007 might be bigger than this method indicates.

Just to get an indication, the volumes have been determined and are visualised in Table V - 12.

Volumes of sand present per profile in the area above mean sea level

profile number	volume in 1998 [m3/m]	volume in 1999 [m3/m]	volume in 2007 [m3/m]
P01	7.783	16.004	5.045
P02	7.863	20.686	6.839
P03	2.344	18.984	1.165
P04	986	19.837	335
P05	1.250	19.782	1.251
P06	5.121	19.771	3.616
P07	4.129	20.127	4.134
P08	4.137	20.435	4.949
P09	4.647	19.675	7.273
P10	4.318	20.489	6.484
P11	4.487	19.267	6.936
P12	4.490	18.435	9.944
P13	6.610	22.185	12.045
P14	8.754	19.176	13.018
P15	12.580	19.854	15.697
P16	9.772	19.150	16.655
P17	14.000	20.975	19.016
P18	12.749	20.117	19.381
P19	14.922	19.341	19.105
P20	14.132	19.871	18.721
P21	16.172	23.269	21.499
Total	161.246	417.430	213.108

Table V - 12 Volumes of sand present in the area above mean sea level in 1998, 1999 and 2007

According to these data, 256,184 m^3 sand has been placed above the waterlevel during the nourishment. Since the nourishment 204,322 m^3 has dissapeared. This sand has been displaced to below the waterline. If this sand is within the closure depth, it still serves a purpose to reduce wave energy and serves as a storm buffer. When the sand has been placed outside the closure depth, the sand is lost and serves no purpose anymore.

V.3.3.Shoreline changes

The shoreline changes are determined using historical photos, remote sensing, maps and bathymetrical charts and beach profiles [2]. On all the photos and maps the interface between water and land is detected. These lines are compared to one another to determine the change in a certain time period.

The results after analysing photos and measurements are visualised in Figure V - 10. Only the nourished profiles have been shown, since these are most relevant.

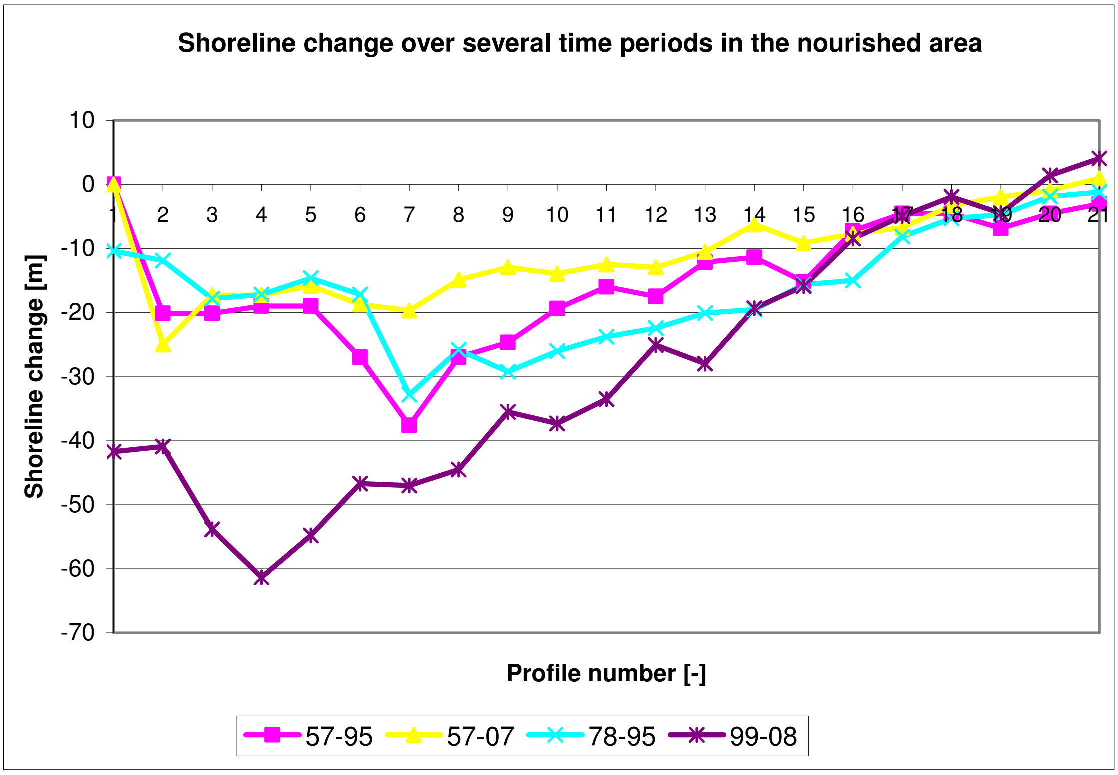


Figure V - 10 Shoreline changes over several time periods in the nourished area

It is visible that in 1999 until 2008 the erosion is highest, especially in the profiles near the river jetty. In the northern area of Piçarras beach the shore line changes are almost equal, though this is over a different time period.

Figure V - 11 gives the shoreline changes per year, which makes it easy to compare them. These are taken from three years only, to make a simplified comparison. It is easy to see that the shoreline changes have increased throughout the years until 1995. The coast seems almost stable from 1957 until 1995. After the nourishment the southern part of the shoreline has decreased faster than before the nourishment. In the northern area, the shoreline has decreased slower. There is an obvious peak in shoreline change around profile 5.

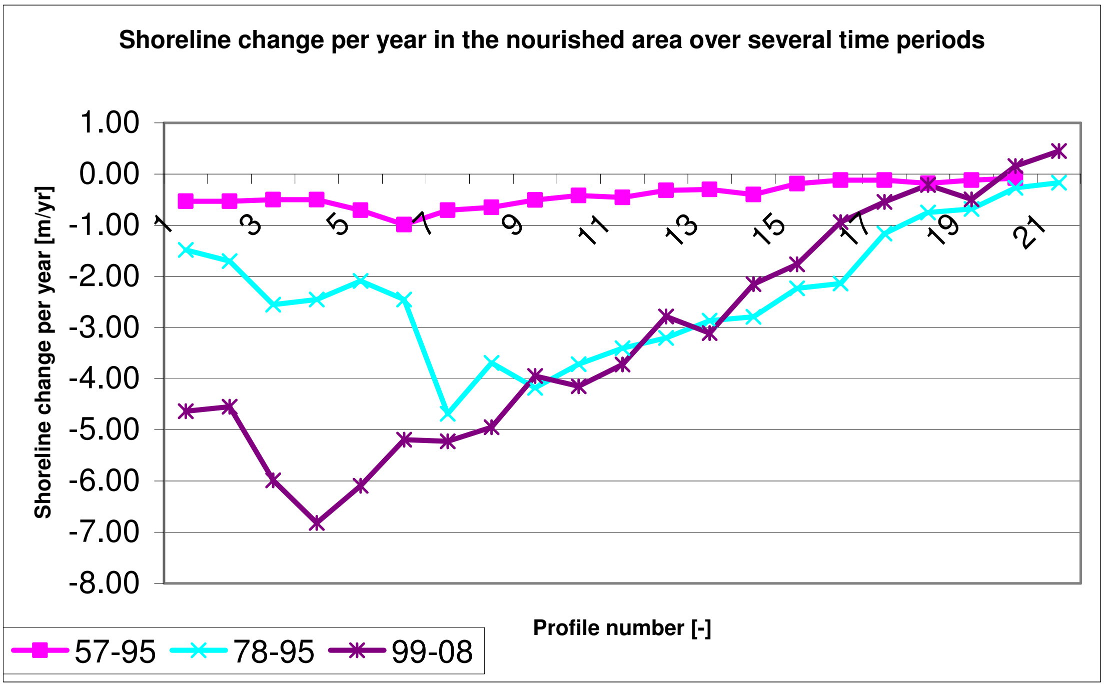


Figure V - 11 Shoreline change per year in the nourished area over several time periods

With these data an estimate of the eroded volumes can be made using the following formula. This calculation has been made for the most recent data, from 1999 till 2008. The results are given in Table V - 13.

$$EV = (d_* + B) \times SLC$$

Where:

EV = Eroded volume [m^3/m]

d_* = closure depth [m]

B = berm height, 3.0m

SLC = shoreline change [m]

Calculation of eroded volumes by shoreline changes

profile number	profile	d* [m]	erosion rate [m/yr]	yearly erosion	eroded volume	total eroded volume
P01	150	2.36	-5.21	27.97	4,197	25,181
P02	100	2.46	-5.11	27.90	2,791	25,116
P03	100	2.54	-6.73	37.32	3,732	33,589
P04	100	2.57	-7.67	42.72	4,273	38,454
P05	100	2.67	-6.85	38.84	3,885	34,962
P06	100	2.77	-5.83	33.65	3,366	30,292
P07	100	2.82	-5.87	34.20	3,420	30,784
P08	100	2.91	-5.56	32.87	3,288	29,590
P09	100	2.97	-4.44	26.50	2,651	23,855
P10	100	2.94	-4.66	27.74	2,774	24,966
P11	100	3.05	-4.18	25.33	2,534	22,803
P12	100	2.99	-3.13	18.76	1,877	16,892
P13	100	3.09	-3.50	21.30	2,131	19,178
P14	100	3.18	-2.41	14.94	1,494	13,446
P15	100	2.86	-1.98	11.64	1,164	10,477
P16	100	3.37	-1.05	6.72	672	6,050
P17	100	3.59	-0.61	4.06	406	3,654
P18	100	3.59	-0.24	1.59	160	1,439
P19	100	3.60	-0.55	3.68	369	3,320
P20	100	3.54	0.17	-1.15	0	0
P21	50	3.38	0.50	-3.22	0	0
Mean		3.01	-3.57			
Total	2,100				45,182	394,047

Table V - 13 Calculation of eroded volumes by shoreline changes

The last two profiles, profile 20 and 21, have a positive shoreline change, which means there has been accretion. To make sure there are only eroded volumes used, these profiles have been set to an erosion of $0m^3$. These calculations lead to an eroded volume of $394,047m^3$.

V.3.4.Profile changes

Every month the beach profiles are measured until a depth of about 1.5 m [2]. These profiles have been plotted together with the profiles of 1998 (pré-nourishment) and 1999 (post-nourishment). In Figure V - 12, Figure V - 13 and Figure V - 14 these profiles are shown, from ray 1 until 21, the nourished area.

Using these pictures, the eroded volume has been determined. This is done by determining the surface area between the line and the closure depth. The volume below the multiple coloured lines (2008) has been substracted from the volume below the pink line (1999). The results of these calculations are shown in Table V - 14.

Again the profiles where accretion has occurred have not been taken into account for the calculation of the eroded volume.

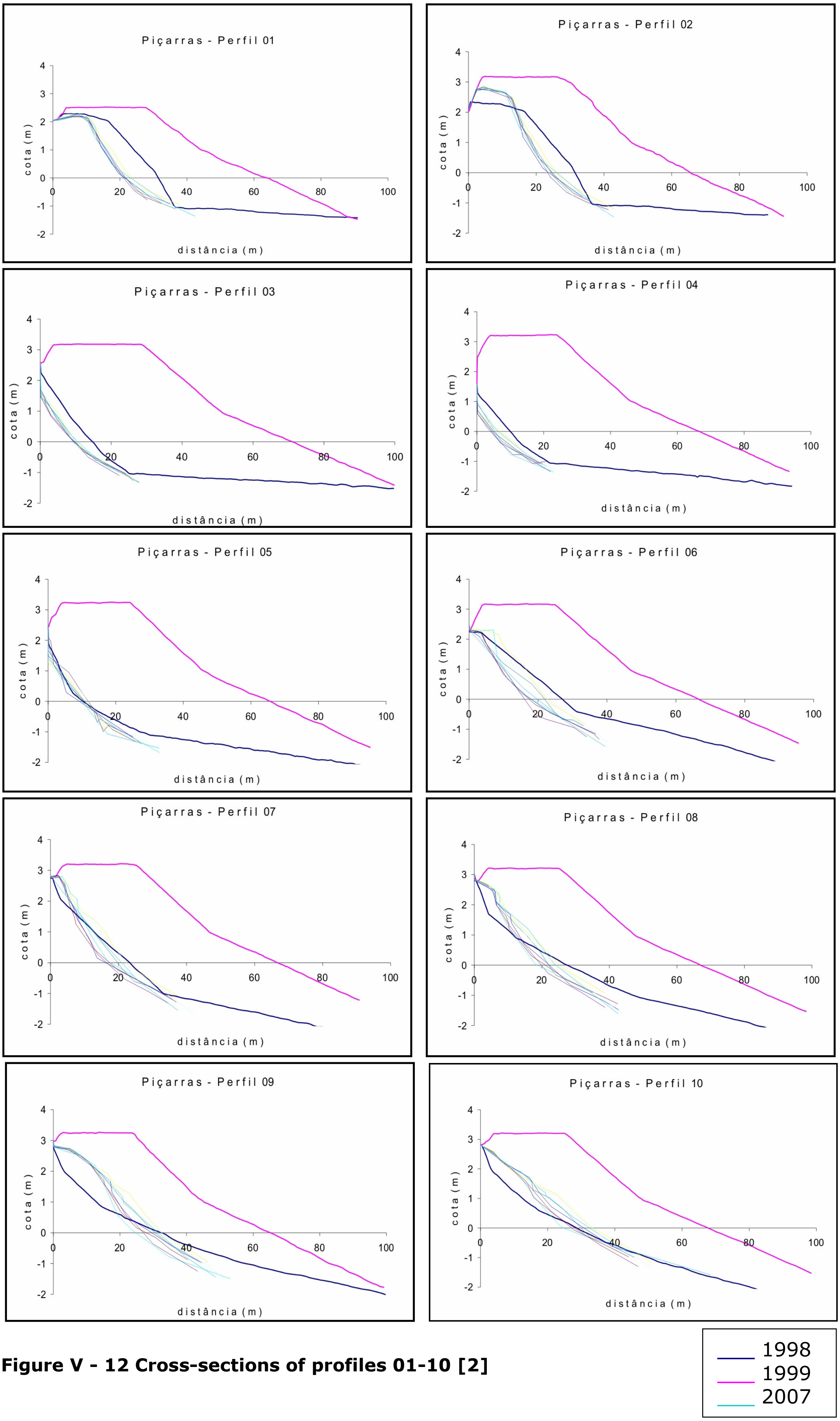


Figure V - 12 Cross-sections of profiles 01-10 [2]

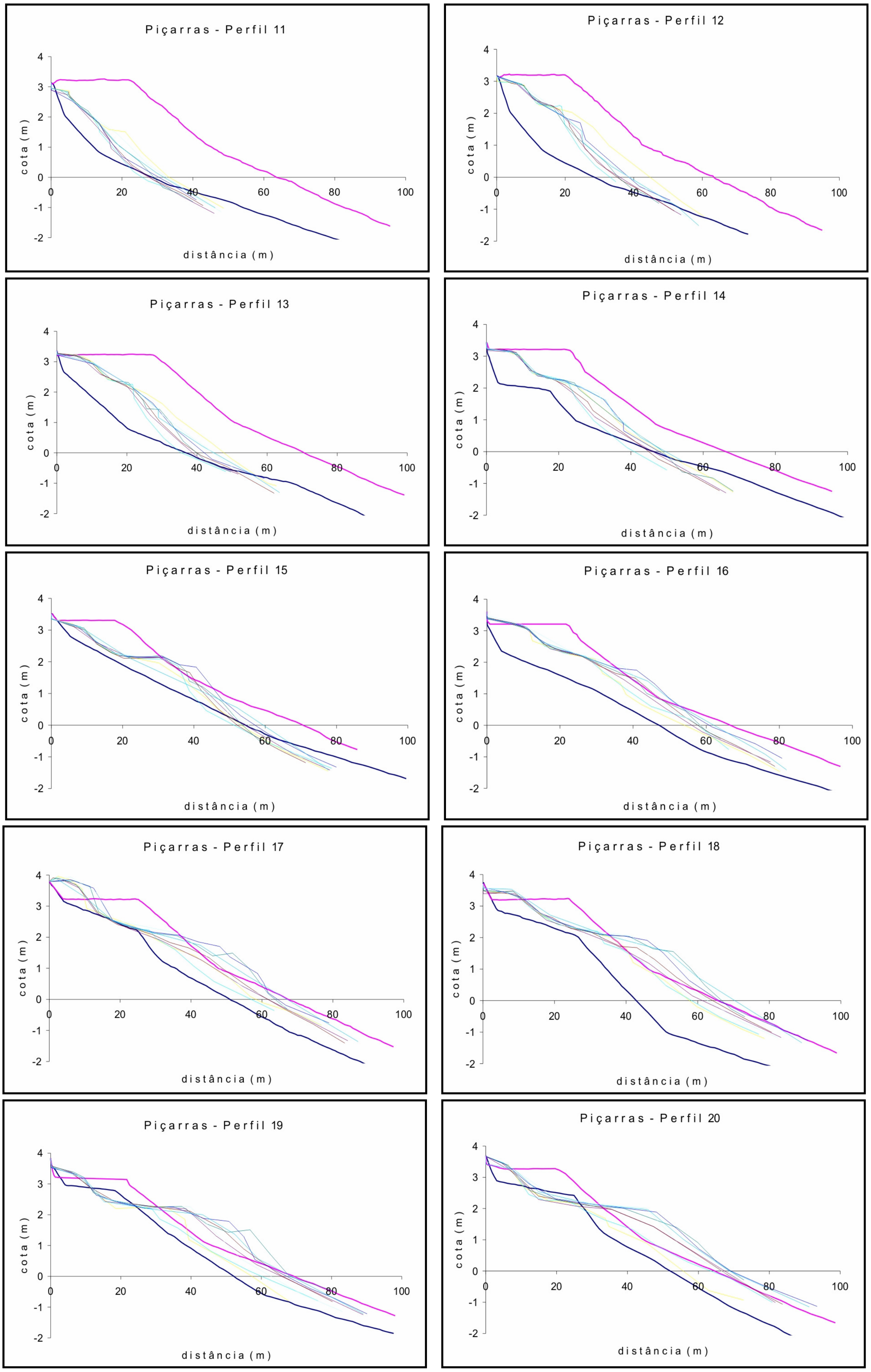
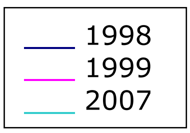


Figure V - 13 Cross-sections of profiles 11-20 [2]



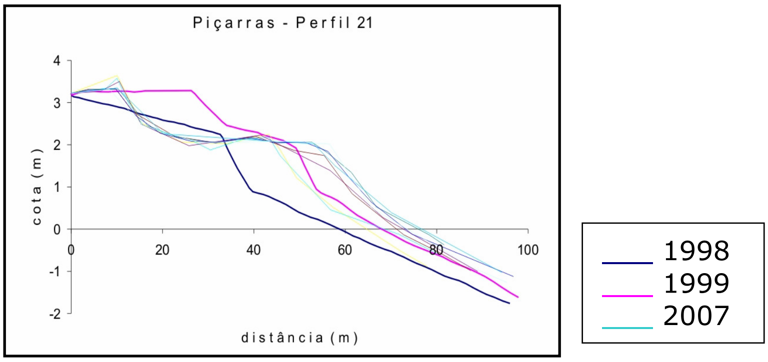


Figure V - 14 Cross-sections of profile 21 [2]

Volumes present in the cross-section of profiles 1-21

profile number	d* [m]	volume	volume 2008 [m2]	volume 1999	volume 2008	volume eroded [m3]
P01	2.36	348	165	52,238	24,773	27,465
P02	2.46	447	197	44,668	19,671	24,997
P03	2.54	400	96	39,972	9,626	30,346
P04	2.57	364	87	36,361	8,680	27,681
P05	2.67	383	109	38,310	10,867	27,443
P06	2.77	388	154	38,760	15,444	23,316
P07	2.82	407	158	40,681	15,774	24,907
P08	2.91	417	170	41,695	16,968	24,727
P09	2.97	407	179	40,724	17,869	22,855
P10	2.94	425	203	42,507	20,326	22,181
P11	3.05	418	196	41,784	19,631	22,153
P12	2.99	398	259	39,846	25,891	13,955
P13	3.09	459	279	45,900	27,900	18,000
P14	3.18	469	299	46,900	29,900	17,000
P15	2.86	480	337	48,000	33,700	14,300
P16	3.37	491	393	49,100	39,300	9,800
P17	3.59	510	456	51,000	45,600	5,400
P18	3.59	493	461	49,300	46,100	3,200
P19	3.60	518	484	51,800	48,400	3,400
P20	3.54	500	465	50,000	46,500	3,500
P21	3.38	435	439	21,750	219,500	-200
Total		9,156	5,586	911,296	544,87	366,626

Table V - 14 Calculation of eroded volumes by comparison of volumes present in the cross-sections of the measured profiles

From these calculations the eroded volume is established to be 366,626 m^3 in a period of 9 years.

V.3.5.Conclusion

The erosion rates of the above mentioned methods are compared to establish a governing erosion rate. This number will be used for UB and SMC, as well for the design of the nourishment.

In Table V - 15 the results are presented per method.

Eroded volume per method

method	eroded volume [m3]
sub-aereal volumes	204,323
shoreline changes	394,047
profile changes	366,626

Table V - 15 Eroded volumes per method

The erosion calculated with the sub-aereal volumes is just an indication, since it does not take the sand volumes under water into account. It also gives no explanation where the sand has gone, whether it stayed inside the closure depth or went outside.The last two methods result in a comparable eroded volume. Therefore the largest volume will be chosen. This means the eroded volume from 1999 until 2008 is 395,000 m^3.

VI. UNIBEST-CL+

VI.1 Introduction

This Appendix is about Unibest (UB). With the help of the program large scale morphology and coastal erosion can be analyzed. It is a very useful tool for predicting coastline changes. One of our main goals is to get insight in the causes of the structural erosion. UB can help to find these causes. Another goal is to use the program to predict the behaviour of the Prosul plan and the nourishment that will be designed by the authors of this report. In that way it is possible to criticize and to improve the nourishments.

There are different versions of UB available. For this project the CL+ version will be used, which is designed for the simulation of coastline changes due to longshore sediment transport gradients. Because of the orientation of Piçarras beach longshore gradients are expected to be responsible for the erosion problems. Cross-shore sediment transport will be investigated too. This can be simulated in the CL+ version in a schematized way.

VI.2 Program description

The program exists of two parts. The longshore-module (LT-module) is designed to compute tide- and wave-induced longshore currents and sediment transport on any beach or arbitrary profile. The model transforms nearshore wave data to the coast, taking into account bottom refraction, shoaling and dissipation by wave breaking and bottom friction. The results of the LT-calculation will be transferred to a function that describes the integrated longshore transport as function of the coastline orientation. The result from the LT-module is input for the coastline-module of the program (CL-module).

The CL-module is designed to compute coastline changes due to longshore sediment transport gradients of an alongshore nearly uniform coast, which can be computed with the output of the LT-module. This is done on the basis of the single line theory (by Pelnard Considère 1957), see Figure VI - 1.

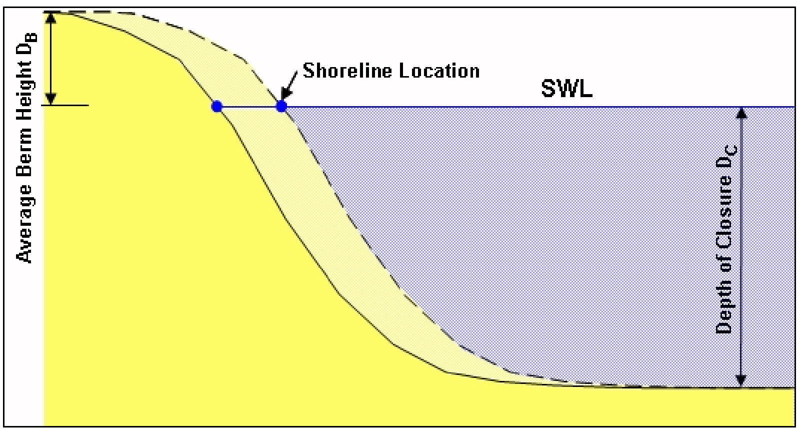


Figure VI - 1 Single line theory [17]

The single line theory schematizes the coastline into a single line. The displacement of this line is described as a function of time and longshore position. In this way the beach profile moves parallel to its old position, without changing its shape during erosion or accretion. Only the bottom profile within the active profile height will move. This height is the total of the depth of closure and the berm, see Figure VI - 1. The shoreward limit is located at the top of the active profile. As a consequence of this only longshore sediment transport can be taken into account and the beach profile is always in equilibrium. The CL-module is capable of modelling the morphological effects of various engineering measures like groynes, jetties, headlands, breakwaters and beach nourishments.

Piçarras was nourished in 1999. There is data from this point and there are measurements from the beach from August 2007 until April 2008. With these data the model can be checked on its reliability.

VI.3 Input LT-module

The input will be summed up in the order that is used while using the program.

VI.3.1. Cross-shore profiles and closure depth

Though Piçarras is not a nearly uniform coast UB can be useful. This non-uniformity is tried to solve by taking a lot of cross-sections. The transition between these cross-sections can be considered as uniform. A cross-shore profile must be defined along the normal of a coast section. Piçarras beach is split up in 26 cross-sections and Alegre beach in 4 cross-sections. These cross-shore profiles are used to get a good representation of the bathymetry. The locations of these profiles are determined by on-shore measurements [25] and are represented in Figure VI - 2. Only this part of the Itapocorói bay was modelled, because only from these 30 locations onshore measurements were available. These measurements stop around 1-2m below mean sea-level. ArcGIS was able to couple these onshore measurements with nearshore bathymetry (Appendix I). The input is given in Box VI - 1 until Box VI - 11. Besides the cross-sections the closure depth has to be given. The closure depth is determined for each cross-section and can be found in Appendix IV. For UB the distance from the seaward boundary until the closure depth is of importance.

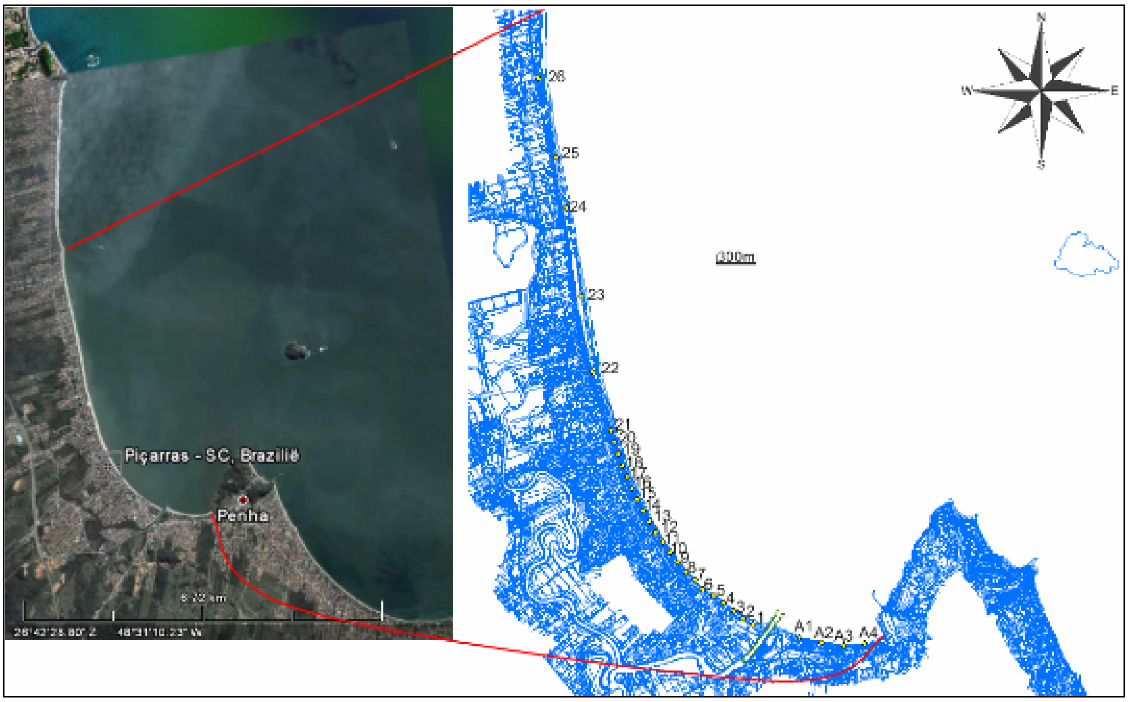


Figure VI - 2 Modelled area. Note that both figures have a different scale. [16][34]

Profiel 1		Profiel 2		Profiel 3		Profiel 4		Profiel 5		Profiel 6		Profiel 7		Profiel 8		Profiel 9		Profiel 10		Profiel 11		Profiel 12	
x [m]	depth [m]	x [m]	depth [m]	x [m]	depth [m]	x [m]	depth [m]	x [m]	depth [m]	x [m]	depth [m]	x [m]	depth [m]	x [m]	depth [m]	x [m]	depth [m]	x [m]	depth [m]	x [m]	depth [m]	x [m]	depth [m]
0.000	6.238	0.000	6.181	0.000	6.152	0.000	6.130	0.000	6.084	0.000	6.085	0.000	6.043	0.000	5.863	0.000	6.038	0.000	6.226	0.000	6.282	0.000	6.256
5.000	6.235	5.000	6.173	5.000	6.144	5.000	6.122	5.000	6.076	5.000	6.073	5.000	6.016	5.000	5.841	5.000	6.024	5.000	6.210	5.000	6.261	5.000	6.238
10.000	6.226	15.000	6.164	15.000	6.135	10.000	6.114	10.000	6.069	10.000	6.063	15.000	5.982	10.000	5.819	15.000	6.001	10.000	6.206	10.000	6.248	15.000	6.212
15.000	6.215	20.000	6.155	20.000	6.127	15.000	6.106	20.000	6.047	15.000	6.054	20.000	5.966	15.000	5.811	20.000	5.990	15.000	6.194	20.000	6.219	20.000	6.202
20.000	6.206	30.000	6.138	30.000	6.110	20.000	6.099	25.000	6.041	20.000	6.037	25.000	5.939	20.000	5.809	30.000	5.967	20.000	6.177	25.000	6.207	30.000	6.175
25.000	6.204	35.000	6.128	35.000	6.102	25.000	6.091	30.000	6.034	25.000	6.030	40.000	5.899	25.000	5.810	35.000	5.957	25.000	6.164	35.000	6.175	35.000	6.168
30.000	6.196	40.000	6.119	45.000	6.084	30.000	6.083	40.000	6.020	30.000	6.023	45.000	5.894	30.000	5.815	45.000	5.941	30.000	6.148	40.000	6.160	45.000	6.142
35.000	6.186	50.000	6.106	50.000	6.073	35.000	6.068	45.000	6.014	35.000	6.016	55.000	5.886	35.000	5.817	50.000	5.934	35.000	6.136	55.000	6.119	50.000	6.126
40.000	6.185	55.000	6.095	60.000	6.056	40.000	6.060	55.000	5.994	40.000	6.004	65.000	5.875	40.000	5.819	60.000	5.925	40.000	6.119	60.000	6.101	60.000	6.104
45.000	6.175	60.000	6.085	65.000	6.045	45.000	6.052	60.000	5.987	45.000	5.998	70.000	5.873	45.000	5.823	65.000	5.922	45.000	6.107	65.000	6.090	65.000	6.095
50.000	6.163	70.000	6.071	75.000	6.027	50.000	6.044	65.000	5.980	50.000	5.992	75.000	5.866	50.000	5.825	75.000	5.922	50.000	6.096	70.000	6.083	75.000	6.074
55.000	6.153	80.000	6.049	80.000	6.016	55.000	6.036	70.000	5.973	55.000	5.986	80.000	5.865	55.000	5.827	80.000	5.922	55.000	6.085	85.000	6.040	80.000	6.060
60.000	6.150	90.000	6.025	85.000	6.013	60.000	6.027	75.000	5.967	60.000	5.974	95.000	5.857	60.000	5.830	90.000	5.929	60.000	6.074	90.000	6.031	85.000	6.051
65.000	6.139	95.000	6.015	95.000	5.992	65.000	6.019	85.000	5.952	65.000	5.968	100.000	5.858	65.000	5.831	95.000	5.929	65.000	6.056	95.000	6.016	90.000	6.037
70.000	6.126	100.000	6.008	100.000	5.982	70.000	6.011	90.000	5.940	70.000	5.962	105.000	5.856	70.000	5.832	100.000	5.932	70.000	6.045	100.000	6.010	95.000	6.028
75.000	6.124	110.000	5.983	110.000	5.959	75.000	6.001	95.000	5.933	75.000	5.957	110.000	5.852	75.000	5.835	105.000	5.931	75.000	6.034	115.000	5.979	105.000	6.009
80.000	6.110	115.000	5.971	115.000	5.945	80.000	5.993	100.000	5.927	80.000	5.951	115.000	5.851	80.000	5.835	110.000	5.928	80.000	6.017	120.000	5.965	110.000	5.995
85.000	6.099	125.000	5.951	120.000	5.935	85.000	5.985	105.000	5.918	85.000	5.940	125.000	5.848	85.000	5.836	120.000	5.919	85.000	6.007	125.000	5.957	115.000	5.987
90.000	6.093	130.000	5.939	125.000	5.924	95.000	5.966	115.000	5.903	95.000	5.929	130.000	5.844	90.000	5.838	125.000	5.912	90.000	5.993	130.000	5.947	120.000	5.977
95.000	6.081	135.000	5.923	130.000	5.909	100.000	5.958	120.000	5.896	100.000	5.923	135.000	5.843	100.000	5.839	135.000	5.901	95.000	5.984	140.000	5.926	125.000	5.969
100.000	6.066	145.000	5.892	140.000	5.887	110.000	5.937	125.000	5.883	110.000	5.908	145.000	5.839	105.000	5.840	140.000	5.893	100.000	5.980	145.000	5.918	135.000	5.948
105.000	6.053	155.000	5.868	145.000	5.870	115.000	5.928	135.000	5.864	115.000	5.902	150.000	5.836	115.000	5.840	150.000	5.877	105.000	5.967	150.000	5.905	140.000	5.938
110.000	6.046	160.000	5.855	150.000	5.859	125.000	5.906	145.000	5.847	120.000	5.896	155.000	5.834	120.000	5.841	155.000	5.871	110.000	5.959	155.000	5.897	145.000	5.930
120.000	6.016	165.000	5.835	155.000	5.841	130.000	5.896	150.000	5.838	130.000	5.880	160.000	5.833	125.000	5.841	160.000	5.864	115.000	5.946	160.000	5.892	150.000	5.918
125.000	6.011	175.000	5.807	160.000	5.836	140.000	5.872	155.000	5.825	135.000	5.874	170.000	5.826	135.000	5.842	165.000	5.853	120.000	5.939	165.000	5.880	155.000	5.910
130.000	5.993	180.000	5.793	170.000	5.805	145.000	5.862	160.000	5.811	140.000	5.868	175.000	5.823	140.000	5.841	170.000	5.846	125.000	5.931	170.000	5.872	165.000	5.893
140.000	5.960	190.000	5.757	175.000	5.792	155.000	5.835	170.000	5.792	150.000	5.851	180.000	5.821	145.000	5.841	180.000	5.829	130.000	5.919	175.000	5.859	170.000	5.885
145.000	5.955	195.000	5.742	185.000	5.759	160.000	5.819	175.000	5.777	155.000	5.844	185.000	5.817	155.000	5.841	185.000	5.821	135.000	5.912	180.000	5.851	175.000	5.873
150.000	5.934	200.000	5.719	190.000	5.746	170.000	5.797	180.000	5.767	160.000	5.834	200.000	5.805	160.000	5.840	190.000	5.807	140.000	5.900	185.000	5.838	180.000	5.868
160.000	5.906	205.000	5.704	195.000	5.725	175.000	5.779	190.000	5.747	170.000	5.816	205.000	5.801	165.000	5.839	195.000	5.798	145.000	5.896	190.000	5.834	185.000	5.856
165.000	5.891	215.000	5.671	200.000	5.711	185.000	5.756	195.000	5.732	175.000	5.808	215.000	5.792	175.000	5.834	200.000	5.789	150.000	5.884	200.000	5.813	195.000	5.837
170.000	5.869	220.000	5.646	205.000	5.697	190.000	5.737	200.000	5.715	190.000	5.784	220.000	5.787	180.000	5.829	210.000	5.763	155.000	5.877	205.000	5.804	200.000	5.829
175.000	5.854	225.000	5.629	215.000	5.660	195.000	5.725	205.000	5.703	195.000	5.773	225.000	5.782	190.000	5.819	215.000	5.753	160.000	5.869	210.000	5.792	205.000	5.820
180.000	5.838	235.000	5.593	220.000	5.644	205.000	5.699	215.000	5.680	200.000	5.759	235.000	5.770	195.000	5.808	225.000	5.725	165.000	5.857	215.000	5.787	210.000	5.812
185.000	5.822	240.000	5.576	230.000	5.605	210.000	5.679	220.000	5.668	210.000	5.741	240.000	5.765	205.000	5.790	230.000	5.707	170.000	5.849	220.000	5.774	215.000	5.800
190.000	5.798	245.000	5.548	235.000	5.580	220.000	5.652	225.000	5.649	215.000	5.729	245.000	5.750	210.000	5.779	235.000	5.696	175.000	5.836	225.000	5.765	225.000	5.783
195.000	5.789	250.000	5.531	240.000	5.570	225.000	5.629	230.000	5.631	225.000	5.709	250.000	5.741	215.000	5.759	240.000	5.685	180.000	5.828	230.000	5.752	230.000	5.775
200.000	5.764	260.000	5.484	245.000	5.554	230.000	5.615	240.000	5.605	235.000	5.685	260.000	5.719	225.000	5.733	245.000	5.667	185.000	5.820	235.000	5.743	235.000	5.763
205.000	5.748	265.000	5.462	250.000	5.527	240.000	5.577	245.000	5.583	250.000	5.644	265.000	5.706	230.000	5.712	255.000	5.643	190.000	5.810	240.000	5.730	240.000	5.755
210.000	5.729	270.000	5.444	260.000	5.482	245.000	5.561	250.000	5.568	260.000	5.616	270.000	5.692	240.000	5.685	260.000	5.625	195.000	5.802	245.000	5.725	245.000	5.746
215.000	5.712	275.000	5.426	265.000	5.465	250.000	5.546	260.000	5.539	265.000	5.603	275.000	5.672	245.000	5.663	265.000	5.618	200.000	5.788	250.000	5.716	255.000	5.725
220.000	5.685	285.000	5.378	270.000	5.447	260.000	5.503	265.000	5.519	270.000	5.590	290.000	5.620	250.000	5.650	270.000	5.600	205.000	5.780	260.000	5.693	260.000	5.717
225.000	5.668	290.000	5.356	275.000	5.418	265.000	5.487	270.000	5.492	280.000	5.547	295.000	5.604	260.000	5.614	275.000	5.588	210.000	5.771	265.000	5.679	270.000	5.700
230.000	5.647	295.000	5.337	280.000	5.399	270.000	5.463	275.000	5.476	285.000	5.532	305.000	5.573	265.000	5.600	285.000	5.556	215.000	5.756	270.000	5.669	275.000	5.687
235.000	5.629	300.000	5.307	290.000	5.350	275.000	5.435	285.000	5.441	305.000	5.461	310.000	5.552	275.000	5.564	290.000	5.544	220.000	5.747	275.000	5.659	280.000	5.678
240.000	5.601	310.000	5.257	295.000	5.331	285.000	5.399	290.000	5.423	320.000	5.397	315.000	5.537	280.000	5.550	295.000	5.531	225.000	5.732	280.000	5.649	285.000	5.665
245.000	5.590	315.000	5.238	300.000	5.301	290.000	5.368	295.000	5.392	345.000	5.312	320.000	5.512	285.000	5.535	300.000	5.511	230.000	5.722	290.000	5.624	290.000	5.660
250.000	5.561	320.000	5.215	305.000	5.281	295.000	5.349	305.000	5.348	355.000	5.284	325.000	5.490	295.000	5.497	305.000	5.498	235.000	5.712	295.000	5.614	300.000	5.637

Box VI - 1 Cross-sections from profiles 1-12 part 1/4

255.000	5.543	325.000	5.195	310.000	5.262	300.000	5.330	310.000	5.329	370.000	5.240	335.000	5.458	300.000	5.482	310.000	5.478	240.000	5.701	300.000	5.599	305.000	5.628
260.000	5.515	335.000	5.145	320.000	5.219	320.000	5.241	315.000	5.297	375.000	5.232	345.000	5.418	305.000	5.459	315.000	5.465	245.000	5.691	305.000	5.594	310.000	5.619
265.000	5.504	340.000	5.125	325.000	5.200	330.000	5.189	320.000	5.278	385.000	5.220	350.000	5.400	315.000	5.429	320.000	5.451	250.000	5.675	310.000	5.578	315.000	5.610
270.000	5.475	350.000	5.083	330.000	5.169	340.000	5.137	330.000	5.239	395.000	5.185	355.000	5.383	320.000	5.405	325.000	5.431	255.000	5.665	315.000	5.568	320.000	5.595
275.000	5.457	355.000	5.052	335.000	5.149	350.000	5.098	335.000	5.213	405.000	5.126	365.000	5.340	325.000	5.389	330.000	5.417	260.000	5.655	320.000	5.552	330.000	5.576
280.000	5.435	365.000	5.001	340.000	5.118	355.000	5.078	340.000	5.179	410.000	5.094	370.000	5.322	330.000	5.374	335.000	5.403	265.000	5.638	325.000	5.542	335.000	5.567
285.000	5.417	370.000	4.981	345.000	5.099	365.000	5.028	345.000	5.159	420.000	5.049	380.000	5.278	340.000	5.334	340.000	5.383	270.000	5.628	335.000	5.520	340.000	5.552
290.000	5.388	375.000	4.957	350.000	5.079	370.000	5.009	355.000	5.117	425.000	5.027	385.000	5.260	345.000	5.318	350.000	5.348	275.000	5.611	340.000	5.510	345.000	5.543
295.000	5.369	380.000	4.937	355.000	5.048	380.000	4.959	360.000	5.096	430.000	5.005	395.000	5.214	350.000	5.294	355.000	5.341	280.000	5.600	345.000	5.494	350.000	5.533
300.000	5.347	385.000	4.917	365.000	4.997	385.000	4.932	365.000	5.061	435.000	4.976	400.000	5.187	355.000	5.277	360.000	5.327	285.000	5.589	350.000	5.483	360.000	5.508
305.000	5.329	395.000	4.865	370.000	4.978	395.000	4.882	375.000	5.009	440.000	4.941	405.000	5.169	360.000	5.261	365.000	5.305	290.000	5.578	355.000	5.466	365.000	5.498
310.000	5.299	405.000	4.820	375.000	4.958	400.000	4.863	380.000	4.988	445.000	4.919	410.000	5.150	365.000	5.236	370.000	5.291	295.000	5.567	360.000	5.455	370.000	5.489
315.000	5.288	410.000	4.787	380.000	4.927	405.000	4.844	385.000	4.959	455.000	4.870	415.000	5.124	370.000	5.219	375.000	5.276	300.000	5.550	365.000	5.445	375.000	5.479
320.000	5.258	415.000	4.767	385.000	4.907	415.000	4.794	395.000	4.924	465.000	4.828	425.000	5.086	375.000	5.202	380.000	5.254	305.000	5.538	370.000	5.433	380.000	5.464
325.000	5.239	430.000	4.700	390.000	4.895	420.000	4.775	400.000	4.908	470.000	4.807	430.000	5.067	380.000	5.178	385.000	5.239	310.000	5.521	380.000	5.405	390.000	5.438
330.000	5.216	435.000	4.667	395.000	4.864	425.000	4.744	405.000	4.891	480.000	4.745	435.000	5.040	385.000	5.161	395.000	5.202	315.000	5.510	385.000	5.389	395.000	5.433
340.000	5.168	440.000	4.646	400.000	4.844	435.000	4.706	410.000	4.858	485.000	4.724	440.000	5.021	390.000	5.143	400.000	5.187	320.000	5.498	390.000	5.383	405.000	5.407
345.000	5.138	445.000	4.612	410.000	4.792	440.000	4.676	420.000	4.825	495.000	4.682	445.000	5.002	395.000	5.118	405.000	5.164	325.000	5.480	395.000	5.372	410.000	5.391
350.000	5.126	450.000	4.591	415.000	4.772	445.000	4.657	425.000	4.808	500.000	4.653	455.000	4.956	400.000	5.101	410.000	5.149	330.000	5.474	400.000	5.354	415.000	5.386
355.000	5.096	465.000	4.511	425.000	4.720	450.000	4.638	430.000	4.778	505.000	4.632	460.000	4.937	405.000	5.083	415.000	5.133	335.000	5.457	405.000	5.343	420.000	5.370
360.000	5.077	470.000	4.490	430.000	4.701	465.000	4.571	440.000	4.744	510.000	4.611	465.000	4.906	410.000	5.058	420.000	5.110	340.000	5.444	410.000	5.325	425.000	5.359
370.000	5.035	480.000	4.435	435.000	4.669	470.000	4.553	445.000	4.722	515.000	4.590	470.000	4.878	415.000	5.040	425.000	5.094	345.000	5.432	415.000	5.313	435.000	5.338
375.000	5.005	485.000	4.422	440.000	4.649	475.000	4.522	455.000	4.673	520.000	4.548	475.000	4.859	420.000	5.022	430.000	5.071	350.000	5.414	425.000	5.290	440.000	5.326
380.000	4.985	490.000	4.388	445.000	4.617	480.000	4.504	460.000	4.655	525.000	4.527	485.000	4.819	425.000	4.997	440.000	5.048	355.000	5.402	430.000	5.272	445.000	5.309
385.000	4.962	495.000	4.367	455.000	4.578	485.000	4.486	465.000	4.637	530.000	4.507	490.000	4.792	430.000	4.978	445.000	5.025	360.000	5.383	435.000	5.260	450.000	5.297
390.000	4.942	500.000	4.332	460.000	4.546	500.000	4.421	475.000	4.601	535.000	4.487	495.000	4.772	435.000	4.960	450.000	5.009	365.000	5.370	440.000	5.247	455.000	5.285
400.000	4.898	505.000	4.311	465.000	4.534	505.000	4.397	480.000	4.565	540.000	4.461	500.000	4.752	440.000	4.935	455.000	4.992	370.000	5.358	445.000	5.229	465.000	5.251
405.000	4.865	510.000	4.277	470.000	4.502	510.000	4.368	485.000	4.547	545.000	4.443	505.000	4.724	445.000	4.916	460.000	4.968	375.000	5.346	450.000	5.223	470.000	5.237
410.000	4.844	525.000	4.207	475.000	4.482	515.000	4.350	495.000	4.512	550.000	4.424	515.000	4.685	450.000	4.898	465.000	4.952	380.000	5.333	455.000	5.205	475.000	5.222
415.000	4.811	530.000	4.172	485.000	4.431	520.000	4.333	500.000	4.482	555.000	4.406	520.000	4.665	455.000	4.872	470.000	4.928	385.000	5.314	460.000	5.192	480.000	5.207
420.000	4.799	535.000	4.152	490.000	4.412	530.000	4.287	505.000	4.465	560.000	4.376	525.000	4.638	460.000	4.853	475.000	4.911	390.000	5.301	470.000	5.159	485.000	5.183
425.000	4.766	540.000	4.138	495.000	4.393	535.000	4.271	515.000	4.427	565.000	4.351	530.000	4.619	475.000	4.790	480.000	4.893	395.000	5.282	475.000	5.140	495.000	5.143
435.000	4.719	545.000	4.103	500.000	4.361	540.000	4.242	520.000	4.410	570.000	4.334	535.000	4.600	480.000	4.771	485.000	4.869	400.000	5.268	480.000	5.134	500.000	5.134
440.000	4.697	550.000	4.082	505.000	4.342	545.000	4.226	525.000	4.384	575.000	4.316	545.000	4.542	485.000	4.745	490.000	4.852	405.000	5.255	485.000	5.121	510.000	5.094
445.000	4.663	555.000	4.048	515.000	4.291	550.000	4.210	535.000	4.354	580.000	4.299	550.000	4.523	490.000	4.726	500.000	4.809	410.000	5.235	490.000	5.101	515.000	5.069
450.000	4.650	560.000	4.027	520.000	4.272	555.000	4.194	540.000	4.339	585.000	4.274	555.000	4.504	495.000	4.707	505.000	4.792	415.000	5.221	500.000	5.068	520.000	5.059
455.000	4.615	570.000	3.979	525.000	4.241	560.000	4.166	545.000	4.324	590.000	4.256	560.000	4.478	500.000	4.681	510.000	4.774	420.000	5.209	505.000	5.054	525.000	5.032
465.000	4.556	575.000	3.944	530.000	4.222	565.000	4.150	555.000	4.281	595.000	4.238	565.000	4.459	505.000	4.662	515.000	4.749	425.000	5.195	510.000	5.041	530.000	5.016
470.000	4.542	580.000	3.925	535.000	4.203	570.000	4.135	560.000	4.267	600.000	4.208	575.000	4.421	515.000	4.617	520.000	4.731	430.000	5.181	515.000	5.027	540.000	4.978
475.000	4.505	585.000	3.906	545.000	4.159	575.000	4.108	565.000	4.252	605.000	4.182	580.000	4.394	525.000	4.579	525.000	4.706	435.000	5.161	520.000	5.006	545.000	4.951
480.000	4.482	590.000	3.873	550.000	4.128	580.000	4.093	570.000	4.227	610.000	4.163	585.000	4.374	535.000	4.534	530.000	4.699	440.000	5.147	530.000	4.978	550.000	4.935
485.000	4.454	595.000	3.859	555.000	4.109	585.000	4.078	575.000	4.212	615.000	4.143	590.000	4.354	540.000	4.515	535.000	4.681	445.000	5.126	535.000	4.956	555.000	4.908
495.000	4.391	600.000	3.826	560.000	4.091	590.000	4.051	580.000	4.198	620.000	4.124	595.000	4.326	550.000	4.469	545.000	4.637	450.000	5.112	540.000	4.949	560.000	4.898
500.000	4.367	605.000	3.806	565.000	4.060	595.000	4.036	585.000	4.177	625.000	4.104	605.000	4.285	555.000	4.449	550.000	4.618	455.000	5.097	545.000	4.928	570.000	4.855
505.000	4.337	615.000	3.753	575.000	4.012	600.000	4.022	590.000	4.162	630.000	4.075	610.000	4.252	560.000	4.422	555.000	4.592	470.000	5.049	555.000	4.892	575.000	4.839
515.000	4.271	620.000	3.718	580.000	3.995	605.000	4.007	595.000	4.137	635.000	4.054	615.000	4.223	565.000	4.402	560.000	4.573	480.000	5.019	560.000	4.877	580.000	4.813
520.000	4.255	625.000	3.703	585.000	3.978	610.000	3.980	600.000	4.122	640.000	4.021	620.000	4.201	570.000	4.382	565.000	4.547	495.000	4.960	570.000	4.843	585.000	4.803
525.000	4.214	630.000	3.668	590.000	3.948	615.000	3.966	605.000	4.106	645.000	4.000	625.000	4.180	575.000	4.354	570.000	4.527	500.000	4.944	575.000	4.826	590.000	4.777
530.000	4.189	635.000	3.648	595.000	3.932	620.000	3.949	610.000	4.089	650.000	3.968	630.000	4.149	580.000	4.333	575.000	4.508	510.000	4.916	580.000	4.797	595.000	4.761
535.000	4.148	645.000	3.592	605.000	3.885	625.000	3.922	615.000	4.072	655.000	3.946	635.000	4.127	585.000	4.312	580.000	4.481	515.000	4.900	585.000	4.779	600.000	4.735

Box VI - 2 Cross-sections from profiles 1-12 part 2/4

540.000	4.132	650.000	3.576	610.000	3.868	630.000	3.908	620.000	4.036	660.000	3.923	640.000	4.105	590.000	4.283	585.000	4.461	525.000	4.862	590.000	4.748	605.000	4.726
545.000	4.091	655.000	3.540	615.000	3.841	635.000	3.894	625.000	4.017	665.000	3.901	650.000	4.051	595.000	4.262	590.000	4.441	530.000	4.840	600.000	4.706	615.000	4.684
550.000	4.066	660.000	3.520	620.000	3.824	640.000	3.866	630.000	3.997	670.000	3.867	655.000	4.029	600.000	4.240	595.000	4.414	540.000	4.807	605.000	4.686	620.000	4.659
555.000	4.033	665.000	3.483	625.000	3.807	645.000	3.852	635.000	3.977	675.000	3.844	660.000	4.006	605.000	4.210	600.000	4.395	555.000	4.745	610.000	4.655	625.000	4.649
560.000	4.010	675.000	3.425	635.000	3.758	650.000	3.837	640.000	3.946	680.000	3.808	665.000	3.973	610.000	4.188	605.000	4.367	560.000	4.739	615.000	4.635	630.000	4.624
565.000	3.971	680.000	3.408	640.000	3.741	655.000	3.823	645.000	3.925	685.000	3.784	670.000	3.950	615.000	4.166	610.000	4.347	570.000	4.698	620.000	4.615	635.000	4.608
570.000	3.955	685.000	3.372	645.000	3.709	660.000	3.794	650.000	3.904	690.000	3.760	675.000	3.926	625.000	4.113	615.000	4.327	575.000	4.680	625.000	4.592	645.000	4.574
575.000	3.915	690.000	3.352	650.000	3.691	665.000	3.779	655.000	3.870	695.000	3.725	680.000	3.903	630.000	4.090	620.000	4.312	590.000	4.615	630.000	4.571	650.000	4.550
580.000	3.893	695.000	3.333	655.000	3.658	670.000	3.764	660.000	3.847	700.000	3.700	685.000	3.855	635.000	4.058	625.000	4.292	600.000	4.568	635.000	4.539	655.000	4.533
585.000	3.853	705.000	3.281	665.000	3.622	675.000	3.731	665.000	3.813	705.000	3.675	690.000	3.831	645.000	4.011	630.000	4.271	605.000	4.553	640.000	4.518	660.000	4.508
590.000	3.835	710.000	3.245	670.000	3.588	680.000	3.713	670.000	3.789	710.000	3.651	695.000	3.806	650.000	3.978	635.000	4.243	615.000	4.506	650.000	4.465	665.000	4.501
595.000	3.795	715.000	3.227	675.000	3.569	690.000	3.639	675.000	3.765	715.000	3.614	700.000	3.782	655.000	3.954	640.000	4.222	620.000	4.486	655.000	4.441	670.000	4.477
600.000	3.772	720.000	3.191	680.000	3.549	695.000	3.609	680.000	3.740	720.000	3.574	705.000	3.747	660.000	3.930	645.000	4.193	635.000	4.420	660.000	4.420	675.000	4.459
605.000	3.736	725.000	3.171	685.000	3.514	705.000	3.557	685.000	3.714	725.000	3.549	710.000	3.721	665.000	3.897	650.000	4.172	645.000	4.375	670.000	4.364	680.000	4.435
610.000	3.714	735.000	3.101	695.000	3.461	710.000	3.507	690.000	3.662	730.000	3.523	715.000	3.696	670.000	3.873	655.000	4.150	655.000	4.342	675.000	4.341	690.000	4.405
615.000	3.674	740.000	3.075	700.000	3.441	715.000	3.479	695.000	3.635	735.000	3.496	720.000	3.660	675.000	3.848	660.000	4.120	660.000	4.324	680.000	4.306	695.000	4.386
620.000	3.652	745.000	3.023	710.000	3.381	725.000	3.397	700.000	3.608	740.000	3.458	725.000	3.634	680.000	3.815	665.000	4.098	675.000	4.269	685.000	4.293	700.000	4.361
625.000	3.615	750.000	2.995	715.000	3.355	730.000	3.367	705.000	3.581	745.000	3.431	730.000	3.609	685.000	3.790	670.000	4.076	680.000	4.249	690.000	4.256	705.000	4.341
630.000	3.574	755.000	2.942	720.000	3.309	735.000	3.336	710.000	3.539	750.000	3.405	735.000	3.583	690.000	3.766	675.000	4.045	695.000	4.213	695.000	4.233	710.000	4.337
635.000	3.552	760.000	2.913	725.000	3.280	740.000	3.274	715.000	3.512	755.000	3.378	740.000	3.546	695.000	3.732	680.000	4.023	705.000	4.188	700.000	4.197	720.000	4.289
640.000	3.515	765.000	2.864	730.000	3.249	745.000	3.243	720.000	3.484	760.000	3.324	745.000	3.520	700.000	3.707	685.000	3.995	715.000	4.168	705.000	4.175	725.000	4.260
645.000	3.493	770.000	2.835	735.000	3.198	750.000	3.211	725.000	3.442	765.000	3.297	750.000	3.493	705.000	3.681	690.000	3.974	720.000	4.159	710.000	4.143	730.000	4.256
650.000	3.453	775.000	2.781	740.000	3.166	755.000	3.180	730.000	3.414	770.000	3.269	755.000	3.455	710.000	3.646	695.000	3.953	725.000	4.132	715.000	4.129	735.000	4.223
655.000	3.431	780.000	2.750	745.000	3.134	760.000	3.128	735.000	3.370	775.000	3.242	760.000	3.413	715.000	3.620	700.000	3.925	730.000	4.112	720.000	4.112	740.000	4.186
660.000	3.393	785.000	2.696	755.000	3.050	765.000	3.096	740.000	3.342	780.000	3.202	765.000	3.386	720.000	3.594	705.000	3.903	735.000	4.089	725.000	4.077	745.000	4.126
665.000	3.371	790.000	2.672	760.000	2.999	770.000	3.065	745.000	3.313	785.000	3.174	770.000	3.359	725.000	3.557	710.000	3.896	745.000	4.017	730.000	4.054	750.000	4.112
670.000	3.329	795.000	2.641	765.000	2.967	775.000	3.013	750.000	3.284	790.000	3.146	775.000	3.320	730.000	3.530	715.000	3.867	750.000	3.958	735.000	4.010	755.000	4.040
675.000	3.311	800.000	2.587	770.000	2.947	780.000	2.981	755.000	3.255	795.000	3.118	780.000	3.292	735.000	3.502	720.000	3.843	760.000	3.880	740.000	3.990	765.000	3.906
680.000	3.268	805.000	2.556	775.000	2.894	785.000	2.950	760.000	3.197	800.000	3.074	785.000	3.265	740.000	3.464	725.000	3.811	765.000	3.809	745.000	3.939	770.000	3.881
685.000	3.244	810.000	2.502	785.000	2.831	790.000	2.898	765.000	3.167	805.000	3.033	790.000	3.225	745.000	3.436	730.000	3.785	775.000	3.695	750.000	3.906	775.000	3.799
690.000	3.206	815.000	2.472	790.000	2.779	795.000	2.866	770.000	3.138	810.000	3.005	795.000	3.197	750.000	3.407	735.000	3.759	780.000	3.652	755.000	3.847	780.000	3.745
695.000	3.181	820.000	2.425	795.000	2.747	800.000	2.835	775.000	3.109	815.000	2.976	800.000	3.169	755.000	3.367	740.000	3.722	785.000	3.622	760.000	3.811	785.000	3.667
700.000	3.135	825.000	2.395	800.000	2.694	805.000	2.803	780.000	3.063	820.000	2.948	805.000	3.141	760.000	3.338	745.000	3.694	790.000	3.550	765.000	3.773	795.000	3.563
705.000	3.108	830.000	2.342	805.000	2.663	810.000	2.751	785.000	3.033	825.000	2.906	810.000	3.100	765.000	3.309	750.000	3.664	795.000	3.507	770.000	3.721	800.000	3.514
710.000	3.068	835.000	2.312	815.000	2.578	815.000	2.720	790.000	3.003	830.000	2.877	815.000	3.072	770.000	3.268	755.000	3.624	800.000	3.435	775.000	3.681	805.000	3.438
715.000	3.041	840.000	2.282	820.000	2.546	820.000	2.688	795.000	2.960	835.000	2.848	820.000	3.043	775.000	3.238	760.000	3.592	805.000	3.392	780.000	3.613	810.000	3.391
720.000	2.999	845.000	2.236	825.000	2.494	825.000	2.636	800.000	2.931	840.000	2.803	825.000	3.014	780.000	3.208	765.000	3.549	810.000	3.349	785.000	3.572	815.000	3.335
725.000	2.988	850.000	2.207	830.000	2.462	830.000	2.605	805.000	2.883	845.000	2.761	830.000	2.956	785.000	3.166	770.000	3.516	815.000	3.276	790.000	3.501	820.000	3.288
730.000	2.959	855.000	2.155	835.000	2.430	835.000	2.574	810.000	2.853	850.000	2.732	835.000	2.927	790.000	3.135	775.000	3.483	820.000	3.233	795.000	3.459	825.000	3.213
735.000	2.938	860.000	2.126	840.000	2.378	840.000	2.521	815.000	2.823	855.000	2.702	840.000	2.898	795.000	3.105	780.000	3.436	825.000	3.161	800.000	3.402	830.000	3.167
740.000	2.895	865.000	2.074	845.000	2.357	845.000	2.490	820.000	2.793	860.000	2.673	845.000	2.856	800.000	3.061	785.000	3.401	830.000	3.118	805.000	3.360	835.000	3.111
745.000	2.875	870.000	2.045	850.000	2.325	850.000	2.459	825.000	2.762	865.000	2.643	850.000	2.826	805.000	3.030	790.000	3.367	835.000	3.089	810.000	3.318	840.000	3.065
750.000	2.825	875.000	2.001	860.000	2.240	855.000	2.427	830.000	2.702	870.000	2.601	855.000	2.796	810.000	2.999	795.000	3.337	840.000	3.017	815.000	3.249	845.000	3.019
755.000	2.796	880.000	1.973	865.000	2.188	860.000	2.364	835.000	2.671	875.000	2.571	860.000	2.766	815.000	2.954	800.000	3.302	845.000	2.974	820.000	3.207	850.000	2.946
760.000	2.749	885.000	1.922	870.000	2.156	865.000	2.333	840.000	2.641	880.000	2.525	865.000	2.723	820.000	2.923	805.000	3.250	850.000	2.902	825.000	3.138	855.000	2.918
765.000	2.718	890.000	1.894	875.000	2.124	870.000	2.302	845.000	2.610	885.000	2.495	870.000	2.693	825.000	2.891	810.000	3.213	855.000	2.860	830.000	3.111	860.000	2.844
770.000	2.662	895.000	1.866	880.000	2.071	875.000	2.249	850.000	2.561	890.000	2.451	875.000	2.663	830.000	2.845	815.000	3.177	860.000	2.788	835.000	3.041	865.000	2.799
775.000	2.630	900.000	1.823	885.000	2.040	880.000	2.217	855.000	2.530	895.000	2.421	880.000	2.619	835.000	2.813	820.000	3.123	865.000	2.745	840.000	2.999	870.000	2.726
780.000	2.578	905.000	1.794	890.000	2.008	885.000	2.185	860.000	2.500	900.000	2.391	885.000	2.588	840.000	2.781	825.000	3.086	870.000	2.702	845.000	2.929	875.000	2.681
785.000	2.547	910.000	1.745	895.000	1.955	890.000	2.131	865.000	2.457	905.000	2.360	890.000	2.558	845.000	2.734	830.000	3.049	875.000	2.631	850.000	2.886	880.000	2.626

Box VI - 3 Cross-sections from profiles 1-12 part 3/4

790.000	2.489	915.000	1.717	905.000	1.871	895.000	2.098	870.000	2.426	910.000	2.316	895.000	2.527	850.000	2.702	835.000	2.994	880.000	2.602	855.000	2.843	885.000	2.581
795.000	2.462	920.000	1.668	910.000	1.839	900.000	2.066	875.000	2.378	915.000	2.285	900.000	2.482	855.000	2.669	840.000	2.956	885.000	2.531	860.000	2.788	890.000	2.508
800.000	2.404	925.000	1.640	911.953	1.417	905.000	2.011	880.000	2.347	920.000	2.237	905.000	2.434	860.000	2.621	845.000	2.900	890.000	2.489	865.000	2.745	895.000	2.464
805.000	2.373	930.000	1.599	914.826	1.281	910.000	1.978	885.000	2.317	925.000	2.206	910.000	2.403	865.000	2.588	850.000	2.862	895.000	2.446	870.000	2.674	900.000	2.409
810.000	2.320	931.190	1.447	917.116	1.174	915.000	1.945	890.000	2.287	930.000	2.175	915.000	2.371	870.000	2.555	855.000	2.824	900.000	2.376	875.000	2.630	905.000	2.364
815.000	2.289	933.768	1.281	922.448	0.886	917.401	1.338	895.000	2.257	935.000	2.129	920.000	2.326	875.000	2.506	860.000	2.766	905.000	2.334	880.000	2.559	910.000	2.292
820.000	2.233	936.467	1.125	925.234	0.764	920.182	1.215	900.000	2.209	940.000	2.097	925.000	2.294	880.000	2.473	865.000	2.727	910.000	2.263	885.000	2.515	915.000	2.248
825.000	2.204	938.999	0.992	927.854	0.647	923.259	1.057	905.000	2.168	945.000	2.065	930.000	2.262	885.000	2.440	870.000	2.688	915.000	2.222	890.000	2.459	920.000	2.193
830.000	2.151	941.810	0.834	930.677	0.491	928.013	0.814	910.000	2.138	950.000	2.033	935.000	2.216	890.000	2.390	875.000	2.629	920.000	2.180	895.000	2.415	925.000	2.148
835.000	2.122	945.076	0.690	932.906	0.388	931.160	0.649	915.000	2.109	955.000	1.986	940.000	2.185	895.000	2.357	880.000	2.590	925.000	2.123	900.000	2.370	930.000	2.077
840.000	2.068	947.801	0.559	935.393	0.283	934.646	0.505	920.000	2.063	960.000	1.936	945.000	2.153	900.000	2.324	885.000	2.547	930.000	2.082	905.000	2.298	935.000	2.032
845.000	2.042	950.480	0.446	938.292	0.138	937.874	0.326	923.574	1.515	960.780	1.678	950.000	2.121	916.664	2.257	890.000	2.507	935.000	2.013	910.000	2.253	940.000	1.978
850.000	1.989	953.174	0.312	940.912	-0.010	940.586	0.185	927.037	1.360	964.052	1.497	955.000	2.075	921.882	2.011	895.000	2.467	940.000	1.973	915.000	2.196	945.000	1.934
855.000	1.963	955.706	0.163	943.608	-0.146	943.495	0.048	930.363	1.189	967.242	1.340	960.000	2.044	925.779	1.813	900.000	2.405	945.000	1.933	920.000	2.151	950.000	1.863
860.000	1.911	958.506	0.027	945.704	-0.224	946.257	-0.085	934.068	0.984	971.183	1.140	960.561	1.627	930.362	1.576	905.000	2.365	947.939	1.640	925.000	2.077	955.000	1.818
865.000	1.886	960.542	-0.124	948.238	-0.362	949.252	-0.231	937.556	0.766	974.657	0.959	963.551	1.497	934.450	1.394	910.000	2.325	956.501	1.199	930.000	2.033	960.000	1.765
870.000	1.836	962.846	-0.245	951.065	-0.487	952.718	-0.393	940.983	0.639	977.913	0.808	967.067	1.306	938.353	1.185	915.000	2.261	960.361	1.005	935.000	1.959	965.000	1.721
875.000	1.812	964.902	-0.362	953.421	-0.601	955.901	-0.565	944.263	0.464	981.134	0.650	971.628	1.091	941.816	1.031	920.000	2.221	964.761	0.773	940.000	1.914	970.000	1.651
880.000	1.763	966.741	-0.507	955.914	-0.736	959.078	-0.717	947.918	0.273	984.786	0.458	975.651	0.894	946.222	0.801	925.000	2.156	968.878	0.554	945.000	1.884	975.000	1.607
885.000	1.740	968.835	-0.615	958.082	-0.831	962.306	-0.877	951.198	0.131	988.143	0.294	978.717	0.742	950.392	0.590	930.000	2.115	972.738	0.376	950.000	1.809	977.211	1.657
890.000	1.693	970.589	-0.724	960.290	-0.934	965.099	-1.024	954.271	-0.052	991.110	0.157	982.101	0.567	954.465	0.384	935.000	2.073	976.628	0.194	955.000	1.764	981.219	1.483
895.000	1.671	972.931	-0.822	961.861	-1.078	967.621	-1.271	957.835	-0.207	994.782	-0.051	985.015	0.403	958.544	0.181	935.968	2.169	981.658	-0.051	960.000	1.688	984.562	1.275
900.000	1.625	975.050	-0.928	963.941	-1.266	970.214	-1.538	961.631	-0.394	998.140	-0.222	988.121	0.251	962.899	-0.021	941.876	1.847	987.465	-0.336	965.000	1.642	989.624	1.097
905.000	1.603	976.763	-1.059	966.001	-1.474	972.426	-1.752	964.785	-0.538	1002.055	-0.398	991.506	0.070	966.877	-0.211	947.548	1.575	991.925	-0.549	967.037	1.619	993.397	0.869
910.000	1.560	978.725	-1.268	968.123	-1.702	975.348	-2.037	968.025	-0.699	1005.763	-0.590	994.652	-0.084	971.203	-0.433	953.244	1.279	996.027	-0.775	971.766	1.412	996.674	0.635
915.000	1.538	980.575	-1.478	970.382	-1.927	978.027	-2.299	970.844	-0.862	1008.436	-0.726	997.439	-0.234	975.745	-0.669	959.107	0.999	999.871	-0.931	975.804	1.168	999.768	0.470
920.000	1.495	982.436	-1.722	972.268	-2.106	980.361	-2.543	973.138	-1.009	1011.550	-0.851	1000.758	-0.385	979.153	-0.837	964.403	0.667	1003.341	-1.240	980.634	0.971	1002.746	0.318
925.000	1.455	984.585	-1.904	974.089	-2.277	982.996	-2.850	974.976	-1.197	1014.066	-1.008	1004.087	-0.532	982.632	-1.049	969.644	0.404	1007.130	-1.596	985.525	0.722	1006.443	0.152
930.000	1.434	986.354	-2.088	975.778	-2.446	985.269	-3.074	977.816	-1.476	1016.516	-1.250	1007.462	-0.716	986.143	-1.387	973.827	0.159	1010.591	-1.942	989.994	0.457	1009.162	-0.040
932.582	1.281	987.591	-2.310	977.681	-2.650	986.902	-3.219	980.449	-1.729	1019.602	-1.562	1010.765	-0.872	988.767	-1.652	978.906	-0.087	1013.961	-2.294	993.565	0.235	1012.667	-0.177
939.114	1.007	989.200	-2.492	979.888	-2.863	988.735	-3.235	982.895	-1.993	1022.311	-1.823	1013.532	-1.041	991.592	-1.950	983.832	-0.356	1017.644	-2.637	996.427	0.077	1015.345	-0.358
946.032	0.699	991.462	-2.678	981.948	-3.059	991.706	-3.222	985.422	-2.260	1024.382	-2.010	1016.420	-1.343	994.054	-2.200	989.366	-0.619	1020.833	-2.979	1000.065	-0.067	1018.236	-0.485
952.772	0.393	993.324	-2.895	983.128	-3.166	994.039	-3.212	987.544	-2.501	1026.361	-2.207	1019.425	-1.640	996.773	-2.456	993.902	-0.859	1023.373	-3.205	1004.443	-0.265	1022.168	-0.636
960.438	0.052	995.873	-3.079	984.552	-3.177	996.276	-3.208	990.278	-2.778	1028.426	-2.442	1022.157	-1.903	999.547	-2.743	998.455	-1.122	1026.079	-3.201	1008.710	-0.490	1026.420	-0.841
967.178	-0.259	998.550	-3.170	986.762	-3.179	998.640	-3.211	992.542	-3.027	1030.776	-2.675	1024.802	-2.181	1002.967	-3.075	1002.720	-1.574	1029.143	-3.218	1012.931	-0.700	1029.894	-1.020
974.201	-0.556	1000.994	-3.169	989.022	-3.183	1000.721	-3.214	994.992	-3.242	1033.095	-2.901	1027.619	-2.463	1005.186	-3.207	1006.778	-1.970	1032.110	-3.208	1016.673	-0.944	1033.530	-1.415
981.614	-0.866	1003.498	-3.165	991.363	-3.174	1002.705	-3.203	997.371	-3.234	1035.414	-3.132	1030.568	-2.766	1008.940	-3.213	1010.470	-2.379	1035.576	-3.202	1020.532	-1.253	1036.852	-1.760
987.337	-1.138	1005.689	-3.166	993.547	-3.180	1004.826	-3.206	1000.058	-3.249	1037.366	-3.161	1032.935	-3.006	1011.751	-3.206	1014.173	-2.760	1039.250	-3.206	1024.357	-1.612	1040.508	-2.091
992.211	-1.563	1007.662	-3.161	996.218	-3.180	1006.496	-3.211	1002.679	-3.233	1039.561	-3.168	1035.509	-3.190	1014.779	-3.193	1016.977	-3.093	1042.187	-3.209	1027.674	-1.991	1043.592	-2.393
997.318	-2.000	1010.480	-3.152	998.498	-3.180	1007.885	-3.094	1005.240	-3.233	1042.247	-3.163	1038.133	-3.210	1019.832	-3.212	1020.090	-3.246	1044.735	-3.160	1030.808	-2.308	1047.537	-2.803
1002.380	-2.446	1012.605	-3.163	1000.814	-3.187	1009.327	-2.828	1007.366	-3.233	1044.280	-3.176	1041.270	-3.193	1022.865	-3.196	1023.811	-3.251	1046.491	-2.937	1034.617	-2.611	1051.230	-3.128
1006.702	-2.838	1015.216	-3.171	1003.008	-3.174	1010.288	-2.592	1010.255	-3.216	1046.308	-3.158	1044.006	-3.190	1025.224	-3.218	1027.551	-3.258	1048.080	-2.811	1037.684	-2.973	1054.729	-3.193
1010.180	-3.148	1017.630	-3.182	1005.400	-3.177	1010.968	-1.593	1012.310	-3.227	1048.868	-3.161	1046.646	-3.198	1027.150	-2.978	1030.857	-3.251	1048.409	-2.808	1040.862	-3.229	1057.951	-3.190
1014.877	-3.163	1019.608	-3.180	1007.371	-3.163			1014.051	-3.238	1051.463	-3.146	1049.280	-3.204	1028.844	-2.801	1034.006	-3.242			1044.673	-3.217	1060.585	-3.192
1019.502	-3.178	1020.855	-3.035	1008.604	-3.084			1015.164	-3.187	1054.008	-3.160	1052.655	-3.193	1029.565	-3.016	1037.003	-3.235			1048.746	-3.254	1064.636	-3.199
1024.654	-3.193	1021.776	-2.803	1009.661	-2.896			1016.245	-2.966	1056.264	-3.158	1055.178	-3.192			1039.032	-3.260			1052.419	-3.213	1067.783	-3.200
1027.873	-3.210	1022.808	-2.506	1010.661	-2.667			1017.549	-2.772	1057.539	-2.943	1057.311	-2.970			1041.249	-2.999			1056.012	-3.207	1069.648	-3.200
1029.755	-3.280	1023.607	-2.214	1011.854	-2.562			1018.585	-2.530	1058.991	-2.610	1058.851	-2.783			1042.019	-2.960			1059.021	-3.231	1071.405	-3.110
1030.700	-3.834	1024.175	-2.027					1018.967	-2.442	1060.199	-2.289	1059.785	-2.783							1061.593	-3.144	1072.215	-3.169
		1024.312	-2.079							1060.495	-2.440									1062.657	-3.138		

Box VI - 4 Cross-sections from profiles 1-12 part 4/4

Profiel 13		Profiel 14		Profiel 15		Profiel 16		Profiel 17		Profiel 18		Profiel 19		Profiel 20		Profiel 21		Profiel 22		Profiel 23		Profiel 24	
x (m)	depth (m)	x (m)	depth (m)	x (m)	depth (m)	x (m)	depth (m)	x (m)	depth (m)	x (m)	depth (m)	x (m)	depth (m)	x (m)	depth (m)	x (m)	depth (m)	x (m)	depth (m)	x (m)	depth (m)	x (m)	depth (m)
0.000	6.224	0.000	6.187	0.000	6.151	0.000	6.262	0.000	6.521	0.000	6.365	0.000	6.236	0.000	6.062	0.000	5.295	0.000	6.322	0.000	6.337	0.000	6.436
10.000	6.201	5.000	6.181	10.000	6.138	5.000	6.259	5.000	6.487	10.000	6.321	5.000	6.229	5.000	6.032	5.000	5.324	10.000	6.297	5.000	6.308	5.000	6.418
20.000	6.180	25.000	6.142	15.000	6.134	10.000	6.237	10.000	6.455	15.000	6.311	15.000	6.186	10.000	6.006	10.000	5.313	30.000	6.253	10.000	6.279	10.000	6.408
25.000	6.165	35.000	6.125	25.000	6.116	15.000	6.233	15.000	6.436	25.000	6.276	20.000	6.175	15.000	5.989	15.000	5.339	35.000	6.234	20.000	6.227	15.000	6.389
35.000	6.145	45.000	6.108	30.000	6.110	20.000	6.211	20.000	6.404	30.000	6.251	35.000	6.117	25.000	5.947	20.000	5.320	45.000	6.216	25.000	6.202	20.000	6.370
40.000	6.137	50.000	6.102	40.000	6.095	25.000	6.204	25.000	6.385	35.000	6.226	45.000	6.083	30.000	5.916	25.000	5.312	55.000	6.187	30.000	6.189	25.000	6.361
45.000	6.125	70.000	6.065	45.000	6.084	30.000	6.185	30.000	6.354	40.000	6.215	60.000	6.022	40.000	5.879	30.000	5.338	65.000	6.173	40.000	6.153	30.000	6.341
50.000	6.118	75.000	6.059	55.000	6.069	35.000	6.163	35.000	6.319	50.000	6.179	65.000	5.998	45.000	5.858	35.000	5.325	70.000	6.158	45.000	6.137	35.000	6.320
55.000	6.104	90.000	6.034	60.000	6.061	40.000	6.159	40.000	6.304	55.000	6.153	75.000	5.958	50.000	5.845	40.000	5.319	75.000	6.155	50.000	6.120	40.000	6.310
65.000	6.086	100.000	6.017	70.000	6.043	45.000	6.137	45.000	6.269	65.000	6.116	90.000	5.898	55.000	5.819	45.000	5.343	85.000	6.140	60.000	6.087	45.000	6.290
70.000	6.078	110.000	6.001	75.000	6.039	50.000	6.133	50.000	6.254	70.000	6.092	95.000	5.884	60.000	5.802	50.000	5.338	95.000	6.136	65.000	6.067	50.000	6.269
75.000	6.067	115.000	5.991	85.000	6.024	55.000	6.111	55.000	6.224	80.000	6.055	105.000	5.834	70.000	5.774	55.000	5.361	105.000	6.124	70.000	6.051	55.000	6.257
80.000	6.060	130.000	5.971	90.000	6.014	60.000	6.103	60.000	6.189	85.000	6.032	120.000	5.782	75.000	5.753	60.000	5.352	110.000	6.120	80.000	6.008	60.000	6.236
85.000	6.047	140.000	5.954	95.000	6.006	65.000	6.085	65.000	6.174	95.000	5.997	125.000	5.758	80.000	5.743	65.000	5.349	115.000	6.118	85.000	5.997	65.000	6.214
95.000	6.029	145.000	5.945	105.000	5.991	70.000	6.076	70.000	6.139	100.000	5.974	130.000	5.731	85.000	5.730	70.000	5.369	120.000	6.101	95.000	5.945	70.000	6.203
100.000	6.022	160.000	5.924	110.000	5.987	75.000	6.058	75.000	6.125	110.000	5.940	140.000	5.704	90.000	5.720	75.000	5.362	130.000	6.094	100.000	5.933	75.000	6.179
105.000	6.009	165.000	5.913	115.000	5.978	80.000	6.048	80.000	6.093	115.000	5.929	145.000	5.690	100.000	5.693	80.000	5.358	135.000	6.075	105.000	5.909	80.000	6.167
110.000	6.005	175.000	5.899	125.000	5.965	85.000	6.031	85.000	6.068	125.000	5.888	150.000	5.687	105.000	5.686	85.000	5.375	140.000	6.072	115.000	5.865	85.000	6.144
115.000	5.992	180.000	5.888	130.000	5.958	90.000	6.013	90.000	6.050	130.000	5.878	160.000	5.670	110.000	5.678	90.000	5.371	150.000	6.051	120.000	5.840	90.000	6.122
125.000	5.975	195.000	5.869	135.000	5.953	95.000	5.992	95.000	6.028	135.000	5.858	165.000	5.659	115.000	5.665	105.000	5.372	155.000	6.051	125.000	5.821	95.000	6.111
130.000	5.968	205.000	5.852	145.000	5.940	100.000	5.986	100.000	6.013	140.000	5.848	175.000	5.641	120.000	5.665	115.000	5.367	160.000	6.050	130.000	5.795	100.000	6.087
140.000	5.946	215.000	5.838	150.000	5.931	105.000	5.975	105.000	5.992	145.000	5.828	180.000	5.629	130.000	5.650	120.000	5.361	180.000	6.036	140.000	5.757	105.000	6.064
145.000	5.939	220.000	5.827	155.000	5.927	110.000	5.970	110.000	5.970	155.000	5.799	185.000	5.621	135.000	5.648	125.000	5.362	185.000	6.019	155.000	5.687	110.000	6.054
150.000	5.927	225.000	5.820	165.000	5.915	115.000	5.960	115.000	5.961	160.000	5.778	195.000	5.594	140.000	5.641	135.000	5.358	195.000	6.026	160.000	5.663	115.000	6.032
155.000	5.923	230.000	5.813	170.000	5.906	120.000	5.950	120.000	5.941	170.000	5.749	200.000	5.585	145.000	5.643	145.000	5.345	200.000	6.011	170.000	5.621	120.000	6.008
160.000	5.911	235.000	5.806	175.000	5.898	125.000	5.945	125.000	5.933	175.000	5.731	210.000	5.552	150.000	5.638	150.000	5.352	215.000	6.019	180.000	5.580	125.000	5.997
170.000	5.892	240.000	5.799	185.000	5.884	130.000	5.935	130.000	5.915	185.000	5.705	220.000	5.528	160.000	5.636	160.000	5.346	220.000	6.010	190.000	5.538	130.000	5.976
175.000	5.887	250.000	5.785	190.000	5.881	135.000	5.930	135.000	5.901	190.000	5.696	225.000	5.517	165.000	5.633	165.000	5.357	225.000	6.011	195.000	5.528	135.000	5.955
180.000	5.876	255.000	5.775	195.000	5.872	140.000	5.919	140.000	5.892	195.000	5.680	240.000	5.470	170.000	5.637	180.000	5.360	230.000	6.009	210.000	5.472	140.000	5.943
185.000	5.868	265.000	5.761	205.000	5.860	145.000	5.914	145.000	5.879	200.000	5.666	245.000	5.451	175.000	5.635	185.000	5.356	240.000	5.992	215.000	5.454	145.000	5.922
190.000	5.860	270.000	5.750	210.000	5.853	150.000	5.904	150.000	5.871	205.000	5.658	250.000	5.439	180.000	5.635	190.000	5.365	245.000	5.958	220.000	5.429	150.000	5.902
200.000	5.841	275.000	5.747	215.000	5.848	155.000	5.894	155.000	5.857	215.000	5.630	260.000	5.398	190.000	5.642	200.000	5.346	255.000	5.911	230.000	5.403	155.000	5.893
205.000	5.837	280.000	5.736	225.000	5.837	160.000	5.889	160.000	5.843	220.000	5.625	265.000	5.388	195.000	5.647	205.000	5.355	270.000	5.834	240.000	5.373	160.000	5.871
215.000	5.818	285.000	5.729	230.000	5.828	165.000	5.878	165.000	5.837	230.000	5.605	270.000	5.374	205.000	5.656	210.000	5.347	275.000	5.803	245.000	5.358	165.000	5.852
220.000	5.810	290.000	5.722	235.000	5.825	170.000	5.873	170.000	5.822	235.000	5.591	275.000	5.357	210.000	5.661	215.000	5.361	280.000	5.787	250.000	5.343	170.000	5.842
225.000	5.802	295.000	5.714	245.000	5.810	175.000	5.863	175.000	5.815	245.000	5.573	280.000	5.350	215.000	5.667	225.000	5.350	295.000	5.722	265.000	5.311	175.000	5.824
230.000	5.791	300.000	5.707	250.000	5.802	180.000	5.852	185.000	5.793	250.000	5.559	285.000	5.354	220.000	5.676	230.000	5.372	300.000	5.701	270.000	5.293	180.000	5.813
235.000	5.787	305.000	5.700	255.000	5.781	185.000	5.847	190.000	5.779	255.000	5.554	295.000	5.372	225.000	5.680	240.000	5.371	305.000	5.676	275.000	5.281	185.000	5.795
245.000	5.768	310.000	5.688	265.000	5.734	190.000	5.836	195.000	5.764	260.000	5.542	300.000	5.383	235.000	5.691	245.000	5.398	310.000	5.664	285.000	5.265	190.000	5.779
250.000	5.757	315.000	5.685	270.000	5.698	195.000	5.830	205.000	5.744	265.000	5.530	305.000	5.391	240.000	5.697	255.000	5.423	315.000	5.647	290.000	5.251	195.000	5.770
255.000	5.753	320.000	5.673	275.000	5.599	200.000	5.818	210.000	5.737	275.000	5.512	310.000	5.421	245.000	5.699	260.000	5.415	325.000	5.614	295.000	5.246	200.000	5.754
260.000	5.742	325.000	5.665	285.000	5.359	205.000	5.812	220.000	5.709	280.000	5.506	315.000	5.433	250.000	5.687	265.000	5.410	330.000	5.593	305.000	5.229	205.000	5.737
265.000	5.735	330.000	5.657	290.000	5.247	210.000	5.797	225.000	5.703	290.000	5.483	325.000	5.485	255.000	5.681	275.000	5.413	335.000	5.590	310.000	5.221	210.000	5.730
275.000	5.715	335.000	5.644	295.000	5.302	215.000	5.785	230.000	5.688	295.000	5.478	335.000	5.523	260.000	5.669	280.000	5.400	350.000	5.553	320.000	5.209	215.000	5.716
280.000	5.708	340.000	5.639	305.000	5.380	220.000	5.775	235.000	5.681	300.000	5.466	340.000	5.550	265.000	5.671	285.000	5.407	355.000	5.538	325.000	5.203	220.000	5.703
290.000	5.692	345.000	5.625	310.000	5.440	225.000	5.762	245.000	5.651	305.000	5.460	350.000	5.584	270.000	5.681	295.000	5.406	365.000	5.524	330.000	5.198	225.000	5.695
295.000	5.680	350.000	5.616	315.000	5.472	230.000	5.751	250.000	5.643	310.000	5.448	360.000	5.556	280.000	5.688	300.000	5.394	370.000	5.513	335.000	5.196	230.000	5.684
305.000	5.664	355.000	5.605	320.000	5.496	235.000	5.739	255.000	5.628	320.000	5.432	365.000	5.534	285.000	5.683	305.000	5.388	380.000	5.505	340.000	5.193	235.000	5.673

Box VI - 5 Cross-sections from profiles13-24 part 1/4

310.000	5.656	360.000	5.595	325.000	5.503	240.000	5.721	260.000	5.620	325.000	5.420	370.000	5.517	290.000	5.682	310.000	5.393	385.000	5.498	350.000	5.188	240.000	5.669
315.000	5.647	365.000	5.582	335.000	5.518	245.000	5.705	270.000	5.587	335.000	5.401	375.000	5.495	295.000	5.678	315.000	5.387	395.000	5.493	355.000	5.188	245.000	5.661
320.000	5.639	370.000	5.572	340.000	5.511	250.000	5.693	275.000	5.579	340.000	5.391	380.000	5.478	300.000	5.671	325.000	5.382	400.000	5.496	360.000	5.189	250.000	5.655
325.000	5.626	375.000	5.554	345.000	5.502	255.000	5.668	285.000	5.553	345.000	5.382	385.000	5.456	310.000	5.651	330.000	5.377	405.000	5.494	365.000	5.189	255.000	5.652
335.000	5.609	380.000	5.536	350.000	5.492	260.000	5.647	290.000	5.536	350.000	5.372	390.000	5.434	315.000	5.647	335.000	5.381	420.000	5.457	370.000	5.192	260.000	5.645
340.000	5.601	385.000	5.524	360.000	5.451	265.000	5.617	300.000	5.509	355.000	5.360	400.000	5.395	320.000	5.637	340.000	5.372	425.000	5.441	380.000	5.200	265.000	5.641
350.000	5.584	390.000	5.501	365.000	5.440	270.000	5.623	305.000	5.490	365.000	5.336	405.000	5.368	325.000	5.623	350.000	5.371	430.000	5.422	385.000	5.208	270.000	5.637
355.000	5.571	395.000	5.486	370.000	5.413	275.000	5.611	310.000	5.482	370.000	5.323	410.000	5.357	330.000	5.618	355.000	5.367	435.000	5.414	390.000	5.218	275.000	5.630
360.000	5.562	400.000	5.455	375.000	5.398	280.000	5.609	315.000	5.462	375.000	5.308	415.000	5.335	340.000	5.599	360.000	5.359	445.000	5.392	395.000	5.223	280.000	5.626
365.000	5.554	410.000	5.405	385.000	5.352	285.000	5.588	320.000	5.445	380.000	5.285	420.000	5.318	345.000	5.587	365.000	5.362	460.000	5.351	400.000	5.237	285.000	5.622
370.000	5.545	415.000	5.389	390.000	5.319	290.000	5.583	325.000	5.434	385.000	5.276	425.000	5.297	350.000	5.573	375.000	5.360	465.000	5.333	405.000	5.244	290.000	5.614
380.000	5.527	420.000	5.357	395.000	5.289	295.000	5.561	330.000	5.416	395.000	5.242	430.000	5.269	355.000	5.567	380.000	5.352	475.000	5.312	410.000	5.259	295.000	5.610
385.000	5.514	425.000	5.325	405.000	5.238	300.000	5.548	335.000	5.404	400.000	5.221	435.000	5.258	360.000	5.552	390.000	5.348	485.000	5.280	415.000	5.278	300.000	5.602
390.000	5.505	430.000	5.310	410.000	5.223	310.000	5.517	340.000	5.386	405.000	5.193	440.000	5.229	370.000	5.531	395.000	5.344	490.000	5.273	420.000	5.289	305.000	5.593
395.000	5.496	435.000	5.281	415.000	5.190	315.000	5.503	350.000	5.356	410.000	5.182	445.000	5.219	375.000	5.515	405.000	5.335	500.000	5.250	425.000	5.311	310.000	5.593
405.000	5.474	440.000	5.266	425.000	5.142	320.000	5.487	355.000	5.337	415.000	5.150	450.000	5.197	380.000	5.507	410.000	5.331	505.000	5.237	430.000	5.337	315.000	5.583
410.000	5.465	445.000	5.238	430.000	5.112	330.000	5.455	360.000	5.324	425.000	5.103	455.000	5.167	385.000	5.489	420.000	5.319	515.000	5.215	435.000	5.352	320.000	5.574
415.000	5.456	450.000	5.224	435.000	5.095	335.000	5.431	365.000	5.306	430.000	5.076	460.000	5.156	390.000	5.473	425.000	5.315	525.000	5.191	440.000	5.378	325.000	5.569
420.000	5.443	455.000	5.197	440.000	5.073	340.000	5.422	370.000	5.282	435.000	5.062	465.000	5.125	400.000	5.446	435.000	5.306	530.000	5.182	445.000	5.404	330.000	5.563
425.000	5.434	460.000	5.185	445.000	5.062	345.000	5.397	380.000	5.249	440.000	5.027	470.000	5.102	405.000	5.438	440.000	5.299	535.000	5.171	450.000	5.417	335.000	5.551
435.000	5.416	470.000	5.147	450.000	5.044	355.000	5.362	385.000	5.239	445.000	5.013	475.000	5.090	410.000	5.418	450.000	5.284	555.000	5.132	455.000	5.445	340.000	5.545
440.000	5.399	475.000	5.124	455.000	5.035	360.000	5.336	390.000	5.214	455.000	4.949	480.000	5.058	420.000	5.391	455.000	5.276	560.000	5.127	460.000	5.469	345.000	5.531
445.000	5.384	480.000	5.101	460.000	5.017	370.000	5.297	395.000	5.203	460.000	4.927	485.000	5.046	425.000	5.370	465.000	5.260	570.000	5.112	465.000	5.480	350.000	5.520
450.000	5.354	490.000	5.066	465.000	4.998	375.000	5.285	400.000	5.177	465.000	4.898	490.000	5.012	430.000	5.352	470.000	5.250	575.000	5.104	470.000	5.497	355.000	5.511
455.000	5.336	495.000	5.055	470.000	4.990	380.000	5.256	405.000	5.156	470.000	4.860	495.000	4.988	435.000	5.340	475.000	5.244	580.000	5.094	475.000	5.503	360.000	5.491
465.000	5.289	500.000	5.031	475.000	4.971	385.000	5.244	410.000	5.139	475.000	4.845	500.000	4.976	445.000	5.313	480.000	5.233	585.000	5.090	480.000	5.511	365.000	5.469
470.000	5.256	505.000	5.019	480.000	4.963	395.000	5.189	415.000	5.117	485.000	4.792	505.000	4.941	450.000	5.291	485.000	5.220	590.000	5.084	485.000	5.511	370.000	5.460
480.000	5.209	510.000	4.996	485.000	4.946	400.000	5.171	425.000	5.077	490.000	4.761	510.000	4.929	455.000	5.274	490.000	5.214	595.000	5.075	490.000	5.507	375.000	5.435
485.000	5.191	515.000	4.983	490.000	4.937	405.000	5.144	430.000	5.048	500.000	4.706	515.000	4.892	465.000	5.243	495.000	5.199	600.000	5.073	495.000	5.492	380.000	5.422
495.000	5.146	520.000	4.960	495.000	4.920	415.000	5.099	435.000	5.036	505.000	4.666	520.000	4.867	470.000	5.234	500.000	5.184	605.000	5.068	500.000	5.466	385.000	5.395
500.000	5.116	525.000	4.947	500.000	4.911	420.000	5.066	440.000	5.007	510.000	4.650	525.000	4.841	475.000	5.211	505.000	5.177	610.000	5.061	505.000	5.449	390.000	5.365
505.000	5.103	530.000	4.922	505.000	4.896	430.000	5.019	450.000	4.954	515.000	4.617	530.000	4.815	480.000	5.194	510.000	5.158	620.000	5.057	510.000	5.404	395.000	5.352
510.000	5.074	535.000	4.898	510.000	4.879	435.000	5.005	455.000	4.923	520.000	4.576	535.000	4.789	485.000	5.185	515.000	5.151	625.000	5.056	515.000	5.351	400.000	5.318
515.000	5.059	540.000	4.884	515.000	4.873	445.000	4.958	460.000	4.898	530.000	4.517	540.000	4.763	495.000	5.145	520.000	5.133	630.000	5.051	520.000	5.324	405.000	5.280
525.000	5.019	545.000	4.858	520.000	4.859	450.000	4.925	465.000	4.867	535.000	4.500	545.000	4.736	500.000	5.131	525.000	5.118	635.000	5.051	525.000	5.267	410.000	5.260
530.000	4.992	550.000	4.846	525.000	4.852	455.000	4.892	475.000	4.811	540.000	4.456	550.000	4.709	505.000	5.114	530.000	5.111	640.000	5.051	530.000	5.213	415.000	5.220
535.000	4.978	555.000	4.820	530.000	4.838	465.000	4.842	480.000	4.771	545.000	4.421	555.000	4.682	510.000	5.105	535.000	5.093	645.000	5.047	535.000	5.187	420.000	5.174
540.000	4.955	560.000	4.808	535.000	4.831	470.000	4.826	485.000	4.755	550.000	4.393	560.000	4.655	515.000	5.083	540.000	5.079	650.000	5.048	540.000	5.134	425.000	5.150
545.000	4.930	565.000	4.782	540.000	4.817	475.000	4.790	495.000	4.699	560.000	4.338	565.000	4.626	525.000	5.052	545.000	5.072	655.000	5.048	545.000	5.103	430.000	5.100
550.000	4.916	575.000	4.744	545.000	4.805	485.000	4.736	500.000	4.667	565.000	4.290	570.000	4.598	530.000	5.035	550.000	5.056	660.000	5.044	550.000	5.050	435.000	5.050
555.000	4.893	580.000	4.718	550.000	4.797	490.000	4.699	505.000	4.626	570.000	4.251	575.000	4.569	535.000	5.019	555.000	5.050	665.000	5.044	555.000	4.997	440.000	5.022
560.000	4.880	585.000	4.706	555.000	4.785	500.000	4.641	510.000	4.610	575.000	4.221	580.000	4.541	540.000	5.004	560.000	5.034	670.000	5.044	560.000	4.971	445.000	4.966
570.000	4.845	595.000	4.665	560.000	4.775	505.000	4.622	520.000	4.554	580.000	4.180	585.000	4.496	545.000	4.988	565.000	5.022	680.000	5.028	565.000	4.913	450.000	4.907
575.000	4.821	600.000	4.641	565.000	4.757	510.000	4.579	525.000	4.513	590.000	4.104	590.000	4.482	555.000	4.958	570.000	5.016	685.000	5.016	570.000	4.860	455.000	4.878
585.000	4.788	605.000	4.627	570.000	4.751	515.000	4.537	530.000	4.481	595.000	4.046	595.000	4.453	560.000	4.942	575.000	5.002	690.000	4.999	575.000	4.834	460.000	4.817
590.000	4.775	610.000	4.600	575.000	4.734	520.000	4.513	540.000	4.424	600.000	4.022	600.000	4.406	565.000	4.927	580.000	4.990	695.000	4.977	580.000	4.775	465.000	4.754
595.000	4.753	620.000	4.561	580.000	4.724	530.000	4.439	545.000	4.400	605.000	3.972	605.000	4.392	570.000	4.912	585.000	4.984	700.000	4.954	585.000	4.723	470.000	4.722
600.000	4.741	625.000	4.548	585.000	4.714	535.000	4.387	550.000	4.367	610.000	3.905	610.000	4.344	575.000	4.897	590.000	4.972	705.000	4.924	590.000	4.697	475.000	4.658
605.000	4.722	630.000	4.523	590.000	4.707	540.000	4.353	560.000	4.311	620.000	3.803	615.000	4.329	580.000	4.882	595.000	4.966	710.000	4.894	595.000	4.644	480.000	4.625
615.000	4.690	635.000	4.499	595.000	4.697	550.000	4.338	565.000	4.272	625.000	3.773	620.000	4.299	585.000	4.868	600.000	4.955	715.000	4.852	600.000	4.585	485.000	4.558

Box VI - 6 Cross-sections from profiles13-24 part 2/4

620.000	4.681	640.000	4.488	600.000	4.686	555.000	4.375	570.000	4.255	630.000	3.695	625.000	4.250	590.000	4.852	605.000	4.946	725.000	4.754	605.000	4.559	490.000	4.489
625.000	4.662	645.000	4.468	605.000	4.684	565.000	4.403	580.000	4.201	635.000	3.632	630.000	4.235	595.000	4.838	610.000	4.942	730.000	4.671	610.000	4.505	495.000	4.454
630.000	4.650	650.000	4.458	610.000	4.675	570.000	4.418	585.000	4.165	640.000	3.601	635.000	4.187	600.000	4.812	615.000	4.933	735.000	4.580	615.000	4.450	500.000	4.384
635.000	4.633	655.000	4.434	615.000	4.673	575.000	4.407	590.000	4.132	650.000	3.487	640.000	4.173	605.000	4.805	620.000	4.925	740.000	4.534	620.000	4.417	505.000	4.310
645.000	4.603	660.000	4.421	620.000	4.666	580.000	4.420	595.000	4.115	655.000	3.401	645.000	4.145	610.000	4.789	625.000	4.922	745.000	4.435	625.000	4.362	510.000	4.274
650.000	4.594	665.000	4.397	625.000	4.662	590.000	4.416	600.000	4.082	660.000	3.344	650.000	4.096	615.000	4.762	630.000	4.912	750.000	4.389	630.000	4.334	515.000	4.200
655.000	4.575	670.000	4.381	630.000	4.656	600.000	4.408	610.000	4.036	665.000	3.287	655.000	4.084	620.000	4.740	635.000	4.909	755.000	4.298	635.000	4.272	520.000	4.129
660.000	4.565	675.000	4.351	635.000	4.647	605.000	4.392	615.000	4.012	670.000	3.248	660.000	4.044	625.000	4.698	640.000	4.895	760.000	4.199	640.000	4.216	525.000	4.092
665.000	4.548	680.000	4.337	640.000	4.643	615.000	4.379	620.000	3.996	675.000	3.213	665.000	4.035	630.000	4.685	645.000	4.880	770.000	4.066	645.000	4.188	530.000	4.018
675.000	4.523	685.000	4.303	645.000	4.634	620.000	4.374	625.000	3.980	680.000	3.252	670.000	4.013	635.000	4.657	650.000	4.871	775.000	3.968	650.000	4.131	535.000	3.944
680.000	4.507	690.000	4.275	650.000	4.625	625.000	4.365	635.000	3.963	685.000	3.297	675.000	4.013	640.000	4.605	655.000	4.839	780.000	3.924	655.000	4.068	540.000	3.910
685.000	4.500	695.000	4.252	655.000	4.621	635.000	4.339	640.000	3.944	690.000	3.295	680.000	4.012	645.000	4.584	660.000	4.814	785.000	3.838	660.000	4.040	545.000	3.836
690.000	4.486	700.000	4.212	660.000	4.611	640.000	4.337	645.000	3.972	695.000	3.339	685.000	3.994	650.000	4.519	665.000	4.800	790.000	3.752	665.000	3.983	550.000	3.762
695.000	4.481	705.000	4.196	665.000	4.608	645.000	4.315	650.000	3.970	700.000	3.355	690.000	3.993	655.000	4.495	670.000	4.755	795.000	3.697	670.000	3.926	555.000	3.724
705.000	4.464	710.000	4.152	670.000	4.599	655.000	4.287	660.000	3.909	705.000	3.377	695.000	3.980	660.000	4.450	675.000	4.738	800.000	3.612	675.000	3.890	560.000	3.653
710.000	4.455	715.000	4.124	675.000	4.593	660.000	4.281	665.000	3.833	710.000	3.392	700.000	3.981	665.000	4.386	680.000	4.686	805.000	3.570	680.000	3.833	565.000	3.615
715.000	4.446	720.000	4.089	680.000	4.583	665.000	4.262	675.000	3.747	715.000	3.414	705.000	3.982	670.000	4.365	685.000	4.653	810.000	3.472	685.000	3.774	570.000	3.540
720.000	4.434	725.000	4.058	685.000	4.574	675.000	4.226	680.000	3.733	720.000	3.458	710.000	3.975	675.000	4.322	690.000	4.637	815.000	3.390	690.000	3.736	575.000	3.464
725.000	4.430	730.000	4.025	690.000	4.556	680.000	4.196	690.000	3.654	725.000	3.479	715.000	3.978	680.000	4.280	695.000	4.588	820.000	3.350	695.000	3.676	580.000	3.430
735.000	4.370	735.000	3.977	695.000	4.508	685.000	4.185	695.000	3.635	730.000	3.500	720.000	3.973	685.000	4.239	700.000	4.557	825.000	3.256	700.000	3.645	585.000	3.354
740.000	4.315	740.000	3.941	700.000	4.477	690.000	4.151	705.000	3.602	735.000	3.517	725.000	3.978	690.000	4.176	705.000	4.543	830.000	3.181	705.000	3.584	590.000	3.277
745.000	4.279	745.000	3.903	705.000	4.414	695.000	4.117	710.000	3.587	740.000	3.536	730.000	3.980	695.000	4.156	710.000	4.496	835.000	3.144	710.000	3.512	595.000	3.239
750.000	4.221	750.000	3.864	710.000	4.377	700.000	4.097	715.000	3.562	745.000	3.547	735.000	3.983	700.000	4.116	715.000	4.482	840.000	3.056	715.000	3.481	600.000	3.161
755.000	4.192	755.000	3.822	715.000	4.307	705.000	4.058	725.000	3.537	750.000	3.580	740.000	3.988	705.000	4.053	720.000	4.437	845.000	2.984	720.000	3.419	605.000	3.088
765.000	4.061	760.000	3.781	720.000	4.274	710.000	4.036	730.000	3.536	755.000	3.571	745.000	3.991	715.000	3.970	725.000	4.411	850.000	2.949	725.000	3.345	610.000	3.049
770.000	3.956	765.000	3.715	725.000	4.203	715.000	3.993	740.000	3.500	760.000	3.602	750.000	3.994	725.000	3.917	730.000	4.398	855.000	2.878	730.000	3.314	615.000	2.971
775.000	3.900	770.000	3.691	730.000	4.141	720.000	3.970	745.000	3.489	765.000	3.618	755.000	3.999	730.000	3.858	735.000	4.354	860.000	2.826	735.000	3.252	620.000	2.892
780.000	3.809	775.000	3.623	735.000	4.100	725.000	3.924	755.000	3.461	770.000	3.621	760.000	3.999	740.000	3.811	740.000	4.342	865.000	2.754	740.000	3.189	625.000	2.858
785.000	3.756	780.000	3.579	740.000	4.040	730.000	3.878	760.000	3.442	775.000	3.651	765.000	4.006	745.000	3.813	745.000	4.318	870.000	2.683	745.000	3.145	630.000	2.778
790.000	3.664	785.000	3.530	745.000	4.000	735.000	3.853	770.000	3.408	780.000	3.632	770.000	4.025	755.000	3.840	750.000	4.275	875.000	2.630	750.000	3.083	635.000	2.699
795.000	3.625	790.000	3.463	750.000	3.931	740.000	3.806	775.000	3.383	785.000	3.642	775.000	4.045	760.000	3.853	755.000	4.264	880.000	2.558	755.000	3.021	640.000	2.658
800.000	3.540	795.000	3.438	755.000	3.902	745.000	3.780	780.000	3.370	790.000	3.613	780.000	4.053	765.000	3.881	760.000	4.226	885.000	2.486	760.000	2.990	645.000	2.583
805.000	3.458	800.000	3.371	760.000	3.834	750.000	3.733	785.000	3.345	795.000	3.606	785.000	4.047	770.000	3.905	765.000	4.207	890.000	2.433	765.000	2.914	650.000	2.502
810.000	3.423	805.000	3.330	765.000	3.778	755.000	3.683	790.000	3.330	800.000	3.589	790.000	4.025	775.000	3.917	770.000	4.198	895.000	2.362	770.000	2.883	655.000	2.462
815.000	3.344	810.000	3.281	770.000	3.739	760.000	3.659	795.000	3.305	805.000	3.554	795.000	4.006	780.000	3.942	775.000	4.164	900.000	2.290	775.000	2.822	660.000	2.380
820.000	3.301	815.000	3.242	775.000	3.683	765.000	3.608	800.000	3.274	810.000	3.530	800.000	3.971	785.000	3.953	780.000	4.156	905.000	2.254	780.000	2.746	665.000	2.345
825.000	3.235	820.000	3.193	780.000	3.644	770.000	3.585	805.000	3.261	815.000	3.493	805.000	3.922	790.000	3.978	785.000	4.141	910.000	2.166	785.000	2.715	670.000	2.263
830.000	3.192	825.000	3.154	785.000	3.578	775.000	3.534	810.000	3.234	820.000	3.460	810.000	3.901	795.000	3.999	790.000	4.111	915.000	2.130	790.000	2.654	675.000	2.180
835.000	3.118	830.000	3.090	790.000	3.551	780.000	3.506	815.000	3.215	825.000	3.402	815.000	3.857	800.000	4.010	795.000	4.104	920.000	2.057	795.000	2.594	680.000	2.139
840.000	3.087	835.000	3.065	795.000	3.485	785.000	3.460	820.000	3.187	830.000	3.381	820.000	3.799	805.000	4.033	800.000	4.074	925.000	1.969	800.000	2.548	685.000	2.056
845.000	3.014	840.000	3.001	800.000	3.431	790.000	3.408	825.000	3.152	835.000	3.317	825.000	3.775	810.000	4.054	805.000	4.059	930.000	1.933	805.000	2.488	690.000	1.977
850.000	2.973	845.000	2.937	805.000	3.392	795.000	3.385	830.000	3.138	840.000	3.265	830.000	3.711	815.000	4.067	810.000	4.051	935.000	1.861	810.000	2.429	695.000	1.936
855.000	2.901	850.000	2.912	810.000	3.339	800.000	3.333	835.000	3.101	845.000	3.236	835.000	3.686	820.000	4.088	815.000	4.019	940.000	1.772	815.000	2.399	700.000	1.852
860.000	2.871	855.000	2.847	815.000	3.300	805.000	3.310	840.000	3.087	850.000	3.161	840.000	3.619	825.000	4.098	820.000	4.010	945.000	1.736	820.000	2.324	705.000	1.768
865.000	2.800	860.000	2.821	820.000	3.235	810.000	3.257	845.000	3.048	855.000	3.128	845.000	3.565	830.000	4.123	825.000	3.991	950.000	1.665	825.000	2.266	710.000	1.730
870.000	2.760	865.000	2.756	825.000	3.209	815.000	3.212	850.000	3.019	860.000	3.048	850.000	3.538	835.000	4.142	830.000	3.957	955.000	1.577	830.000	2.237	715.000	1.645
875.000	2.701	870.000	2.717	830.000	3.143	820.000	3.181	855.000	2.993	865.000	2.980	855.000	3.465	840.000	4.138	835.000	3.946	960.000	1.542	835.000	2.163	720.000	1.560
880.000	2.660	875.000	2.665	835.000	3.092	825.000	3.136	860.000	2.964	870.000	2.932	860.000	3.436	845.000	4.135	840.000	3.908	965.000	1.473	840.000	2.134	725.000	1.517
885.000	2.591	880.000	2.625	840.000	3.052	830.000	3.104	865.000	2.936	875.000	2.864	865.000	3.360	850.000	4.119	845.000	3.881	970.000	1.404	845.000	2.077	730.000	1.434
890.000	2.562	885.000	2.573	845.000	3.000	835.000	3.060	870.000	2.907	880.000	2.829	870.000	3.299	855.000	4.062	850.000	3.867	975.000	1.354	850.000	2.020	735.000	1.348

Box VI - 7 Cross-sections from profiles13-24 part 3/4

895.000	2.494	890.000	2.507	850.000	2.961	840.000	3.027	875.000	2.861	885.000	2.746	875.000	3.268	860.000	3.994	855.000	3.821	980.000	1.288	855.000	1.975	740.000	1.305
900.000	2.453	895.000	2.468	855.000	2.909	845.000	2.982	880.000	2.843	890.000	2.677	880.000	3.187	865.000	3.921	860.000	3.803	985.000	1.256	860.000	1.920	745.000	1.219
905.000	2.397	900.000	2.415	860.000	2.869	850.000	2.925	885.000	2.782	895.000	2.628	885.000	3.122	870.000	3.840	865.000	3.763	990.000	1.173	865.000	1.864	750.000	1.134
910.000	2.357	905.000	2.375	865.000	2.803	855.000	2.902	890.000	2.755	900.000	2.558	890.000	3.071	875.000	3.754	870.000	3.703	995.000	1.109	870.000	1.837	755.000	1.091
915.000	2.289	910.000	2.309	870.000	2.778	860.000	2.844	895.000	2.680	905.000	2.510	895.000	3.004	880.000	3.683	875.000	3.678	1000.000	1.076	875.000	1.767	760.000	1.005
920.000	2.261	915.000	2.283	875.000	2.711	865.000	2.821	900.000	2.617	910.000	2.439	900.000	2.970	885.000	3.594	880.000	3.607	1005.000	0.950	880.000	1.714	765.000	0.962
925.000	2.193	920.000	2.217	880.000	2.660	870.000	2.762	905.000	2.571	915.000	2.355	905.000	2.883	890.000	3.549	885.000	3.540	1014.366	1.037	885.000	1.688	770.000	0.872
930.000	2.154	925.000	2.191	885.000	2.619	875.000	2.739	910.000	2.504	920.000	2.319	910.000	2.813	895.000	3.436	890.000	3.503	1016.866	0.916	890.000	1.621	777.438	0.788
935.000	2.099	930.000	2.125	890.000	2.567	880.000	2.678	915.000	2.458	925.000	2.247	915.000	2.760	900.000	3.343	895.000	3.402	1019.366	0.773	895.000	1.571	779.938	0.617
940.000	2.032	935.000	2.085	895.000	2.526	885.000	2.617	920.000	2.389	930.000	2.199	920.000	2.688	905.000	3.277	900.000	3.360	1021.866	0.735	900.000	1.547	782.438	0.519
945.000	1.992	940.000	2.033	900.000	2.459	890.000	2.593	925.000	2.308	935.000	2.127	925.000	2.634	910.000	3.184	905.000	3.268	1024.366	0.627	905.000	1.499	784.938	0.420
950.000	1.926	945.000	1.967	905.000	2.433	895.000	2.531	930.000	2.272	940.000	2.042	930.000	2.560	915.000	3.090	910.000	3.151	1026.866	0.532	910.000	1.461	787.438	0.395
955.000	1.899	950.000	1.941	910.000	2.365	900.000	2.506	935.000	2.192	945.000	2.006	935.000	2.485	920.000	3.026	915.000	3.104	1029.366	0.385	915.000	1.417	789.938	0.285
960.000	1.832	955.000	1.876	915.000	2.312	905.000	2.442	940.000	2.156	950.000	1.922	940.000	2.430	925.000	2.932	920.000	2.989	1031.866	0.247	920.000	1.375	792.438	0.156
965.000	1.793	960.000	1.837	920.000	2.270	910.000	2.392	945.000	2.076	955.000	1.849	945.000	2.353	930.000	2.869	925.000	2.895	1034.366	0.095	925.000	1.354	794.938	0.098
970.000	1.740	965.000	1.785	925.000	2.217	915.000	2.352	950.000	2.005	960.000	1.813	950.000	2.259	935.000	2.775	930.000	2.848	1036.866	-0.055	930.000	1.304	797.438	-0.020
975.000	1.701	970.000	1.746	930.000	2.175	920.000	2.300	955.000	1.970	965.000	1.729	955.000	2.219	940.000	2.681	935.000	2.734	1039.366	-0.218	933.785	1.281	799.938	-0.103
980.000	1.636	975.000	1.681	935.000	2.107	925.000	2.259	960.000	1.889	970.000	1.693	960.000	2.141	945.000	2.619	940.000	2.687	1041.866	-0.394	936.285	1.183	802.438	-0.241
982.618	1.388	980.000	1.655	940.000	2.081	930.000	2.205	965.000	1.854	975.000	1.611	965.000	2.085	950.000	2.524	945.000	2.592	1044.366	-0.589	938.785	1.084	804.938	-0.414
987.873	1.165	985.000	1.590	945.000	2.012	935.000	2.163	970.000	1.774	980.000	1.539	970.000	2.006	955.000	2.414	950.000	2.479	1046.866	-0.785	941.285	0.986	807.438	-0.592
992.540	0.941	990.000	1.564	950.000	1.960	940.000	2.109	975.000	1.739	985.000	1.493	975.000	1.910	960.000	2.366	955.000	2.431	1049.366	-0.974	943.785	0.879	809.938	-0.784
997.720	0.659	994.170	1.250	955.000	1.918	945.000	2.040	980.000	1.659	990.000	1.421	980.000	1.870	965.000	2.268	960.000	2.317	1051.866	-1.178	946.285	0.806	812.438	-0.983
1003.016	0.407	1002.405	0.927	960.000	1.865	950.000	2.012	985.000	1.588	995.000	1.374	985.000	1.790	970.000	2.207	965.000	2.221	1054.366	-1.377	948.785	0.702	814.938	-1.185
1008.546	0.141	1009.875	0.592	965.000	1.823	955.000	1.943	990.000	1.544	1000.467	1.439	990.000	1.734	975.000	2.108	970.000	2.172	1056.866	-1.557	951.285	0.590	817.438	-1.406
1012.311	-0.067	1018.100	0.253	970.000	1.755	960.000	1.916	995.000	1.474	1004.054	1.268	995.000	1.653	980.000	1.998	975.000	2.058	1059.366	-1.726	953.785	0.558	819.938	-1.734
1017.475	-0.308	1025.571	-0.088	975.000	1.728	965.000	1.847	995.201	1.527	1008.440	1.053	1000.000	1.558	985.000	1.948	980.000	2.009	1061.866	-1.864	956.285	0.462	822.438	-1.948
1023.157	-0.599	1033.284	-0.429	980.000	1.659	970.000	1.793	1001.083	1.247	1012.058	0.866	1005.000	1.517	990.000	1.849	985.000	1.910	1064.366	-1.981	958.785	0.333	824.938	-2.233
1027.911	-0.847	1041.935	-0.803	985.000	1.606	975.000	1.751	1006.667	0.929	1015.711	0.663	1010.000	1.421	995.000	1.788	990.000	1.795	1066.866	-2.098	961.285	0.200	827.438	-2.560
1032.219	-1.082	1047.371	-1.247	990.000	1.564	980.000	1.697	1012.899	0.607	1019.849	0.484	1015.000	1.338	1000.000	1.689	995.000	1.746	1069.366	-2.217	963.785	0.067	829.938	-3.249
1036.211	-1.453	1053.294	-1.731	995.000	1.510	985.000	1.655	1017.972	0.352	1023.041	0.302	1016.886	1.281	1005.000	1.580	1000.000	1.631	1071.866	-2.322	966.285	-0.059	832.438	-3.224
1040.193	-1.863	1060.058	-2.305	1000.000	1.468	990.000	1.588	1022.601	0.113	1026.188	0.141	1023.418	1.007	1010.000	1.531	1005.000	1.531	1074.366	-2.447	968.785	-0.200	834.938	-3.801
1043.830	-2.213	1065.210	-2.929	1005.000	1.414	993.973	1.305	1027.079	-0.133	1031.116	-0.101	1030.336	0.699	1015.000	1.432	1010.000	1.481	1076.866	-2.581	971.285	-0.307	837.438	-3.789
1047.548	-2.611	1069.262	-3.210	1009.425	0.770	1001.776	0.940	1032.314	-0.404	1035.457	-0.332	1037.076	0.393	1020.000	1.323	1015.000	1.367	1079.366	-2.732	973.785	-0.490	839.938	-3.743
1051.098	-2.958	1075.330	-3.210	1018.102	0.385	1009.081	0.622	1036.903	-0.628	1039.135	-0.506	1044.742	0.052	1025.000	1.274	1020.000	1.317	1081.866	-2.920	976.285	-0.677	842.438	-3.716
1054.328	-3.221	1080.613	-3.210	1024.190	0.026	1016.711	0.323	1041.198	-0.840	1042.560	-0.680	1051.482	-0.259	1037.036	1.289	1025.000	1.211	1084.366	-3.112	978.785	-0.855		
1059.051	-3.237	1085.743	-3.220	1030.546	-0.267	1023.525	0.027	1045.276	-1.054	1046.071	-0.870	1058.505	-0.556	1045.663	0.855	1038.508	1.013	1086.866	-3.253	981.285	-1.030		
1063.794	-3.234	1089.275	-3.260	1037.358	-0.537	1030.374	-0.284	1048.796	-1.387	1049.810	-1.097	1065.918	-0.866	1052.965	0.493	1047.984	0.562	1089.366	-3.314	983.785	-1.208		
1068.076	-3.245	1089.871	-3.433	1044.519	-0.839	1036.842	-0.564	1052.669	-1.756	1053.288	-1.422	1071.641	-1.138	1061.085	0.077	1056.630	0.133	1091.866	-3.298	986.285	-1.396		
1072.089	-3.236			1049.482	-1.137	1043.285	-0.832	1055.729	-2.097	1056.761	-1.801	1076.515	-1.563	1068.453	-0.289	1064.421	-0.327	1094.366	-3.261	988.785	-1.618		
1076.031	-3.220			1054.725	-1.418	1048.015	-1.228	1059.208	-2.461	1061.120	-2.214	1081.622	-2.000	1076.344	-0.681	1071.317	-0.806	1096.866	-3.260	991.285	-1.846		
1079.686	-3.200			1060.480	-1.827	1053.348	-1.661	1063.319	-2.854	1066.781	-2.816	1086.684	-2.446	1082.968	-1.038	1075.970	-1.502	1099.366	-3.286	993.785	-2.093		
1081.797	-3.368			1065.738	-2.271	1058.518	-2.112	1066.707	-3.166	1070.304	-3.160	1091.006	-2.838	1089.198	-1.615	1086.210	-2.292	1101.866	-3.302	996.285	-2.360		
				1070.301	-2.748	1064.085	-2.609	1069.601	-3.213	1073.991	-3.225	1094.484	-3.148	1095.321	-2.158	1092.978	-2.458	1104.366	-3.325	998.785	-2.629		
				1075.130	-3.170	1068.098	-3.150	1073.808	-3.212	1077.767	-3.231	1099.181	-3.163	1101.167	-2.755	1099.088	-3.100	1106.866	-3.365	1001.285	-2.911		
				1080.753	-3.305	1073.393	-3.210	1077.485	-3.223	1082.484	-3.215	1103.806	-3.178	1107.479	-3.279	1113.237	-3.252	1109.366	-3.398	1003.785	-3.248		
				1086.332	-3.313	1079.049	-3.210	1081.600	-3.212	1087.555	-3.203	1108.958	-3.193	1113.556	-3.279	1120.640	-3.258	1111.866	-3.407	1006.285	-3.582		
				1091.438	-3.306	1083.953	-3.210	1085.560	-3.223	1092.120	-3.201	1112.177	-3.210	1120.291	-3.269	1126.847	-3.177	1114.366	-3.411	1008.785	-3.527		
				1093.835	-3.337	1088.006	-3.210	1088.418	-3.229	1094.366	-3.624	1114.059	-3.280	1126.327	-3.390	1127.037	-3.218	1116.866	-3.403	1011.285	-3.630		
				1095.252	-3.510	1090.331	-3.270	1092.324	-3.793	1094.944	-3.706	1115.004	-3.834	1127.023	-3.698			1119.366	-3.380	1012.785	-3.867		
						1090.693	-3.607											1119.866	-3.392				

Box VI - 8 Cross-sections from profiles13-24 part 4/4

Profiel 25		Profiel 26		Profiel A1		Profiel A2		Profiel A3		Profiel A4	
x [m]	depth [m]	x [m]	depth [m]	x [m]	depth [m]	x [m]	depth [m]	x [m]	depth [m]	x [m]	depth [m]
0.000	6.246	0.000	6.380	0.000	6.070	0.000	5.893	0.000	5.648	0.000	5.630
5.000	6.222	5.000	6.364	10.000	6.049	10.000	5.867	10.000	5.611	10.000	5.581
10.000	6.198	10.000	6.333	30.000	5.999	20.000	5.833	20.000	5.575	20.000	5.535
15.000	6.186	15.000	6.302	40.000	5.978	40.000	5.767	30.000	5.538	30.000	5.499
20.000	6.163	20.000	6.285	50.000	5.958	50.000	5.731	40.000	5.499	40.000	5.452
25.000	6.132	25.000	6.256	70.000	5.912	60.000	5.702	50.000	5.464	50.000	5.416
30.000	6.121	30.000	6.227	80.000	5.879	80.000	5.626	60.000	5.428	60.000	5.372
35.000	6.100	35.000	6.212	90.000	5.852	90.000	5.598	70.000	5.390	70.000	5.325
40.000	6.080	40.000	6.184	110.000	5.789	100.000	5.563	80.000	5.353	80.000	5.289
45.000	6.060	45.000	6.157	120.000	5.738	110.000	5.522	90.000	5.316	90.000	5.252
50.000	6.042	50.000	6.142	130.000	5.695	130.000	5.446	100.000	5.264	100.000	5.193
55.000	6.033	55.000	6.115	150.000	5.601	140.000	5.394	110.000	5.233	110.000	5.155
60.000	6.017	60.000	6.087	160.000	5.548	150.000	5.355	120.000	5.193	120.000	5.116
65.000	6.002	65.000	6.073	170.000	5.472	170.000	5.264	130.000	5.140	130.000	5.064
70.000	5.983	70.000	6.044	190.000	5.351	180.000	5.198	140.000	5.099	140.000	5.018
75.000	5.968	75.000	6.017	200.000	5.286	190.000	5.154	150.000	5.065	150.000	4.978
80.000	5.952	80.000	6.004	210.000	5.197	200.000	5.109	160.000	5.010	160.000	4.926
85.000	5.944	85.000	5.977	230.000	5.064	220.000	4.997	170.000	4.969	170.000	4.886
90.000	5.928	90.000	5.951	240.000	4.997	230.000	4.950	180.000	4.934	180.000	4.840
95.000	5.900	95.000	5.937	250.000	4.929	240.000	4.901	190.000	4.879	190.000	4.788
100.000	5.892	100.000	5.911	260.000	4.838	250.000	4.839	200.000	4.838	200.000	4.749
105.000	5.876	105.000	5.901	280.000	4.746	270.000	4.746	210.000	4.797	210.000	4.710
110.000	5.859	110.000	5.875	290.000	4.708	280.000	4.701	220.000	4.748	220.000	4.666
115.000	5.839	115.000	5.849	310.000	4.615	290.000	4.640	230.000	4.707	230.000	4.615
120.000	5.822	120.000	5.836	320.000	4.575	300.000	4.598	240.000	4.667	240.000	4.578
125.000	5.806	125.000	5.811	330.000	4.534	320.000	4.516	250.000	4.618	250.000	4.541
130.000	5.797	130.000	5.785	350.000	4.455	330.000	4.464	260.000	4.578	260.000	4.486
135.000	5.781	135.000	5.778	360.000	4.420	340.000	4.425	270.000	4.539	270.000	4.449
140.000	5.752	140.000	5.753	370.000	4.385	350.000	4.387	280.000	4.487	280.000	4.413
145.000	5.744	145.000	5.728	380.000	4.351	360.000	4.337	290.000	4.453	290.000	4.365
150.000	5.727	150.000	5.715	400.000	4.277	380.000	4.266	300.000	4.415	300.000	4.325
155.000	5.710	155.000	5.690	410.000	4.245	390.000	4.232	310.000	4.378	310.000	4.291
160.000	5.690	160.000	5.674	420.000	4.214	400.000	4.188	320.000	4.333	320.000	4.246
165.000	5.673	165.000	5.661	430.000	4.183	410.000	4.156	330.000	4.298	330.000	4.213
170.000	5.656	170.000	5.637	440.000	4.144	430.000	4.096	340.000	4.264	340.000	4.176
175.000	5.647	175.000	5.613	450.000	4.114	440.000	4.059	350.000	4.219	350.000	4.135
180.000	5.630	180.000	5.601	460.000	4.085	450.000	4.031	360.000	4.189	360.000	4.105
185.000	5.609	185.000	5.577	470.000	4.057	460.000	4.002	370.000	4.156	370.000	4.075
190.000	5.591	190.000	5.565	480.000	4.020	470.000	3.965	380.000	4.114	380.000	4.032
195.000	5.573	195.000	5.554	490.000	3.992	490.000	3.909	390.000	4.085	390.000	4.004
200.000	5.564	200.000	5.530	500.000	3.964	500.000	3.882	400.000	4.055	400.000	3.977
205.000	5.546	205.000	5.508	510.000	3.936	510.000	3.844	410.000	4.015	410.000	3.942
210.000	5.514	210.000	5.497	520.000	3.908	520.000	3.816	420.000	3.985	420.000	3.913
215.000	5.505	215.000	5.476	530.000	3.872	530.000	3.789	430.000	3.957	430.000	3.886
220.000	5.486	220.000	5.474	540.000	3.845	540.000	3.761	440.000	3.916	440.000	3.847
225.000	5.467	225.000	5.465	550.000	3.817	560.000	3.697	450.000	3.886	450.000	3.816
230.000	5.444	230.000	5.448	560.000	3.790	570.000	3.670	460.000	3.856	460.000	3.781
235.000	5.425	235.000	5.430	570.000	3.753	580.000	3.634	470.000	3.818	470.000	3.734

Box VI - 9 Cross-sections from profiles 25, 26, A1-A4 part 1/4

240.000	5.404	240.000	5.421	580.000	3.726	590.000	3.607	480.000	3.787	480.000	3.697
245.000	5.394	245.000	5.419	590.000	3.698	600.000	3.581	490.000	3.755	490.000	3.657
250.000	5.372	250.000	5.406	600.000	3.667	620.000	3.520	500.000	3.714	500.000	3.594
255.000	5.337	255.000	5.402	610.000	3.633	630.000	3.494	510.000	3.681	510.000	3.547
260.000	5.327	260.000	5.395	620.000	3.579	640.000	3.467	520.000	3.646	520.000	3.499
265.000	5.307	265.000	5.390	630.000	3.532	650.000	3.441	530.000	3.599	530.000	3.434
270.000	5.290	270.000	5.389	640.000	3.480	660.000	3.405	540.000	3.568	540.000	3.377
275.000	5.271	275.000	5.398	650.000	3.422	670.000	3.379	550.000	3.532	550.000	3.325
280.000	5.257	280.000	5.397	660.000	3.338	680.000	3.351	560.000	3.485	560.000	3.272
285.000	5.246	285.000	5.396	670.000	3.279	700.000	3.285	570.000	3.455	570.000	3.200
290.000	5.241	290.000	5.396	680.000	3.193	710.000	3.256	580.000	3.420	580.000	3.133
295.000	5.232	295.000	5.396	690.000	3.097	720.000	3.225	590.000	3.385	590.000	3.074
300.000	5.221	300.000	5.406	700.000	3.001	730.000	3.186	600.000	3.338	600.000	2.993
305.000	5.215	305.000	5.406	710.000	2.883	740.000	3.152	610.000	3.311	610.000	2.929
310.000	5.209	310.000	5.407	720.000	2.789	760.000	3.039	620.000	3.277	620.000	2.844
315.000	5.207	315.000	5.407	730.000	2.696	770.000	2.919	630.000	3.232	630.000	2.746
320.000	5.204	320.000	5.407	740.000	2.626	780.000	2.820	640.000	3.209	640.000	2.667
325.000	5.196	325.000	5.407	750.000	2.508	790.000	2.709	650.000	3.177	650.000	2.583
330.000	5.195	330.000	5.414	760.000	2.414	800.000	2.557	660.000	3.136	660.000	2.442
335.000	5.191	335.000	5.413	770.000	2.320	820.000	2.330	670.000	3.107	670.000	2.351
340.000	5.188	340.000	5.413	780.000	2.227	830.000	2.219	680.000	3.091	680.000	2.257
345.000	5.182	345.000	5.412	790.000	2.133	850.000	1.948	690.000	3.055	690.000	2.126
350.000	5.179	350.000	5.411	800.000	2.015	860.000	1.837	700.000	3.030	700.000	1.992
355.000	5.175	355.000	5.410	810.000	1.942	870.000	1.719	710.000	3.003	710.000	1.886
360.000	5.174	360.000	5.413	820.000	1.846	880.000	1.563	720.000	2.979	720.000	1.739
365.000	5.170	365.000	5.407	830.000	1.750	890.000	1.450	730.000	2.910	730.000	1.628
370.000	5.162	370.000	5.404	840.000	1.627	963.465	1.466	740.000	2.838	740.000	1.485
375.000	5.160	375.000	5.395	850.000	1.530	963.965	1.442	750.000	2.798	750.000	1.436
380.000	5.153	380.000	5.385	860.000	1.432	964.465	1.417	760.000	2.761	760.000	1.438
385.000	5.145	385.000	5.385	870.000	1.333	965.965	1.344	770.000	2.719	770.000	1.439
390.000	5.139	390.000	5.373	880.000	1.252	966.465	1.32	780.000	2.643	780.000	1.416
395.000	5.129	395.000	5.358	890.000	1.125	966.965	1.296	790.000	2.579	790.000	1.406
400.000	5.118	400.000	5.351	971.310	1.191	968.465	1.151	800.000	2.498	800.000	1.370
405.000	5.112	405.000	5.334	971.810	1.170	970.465	1.109	810.000	2.379	810.000	1.302
410.000	5.099	410.000	5.316	972.310	1.149	970.965	1.083	820.000	2.278	941.922	1.301
415.000	5.092	415.000	5.313	972.810	1.128	971.465	1.056	830.000	2.177	942.422	1.278
420.000	5.078	420.000	5.292	973.310	1.107	971.965	1.029	840.000	2.037	942.922	1.255
425.000	5.063	425.000	5.270	973.810	1.122	972.465	1.003	850.000	1.928	943.422	1.232
430.000	5.056	430.000	5.259	974.310	0.998	972.965	0.978	860.000	1.803	943.922	1.207
435.000	5.042	435.000	5.235	974.810	0.976	975.465	0.857	870.000	1.688	944.422	1.184
440.000	5.027	440.000	5.216	975.310	0.920	978.465	0.732	880.000	1.530	944.922	1.161
445.000	5.020	445.000	5.203	975.810	0.899	980.465	0.641	890.000	1.396	945.422	1.146
450.000	5.005	450.000	5.175	976.310	0.910	980.965	0.62	900.000	1.273	945.922	1.121
455.000	4.990	455.000	5.160	976.810	0.891	981.465	0.598	956.219	1.267	946.422	1.096
460.000	4.980	460.000	5.130	977.310	0.866	982.465	0.557	956.719	1.039	946.922	1.035
465.000	4.962	465.000	5.098	977.810	0.859	982.965	0.538	957.219	1.020	947.422	0.972
470.000	4.944	470.000	5.089	978.310	0.834	983.465	0.519	957.719	1.000	947.922	0.947
475.000	4.935	475.000	5.055	978.810	0.808	983.965	0.499	958.219	0.980	948.422	0.922
480.000	4.916	480.000	5.018	979.310	0.783	984.465	0.479	958.719	0.961	948.922	0.896
485.000	4.888	485.000	4.998	979.810	0.760	984.965	0.46	959.219	0.941	949.422	0.883

Box VI - 10 Cross-sections from profiles 25, 26, A1-A4 part 2/4

490.000	4.877	490.000	4.957	980.310	0.736	985.465	0.441	959.719	0.979	949.922	0.856
495.000	4.856	495.000	4.914	980.810	0.713	985.965	0.421	960.219	0.927	950.422	0.829
500.000	4.835	500.000	4.896	981.310	0.689	986.465	0.402	960.719	0.921	950.922	0.803
505.000	4.810	505.000	4.848	981.810	0.667	986.965	0.382	961.219	0.899	951.422	0.777
510.000	4.787	510.000	4.797	982.310	0.645	987.465	0.361	961.719	0.878	951.922	0.751
515.000	4.763	515.000	4.771	982.810	0.623	987.965	0.34	962.219	0.856	952.422	0.726
520.000	4.751	520.000	4.715	983.310	0.602	988.465	0.319	962.719	0.835	952.922	0.69
525.000	4.726	525.000	4.660	983.810	0.582	988.965	0.299	963.219	0.813	953.422	0.651
530.000	4.692	530.000	4.629	984.310	0.561	989.465	0.278	963.719	0.792	953.922	0.626
535.000	4.663	535.000	4.567	984.810	0.539	989.965	0.256	964.219	0.770	954.422	0.602
540.000	4.629	540.000	4.502	985.310	0.518	990.465	0.233	964.719	0.749	954.922	0.577
545.000	4.611	545.000	4.469	985.810	0.498	990.965	0.21	965.219	0.727	955.422	0.554
550.000	4.534	550.000	4.402	986.310	0.479	991.465	0.188	965.719	0.713	955.922	0.531
555.000	4.484	555.000	4.329	986.810	0.459	991.965	0.165	966.219	0.692	956.422	0.508
560.000	4.457	560.000	4.293	987.310	0.440	992.465	0.141	966.719	0.671	956.922	0.485
565.000	4.401	565.000	4.219	987.810	0.420	992.965	0.117	967.219	0.651	957.422	0.462
570.000	4.339	570.000	4.143	988.310	0.400	993.465	0.093	967.719	0.631	957.922	0.439
575.000	4.267	575.000	4.105	988.810	0.381	993.965	0.067	968.219	0.611	958.422	0.416
580.000	4.198	580.000	4.028	990.810	0.301	994.465	0.04	968.719	0.591	958.922	0.393
585.000	4.125	585.000	3.944	991.310	0.281	994.965	0.011	969.219	0.570	959.422	0.37
590.000	4.086	590.000	3.905	991.810	0.262	995.465	-0.018	969.719	0.550	959.922	0.348
595.000	4.006	595.000	3.827	992.310	0.242	995.965	-0.047	970.219	0.530	960.422	0.325
600.000	3.883	600.000	3.748	992.810	0.222	996.465	-0.075	970.719	0.510	960.922	0.303
605.000	3.839	605.000	3.709	993.310	0.203	996.965	-0.104	971.219	0.490	961.422	0.281
610.000	3.748	610.000	3.620	993.810	0.183	997.465	-0.132	971.719	0.470	961.922	0.258
615.000	3.653	615.000	3.540	996.310	0.086	997.965	-0.161	972.219	0.448	962.422	0.236
620.000	3.571	620.000	3.500	996.810	0.066	998.465	-0.19	972.719	0.427	962.922	0.214
625.000	3.471	625.000	3.420	997.310	0.045	998.965	-0.218	973.219	0.406	963.422	0.192
630.000	3.368	630.000	3.379	997.810	0.023	999.465	-0.247	973.719	0.385	963.922	0.17
635.000	3.315	635.000	3.298	998.310	0.001	999.965	-0.28	974.219	0.364	964.422	0.148
640.000	3.206	640.000	3.203	998.810	-0.021	1001.965	-0.437	974.719	0.343	964.922	0.125
645.000	3.124	645.000	3.162	999.310	-0.044	1002.465	-0.477	975.219	0.323	965.422	0.103
650.000	3.010	650.000	3.078	999.810	-0.067	1002.965	-0.514	975.719	0.302	965.922	0.081
655.000	2.892	655.000	2.993	1000.310	-0.092	1003.465	-0.55	976.219	0.281	966.422	0.059
660.000	2.832	660.000	2.950	1000.810	-0.119	1005.965	-0.733	976.719	0.258	966.922	0.037
665.000	2.690	665.000	2.848	1001.310	-0.147	1006.465	-0.77	977.219	0.235	967.422	0.015
670.000	2.567	670.000	2.758	1001.810	-0.176	1006.965	-0.808	977.719	0.213	967.922	-0.008
675.000	2.506	675.000	2.713	1002.310	-0.208	1007.465	-0.845	978.219	0.190	968.422	-0.031
680.000	2.383	680.000	2.621	1002.810	-0.241	1009.465	-0.984	978.719	0.167	968.922	-0.052
685.000	2.260	685.000	2.528	1003.310	-0.273	1009.965	-1.017	979.219	0.144	970.922	-0.149
690.000	2.179	690.000	2.482	1003.810	-0.305	1012.465	-1.178	979.719	0.121	971.422	-0.176
695.000	2.056	695.000	2.371	1004.310	-0.337	1012.965	-1.209	980.219	0.097	973.422	-0.284
700.000	1.932	700.000	2.278	1004.810	-0.369	1014.465	-1.295	980.719	0.073	973.922	-0.312
705.000	1.871	705.000	2.231	1005.310	-0.401	1014.965	-1.318	981.219	0.049	976.422	-0.467
710.000	1.747	710.000	2.138	1007.310	-0.536	1017.465	-1.39	981.719	0.025	976.922	-0.502
715.000	1.605	715.000	2.045	1007.810	-0.571	1020.465	-1.438	982.219	0.001	978.922	-0.648
720.000	1.544	720.000	1.998	1008.310	-0.609	1020.965	-1.444	982.719	-0.023	979.422	-0.685
725.000	1.420	725.000	1.886	1008.810	-0.650	1021.465	-1.45	983.219	-0.047	981.422	-0.842
730.000	1.296	730.000	1.792	1009.310	-0.693	1022.465	-1.461	983.719	-0.072	981.922	-0.883
735.000	1.217	735.000	1.745	1011.810	-0.910	1022.965	-1.467	984.219	-0.096	984.922	-1.136

Box VI - 11 Cross-sections from profiles 25, 26, A1-A4 part 3/4

740.000	1.094	740.000	1.651	1012.310	-0.952	1026.465	-1.541	984.719	-0.121	985.422	-1.177
745.000	0.969	745.000	1.557	1012.810	-0.993	1026.965	-1.556	985.219	-0.145	985.922	-1.22
750.000	0.907	750.000	1.491	1013.310	-1.031	1027.465	-1.571	985.719	-0.170	988.422	-1.441
755.000	0.781	755.000	1.398	1013.810	-1.068	1030.465	-1.676	986.219	-0.196	989.922	-1.585
761.810	0.692	760.000	1.305	1014.310	-1.105	1030.965	-1.696	986.719	-0.222	990.422	-1.633
764.310	0.472	765.000	1.259	1014.810	-1.141	1031.465	-1.716	987.219	-0.248	992.922	-1.889
766.810	0.317	770.000	1.169	1015.310	-1.175	1034.465	-1.837	987.719	-0.274	995.422	-1.967
769.310	0.315	775.000	1.082	1015.810	-1.210	1034.965	-1.854	988.219	-0.302	995.922	-1.972
771.810	0.180	780.000	1.019	1016.310	-1.245	1035.465	-1.87	988.719	-0.330	1011.922	-2.197
774.310	0.144	785.000	0.938	1016.810	-1.279	1037.965	-1.948	989.219	-0.359		
776.810	0.030	786.447	0.933	1017.310	-1.314	1038.465	-1.958	989.719	-0.388		
779.310	-0.080	788.947	0.850	1017.810	-1.347			990.219	-0.419		
781.810	-0.201	791.447	0.775	1018.310	-1.382			990.719	-0.451		
784.310	-0.319	793.947	0.694	1020.310	-1.529			991.219	-0.485		
786.810	-0.446	796.447	0.613	1020.810	-1.566			991.719	-0.518		
789.310	-0.601	798.947	0.522	1021.310	-1.602			992.219	-0.552		
791.810	-0.810	801.447	0.462	1024.810	-1.809			992.719	-0.588		
794.310	-1.005	803.947	0.408	1025.310	-1.830			993.219	-0.626		
796.810	-1.209	806.447	0.408	1025.810	-1.845			993.719	-0.664		
799.310	-1.509	808.947	0.315	1026.310	-1.855			994.219	-0.702		
801.810	-1.816	811.447	0.202	1026.810	-1.862			994.719	-0.740		
804.310	-2.024	813.947	0.090	1027.310	-1.871			998.219	-1.007		
806.810	-2.322	816.447	-0.054	1027.810	-1.879			998.719	-1.045		
809.310	-2.556	818.947	-0.203	1028.310	-1.889			999.219	-1.084		
811.810	-2.836	821.447	-0.362	1028.810	-1.898			1002.219	-1.308		
814.310	-3.013	823.947	-0.527	1037.810	-2.062			1002.719	-1.343		
816.810	-2.987	826.447	-0.704					1004.719	-1.464		
819.310	-3.772	828.947	-0.893					1005.219	-1.489		
820.310	-3.879	831.447	-1.081					1008.219	-1.589		
		833.947	-1.266					1008.719	-1.604		
		836.447	-1.455					1009.219	-1.622		
		838.947	-1.721					1013.219	-1.850		
		841.447	-2.010					1017.219	-1.896		
		843.947	-2.276					1017.719	-1.902		
		846.447	-2.492					1020.719	-1.969		
		848.947	-2.699					1021.219	-1.983		
		851.447	-2.772					1024.719	-2.080		
		853.947	-2.803								
		856.447	-2.832								
		858.947	-2.859								
		861.447	-2.885								
		862.447	-2.896								

Box VI - 12 Cross-sections from profiles 25, 26, A1-A4 part 4/4

VI.3.2. Wave/Current Scenario

Wave input for UB is necessary at the seaward end of the cross-sections that were mentioned before. The wave conditions are used as a boundary condition at the seaward boundary of a cross-shore profile defined along the normal of a coast section. The parameters of importance:
- significant wave height,
- water level,
- peak period,
- wave angle with respect to the north,
- duration.

Offshore wave conditions are transformed to nearshore wave conditions. At the beginning of a cross-section the parameters of importance are extracted from the modelling done with Delft3D-wave. More information about this subject can be found in Appendix III. Wave data for all the profiles are given in Table VI - 1 and Table VI - 2.

Profiel 1	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.683	8.348	36.67	25.55
E	0.054	0.734	8.348	50.76	110.23
SE	0.054	0.421	12.14	50.82	76.65
S	0.054	0.165	12.139	53.85	97.09

Profiel 2	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.682	8.347	37.53	25.55
E	0.054	0.73	8.348	51.26	110.23
SE	0.054	0.418	12.14	51.27	76.65
S	0.054	0.164	12.139	54.49	97.09

Profiel 3	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.683	8.348	38.01	25.55
E	0.054	0.73	8.348	51.52	110.23
SE	0.054	0.417	12.14	51.52	76.65
S	0.054	0.164	12.139	54.89	97.09

Profiel 4	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.686	8.348	38.47	25.55
E	0.054	0.733	8.348	51.76	110.23
SE	0.054	0.418	12.139	51.73	76.65
S	0.054	0.163	12.139	55.26	97.09

Profiel 5	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.691	8.348	39.07	25.55
E	0.054	0.737	8.348	51.97	110.23
SE	0.054	0.42	12.139	51.85	76.65
S	0.054	0.164	12.139	55.53	97.09

Profiel 6	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.697	8.348	39.33	25.55
E	0.054	0.742	8.348	52.01	110.23
SE	0.054	0.422	12.139	51.8	76.65
S	0.054	0.164	12.139	55.54	97.09

Profiel 7	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.705	8.348	40.1	25.55
E	0.054	0.752	8.348	51.74	110.23
SE	0.054	0.426	12.139	50.79	76.65
S	0.054	0.161	12.139	53.8	97.09

Profiel 8	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.701	8.348	40.83	25.55
E	0.054	0.755	8.348	51.72	110.23
SE	0.054	0.428	12.139	50.36	76.65
S	0.054	0.159	12.139	52.64	97.09

Profiel 9	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.708	8.348	42.64	25.55
E	0.054	0.772	8.348	53.46	110.23
SE	0.054	0.438	12.139	51.8	76.65
S	0.054	0.157	12.139	52.37	97.09

Profiel 10	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.718	8.348	44.03	25.55
E	0.054	0.786	8.348	54.8	110.23
SE	0.054	0.445	12.139	52.83	76.65
S	0.054	0.157	12.139	52.53	97.09

Profiel 11	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.727	8.348	44.76	25.55
E	0.054	0.789	8.348	55.63	110.23
SE	0.054	0.449	12.139	53.83	76.65
S	0.054	0.16	12.139	54.67	97.09

Profiel 12	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.752	8.348	45.69	25.55
E	0.054	0.825	8.348	58.08	110.23
SE	0.054	0.477	12.139	57.42	76.65
S	0.054	0.172	12.139	58.63	97.09

Profiel 13	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.791	8.348	46.92	25.55
E	0.054	0.872	8.348	60.32	110.23
SE	0.054	0.507	12.139	60.06	76.65
S	0.054	0.181	12.139	60.4	97.09

Profiel 14	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.827	8.348	47.33	25.55
E	0.054	0.911	8.348	61.39	110.23
SE	0.054	0.53	12.139	61.31	76.65
S	0.054	0.187	12.139	60.78	97.09

Table VI - 1 Wave data profiles 1-14

Profiel 15	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.849	8.348	48.62	25.55
E	0.054	0.954	8.348	63.16	110.23
SE	0.054	0.558	12.139	63.4	76.65
S	0.054	0.195	12.139	62.69	97.09

Profiel 16	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.820	8.348	50.57	25.55
E	0.054	0.952	8.348	65.81	110.23
SE	0.054	0.562	12.139	66.3	76.65
S	0.054	0.196	12.139	65.74	97.09

Profiel 17	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.780	8.348	52.82	25.55
E	0.054	0.943	8.348	70.39	110.23
SE	0.054	0.565	12.139	71.19	76.65
S	0.054	0.195	12.139	70.52	97.09

Profiel 18	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.770	8.348	50.7	25.55
E	0.054	0.938	8.348	72.69	110.23
SE	0.054	0.572	12.139	74.57	76.65
S	0.054	0.199	12.139	74.15	97.09

Profiel 19	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.780	8.348	46.02	25.55
E	0.054	0.869	8.348	73.78	110.23
SE	0.054	0.52	12.139	77.57	76.65
S	0.054	0.185	12.139	77.15	97.09

Profiel 20	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.857	8.348	45.97	25.55
E	0.054	0.887	8.348	75.02	110.23
SE	0.054	0.525	12.139	80.44	76.65
S	0.054	0.186	12.139	79.03	97.09

Profiel 21	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.988	8.348	48.42	25.55
E	0.054	0.976	8.348	78.09	110.23
SE	0.054	0.584	12.139	84.67	76.65
S	0.054	0.206	12.139	81.54	97.09

Profiel 22	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.880	8.348	55.1	25.55
E	0.054	1.007	8.348	74.36	110.23
SE	0.054	0.667	12.139	82.61	76.65
S	0.054	0.26	12.139	82.48	97.09

Profiel 23	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.927	8.348	57.15	25.55
E	0.054	1.016	8.348	75.47	110.23
SE	0.054	0.632	12.139	86.72	76.65
S	0.054	0.255	12.139	90.66	97.09

Profiel 24	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.975	8.348	60	25.55
E	0.054	1.118	8.348	75.21	110.23
SE	0.054	0.664	12.139	82.61	76.65
S	0.054	0.251	12.139	88.26	97.09

Profiel 25	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.983	8.348	60.49	25.55
E	0.054	1.14	8.348	77.97	110.23
SE	0.054	0.717	12.139	85.32	76.65
S	0.054	0.277	12.139	88.69	97.09

Profiel 26	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	1.007	8.348	65.01	25.55
E	0.054	1.249	8.348	83.22	110.23
SE	0.054	0.82	12.139	91.35	76.65
S	0.054	0.317	12.139	94.17	97.09

Profiel A1	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.690	8.348	38.79	25.55
E	0.054	0.794	8.348	52.71	110.23
SE	0.054	0.464	12.139	53.31	76.65
S	0.054	0.183	12.139	54.59	97.09

Profiel A2	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.705	8.348	39.8	25.55
E	0.054	0.834	8.348	51.28	110.23
SE	0.054	0.485	12.139	51.57	76.65
S	0.054	0.188	12.139	52.5	97.09

Profiel A3	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.724	8.348	39.05	25.55
E	0.054	0.846	8.348	49.09	110.23
SE	0.054	0.487	12.139	49.08	76.65
S	0.054	0.185	12.139	49.78	97.09

Profiel A4	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.726	8.348	38.91	25.55
E	0.054	0.845	8.348	48.86	110.23
SE	0.054	0.485	12.139	48.83	76.65
S	0.054	0.184	12.139	49.49	97.09

Table VI - 2 Wave data profiles 15-A4

The tidal variation at Piçarras beach is relatively small. The average tidal range is 0.6m[21]. Currents are very low, as mentioned in Appendix II about hydraulic boundary conditions. For UB no currents are taken into account.

VI.3.3. Wave parameters

In UB parameters used for wave-related calculations can be adjusted. Values that are used for this project are given in Table VI - 3.

Coefficient	Value
Coefficient for wave breaking (gamma)	0.85
Coefficient for wave breaking (alfa)	1
Coefficient for bottom friction (fw)	0.01
The value of the bottom roughness (kb) (m)	0.05

Table VI - 3 Wave parameters

VI.3.4. Transport parameters

UB can handle three types of transport formulae that are relevant for sand. These are: Bijker, Van Rijn and CERC. The CERC-formula is only valid for relatively long and straight beaches. That is why the CERC-formula is not suitable for Piçarras beach. Both the Bijker- and the Van Rijn formula are appropriate for the beach. For this study only Van Rijn is used.

Profiles 1 until 21 are located in the area that was nourished in 1999. Parameters for these profiles are all the same, because the characteristics of the nourished sediment were constant. For the profiles 22 until 26 and A1 until A4 other parameters are used. More information about grain sizes and samples can be found in Appendix V. Parameters used for UB are given in Table VI - 4.

Parameter	Profiles 1-21	Profile 22	Profile 23	Profile 24	Profile 25	Profile 26	Profile A1	Profile A2	Profile A3	Profile A4
D50, Median (50%) grain diameter [μm]	285	307	349	349	267	267	206	156	153	174
D90, 90% grain diameter [μm]	605	547	689	689	445	634	460	363	342	267
Sediment density [kg/m3]	2650	2650	2650	2650	2650	2650	2650	2650	2650	2650
Current related bottom roughness [m]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Wave related bottom roughness [m]	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Fall velocity suspension material [m/s]	0.029	0.032	0.037	0.037	0.026	0.026	0.018	0.012	0.012	0.014
Viscosity (* 10^{-6})	1	1	1	1	1	1	1	1	1	1
Correction factor	1	1	1	1	1	1	1	1	1	1
Relative bottom transport layer thickness [-]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Porosity	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4

Table VI - 4 Transport parameters

VI.4 Input CL-module

The input will be summed up in the order that is used while using the program.

VI.4.1. Basic Model

For creating a model of the beach, the first thing to do is to create a basic line along which the beach width can be defined. In the situation of Piçarras and Alegre beach 30 points were used that are given in Figure VI - 2. These points represent the stone wall, that borders the beach and are given in world coordinates. Since these points don't form a smooth line, some points were shifted. Together, the coordinates of the points of the reference line and the distance to the shoreline form the basic model. The basic model contains the beach as it was in 1999, just after the nourishment and can be found in Table VI - 4. An impression is given in Figure VI - 3.

Profile	X	Y	Distance to shoreline [m]
26	730719.78	7041172.67	47.88
25	730861.23	7040537.63	44.03
24	730939.35	7040130.40	46.57
23	731057.55	7039427.12	48.74
22	731146.66	7038822.01	84.82
21	731297.65	7038357.00	69.07
20	731323.08	7038261.16	65.47
19	731354.82	7038166.69	70.32
18	731385.46	7038071.57	66.99
17	731422.04	7037979.32	68.64
16	731461.05	7037887.19	67.80
15	731504.36	7037797.24	71.53
14	731554.37	7037710.77	67.41
13	731602.11	7037624.13	71.68
12	731654.53	7037539.27	64.38
11	731709.57	7037457.53	65.64
10	731767.20	7037376.95	68.91
9	731826.48	7037297.91	66.03
8	731893.65	7037223.80	67.96
7	731961.51	7037153.39	67.96
6	732031.76	7037083.53	61.93
5	732099.71	7037020.63	86.27
4	732181.10	7036957.69	89.25
3	732262.25	7036903.01	86.35
2	732345.82	7036851.29	66.36
1	732431.99	7036802.56	70.32
A1	732797.62	7036694.78	39.58
A2	732968.43	7036656.05	42.68
A3	733142.41	7036634.13	42.31
A4	733314.12	7036644.00	42.99
End of Alegre	733464.80	7036725.00	0.00

Table VI - 5 Basic model

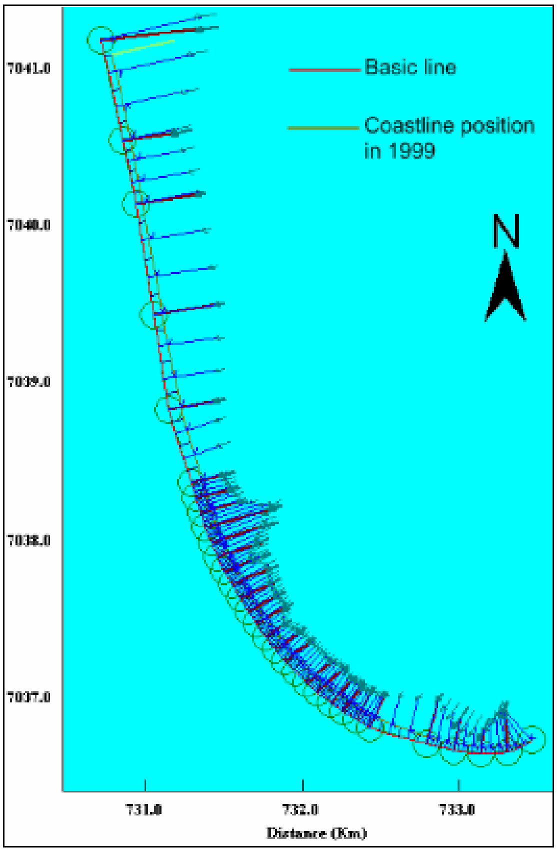


Figure VI - 3 Basic model in drawn in UB

VI.4.2. Boundary Conditions

In the model there are two boundary conditions. One is in the south, the other in the north. Due to the large headlands (Ponta da Penha, Ponta da Vigia and Ponta Negra, see Figure VI - 4) that are situated in the south there is little chance of sediment input from this direction. For that reason the southern boundary condition is treated as a closed boundary.

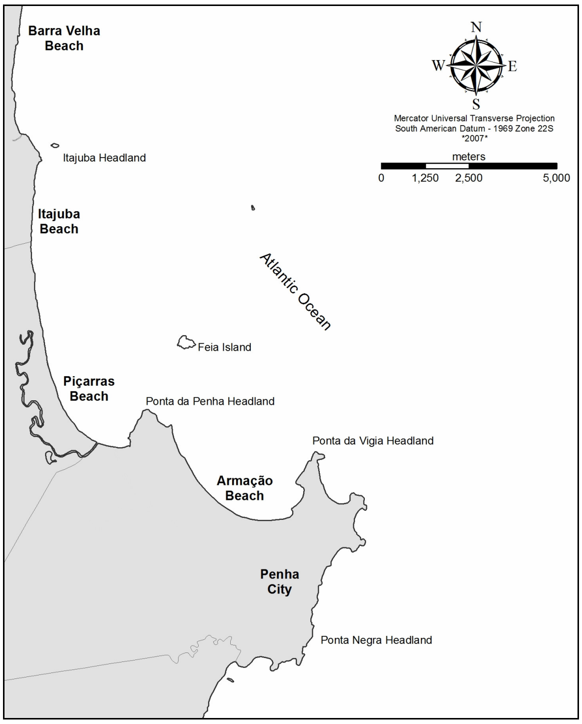


Figure VI - 4 Headlands [2]

The northern boundary condition is not closed. From field observation it is clear that there is no erosion at this point (profile 26, see Figure VI - 2), but there is even some accretion. During the creation of the model it was not really clear how to deal with this boundary. That is why it was decided to first treat this boundary as closed too. In that way it is possible to evaluate the influence of each different wave direction (northeast, east, southeast and south) on the position of the shoreline. In a later stadium adjustment of this boundary condition is necessary.

VI.4.3. Jetties

In the end of the 70's a beginning was made with the fixation of Rio Piçarras. This fixation was developed with the creation of two little jetties. In the end of the 90s these jetties were extended [23]. The southern jetty is about 168m long when the basic model line (Figure VI - 3) is used as a reference. The northern jetty is about 180m long. To make a good representation of the real situation both jetties have to be present in the UB-model. The distance between the jetties is only 35m. Unfortunately, UB can not handle such short distances between engineering measures. For that reason only the northern jetty is modelled, because this one is longer than the southern jetty. The input for the program only exists of the position of the jetty (which can be done in world coordinates), the length and its permeability (in blocking percentages). The position is determined with ArcGIS [34]. The length can be calculated because the position of the jetty on the basic line and the position of the tip of the jetty are known:

	X	Y
Point on reference line	732525.96	7036766.71
Tip of jetty	732626.75	7036916.51

Table VI - 6 Jetty position

The permeability is negligible, which can be represented by 100% blocking. UB maps the position automatically perpendicular to the shoreline. It must be stated that the northern jetty is not positioned in this way, but it is a valid simplification.

VI.4.4. Input Rio Piçarras

In the past Piçarras beach used to be in equilibrium. Probably this was because Rio Piçarras was able to carry enough sediment to maintain this equilibrium. Nowadays the mouth of the river is fixated and upstream there is a dam, which blocks the sediment input. So the input in sediment is negligible, i.e. $0 m^3/yr$.

VI.5 Results

In this paragraph the output from UB will be described. Results are presented with figures. The black line indicates the position of the shoreline in 1999. The border between yellow and blue indicates the position of the coastline after nine years of simulation. To get a good overview of the behaviour of the model the results are divided into a few cases:

Case 1: Closed boundaries on both sides
Case 2: Closed boundary on the south, open boundary in the north
Case 3: Investigation of cross-shore transport
Case 4: Investigation of the influence of the shoals

Each figure contains both boundary conditions (Left Bound = northern boundary, Right Bound = southern boundary), the end of the nourishment area (profile 21) and the area with the most severe erosion (the red line between profile 3 and profile 8). Note that according to Appendix V, the transition from erosion to no erosion (or even some small accretion) starts from profile 18 in northern direction.

VI.5.1. Case 1: Closed boundaries on both sides

Up until now it is not really clear which properties have to be given to the northern boundary condition. This case is used to evaluate the effect of the waves from each direction individually. Closed boundaries are used, to see on what spots erosion or accretion occurs.

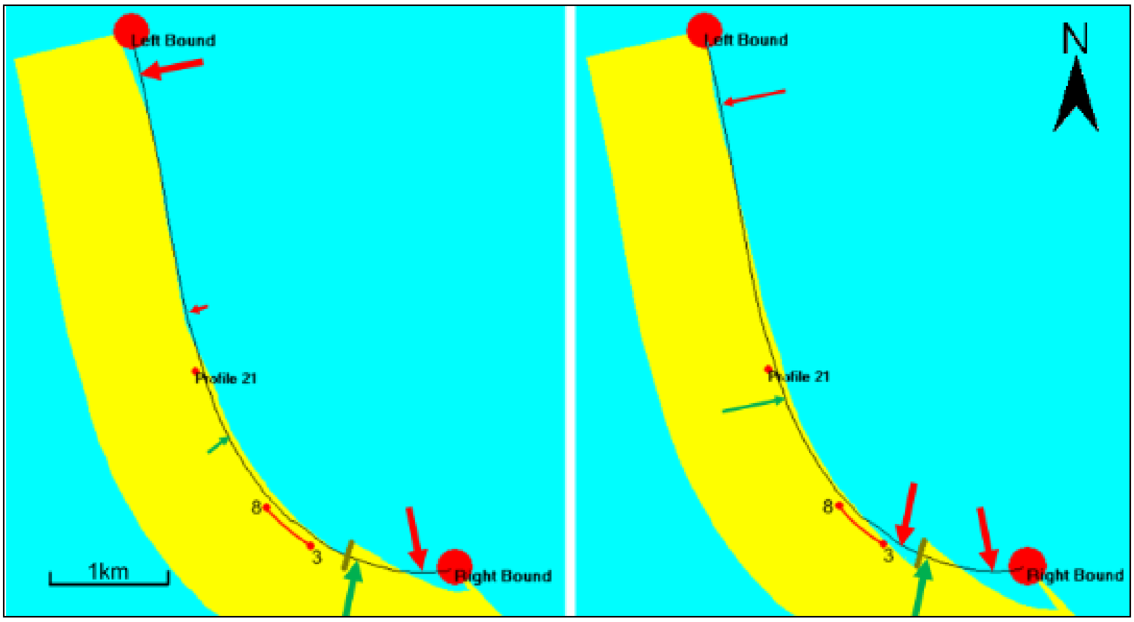


Figure VI - 5 Result with waves from NE (left) and E (right)

Waves from the northeast seem to cause some accretion around profile 21. Only around profile 3 and profile 4 there is some erosion. Alegre beach, which is in equilibrium in reality, shows some severe erosion next to the right boundary.

Waves from the east almost show the same result as waves from the northeast. There is accretion on almost the whole nourished area. The erosion next to the northern jetty is larger due to waves from the east than due to waves from the northeast. Also Alegre seems to show even more erosion next to the right boundary.

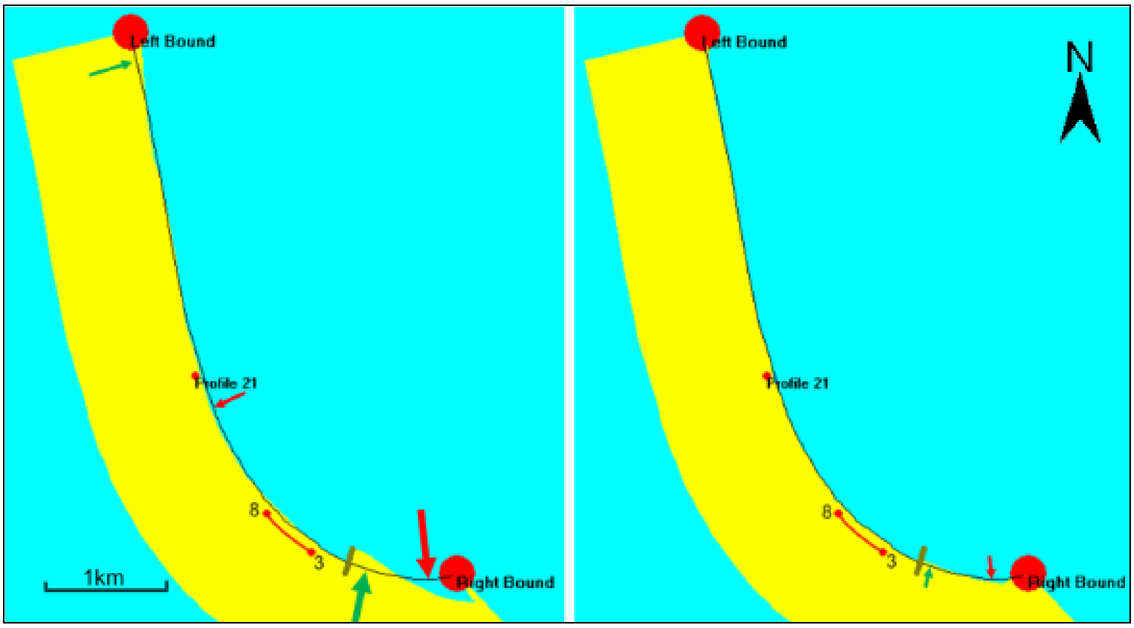


Figure VI - 6 Result with waves from SE (left) and S (right)

Waves from the southeast show little erosion around profile 21. Between profiles 3 and 8 there does not happen a lot. Again Alegre shows severe erosion next to the right boundary and accretion next to the jetty.

Waves from the south don't influence the position of the coastline. Only on Alegre beach there is little movement, but this is almost negligible in comparison with previous results. Next, all wave scenarios will be applied simultaneously.

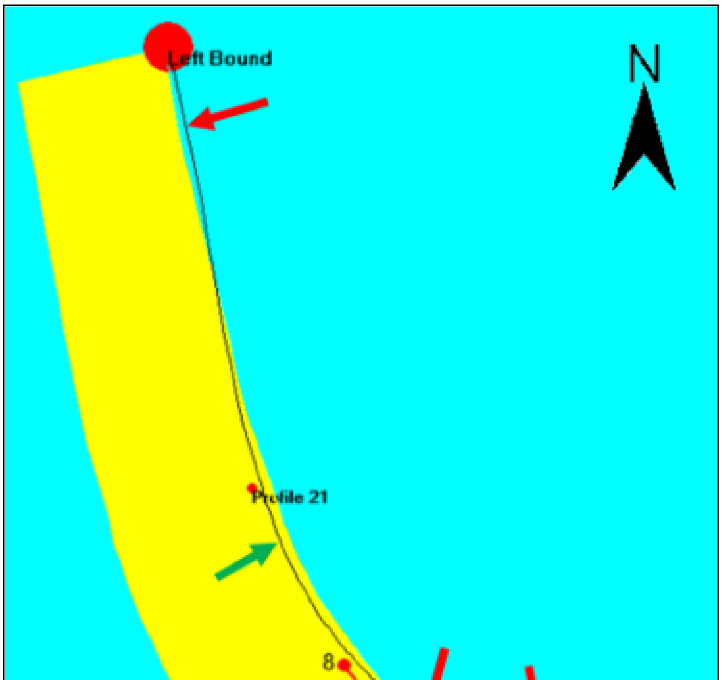


Figure VI - 7 Result with waves from all directions

When all wave scenarios are applied to the nourished coastline it should resemble the position of the coastline at the situation it was during mid 2008. When the nourished area is analyzed, it is clear that there should be erosion from profile 1 until profile 17 (Appendix V). Figure VI - 7 shows that according to the simulation there is accretion along almost the whole nourished area. Only next to the jetty there is erosion, but in reality on that location the erosion is smaller than the rest of the nourished area. Also Alegre shows severe erosion next to the right boundary and some accretion next to the jetty. From measurements it is clear that Alegre beach is in equilibrium. There is no erosion or accretion on this part of the project area. This strange result at Alegre is caused by the fact that UB does not take the shadow zone behind headland Ponta da Penha into account (see Figure VI - 4). The result can be stated as unreliable. Because it is not possible to improve the wave data or the bathymetry the only improvement possible is changing the boundary condition in the north. In case 2 this adjustments of the boundary conditions is explained.

VI.5.2. Case 2: Closed boundary on the south, open boundary in the north

The first case did not show good results. As expected, the closed boundary in the north is one of the causes of this insufficient outcome. In this case the northern boundary condition is adjusted, keeping the waves coming from all directions (northeast, east, southeast an south). The southern boundary can be seen as closed due to the headlands in eastern and southern direction (see Figure VI - 4). For the northern boundary condition there are four options for an open boundary:

Option 1: The coastline position remains constant
Option 2: The coastal angle remains constant
Option 3: The transport Qs is a user-defined constant value
Option 4: The transport Qs is a user-defined function of time

Because of the complexity of the fourth option, it will not be treated in this report.

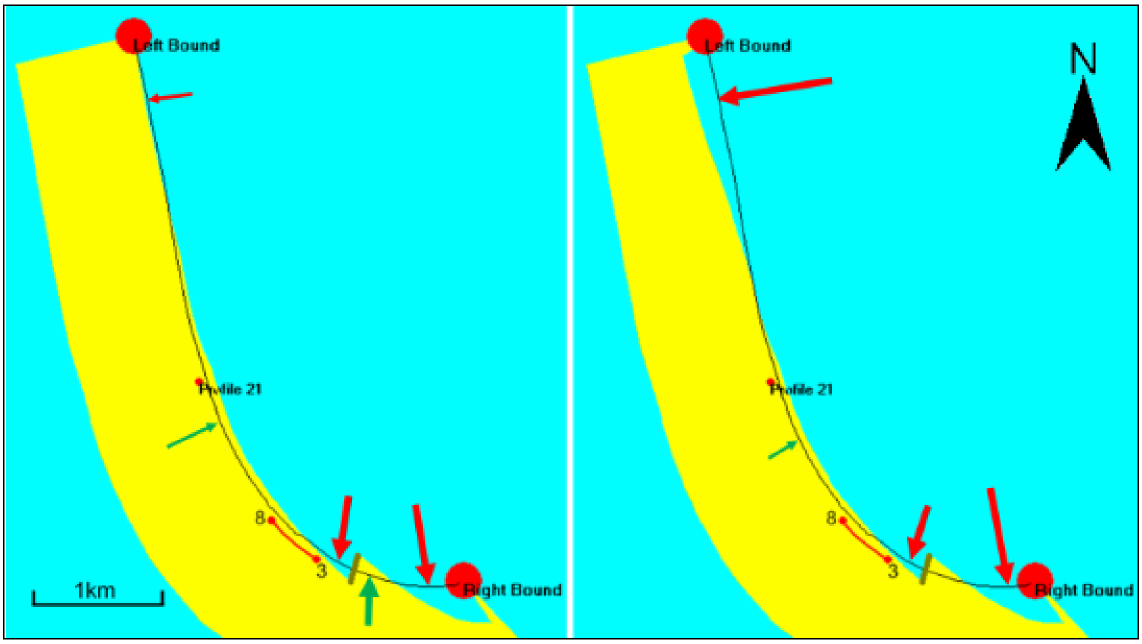


Figure VI - 8 Result from option 1 (left) and option 2 (right)

Figure VI - 8 shows the results of option 1 and option 2. When the coastline position remains constant this means that the program itself will import or export as much sand as needed to keep the coastline on its starting position. When the result is compared with Figure VI - 7 from case 1 it can be concluded that there is not much difference. There is less erosion in the north and slightly more accretion in the middle of Piçarras beach.

When the coastal angle in the northern boundary condition is kept constant this implies that the transport at the boundary is kept stable. It can be concluded that the result doesn't improve when the coastal angle in the north remains constant. It shows very strong erosion in the northern area where there is not any in reality. The results from the middle area of Piçarras beach until the southern boundary condition is comparable with previous results.

The last option for the northern boundary condition is to define a transport Qs. This is a user-defined constant value. This value can either be positive or negative, indicating there is sediment input or output. The volume that is lost from profile 1 until profile 21 resembles 395,000m^3 in 9 years (Appendix V). When we assume that the total eroded volume is lost due to longshore transport, there should be a sediment output of 395,000 / 9 = 43888.89 m^3/yr.

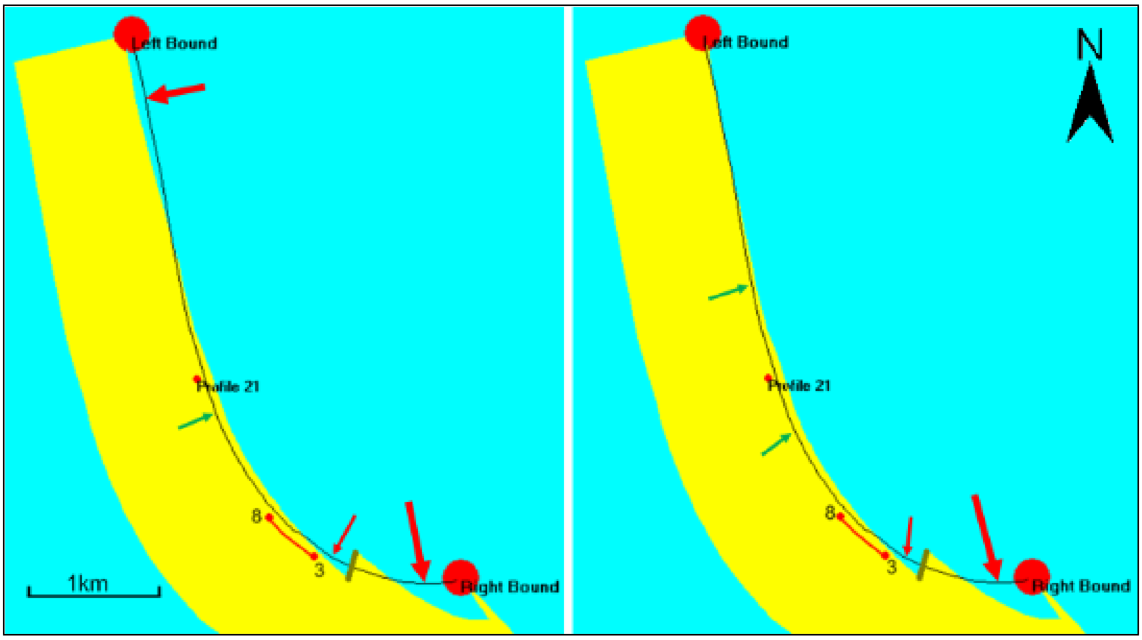


Figure VI - 9 Result option 3 with sediment output (left) and input (right)

The results applying sediment output (Figure VI - 9, left) show that there is more erosion in the north, but there is still accretion in the nourishment area further south than profile 17. It is clear that the result is not improving. It is expected that when the northern boundary condition is changed to sediment input this will result in even more accretion along the nourished area. For the completeness of the modelling results, this input-scenario is still added. The amount of input is set in the same order of magnitude as the output amount from the last run.

The result of the sediment input of 43,900 m^3 (Figure VI - 9, right) shows that there is indeed more accretion. Next to the northern boundary condition there is no erosion or accretion. It is almost the same as the result from option 1 (the coastline position remains constant at the left boundary condition).

When all the results of case 2 are compared, it is clear that none of the chosen boundary conditions result in the erosion pattern that is measured. Moreover, changing the northern boundary condition does not significantly influence the southern part of the project area. When only the northern part of the modelled beach is taken into account the results of option 1, the coastline at the boundary remains constant, and option 3, with sediment input, show reasonable results. Since the latter is not really a realistic option the next model developments will include a northern boundary condition in which the coastline position remains constant and a closed southern boundary.

VI.5.3. Case 3: Investigation of cross-shore transport

UB only takes longshore sediment transport into account. Cross-shore transport is in practice only present when there is a storm surge (see Appendix V). In the last decade there hasn't been a surge like that, so no cross-shore transport should have taken place. Nevertheless, the results until now haven't been satisfying. In this case cross-shore transport will be simulated with sinks, to check results will improve.

First, the output of SMC (Appendix VII) will be compared with the output of UB. Remembering the fact that the simulation time of SMC is only 72 hours and the simulation time of UB is 9 years. That is why the comparison will only be qualitative. When both programs are in agreement with each other, SMC can be used to locate the cross-shore transport positions along the project area. Results from case 1 are used for comparison. These results have closed boundaries in the south and in the north, so the movement of sediment can easily be determined and compared with the output that SMC gives. First the results from waves from the northeast are analyzed.

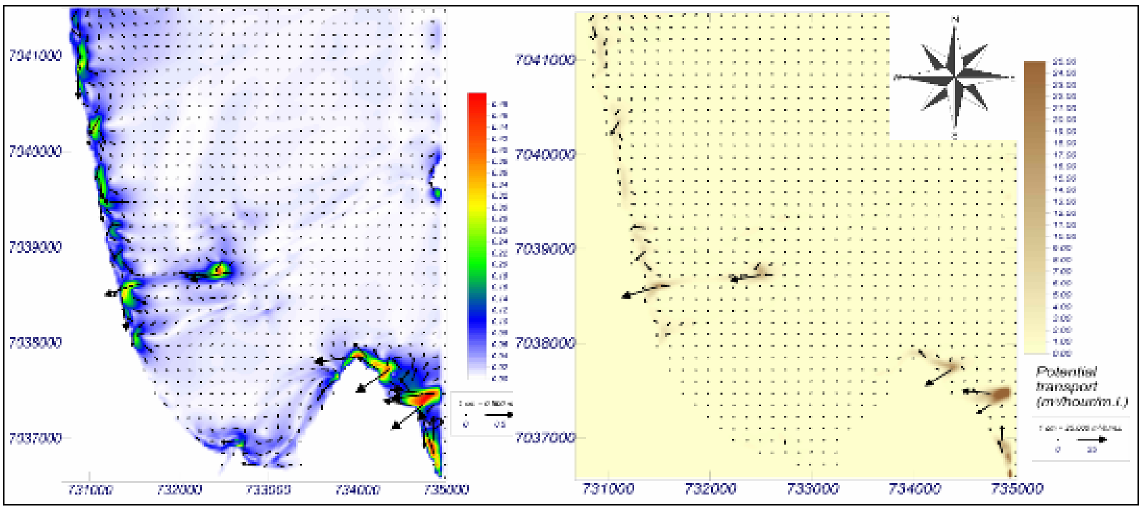


Figure VI - 10 Results SMC with waves from NE, currents (left) and potential transport (right)

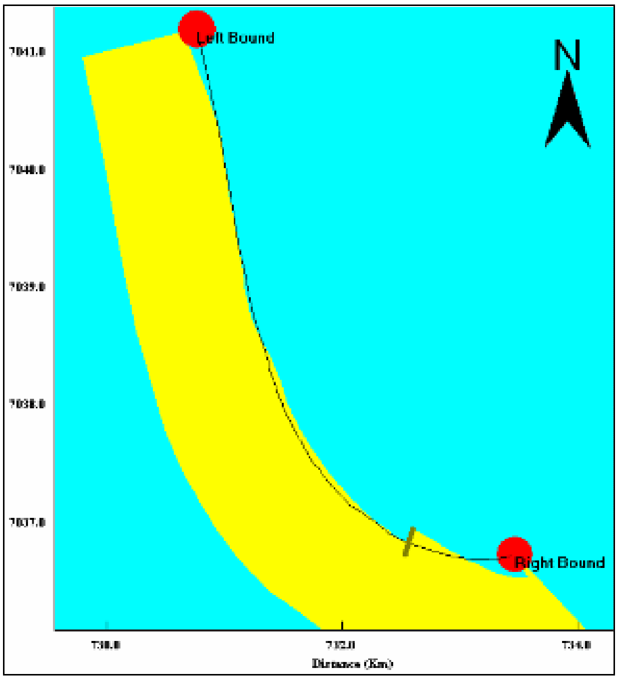


Figure VI - 11 Result UB with waves from NE

Results from both SMC and UB show southern transport in the north. From y=7040000 down there is southern transport according to SMC. North of the jetty there is almost negligible transport in northern direction. The result is accretion between the jetty and y=7038300, which is visible in the UB result.

Results at Alegre beach differ completely. Next, the results with waves coming from the east will be analyzed.

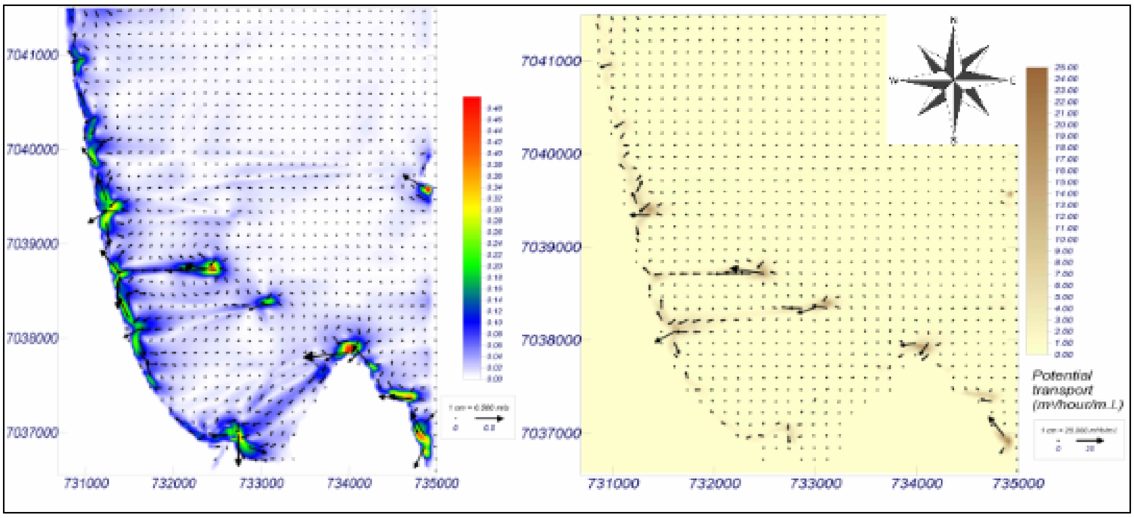


Figure VI - 12 Results SMC with waves from E, currents (left) and potential transport (right)

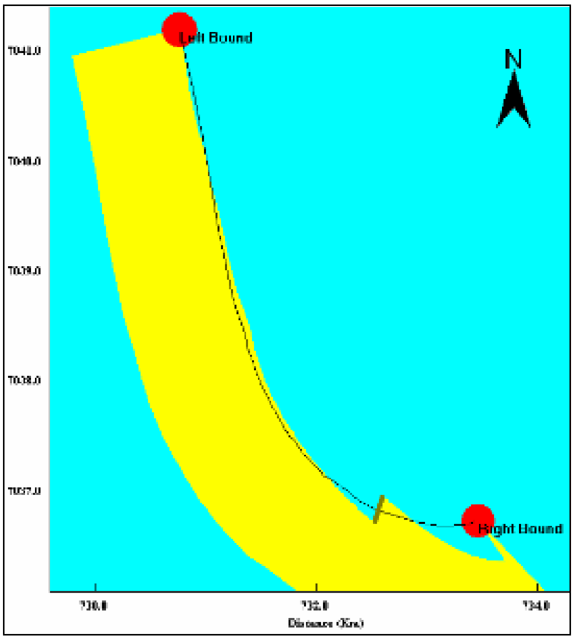


Figure VI - 13 Result UB with waves from E

SMC shows little transport in the north. Between y=7038000 and y=7040000 it is not clear in which direction there is transport. SMC output is chaotic between those points. The location of this chaos seems to match the accretion in UB, although this is not really straightforward. Transport to the north from the jetty is both visible in UB and SMC.

Results at Alegre do not seem to match again. According to SMC there should be little transport, UB shows a lot of transport. Next, the result with waves coming from southeast will be analyzed.

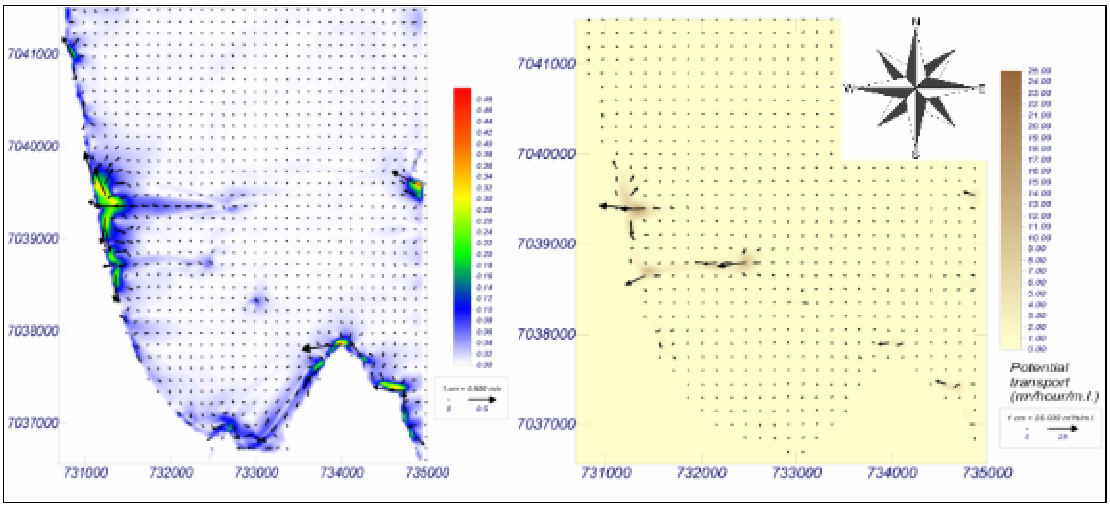


Figure VI - 14 Results SMC with waves from SE, currents (left) and potential transport (right)

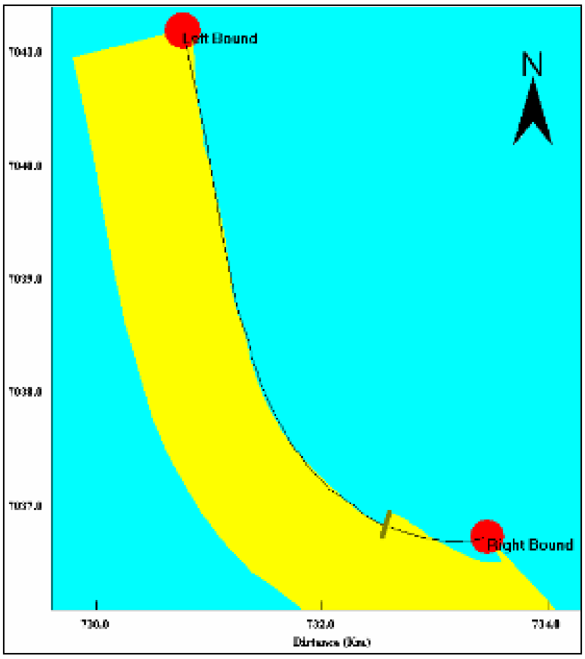


Figure VI - 15 Result UB with waves from SE

SMC shows very little transport along the whole beach, apart from y=7039333. This transport is not visible in UB as erosion. This point (in the SMC output) is probably the result of shoals in front of the coast. These shoals are not present in the cross-sections that form the bathymetry in UB. The accretion in the north of the UB-output is due to the northern transport from y=7039500, which is confirmed by SMC.

Again Alegre beach doesn't seem to match in SMC and UB. Next, the result with waves from south will be analyzed.

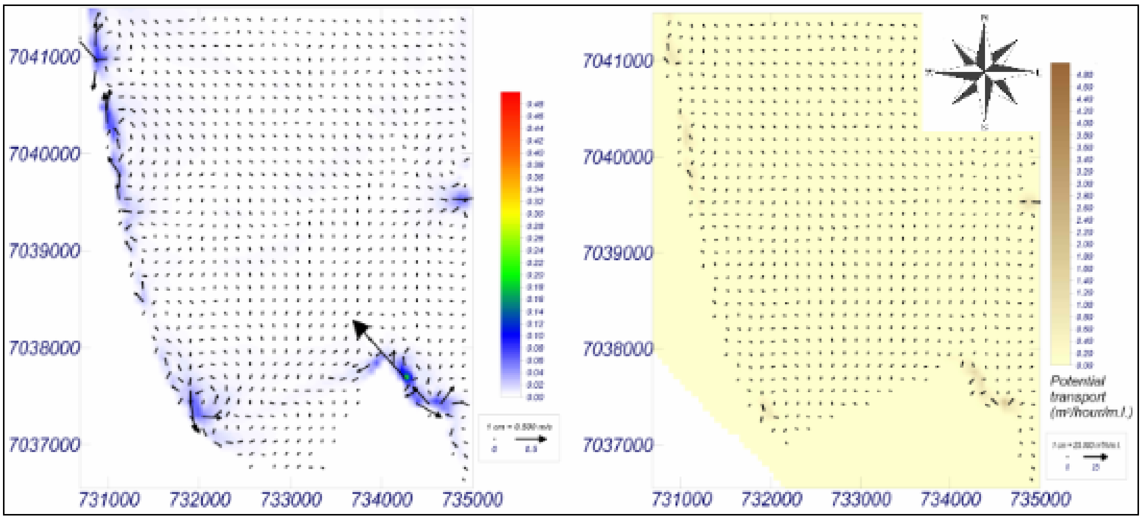


Figure VI - 16 Results SMC with waves from S, currents (left) and potential transport (right)

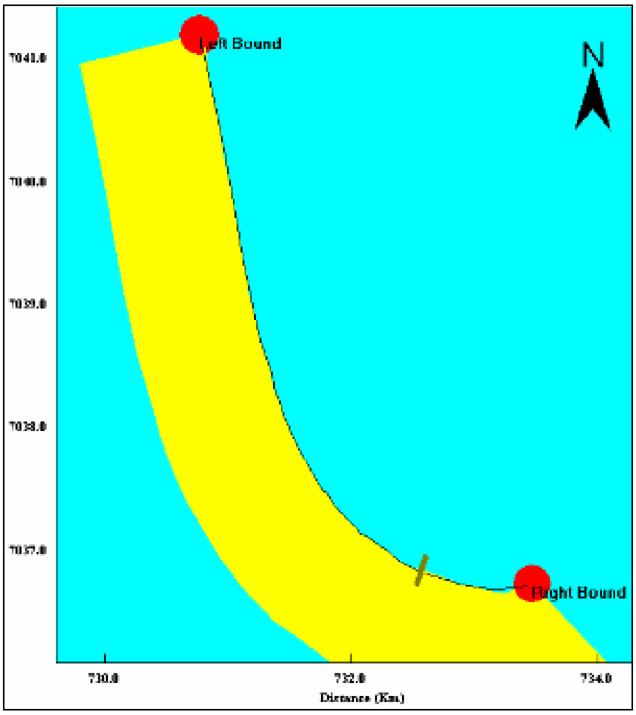


Figure VI - 17 Result UB with waves from S

Once more, SMC shows very little transport according to Figure VI - 17. This is visible in the UB output because the whole beach, including Alegre, shows negligible movement.

The results from SMC and UB correspond most of the time when they are compared in a qualitatively way, apart from Alegre beach. Differences at Alegre beach can be clarified by the fact that UB does not take into account the shadow zone behind the Penha headland and SMC does. Other differences are the result of difference in simulation time, which is a lot longer in UB. Moreover, SMC models its own wave propagation from offshore to nearshore,

With this conclusion it is accepted that output of SMC can be used in UB.

A run in SMC, using storm conditions (Hs = 4.2m, T = 10s), will show possible cross-shore locations. This scenario has also been used to determine the closure depth (Appendix IV). The result is shown in Figure VI - 18. The locations will be used in UB to model cross-shore transport, using sinks. Not every location is influenced equally by cross-shore transport. The amount of sediment lost in 9 years equals 395,000m^3 (Appendix V).

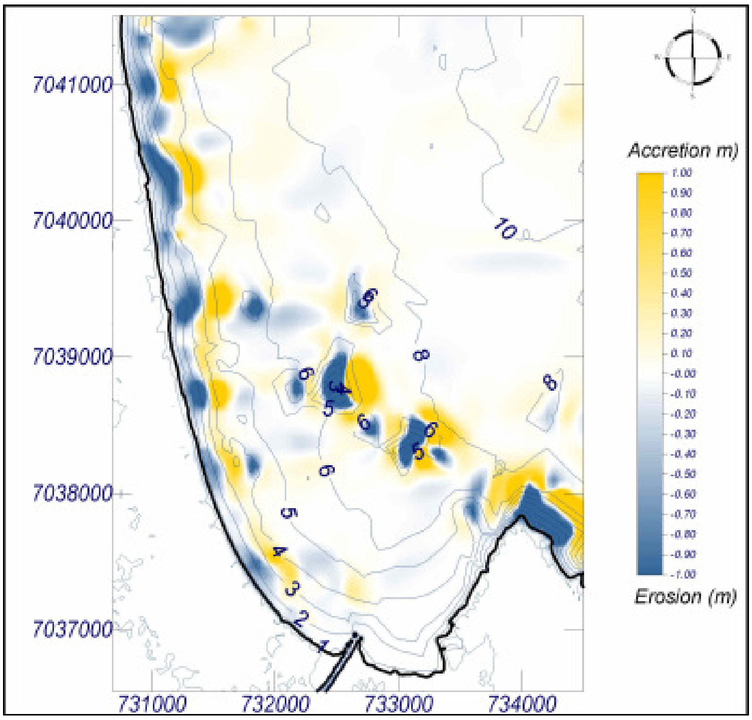


Figure VI - 18 SMC output of storm event

Three runs in UB will be made, in which the amount of lost sediment due to cross-shore transport will be 100%, 50% and 25% of the total amount of eroded volume (Table VI - 7). In this way it may be possible to give estimation about the influence of cross-shore transport. Because the influence of every cross-shore transport location is not equally divided according to Figure VI - 18, an estimation has been made for the influence of every sink individually (Table VI - 8). The northern boundary condition will be such that the coastline will stay on its position (case 2, option 1).

Percentage lost in sinks	Amount of lost sediment in 9 years in m^3	Amount of lost sediment in 1 year in m^3
100	395,000	43,889
50	197,500	21,944
25	98,750	10,972

Table VI - 7 Amount of lost sediment

X	Y	Lost sediment [%]	Lost sediment [m3/yr] (100%)	Lost sediment [m3/yr] (50%)	Lost sediment [m3/yr] (25%)
731770	7037400	10	4,389	2,194	1,097
731404	7038100	10	4,389	2,194	1,097
731251	7038700	15	6,583	3,292	1,646
731100	7039400	25	10,972	5,486	2,743
730940	7040333	25	10,972	5,486	2,743
730816	7041000	15	6,583	3,292	1,646

Table VI - 8 Amount of lost sediment per sink

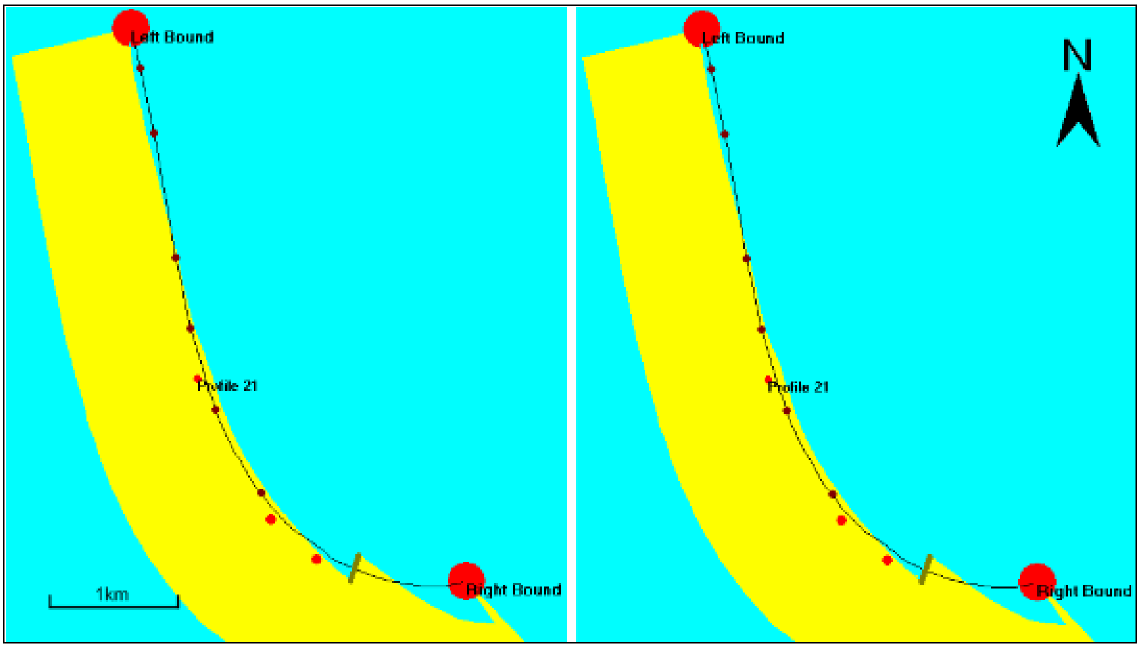


Figure VI - 19 Total sink capacity 100% of the total eroded volume (left) and total sink capacity 50% of the total eroded volume (right)

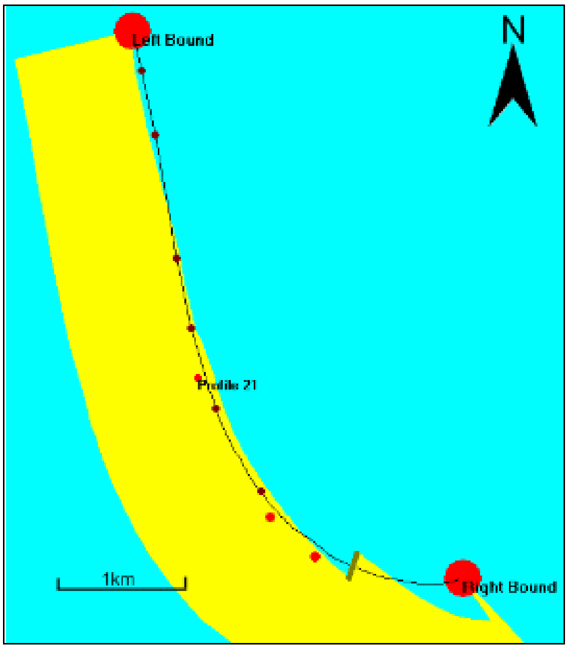


Figure VI - 20 Total sink capacity 25% of the total eroded volume

Results in Figure VI - 19 and Figure VI - 20 show that there is not noticeable more accretion when the sink capacity is reduced from 100% to 25% of the total eroded volume. When the sink capacity is 100% of the total eroded volume no accretion is expected in the model, but the result does not match this expectation. It can be concluded that if the total eroded volume is calculated correctly, the UB model not only shows a wrong erosion/accretion pattern, but also the transported volumes are way too large. As a consequence of this, it is not possible to define if there is any cross-shore transport with the current UB model.

VI.5.4. Case 4: Investigation of the influence of the shoals

The fact is that in the area in front of Piçarras beach a number of rocky outcrops are located. There was noticeable wave focusing in the results of Delft3D (Appendix III). Delft3D also showed refraction behind these outcrops. These outcrops can have some influence on the beach morphology.

The cross-sections that form the bathymetry in the UB model start at the seaward end between the outcrops and the beach. So, only the wave climate will be different than the current input, when a simulation has to be made without the shoals in UB. In Delft3D a run was made after deleting the outcrops. The output is used to see if there is some difference in comparison to the runs that were made before. The UB-models will contain a northern boundary condition that will keep the coastline position constant, as was concluded in case 2.

Profile 1	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.645	8.348	44.28	25.55
E	0.054	0.705	8.348	57.36	110.23
SE	0.054	0.395	12.14	58.57	76.65
S	0.054	0.154	12.14	60.14	97.09

Profile 2	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.648	8.348	44.99	25.55
E	0.054	0.702	8.348	58.06	110.23
SE	0.054	0.392	12.14	59.38	76.65
S	0.054	0.153	12.14	61.08	97.09

Profile 3	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.652	8.348	45.39	25.55
E	0.054	0.703	8.348	58.49	110.23
SE	0.054	0.391	12.14	59.88	76.65
S	0.054	0.152	12.14	61.69	97.09

Profile 4	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.657	8.348	45.8	25.55
E	0.054	0.706	8.348	58.91	110.23
SE	0.054	0.392	12.14	60.4	76.65
S	0.054	0.152	12.14	62.33	97.09

Profile 5	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.666	8.348	46.32	25.55
E	0.054	0.712	8.348	59.38	110.23
SE	0.054	0.394	12.14	60.97	76.65
S	0.054	0.152	12.14	63	97.09

Profile 6	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.674	8.348	46.63	25.55
E	0.054	0.718	8.348	59.62	110.23
SE	0.054	0.397	12.14	61.26	76.65
S	0.054	0.152	12.14	63.35	97.09

Profile 7	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.687	8.348	47.3	25.55
E	0.054	0.73	8.348	59.88	110.23
SE	0.054	0.399	12.14	61.21	76.65
S	0.054	0.149	12.14	62.72	97.09

Profile 8	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.688	8.348	47.66	25.55
E	0.054	0.732	8.348	60	110.23
SE	0.054	0.398	12.14	61.08	76.65
S	0.054	0.146	12.14	62.03	97.09

Profile 9	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.699	8.348	49.2	25.55
E	0.054	0.753	8.348	62.03	110.23
SE	0.054	0.408	12.14	63.12	76.65
S	0.054	0.143	12.14	62.76	97.09

Profile 10	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.714	8.348	50.52	25.55
E	0.054	0.774	8.348	63.91	110.23
SE	0.054	0.421	12.14	65.07	76.65
S	0.054	0.144	12.14	64.29	97.09

Profile 11	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.735	8.348	51.33	25.55
E	0.054	0.789	8.348	65.3	110.23
SE	0.054	0.431	12.14	66.73	76.65
S	0.054	0.149	12.14	66.65	97.09

Profile 12	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.767	8.348	51.48	25.55
E	0.054	0.822	8.348	66.56	110.23
SE	0.054	0.457	12.14	68.9	76.65
S	0.054	0.149	12.14	66.65	97.09

Profile 13	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.798	8.348	51.51	25.55
E	0.054	0.856	8.348	67.34	110.23
SE	0.054	0.482	12.14	70.39	76.65
S	0.054	0.171	12.14	70.7	97.09

Profile 14	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.815	8.348	51.48	25.55
E	0.054	0.886	8.348	67.75	110.23
SE	0.054	0.504	12.14	71.05	76.65
S	0.054	0.175	12.14	70.84	97.09

Profile 15	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.814	8.348	53.38	25.55
E	0.054	0.958	8.348	69.58	110.23
SE	0.054	0.558	12.14	72.3	76.65
S	0.054	0.184	12.14	71.49	97.09

Profile 16	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.781	8.348	55.56	25.55
E	0.054	0.999	8.348	70.87	110.23
SE	0.054	0.604	12.14	73.03	76.65
S	0.054	0.195	12.14	72.8	97.09

Profile 17	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.741	8.348	56.64	25.55
E	0.054	0.949	8.348	72.33	110.23
SE	0.054	0.582	12.14	74.48	76.65
S	0.054	0.192	12.14	75.02	97.09

Profile 18	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.744	8.348	55.75	25.55
E	0.054	0.902	8.348	72.54	110.23
SE	0.054	0.55	12.14	75.01	76.65
S	0.054	0.19	12.14	76.42	97.09

Table VI - 9 Wave climate without shoals, profiles 1-18

Profile 19	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.785	8.348	55.95	25.55
E	0.054	0.93	8.348	73.92	110.23
SE	0.054	0.573	12.14	76.95	76.65
S	0.054	0.196	12.14	77.44	97.09

Profile 20	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.827	8.348	56.89	25.55
E	0.054	0.984	8.348	76.41	110.23
SE	0.054	0.616	12.14	80.24	76.65
S	0.054	0.208	12.14	79.85	97.09

Profile 21	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.876	8.348	56.77	25.55
E	0.054	1.079	8.348	77.09	110.23
SE	0.054	0.697	12.14	81.14	76.65
S	0.054	0.232	12.14	80.28	97.09

Profile 22	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.866	8.348	54.17	25.55
E	0.054	0.986	8.348	76.66	110.23
SE	0.054	0.669	12.14	85.42	76.65
S	0.054	0.259	12.14	87.25	97.09

Profile 23	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.924	8.348	56.31	25.55
E	0.054	1.018	8.348	73.83	110.23
SE	0.054	0.639	12.14	84.42	76.65
S	0.054	0.261	12.14	89.35	97.09

Profile 24	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.97	8.348	59.36	25.55
E	0.054	1.099	8.348	73.8	110.23
SE	0.054	0.647	12.14	80.02	76.65
S	0.054	0.245	12.14	85.15	97.09

Profile 25	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.978	8.348	60	25.55
E	0.054	1.123	8.348	76.78	110.23
SE	0.054	0.701	12.14	83.25	76.65
S	0.054	0.269	12.14	85.93	97.09

Profile 26	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	1.006	8.348	64.78	25.55
E	0.054	1.24	8.348	82.82	110.23
SE	0.054	0.814	12.14	90.84	76.65
S	0.054	0.315	12.14	93.32	97.09

Profile A1	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.686	8.348	41.83	25.55
E	0.054	0.792	8.348	54.43	110.23
SE	0.054	0.458	12.14	55.32	76.65
S	0.054	0.177	12.14	56.04	97.09

Profile A2	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.704	8.348	42	25.55
E	0.054	0.834	8.348	52.4	110.23
SE	0.054	0.48	12.14	52.85	76.65
S	0.054	0.181	12.14	53.43	97.09

Profile A3	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.72	8.348	41.06	25.55
E	0.054	0.844	8.348	50.18	110.23
SE	0.054	0.482	12.14	50.31	76.65
S	0.054	0.178	12.14	50.73	97.09

Profile A4	H0 [m]	Hsig [m]	Tpeak [s]	Direction [°]	Time [days]
NE	0.054	0.721	8.348	40.91	25.55
E	0.054	0.843	8.348	49.95	110.23
SE	0.054	0.48	12.14	50.06	76.65
S	0.054	0.177	12.14	50.45	97.09

Table VI - 10 Wave climate without shoals, profiles 19-A4

These wave data result in the following output.

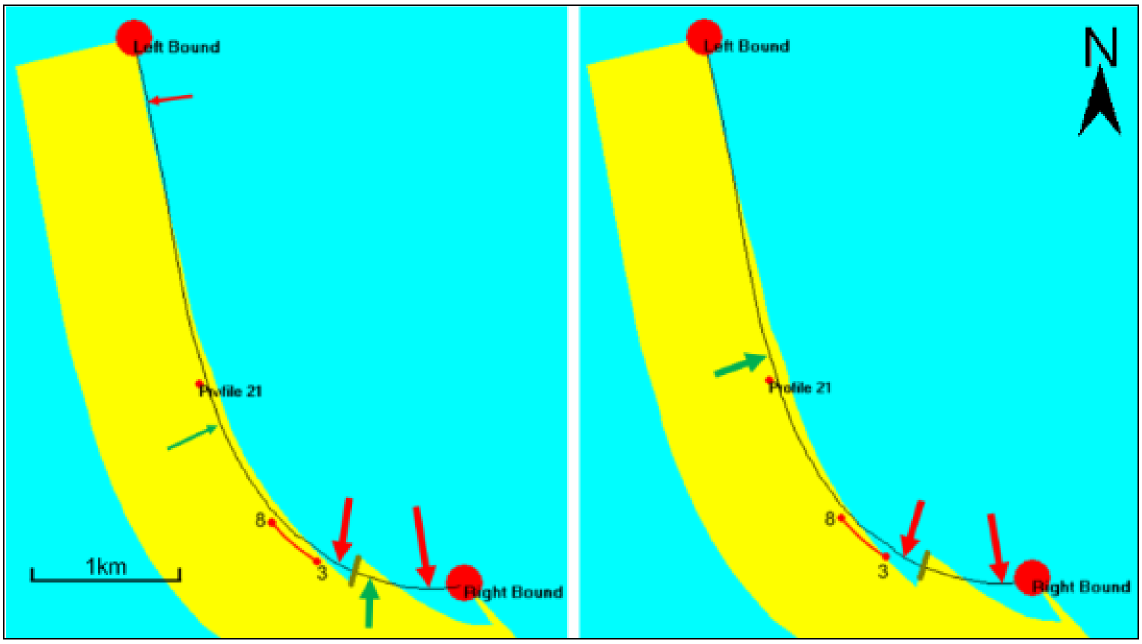


Figure VI - 21 Result with shoals (left) and without shoals (right)

Figure VI - 21 shows different results. Without the shoals, much more accretion is visible. There is also more erosion in the north with shoals. The erosion next to the jetty seems slightly increased and the conversion from erosion to accretion seems to lay closer to profile 8 than to profile 3 without the shoals. A possible conclusion is that the shoals have influence on the beach morphology, but the quantity and quality of this can not be related to the output of UB. This is because the models do not match the reality.

VI.6 Conclusions

Modelling the bay of Piçarras using UB is not possible with the data that is available right now. Accretion occurs on most places where erosion is experienced in reality. The location just north of the northern jetty of Rio Piçarras shows in all results severe erosion, although there is not any in such a strong manner. Alegre beach shows strong sediment transport in every output, although it has been in equilibrium for years. This is probably because this beach lies in the shadow zone of headland Ponta da Penha. Another effect of this headland is that there can't be any sediment transport along this point. As a consequence of this, the southern boundary is a closed one for certain. Improvements were sought by changing the northern boundary condition.

Changing the northern boundary condition did not result in better output along the whole beach of Piçarras. It does not significantly influence the southern part of the project area. When only the northern part was taken into consideration, it was possible to find the most suitable solution for this problem: the model keeps the coastline at fixed position. This is possible due to the ability of the program to im-/export as much sediment as needed to accomplish this.

When the results from SMC and UB are compared in a qualitatively manner, they show lots of resemblance. Because of this it can be concluded that both models are built correctly or contain the same error(s). The results on Alegre beach do not match. This is because UB does not take the influence of the shadow zone behind the headland into account and SMC does.

Furthermore it was tried to define the influence of cross-shore transport. Even when 100% of the total eroded volume was assigned to the modelled sinks, this did not resulted in less accretion in the nourishment zone. It can be concluded that, in assumption that the total eroded volume is correct, the UB model not only shows a wrong erosion/accretion pattern but the transported volumes are also way too large. As a consequence of this, it is not possible to define if there is any influence of cross-shore transport using the current UB model. The only thing that the model could make clear is that shoals have noticeable influence on the beach morphology, but the quantity and quality of this can not be related to the output of UB. Again, this is because the models do not match the reality. Because of this it is not possible to investigate the Prosul plan and the nourishment plan that was created by the writers of this report with the developed UB-model.

There can be several reasons for the model not to function as it should be. The UB-manual mentions the following: *´The required data referring to the specification and schematization of the wave climate on the basis of time series or, at minimum, statistical summaries for a period of at least two years, if possible more than five years (including the period of hindcast). In a case where wave data obtained over a short period is available for the simulation it is necessary to check the meteorological characteristics during the required period before utilizing them.´* [24]. It can be concluded that the wave data that is used for the current model isn't useful for a good estimation of beach development in UB.

Another doubtful aspect is the bathymetry map that was used. Different sources were used to create a map. Although all sources were corrected for the same reference level, this is not the most reliable way to come to a detailed bathymetry that is useful for modelling. Because of the fact that there is not more information available for students than there is used at the moment of writing this report, further development of this model is probably not possible with the current data.

VII. SMC

VII.1 Introduction

SMC (Sistema de Modelado Costero) is a graphical interface, which is part of the project entitled "Model to Assist Coastal Management," a project undertaken by the Panel of Oceanographic and Coastal Engineering (GIOC) of the University Cantabria in Spain, for the Directorate General of Coastal Environment Ministry.

The basic objective of SMC is to provide a numerical tool in the field of coastal engineering. For technical studies this software gives the opportunity to easily apply the theory and working methods proposed in acknowledged trade literature. Pursued through the unification of technical criteria and the systematic organization of numerical models, it raises the quality of education and therefore also increases the reliability of decisions taken [35].

SMC has been divided into five key modules: "Pre-trial", "Short term," "Medium-and long-term", "Modelling the ground" and "Guardian". The module "Pre-trial" fundamentally characterizes and processes information input for the different numerical models. The module "Analysis of beaches in the short term" (Acordes) contains the numerical tools that analyze the morphodynamics of a coastal system, on a short-term scale in space and time. Similarly, within the module "Analysis of long-term beach" (Arpa) tools are presented that allow geomorphological modelling of a system, however on a time scale and space for the medium and long term. The module "Modelling the ground," allows modification of depth contours (bathymetry) and land (cliffs, natural and artificial levees, and so on.), which is essential to study various scenarios within a project. Finally, there is the "Guardian of engineering coasts" (Tic), which runs in SMC and forms the theoretical support, conceptual and basic information for different numerical models of the system. A schematic representation of the structure of SMC and the different modules of the system, including its numerical models are presented in Figure VII - 1.

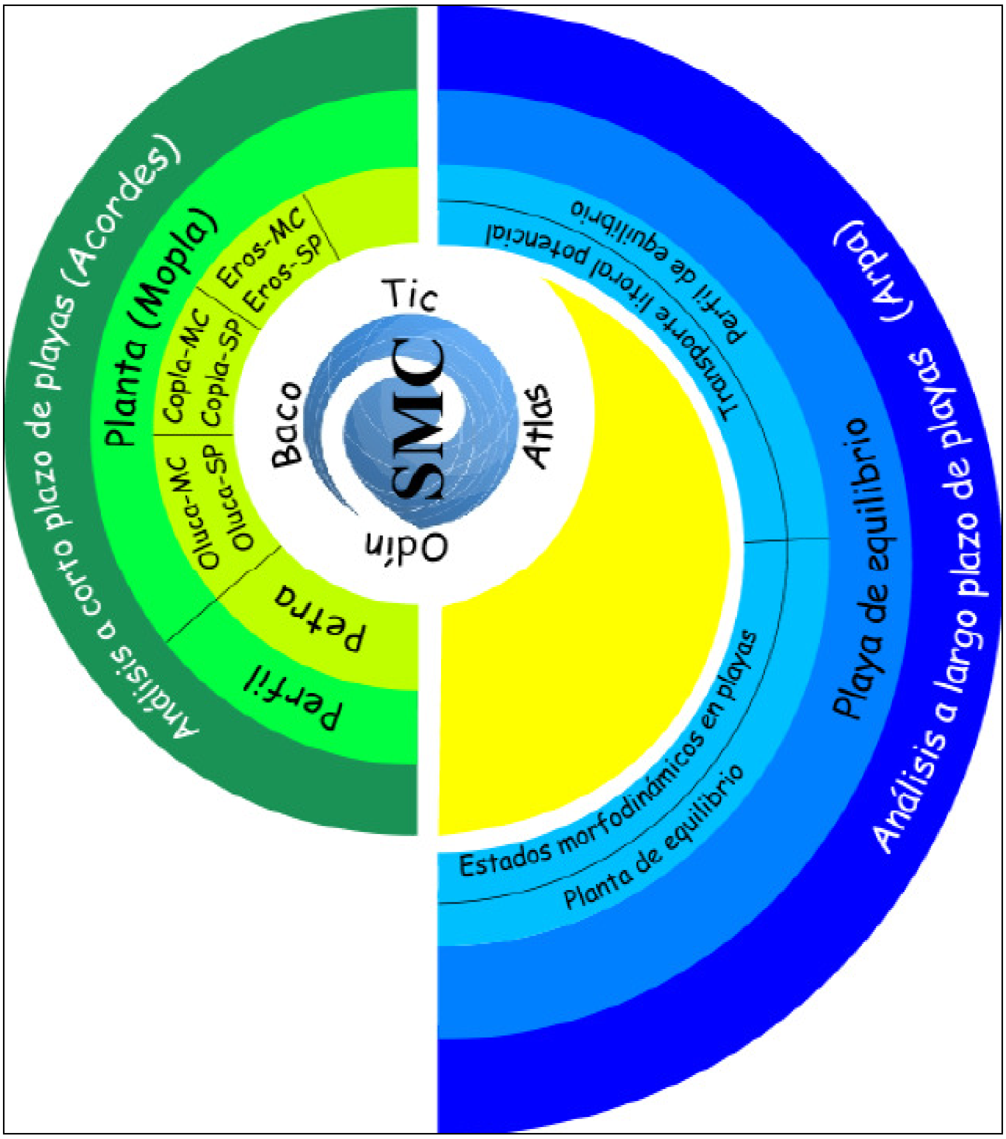


Figure VII - 1 Schematic representation of the structure of SMC [35]

VII.2 Application of SMC

In order to check the erosion patterns provided by Unibest (UB) on reliability, the use of another modelling software program capable of modelling erosion processes along a coastline is required. Despite the fact that SMC is a modelling application with similar capabilities as Delft3D (D3D) has, it will be used in this study. The main reason for this is the more simplistic character of a specific part of SMC, a part that should give insight in the erosion processes along the coastline of Piçarras Beach. As described in Appendix III, in D3D it is possible to do predictions about the morphodynamic evolution of a certain beach for the long term. For the case of Piçarras beach, which is not really a straightforward beach, subject to well-known, standard formula’s due to the shape of the coastline and the present shoals and islands, the morphodynamic part of D3D would be very suitable to obtain good quantitative as well as qualitative information of the erosion processes in the bay. However this specific part requires a lot of study, knowledge and more detailed information to be able to do reliable computations. Because of the short time frame in which the project has to be finished, D3D will not be used to model flow and morphodynamics and SMC will.

The results from SMC will be compared with the results from UB. UB is a program which can make computations for the long term, a time frame of several years. In SMC modelling is possible in a time frame in the order of several days only (72 hours maximum). Therefore the results can only be compared in a qualitative way. SMC concerning, the short time frame of modelling entails the advantage that the calculation time is limited. Another simplification of this program, as far as the short time frame of modelling can be considered as a simplification, is that the results are based on the wave action only in the bay. For this study the use of SMC is justified as there is no significant current (other than wave induced currents) and/or wind action.

The part of SMC that deals with the morphodynamic evolution of the beach is called Mopla (Programa de Morfodinámica de playas). It consists of six models, which simulate the propagation of waves, the system of currents induced by the waves, calculation of sediment transport and evolution of the bathymetry. The models have been organized into two groups. On one hand those which shape the processes associated with the spreading of a train of monochromatic waves, and secondly, the models that shape the processes of a state of the sea, represented by a spectrum of energy waves. The first models are applied mainly to characterize the morphodynamics of a coastline. This first group consists of the following programs:

- Oluca-MC: Models parabolic wave propagation of monochromatic waves
- Copla-MC: Models wave-induced currents of waves broken at the beach.
- Eros-MC: Model of erosion/sedimentation and evolution of the bathymetry at beaches.

As for the second model, spectral waves are applied primarily in the modelling of extraordinary events or in cases when precision in calculating wave heights is required (designs of dams or works in general). This group consists of the following models:

- Oluca-SP: Models parabolic wave propagation of spectral wave spreading.
- Copla-SP: Models wave-induced currents in the breaking wave spectrum at the beach.
- Eros-SP: Model of erosion/sedimentation and evolution of the bathymetry at beaches (due to the wave spectrum).

A detailed description of all these models, is included in the Mopla user manuals [32]

VII.3 Model set up

VII.3.1. Bathymetry

The computations that Mopla makes, are based on the loaded bathymetry points. The program does not interpolate the bathymetry file. Making computations based on the bathymetry file with the raw sample points only would not give accurate and reliable results, because of the limited and irregular number of sample points and therefore limited depth information.

Especially in the area of interest, the area along the coastline, it is very important to have a regular and realistic representation of the depth. Interpolating the file will create a grid with bathymetry points regular spread over the area. Moreover, interpolation can provide a more realistic representation to a certain extent, depending on the chosen interpolation method and interpolation size. After the file has been interpolated, it can be loaded in Mopla and subjected to computations.

As mentioned before, the interpolation method and size plays an important role in getting the most realistic results. An alternative program has to be used to interpolate the file with the raw sample points. A program which is linked to SMC and is capable of executing this interpolation is Surfer [36]. The interpolation method applied is triangular interpolation, this is the same method as applied in D3D modelling part, see Appendix III. Details of different existing interpolation methods will not be treated in this study. The next step is to determine the interpolation size. The number of present raw sample points in a certain area is important for choosing the interpolation size. It does not make sense to choose a very small interpolation size when a very small number of sample points are present in a certain area. Basically interpolating bathymetry is a tool for creating a regular representation of the depth out of raw sample points. It does not provide a more realistic representation of the depth per definition, when minimal data is available. To be able to create a good representation of the bay, the first things to take care of are the reliability and quantity of the depth measurements, interpolation is just a tool to modify this information in such a way that it is more applicable for the modelling software.

A relative small interpolation size is favourable in an area where morphological evolution takes place. Note that this entails the need of sufficiently measured depth points in the area. However the smaller the interpolation size and the bigger the size of the area, the more points need to be created. This will negatively affect the calculation time. So when defining the area of interest it is important to have sufficient sample points in order to justify a small interpolation size, depending on the desired information, and limit the size of the total area and consequently the calculation time. The area of interest in this study is visualised in Figure VII - 2.

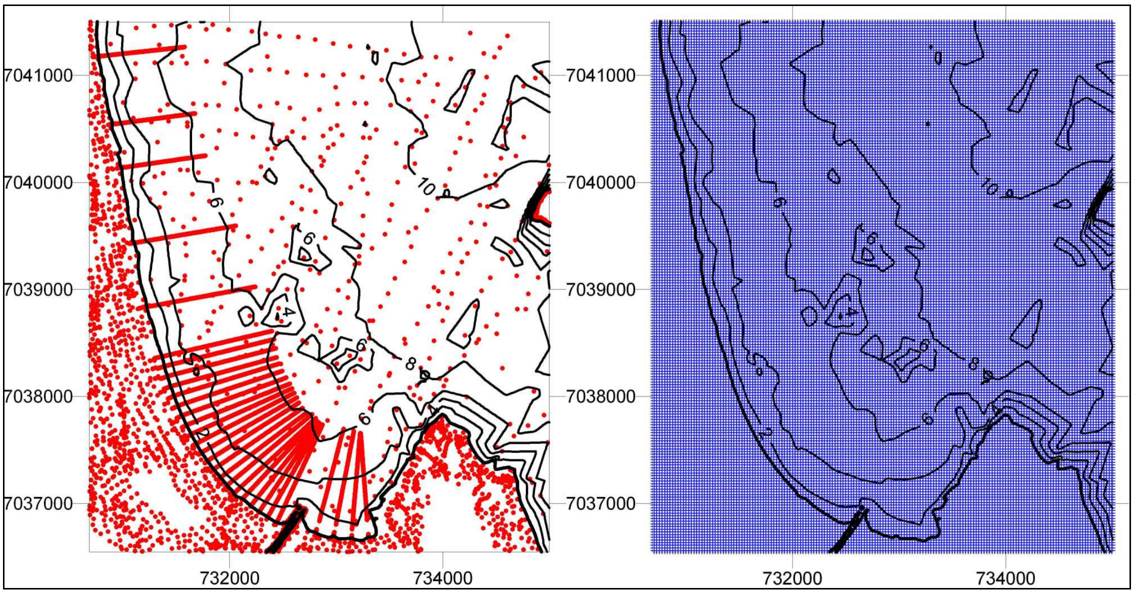


Figure VII - 2 Representation of the area of interest with raw sample points (left) and interpolated bathymetry points in a 25x25m network (right)

The red dots in the left figure represent the raw sample points, the blue network in the right figure represents the interpolated red sample points, resulting in a regular representation of the bathymetry in the Piçarras bay. The interpolation size applied is 25x25m.

In fact the total area that is being used for this modelling part extends beyond the area of interest. The main reason for this is the transformation of waves from the deep ocean to the nearshore, the area of interest. Wave data that is used for this study are obtained from an offshore location, see appendix I. Logically, the wave boundary condition therefore also has to be imposed in a deep part of the ocean. Physically this means a depth where the propagation of waves is still not influenced by the seabed, this mainly depends on the wave period and is described with the deep water wave criterion. Not fulfilling this requirement will disturb the wave propagation process and will consequently not provide useful information of sediment transport processes that take place in the bay. The area that transforms the waves from the deep ocean to the nearshore does not require an interpolation size as small as is applied for the Piçarras bay. Moreover less sample points are measured in this area, which do not justify a small interpolation size. The interpolation size used here is 100x100m. A figure of this area is not included in this Appendix, since the main objective of using this program is to get insight in erosion processes in the nearshore, not to transform waves to the nearshore. Appendix III is devoted to the wave propagation from offshore to nearshore which therefore includes all details concerning this process.

VII.3.2. Formation of the grids

When a realistic representation of the bathymetry is obtained, the file can be loaded in Mopla. This program enables modelling of waves, currents, sediment transport, erosion and accretion. Especially the last two processes are important for this study. To subject the bathymetry to the computations of Mopla, it is required to create a grid which will give the desired results regular spread over the area. This can be done graphically in Mopla.

A few important things have to be taken into account when creating the grids:

- The requirements of the boundary conditions also affect the formation of grids. Since the waves should come in from deep water, the boundary of the first grid is limited to deep water, order of magnitude 100m in this study based on the deep water wave criterion.
- The angle of incidence of the incoming waves should not be larger than 55° compared to the x-axis of the grid, because larger angles give rise to significant numerical errors.
- The size of the grid cells should be in the order of the local interpolation size of the bathymetry. A size of the grid cells significantly larger or smaller than the interpolation size would not make sense.
- The boundaries of all the created grids should be located far away from the area of interest, since these locations give extra rise to numerical noise that can affect the physical behaviour of the wave propagation
- Avoid, as far as possible, boundary conditions defined at locations where there is an abrupt land-water change. If not avoidable, make sure these locations are significantly far away from the area of interest.

In this study the size of the grid cells corresponds to the interpolation size of the sample points as described in the previous paragraph, i.e. a grid cell size of 25x25m in the area of interest and a grid cell size of 100x100m outside of this area, the area that serves to transform the waves from deep to shallow water. For more background information on how to create usable grids, reference is made to the detailed manuals about Mopla [32].

VII.4Input

In this paragraph all the parameters used by Mopla are listed. As far as it was possible, it is tried to use values which properly represent the case of the Piçarras bay for this study. However some information was not accurate enough or even available, so some parameters are standard values or values recommended by the program.

VII.4.1. Wave parameters

The four waves scenario's as obtained for modelling purposes in Appendix III are presented in Table VII - 1.

Wave scenario's	T_{mean} [s]	H_s [m]
NE	8.26	1.50
E	8.67	1.86
SE	11.43	1.81
S	11.91	1.57

Table VII - 1 Wave scenario's

- Tide: 0.6m (see Appendix II)

- Model type: Compuesto
- Model dissipation: Turbulent boundary layer

VII.4.2. Current parameters

Parameters for modelling of wave induced currents partly represent standard values of the program and partly values recommended by the program based on numerical modelling theory.

- Total calculation time: 500s
- Time interval: 1s (recommended by the program based on Courant condition)
- Chezy's roughness coefficient: 10.00
- Eddy viscosity: 12m²/s (recommended by the program)

VII.4.3. Transport parameters

- Sediment D_{50}: 0.29 (see Appendix IV)
- Sediment D_{90}: 0.58 (see Appendix IV)
- Sediment angle of internal friction (φ): 35°
- Sediment density (ρ_s): 2650kg/m³
- Sediment porosity: 0.4
- Sediment standard deviation σ_d: 1.2

- Water density (ρ_w): 1025 kg/m³
- Water viscosity: 10^{-6}m²/s

- Duration of event: 12hr
- Maximum bottom variation: 0.1m

- Model type: Soulsby

VII.4.4. First Run

Initially the original interpolated bathymetry has been processed with the 4 different wave scenario's as listed in the previous paragraph. With the program Surfer (which was also applied for interpolating the bathymetry data) the computational results can be visualised in plots. Below one can find the results for the wave induced currents (Figure VII - 3 & Figure VII - 4), the potential transport (Figure VII - 5 and Figure VII - 6) and the erosion/accretion spots (Figure VII - 7 and Figure VII - 8).

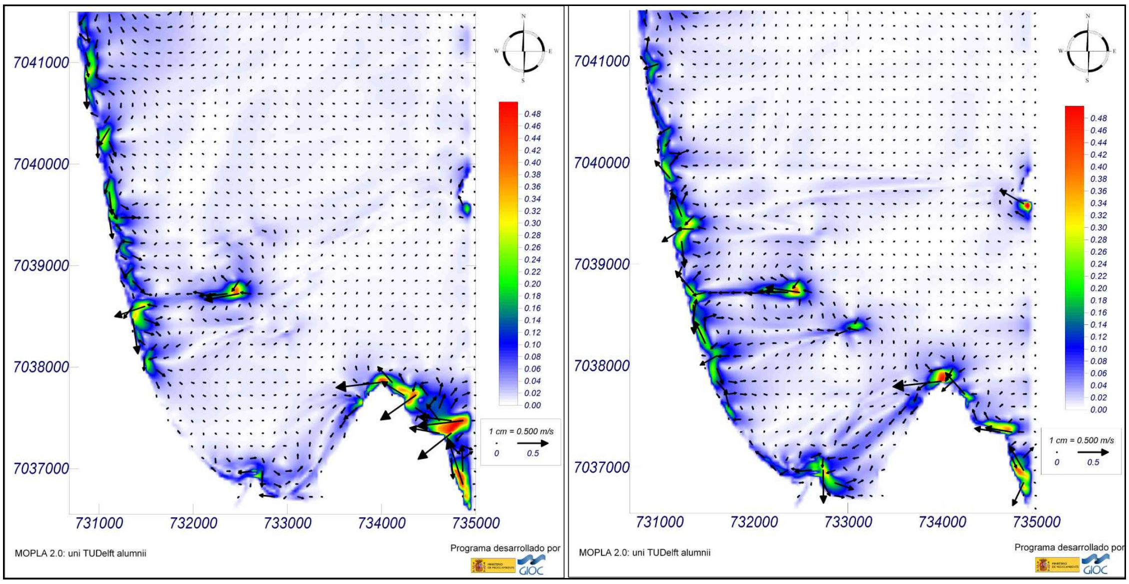


Figure VII - 3 Visualisation of currents for waves from NE (left) and E (right)

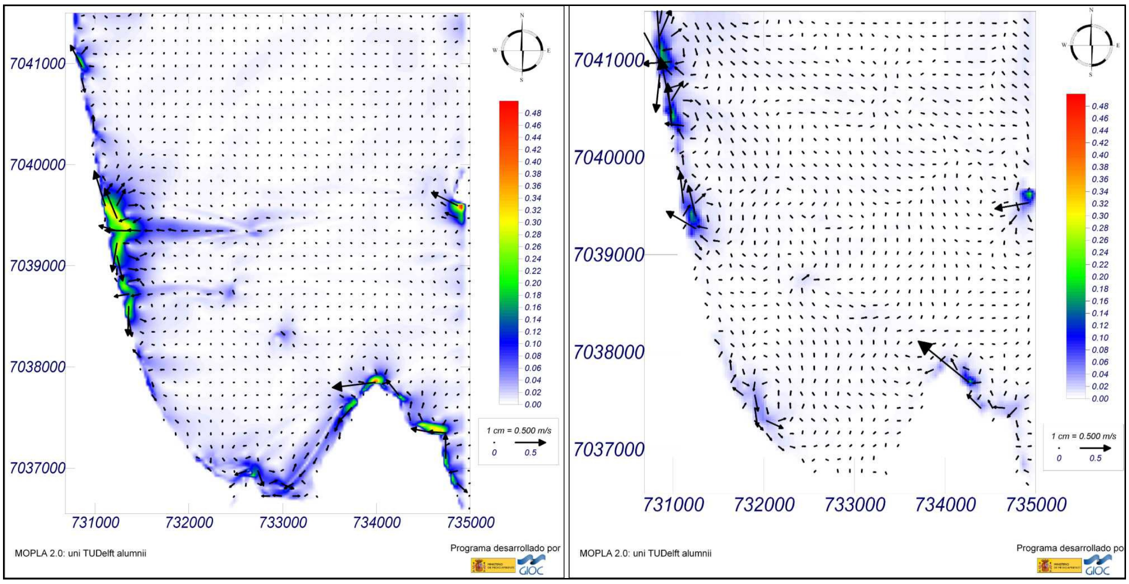


Figure VII - 4 Visualisation of currents for waves from SE (left) and S (right)

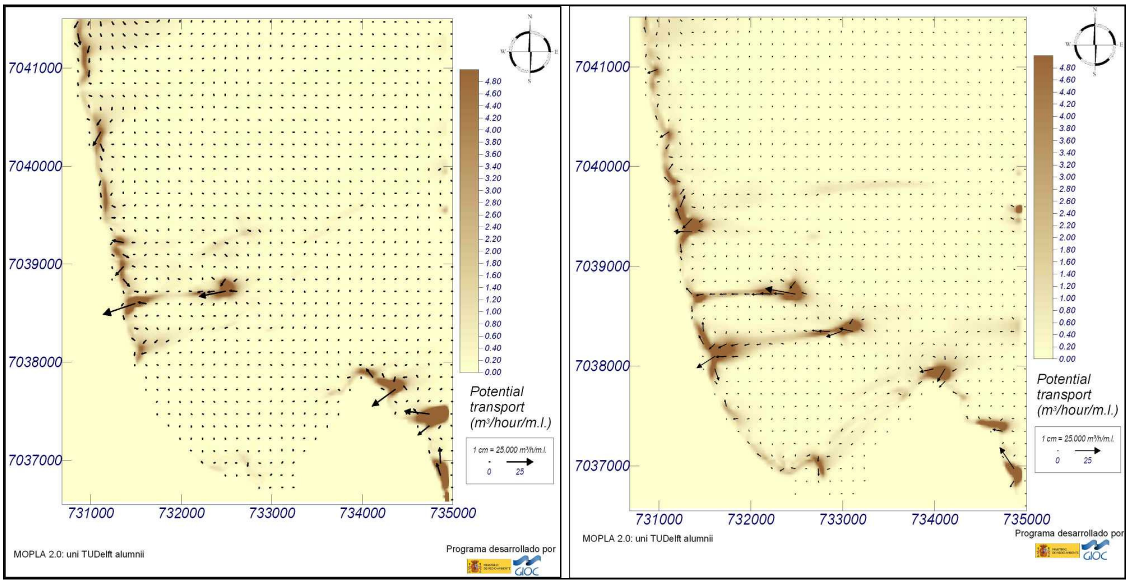


Figure VII - 5 Visualisation of potential transport for waves from NE (left) and E (right)

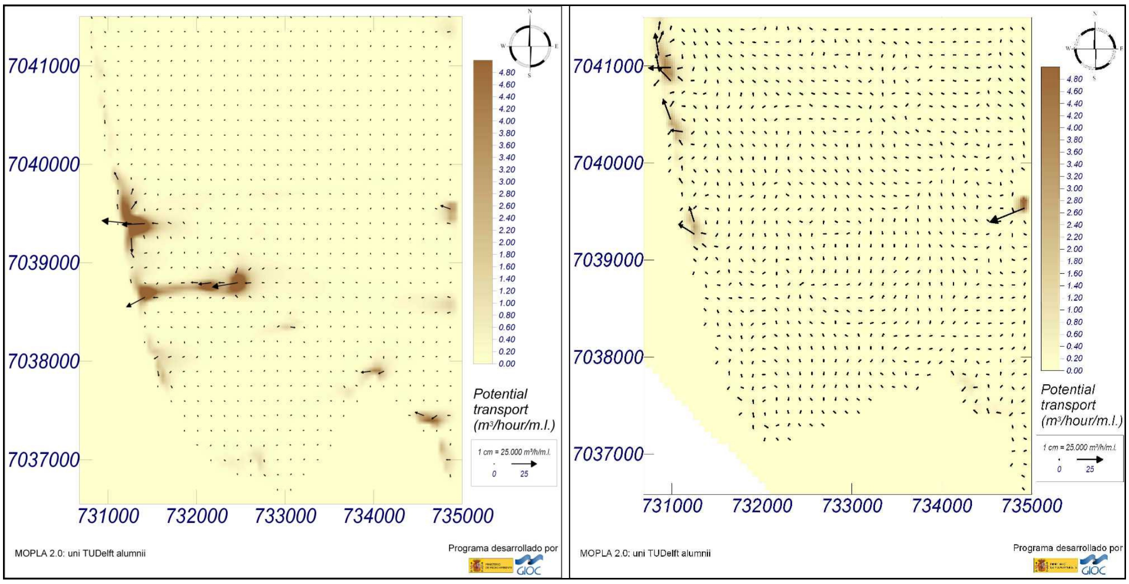


Figure VII - 6 Visualisation of potential transport for waves from SE (left) and S (right)

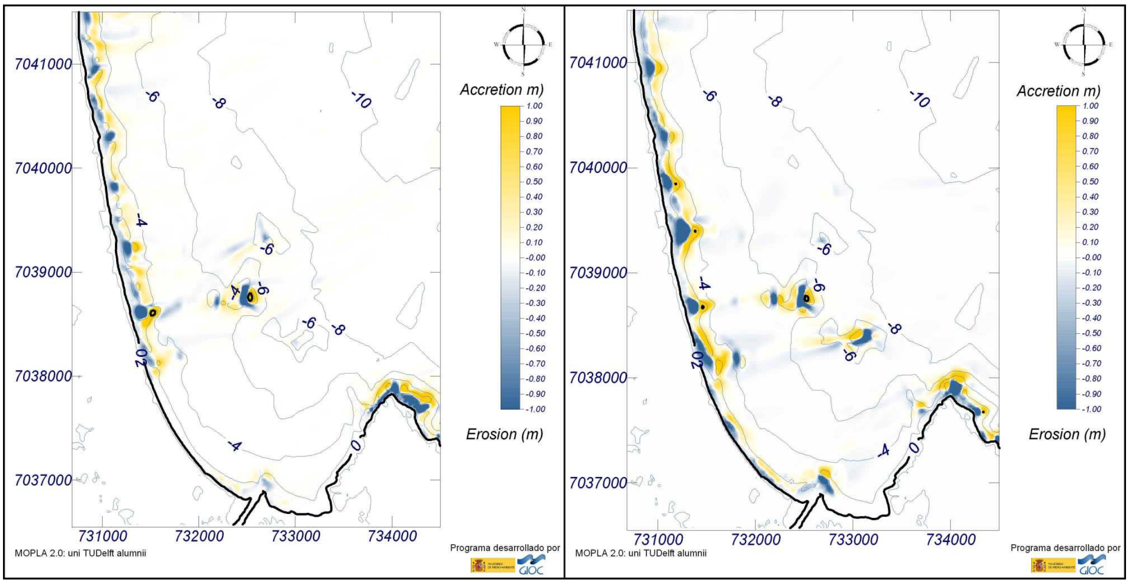


Figure VII - 7 Visualisation of erosion/accretion spots for waves from NE (left) and SE (right)

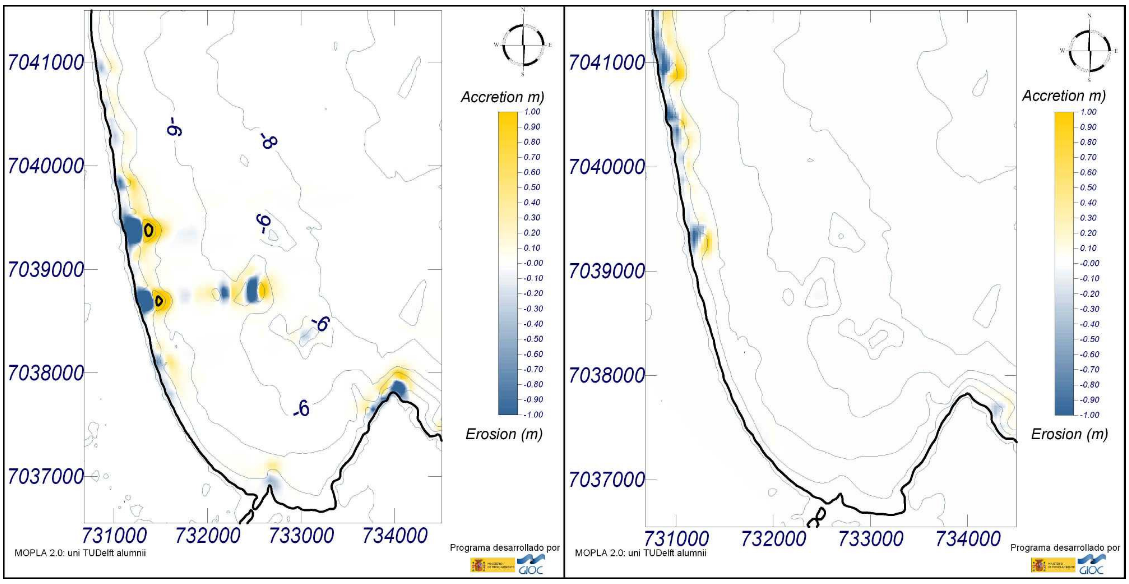


Figure VII - 8 Visualisation of erosion/accretion spots for waves from SE (left) and S (right)

A few clear observations can made from the plots shown above:

- Waves coming from the south hardly induce any erosion in the Piçarras bay.
- There is no significant erosion in the area of the hotspot.
- Waves coming from north-east and east induce regular erosion and accretion spots along the northern part of the bay, in the southern part some erosion spots appear right behind a number of present shoals in the bathymetry.
- Waves coming from south-east induce no remarkable erosion in the northern part of the bay, but in the southern part a few heavy ones appear. Probably this is because of the relative high wave period of waves coming from the South-East. Again these spots show up right behind a few shoals.

The observations from the first run will be used to make some adaptations in the model to see if this will cause a significant change in the results.

These adaptations and the subsequent results will be presented and explained in the next paragraph.

VII.5Second run

The results as presented in the previous paragraph showed that some kind of sediment transport takes place right behind a number of shoals that appear in the nearshore, seen in the direction of the wave propagation. This could be explained by wave refraction on both sides of the single shoals. After being refracted, waves will come together and focus behind the shoals, which means convergence of energy. This locally raised amount of wave energy will be transformed in some kind of sediment transport. The erosion/accretion plot obtained from the first run clearly shows the formation of banks caused by the waves. However the appearance of these banks is not defined as cross shore transport. The formation of banks causes replacement of sediment from the beach seaward, but within the active zone. This means that the sediment can be transported back again by the waves to the beach during mild weather conditions. In fact, no sediment is really lost by the formation of banks, it is temporary displaced. Cross shore transport concerns situations in which the sediment is transported out of the active zone and can not be transported back again by the waves. Therefore it can be concluded that the plots obtained from the first run do not indicate cross shore transport. Moreover, the short time frame which has been applied for this modelling program does not allow concluding that these waves will cause cross-shore transport. Since this is a process observable only in the long term. However, the locations of these spots give an indication of the most vulnerable spots concerning the initiation of sediment transport.

The problem is that the presence of these shoals in real life is doubted. Based on this presumption, the shoals are removed manually (see Figure VII - 9) to check if this has any influence on the transport patterns that showed up after the first run. The left figure represents the original bathymetry with the presence of the shoals, indicated with the green arrows. The right figure represents the bathymetry without the shoals.

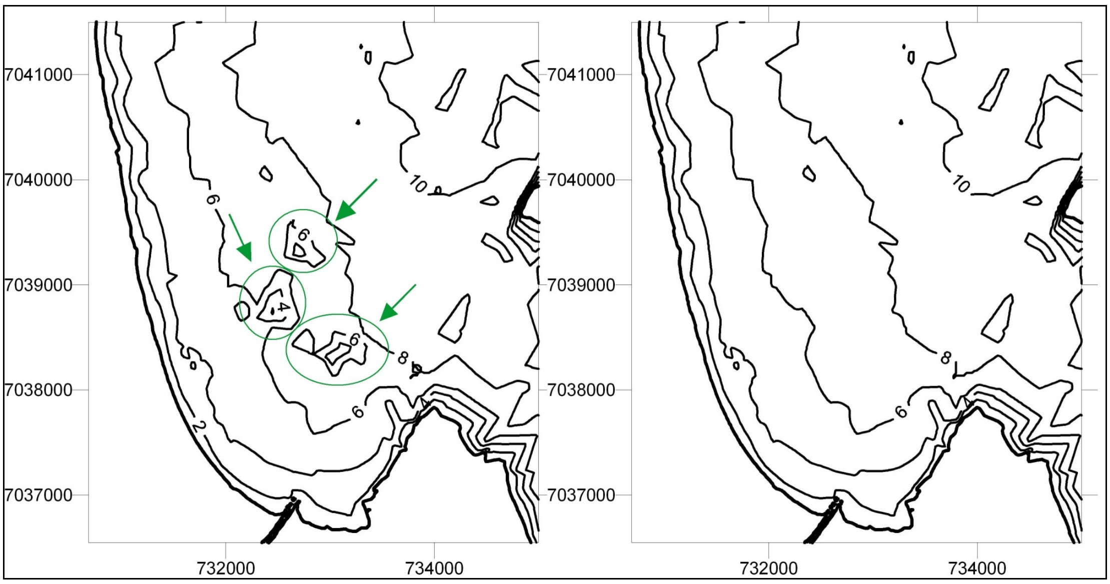


Figure VII - 9 Representation of area of interest with shoals (left) and without shoals (right)

The same run with the four different wave scenarios and all similar parameters has been executed on the adapted bathymetry. Results follow in the same sequence below in Figure VII - 10, Figure VII - 11, Figure VII - 12, Figure VII - 13, Figure VII - 14, Figure VII - 15) as presented above.

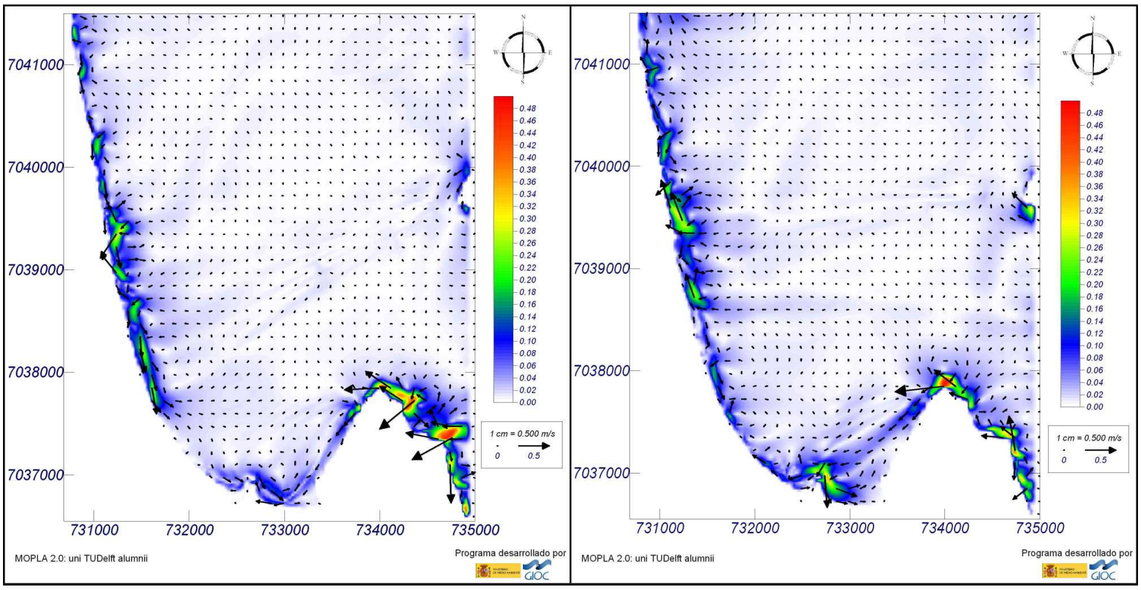


Figure VII - 10 Visualisation of currents without shoals for waves from NE (left) and E (right)

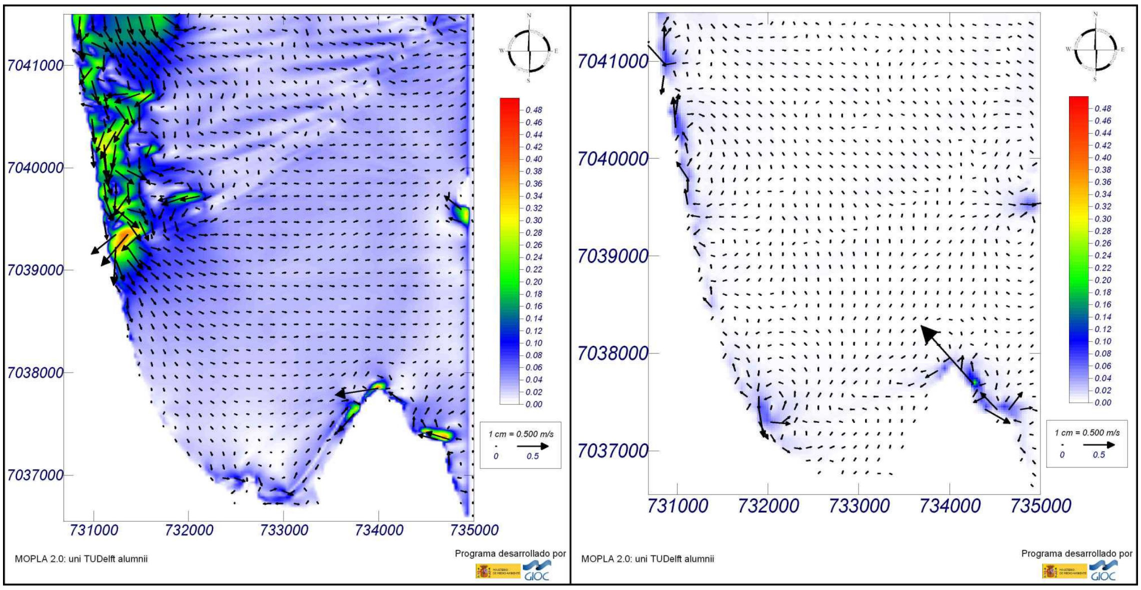


Figure VII - 11 Visualisation of currents without shoals for waves from SE (left) and S (right)

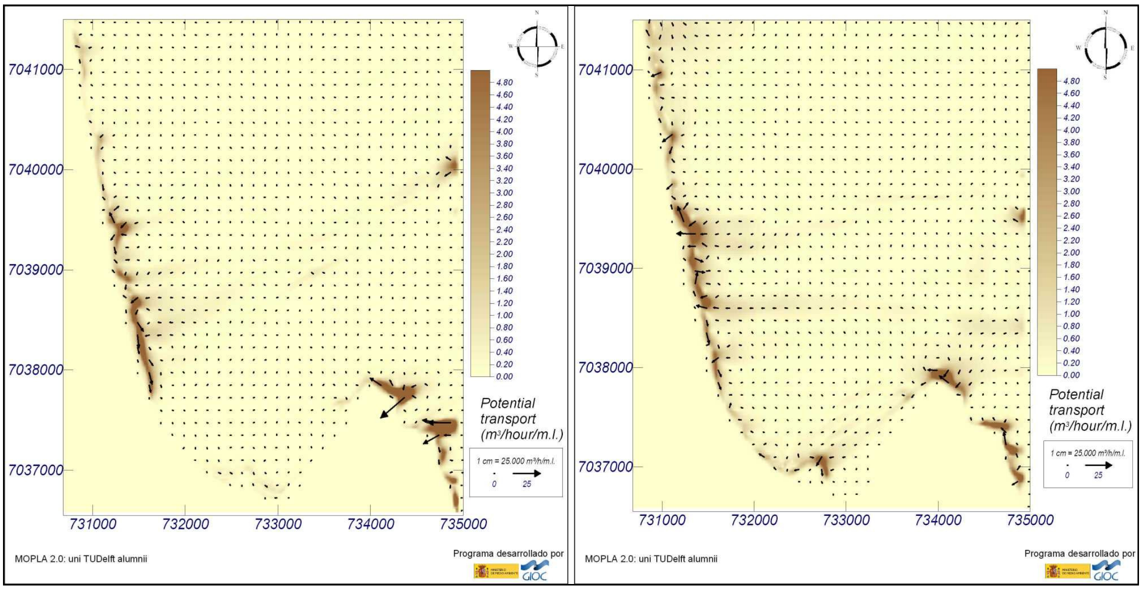


Figure VII - 12 Visualisation of potential transport without shoals for waves from NE (left) and E (right)

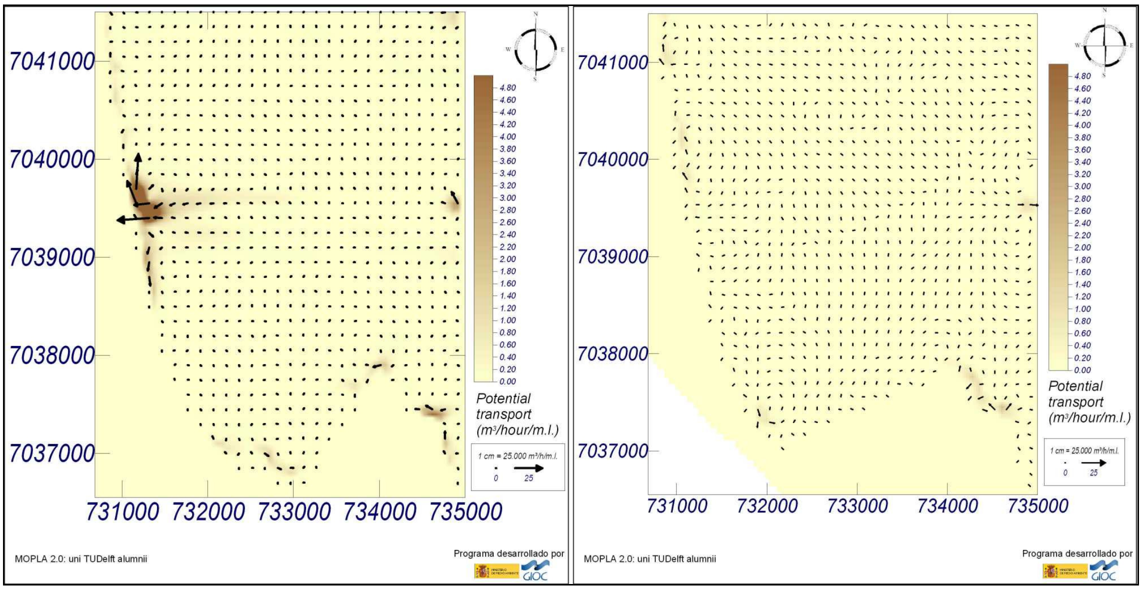


Figure VII - 13 Visualisation of potential transport without shoals for waves from SE (left) and S (right)

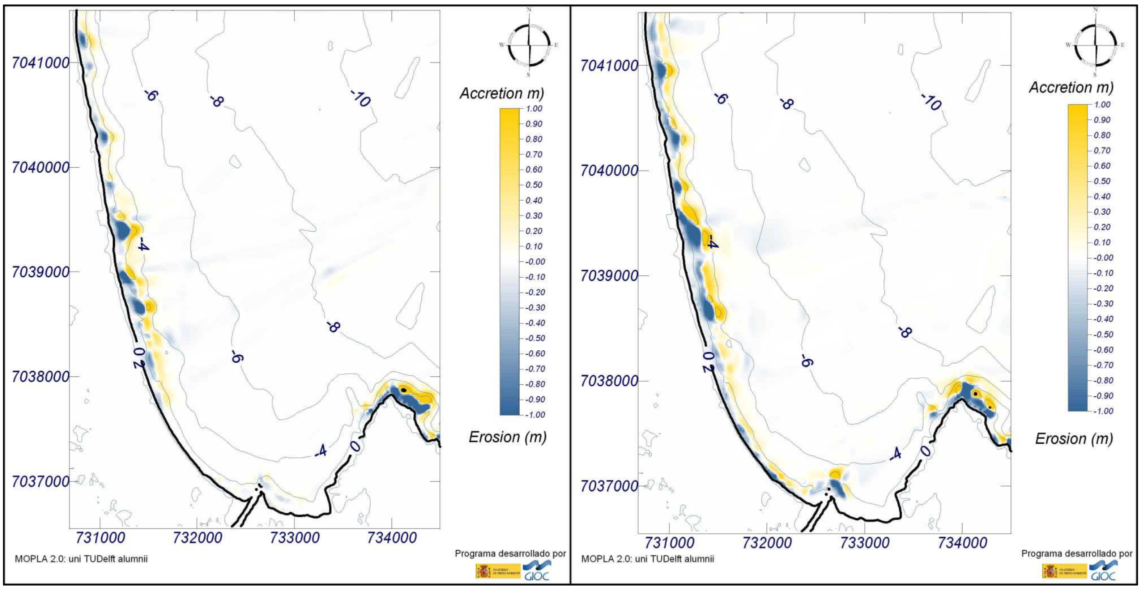


Figure VII - 14 Visualisation of erosion/accretion spots without shoals for waves from NE (left) and E (right)

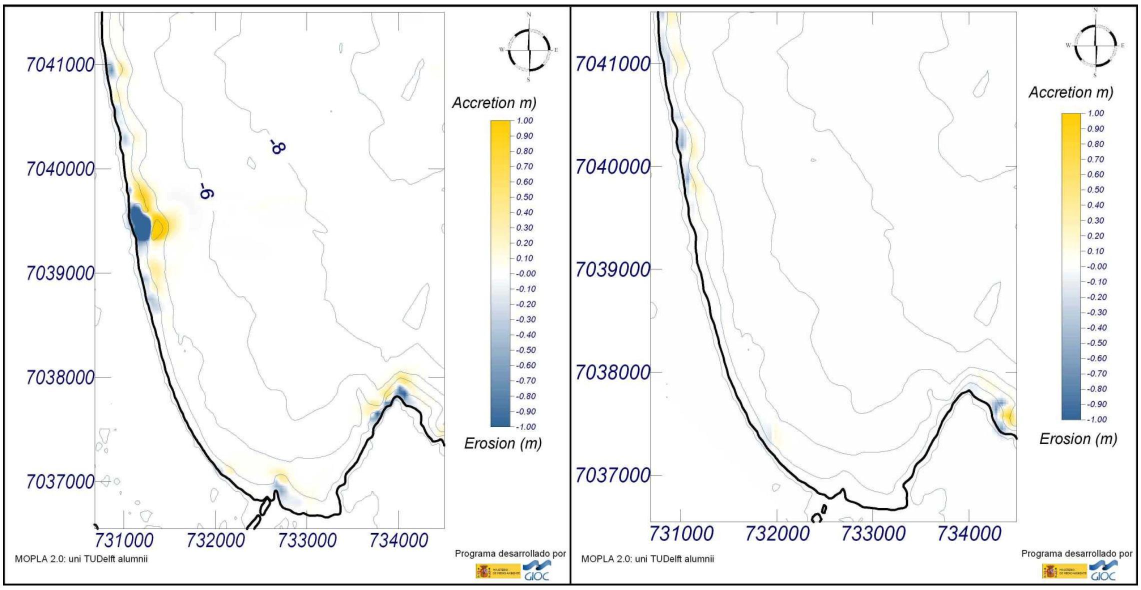


Figure VII - 15 Visualisation of erosion/accretion spots without shoals for waves from SE (left) and S (right)

Clearly the adaptations in the bathymetry have influenced the results.

- Most obvious is the declination of the intensity of the erosion spots behind the removed shoals. In some cases the spots even disappeared totally. The reason that some shoals and accompanying erosion spots at the coastline are still visible could be that there is still a shallow part present in the bathymetry.
- The erosion patterns that showed up in the northern part of the bay in the first run seem to have changed hardly in the second run. This is not surprising since in this part of the bathymetry no adaptations have been implemented.
- The plot that shows the wave induced currents with waves from south-east shows relatively heavy current action in the whole bay. First, this result does not correspond with the transport and erosion/accretion results that follow. Second, in the first run no significant intensity differences were noticeable when comparing the current plots. In the second run, it clearly is caused by this single plot. It seems that this has something to do with the numerical set up of the model.
- All the erosion/accretion plots show erosion as well as accretion spots close to the shoreline. This indicates the process of the formation of banks due to wave action as explained in the beginning of this paragraph.

Conclusion is that the erosion/accretion spots that showed up in the plots after the first run are caused by the presence of shoals, at least in the southern part of the bay. It could be observed that after removal of these shoals, the intensity of these spots decreased or the spots even disappeared. Although sediment is transported in off shore direction, it can not be concluded that cross shore erosion takes place.

VII.5.1. Third run

To get more insight about the possible cross shore transport that takes place in the bay, another run in SMC has been executed. This run is based on the closure depth conditions, The closure depth is a measure for the depth at the seaward end of the active profile. Beyond this depth, waves are incapable to affect the sediment on the bottom. This means that sediment that is transported from the beach in off shore direction beyond the closure depth can not be brought back by the waves and can be considered as lost. Dean [11] proposed a formula how to determine the closure depth in a cross shore profile. This formula is based on a significant wave height with a certain exceedence probability, for details is referred to Appendix IV. The wave scenario used is H_s=4.2m and T=10s from eastern direction, according to the theory these are the governing conditions to determine the closure depth. In this case it is interesting to observe the formation of banks and see whether these banks are (partly) formed beyond the closure depth. Would this be the case, in theory the sediment would be lost, which indicates cross shore transport. Below the results are presented: currents and potential transport in Figure VII - 16 and erosion/accretion in Figure VII - 17.

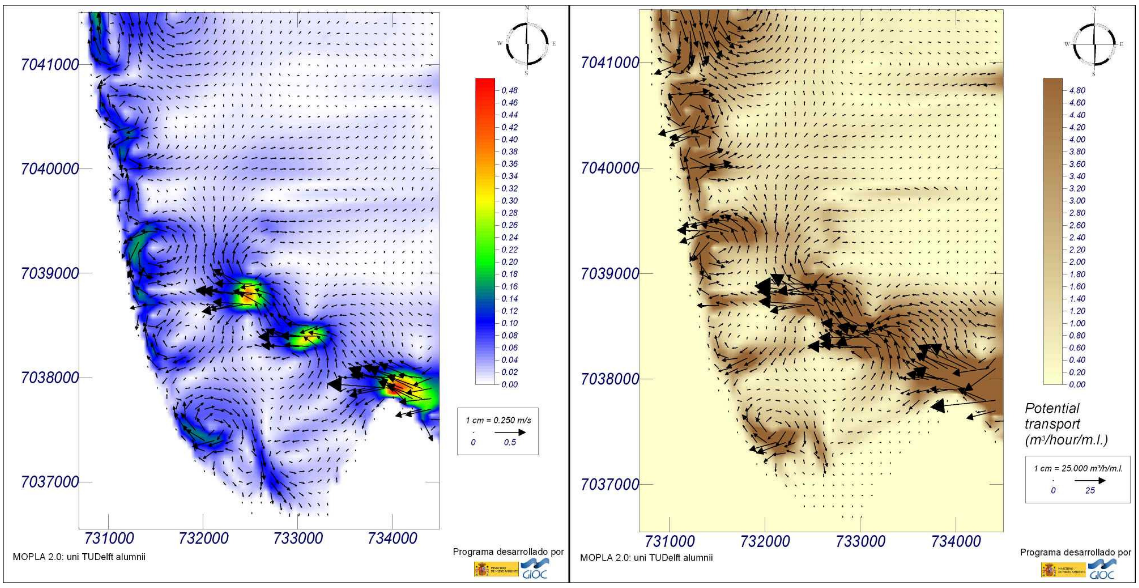


Figure VII - 16 Visualisation of currents and potential transport for closure depth scenario

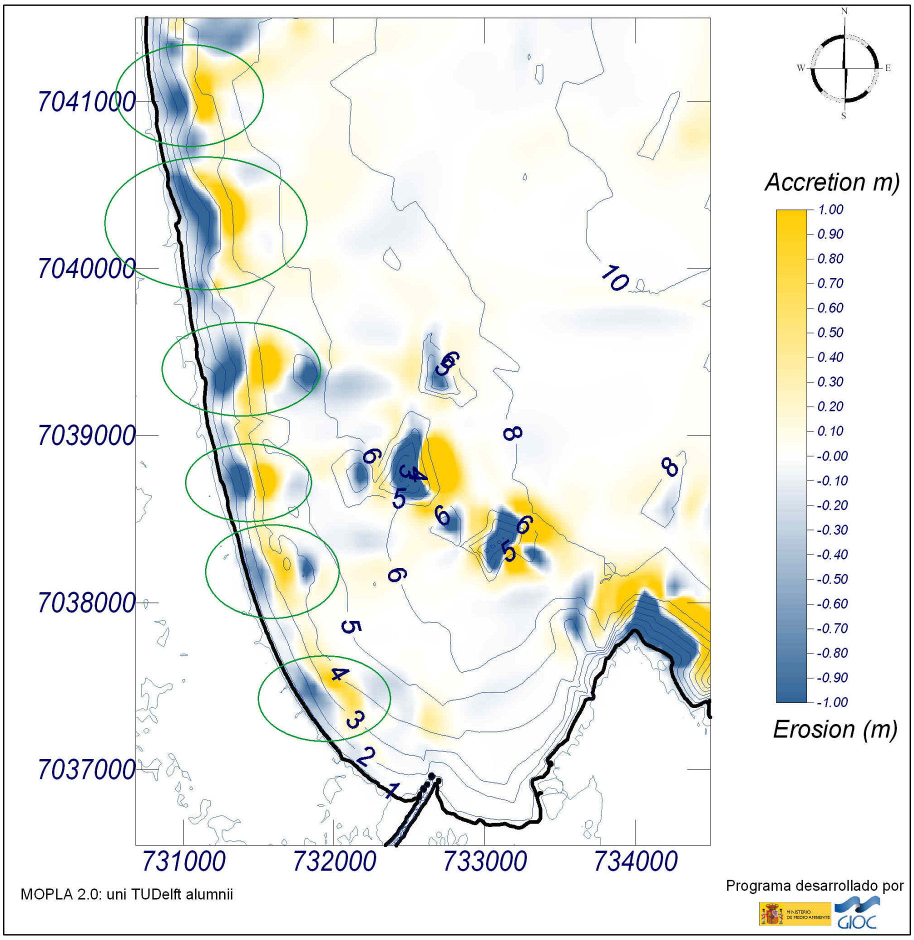


Figure VII - 17 Visualisation of erosion/accretion spots for closure depth scenario

It can be observed clearly that the yellow accretion spots start to appear at a depth of 3m in the southern part of the bay and at 4m in the northern part of the bay, referred to the contour lines. In both parts this is beyond the closure depth, see Appendix IV, which indicates loss of sediment and therefore cross shore transport. From Figure VII - 17 6 of these possible cross shore transport spots can be marked. These spots will be applied in UB as sediment sinks, see Appendix VI.

VIII. Mepbay

VIII.1 Introduction

In the past several empirical models have been derived to study the planform of headland bay beaches. One of those models is the parabolic bay shape equation. In this appendix the model will be applied on Piçarras beach to study the stability of the beach, with help of the software program Mepbay. This program was designed to facilitate the application of the equation. At first some theory of the equation will be explained, after which some features of the program will be explained. In the subsequent paragraph the program is applied on Piçarras beach in a few different ways, which all will be explained. Finally some conclusions will be drawn and remarks will be made.

VIII.2 Theory

VIII.2.1. Headland bay beaches

Approximately 51% of the world's coastline has the feature of a so-called headland bay beach. This term is used to define a sandy shoreline bounded by rocky outcrops or headlands (man-made or natural) and where its shoreline assumes some form of curvature. In most cases, headland bay beaches appear in an asymmetric shape, consisting of a sheltered curved shadow zone, a gently curved transitional zone and a relatively straight tangential end down coast, see also Figure VIII - 1.

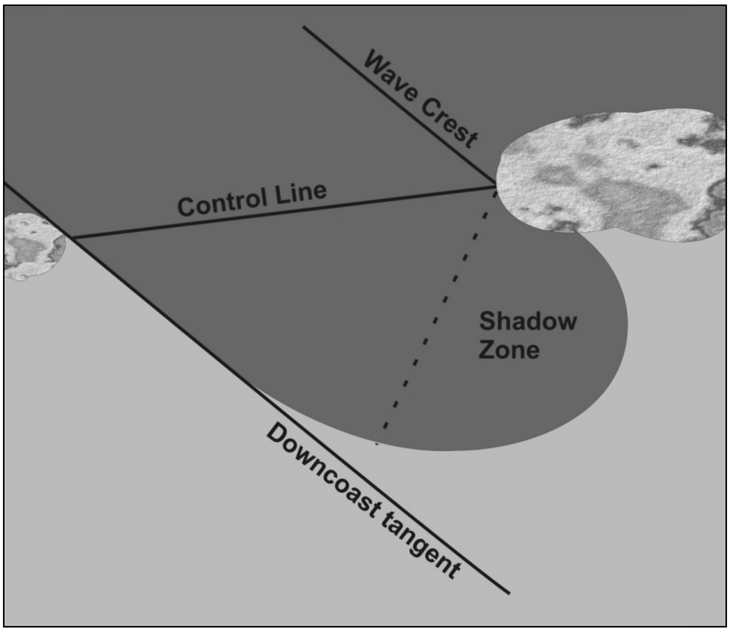


Figure VIII - 1 Principal components of a headland bay beach

Headland bay beaches appear in different scales. It either can appear between to big natural rocky outcrops or appear in the form of a tombolo or salient behind an offshore island or man made structure, on a much smaller scale.

VIII.2.2. Stability

In terms of stability, a headland bay beach can be classified in different catoregies: *static equilibrium, dynamic equilibrium and unstable.*

Static equilibrium: this equilibrium is reached when waves appear to break simultaneously along the whole bay periphery. In this stage littoral drift is almost non-existent, hence without any input of sediment from outside the study area and without long-term erosion.

Dynamic equilibrium: this equilibrium represents a beach where waves appear not to break simultaneously, resulting in a littoral drift. However the beach is considered to be stable because of any input. A balance exists between erosion/accretion processes resulting in a stable beach planform.

Unstable: This is the case when there's no balance between erosion processes and sediment supply, which was both the case in the situation of a static equilibrium (both none existing), and a dynamic equilibrium (both processes in present and in balance). It will result in either a prograding shoreline in case of dominancy by sediment supply over erosion processes or a transgressing coastline in case of dominant erosion.

Categorisation in terms of stability is important since a beach in static equilibrium is suggested by Silvester (1974) to be the most stable form under persistent swell waves. Construction of a headland bay beach in static equilibrium has been recommended as means of stabilizing an eroding shoreline.

VIII.2.3. Empirical model

Several mathematical functions have been empirically derived to curve fit the shoreline planform of a headland bay beach. Three major models are:

- logarithmic spiral (Krumbein, 1944; Yasso 1965)
- parabolic bay shape (Hsu & Evans, 1989; Silvester & Hsu, 1993 & 1997)
- hyperbolic tangent shape (Moreno & Kraus, 1999)

All these models use different coordinate systems, origins and controlling parameters related to wave direction a wave geometry. Wave heights and periods are not included.

The reason to use the parabolic bay shape equation is that in this method the physical location at the point of wave diffraction is used as the origin of the coordinate system. Consequently the effect of relocating the diffraction point by engineering means can be assessed. This makes this model extremely useful for engineering purposes. It will be applied on Piçarras beach and explained in more detail in one of the next paragraphs. Both the logarithmic spiral model and the hyperbolic tangent shape model do not use the location of the wave diffraction point to determine beach stability.

Hsu & Evans (1989) have developed a parabolic equation to fit the planform of 27 mixed cases of prototype and model bays considered to be in static equilibrium. Silvester & Hsu (1993, 1997) have produced necessary verification on this formula.

The parabolic bay shape equation is given by:

$$\frac{R_n}{R_0} = C_1 + C_2\left(\frac{\beta}{\theta}\right) + C_3\left(\frac{\beta}{\theta}\right)^2$$

R_n: radius to any point on the bay periphery in static equilibrium with angle θ
R_0: length of the control line, defined as the line between the wave diffraction point and the
downcoast beach end
β: wave obliquity angle
$C_{1,2,3}$: constants, vary with angle β

The meaning of the different parameters is also visualised in Figure VIII - 2.

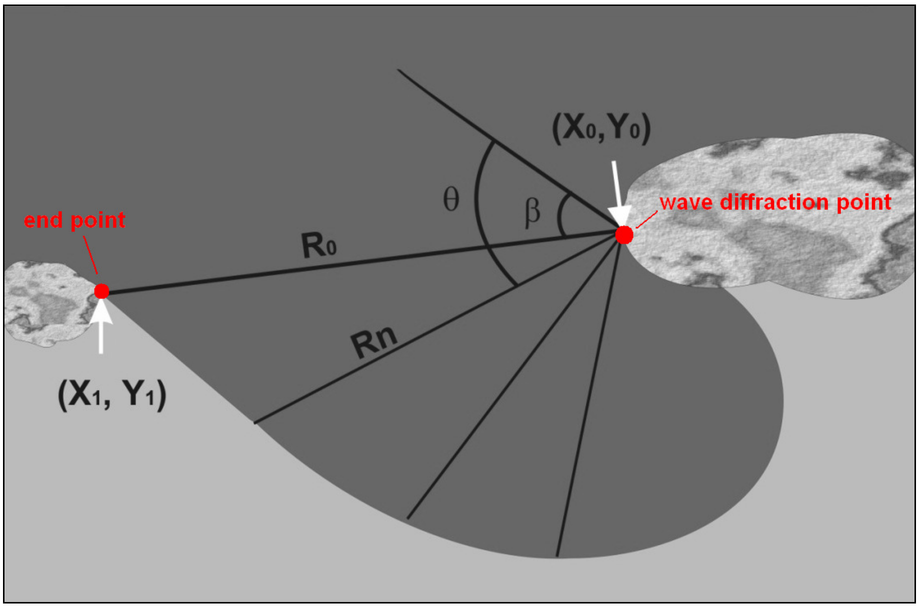


Figure VIII - 2 Definition sketch of the parabolic model given by Hsu & Evans (1989)

So in fact the formula consist of two basic parameters. First, the length of the control line, to be defined from the wave diffraction point to the downcoast beach end. Second, the wave obliqueness. Both values can be determined using an aerial photograph with noticeable wave action and logically clear weather. Consequently the bay periphery can be determined; each value of θ will give an accompanying value for R_n.

For a bay in static equilibrium the direction in which the waves propagate is assumed to be perpendicular to the downcoast tangent and the first wave crest line starting at the point of wave diffraction, see Figure VIII - 3.

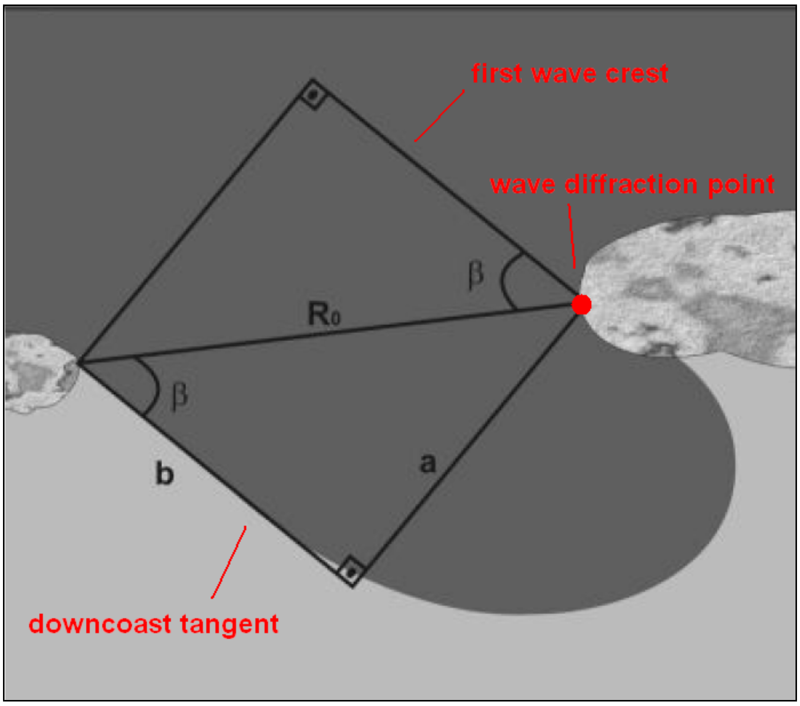


Figure VIII - 3 Definition of first incomming wave crest and downcoast tangent

Under this condition it may be assumed that:

- no further sediment is added/eroding from the bay under persistent swell condition
- waves break simultaneously around the whole bay periphery
- littoral drift and longshore currents are almost non-existent

To facilitate the use of the parabolic bay shape equation a software application is designed, called "<u>M</u>odel for <u>E</u>quilibrium <u>P</u>lanform of <u>Bay</u> Beaches" (Mepbay). It applies the theory as described in the previous paragraph and gives results in graphical form.

VIII.2.4. Application

In this paragraph Piçarras beach will be subjected to the program and its accompanying theory of the parabolic bay shape equation to analyze the stability. Normally the following procedure should be followed in order to get to the required results:

1. Load an image of a beach on a map or an aerial photograph
2. Define the orientation of both the beach and the upcoast control point.
   In this study the orientation of the beach is 'left' and the orientation of the upcoast control point is 'down'.
3. Three points should be defined:
   a. Upcoast control point (point of wave diffraction)
   b. Downcoast control point
   c. End point along the tangent of the beach downcoast

Mepbay then calculates and shows the beach planform in static equilibrium. The results including the allocation of the three different control points are shown in Figure VIII - 4.

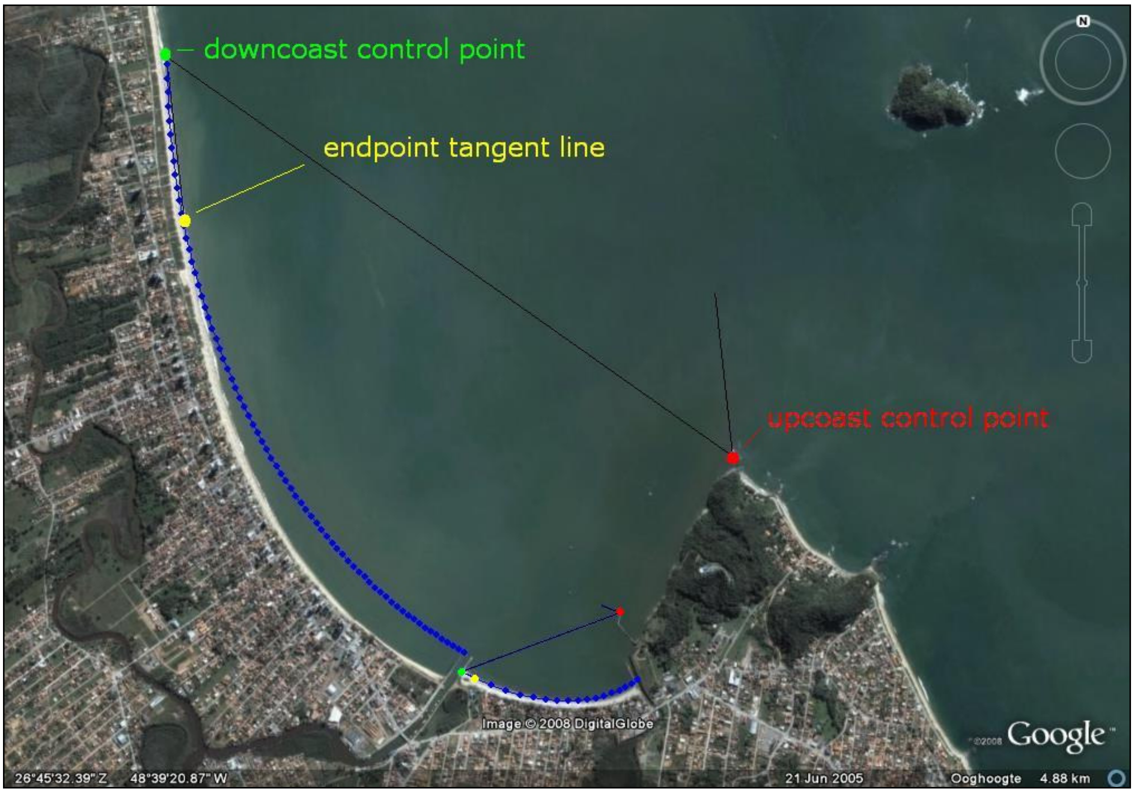


Figure VIII - 4 Aerial photo of Piçarras beach with modeled beach planform in static equilibrium [16]

The figure suggests that the beach is far from a static equilibrium. With enough sediment supply this beach is supposed to be in a dynamic equilibrium, according to the theory behind the parabolic bay shape equation.

However a few physical features in the Piçarras bay do not justify the procedure as described above. First this is the presence of the offshore island (see Figure VIII - 4) and the possible presence of some shoals in the foreshore, see Appendix I. Both these features induce some kind of wave diffraction which possibly affects the beach planform. The presence of more wave diffraction points may disturb the straight downcoast coastline which therefore can not be used anymore as a reference to allocate the end point of the downcoast tangent line. Even though it is not very obvious that the beach is affected by these features, according to the theory it is not justified to make reliable statements about the characteristics of this beach. Second this is the allocation of the downcoast control point. This is rather uncertain since there is no clear downcoast boundary of the bay.

There is another way to apply this program to the Piçarras bay which deals with the above mentioned uncertainties. The theory which this program is based on will be applied in a different way. The first procedure used the straight beach planform as a reference to define the downcoast control point and the end point of the downcoast tangent line.

Two important differences compared to the previously described procedure are to be noted:

- The downcoast control point line will not be defined based on the visual observation of the end of the straight beachline and simultaneously the begin of the curved part of the beach. This point will be allocated on the place where the effect of wave diffraction along the coastline is noticeable as a result of the diffraction caused by the allocated wave diffraction point in the program. According to the theory of a beach in static equilibrium, waves break simultaneously along the whole bay periphery and propagate perpendicular to the coastline. This suggests that the place where the effect of wave diffraction is noticeable, the curvature of the beach will start. Therefore the downcoast control point will be allocated at this point. This point of wave diffraction can be obtained from the results of the D3D modeling part (Appendix III) by visual observation which thus also includes the effect of possible diffraction of waves due to the island/shoals.
- The end point of the downcoast tangent line will be defined based on the wave propagation angle at the diffraction point. According to the theory, the incoming wave crest at the wave diffraction point is parallel to the downcoast tangent line. Since the straight beachline is regarded as unreliable as a reference, the wave propagation angle is a good alternative in this study. It reduces the uncertainty of visual interpretation and uses more reliable model information. Direction of incoming waves at the wave diffraction point can also be obtained from the D3D modelling part (Appendix III).

The new procedure is visualised in Figure VIII - 5.

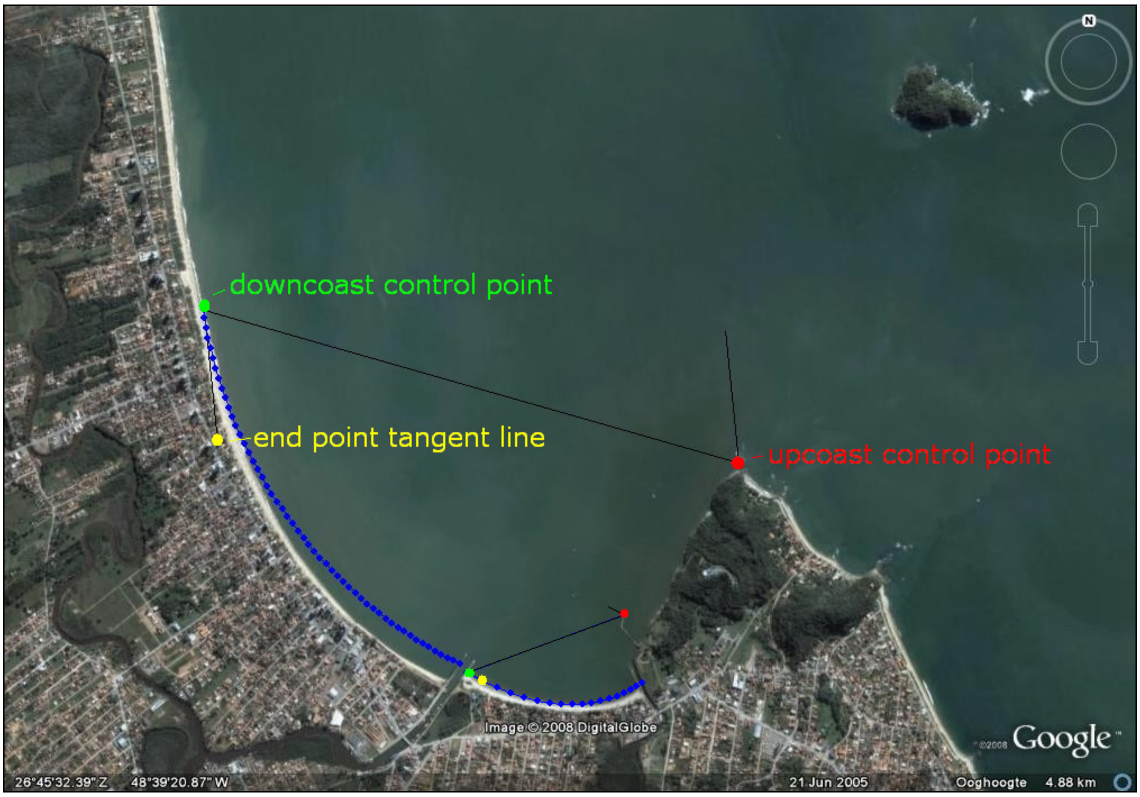


Figure VIII - 5 Aerial photo of Piçarras beach with modeled beach planform in static equilibrium (alternative procedure)[16]

Summarising, the downcoast control point matches the point where the effect of wave diffraction caused by the defined upcoast control point is noticeable. The allocation of the end point of the tangent line is based on the wave propagation angle at the upcoast control point. The tangent line needs to be perpendicular to the wave propagation angle.

Both described procedures show that Piçarras beach is in dynamic equilibrium. Compared to the modelled beach planform according to the first described procedure, a slight transgression of the beach planform in static equilibrium is noticeable if one looks at the groin. The difference is in the order of 10 to 20m.

VIII.2.5. Beach nourishment

The program can be applied when the stability of a new beach planform needs to be checked as a result of a designed beach nourishment. The idea of this stability check is visualised in Figure VIII - 6.

Figure VIII - 6 Aerial photo of Piçarras beach with stabilty illustration of a beach nourishment [16]

Suppose that the blue line is the present day equilibrium shape of the beach planform and a nourishment design is proposed with a width of the beach planform up to the green line. Clearly this design would not be stable according to the blue equilibrium line and the beach would suffer erosion. A relative simple solution is to relocate the wave diffraction point by engineering means and curve fit the consequently changing equilibrium line with the designed beach width of the beach nourishment. This can be accomplished by constructing for example a groin at the top of the headland, indicated with a small brown line in Figure VIII - 6. The longer the design of the groin, the further the beach equilibrium line will be situated seaward.

The beach nourishment as designed in Appendix IX is not subjected to this program for several reasons:

- no accurate wave data is available. A slight change in wave approach angle near the wave diffraction point at the headland will result in a significant change of the equilibrium line of the beach, Figure VIII - 7. Note that a change in wave approach angle will consequently give a change in point with noticeable wave diffraction at the coast.

Figure VIII - 7 Change in equilibrium beachline due to different wave approach angles [16]

- Even though a new procedure is introduced that deals with the uncertainties that came with the visual interpretations that had to be made in the program, still the results depend significant on visual interpretation from the output of D3D. Especially when it comes to the determination of the point of noticeable wave diffraction.
- Moreover, due to a lack of good bathymetry and wave data the results from the D3D models can not be considered as being representative.

VIII.3 Conclusion

Mepbay is a useful tool for engineers to facilitate the use of the parabolic bay shape model on headland bay beaches. It has the capacity to predict the consequence of installing a coastal structure on a sandy beach. However some uncertainties come together with the use of this program which makes it not suitable as a stand alone evaluation program for the Piçarras bay, which is not really a straightforward headland bay beach, because of the presence of shoals and islands. Moreover, the presented results can not be considered as very reliable because of the lack of good data and the inaccuracy that comes with the visual interpretations which the program is based on.

IX. Design of Nourishment

IX.1 Introduction

This appendix will treat the design of the nourishment. First the area to be nourished will be treated. Then the location of the borrow pit will be determined. To determine the volumes to be nourished, the desired beach width and slope will be analysed. Different methods will be applied to determine the volume needed. These methods will be compared using a multicriteria analysis. Also the costs of the nourishment design are calculated to get an idea of the feasibility of the design. The calculation is made with support of the lecture notes Dredging Technology [33]. A lot of standard costs used in this paragraph are taken from these notes. In present day, the two types of dredging vessels mostly used for dredging projects all around the world, are a cutter suction dredger and a trailing suction hopper dredger. The vessel choice for this project will be explained in this chapter. Then the execution time of the project will be calculated since this is logically a very important factor in determining the total project costs. The weekly costs will be determined based on the costs for the chosen vessel (depreciation, interests, maintenance, repair), crew expenses, fuel, insurance etc. Each of these aspects is treated separately. All the used factors, amounts and choices made are being explained as far as possible.

IX.2 Area to be nourished

As a first step of the nourishment design, the area to be nourished will be determined. The previous nourishment, in 1999, was carried out on the first 2100 metres north of Piçarras river. These are profiles 1 till 21. For the numbering of the profiles, see Figure IX - 1.

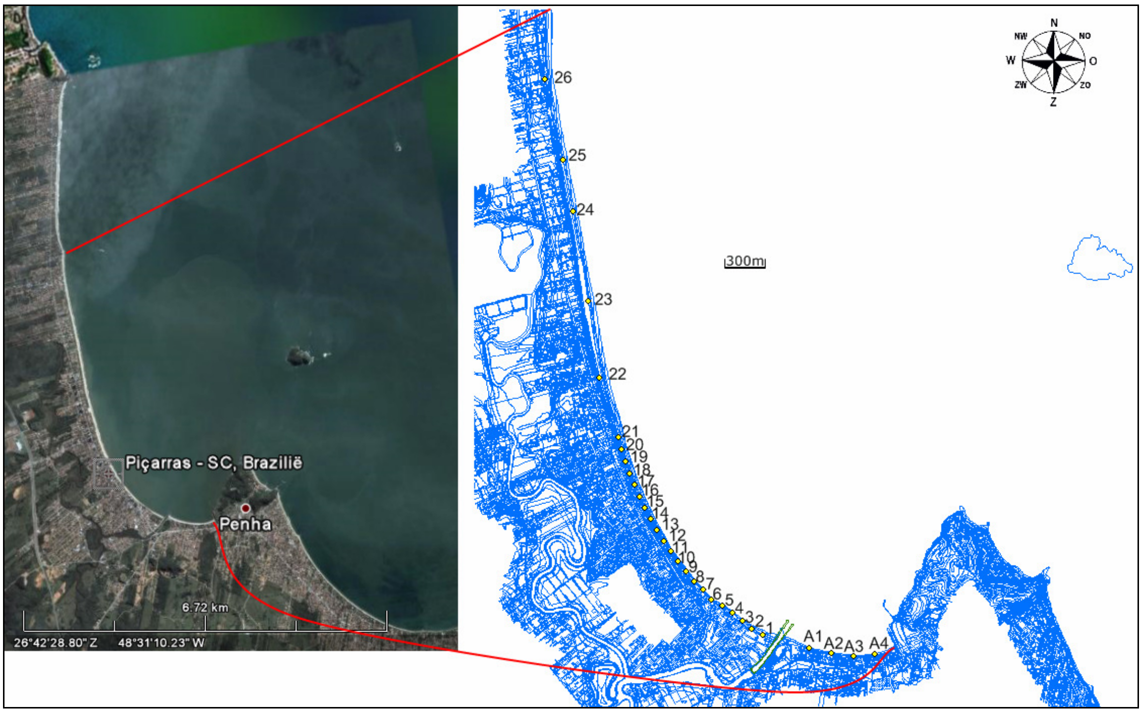


Figure IX - 1 Profile positions [16][34]

It can be seen from Figure IX - 2 till Figure IX - 7 that the beach width increases towards the north. The boundary can be seen between profile 21 and 22. From profile 22 northward on the profiles have sufficient width and no nourishment is needed, see Figure IX - 6. This situation is clarified in Figure IX - 7, where it is clearly shown that the erosion decreases towards the north.

This means the erosion is still largest in the part south of profile 21. Therefore the nourishment will be designed for the same area as in 1999, profile 1 to 21.

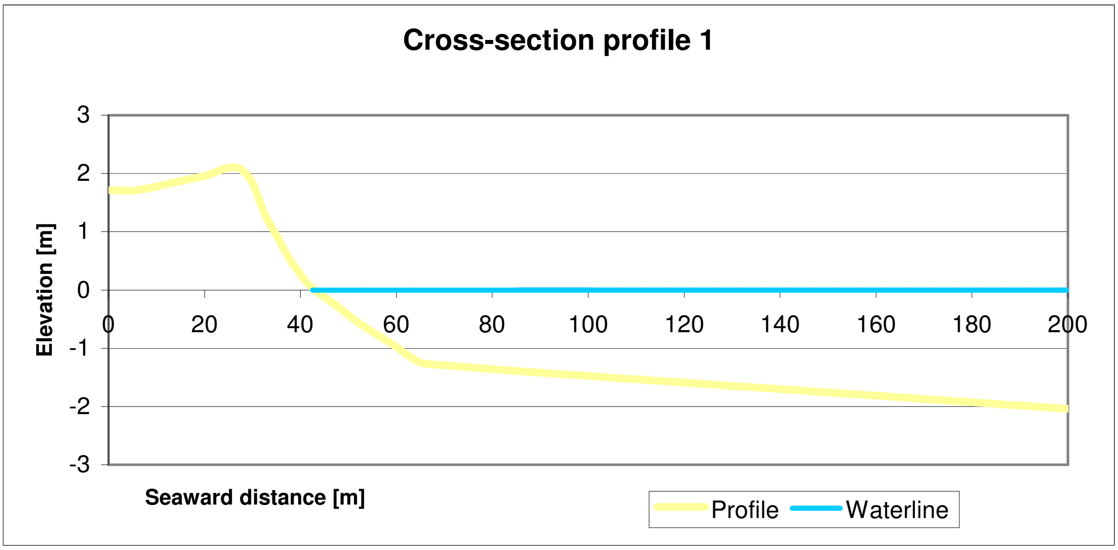


Figure IX - 2 Cross-section profile 1

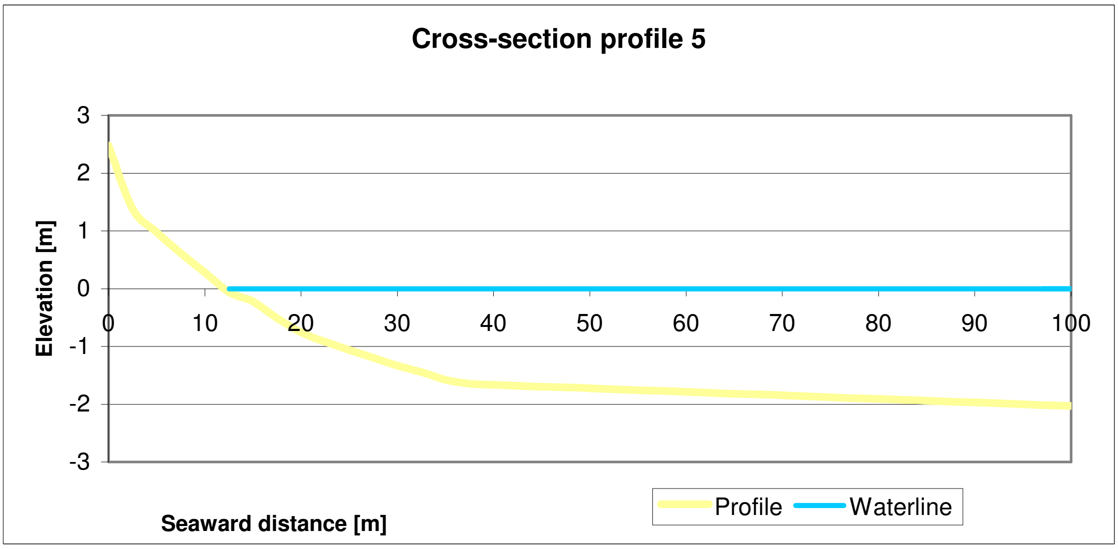


Figure IX - 3 Cross-section profile 5

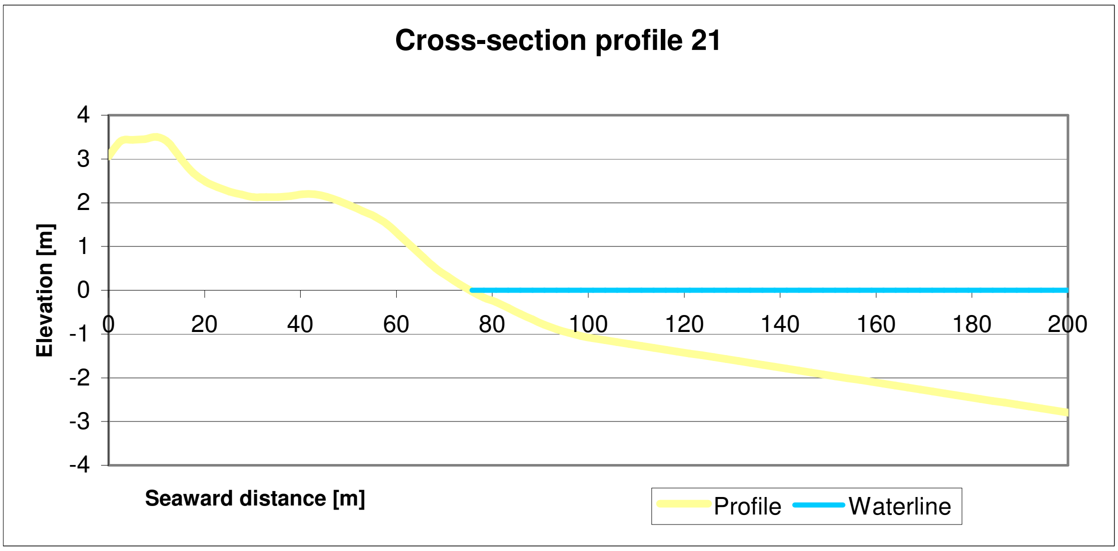


Figure IX - 4 Cross-section profile 21

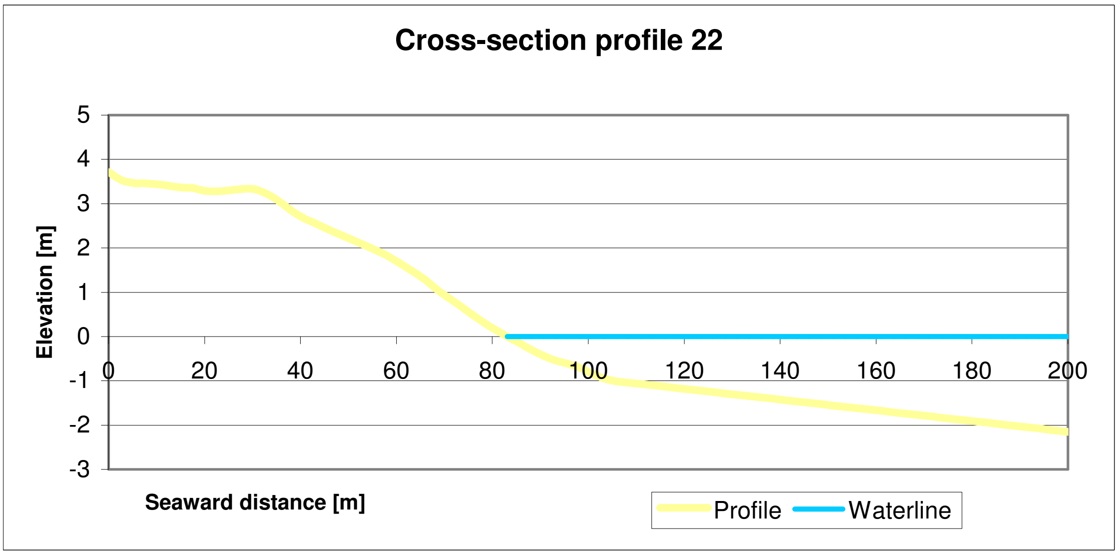


Figure IX - 5 Cross-section profile 22

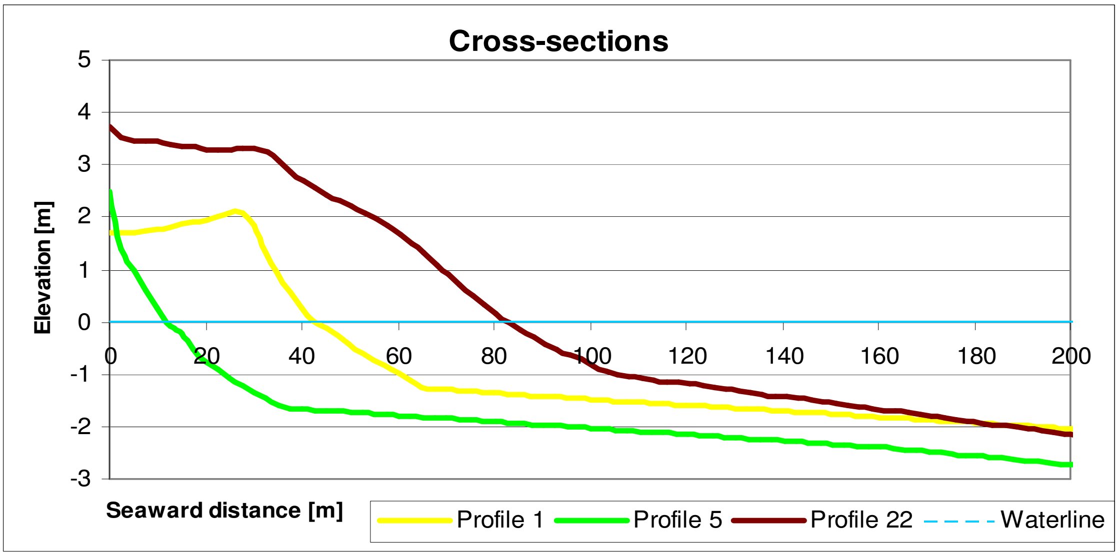


Figure IX - 6 Comparison of profile cross-sections along Piçarras beach

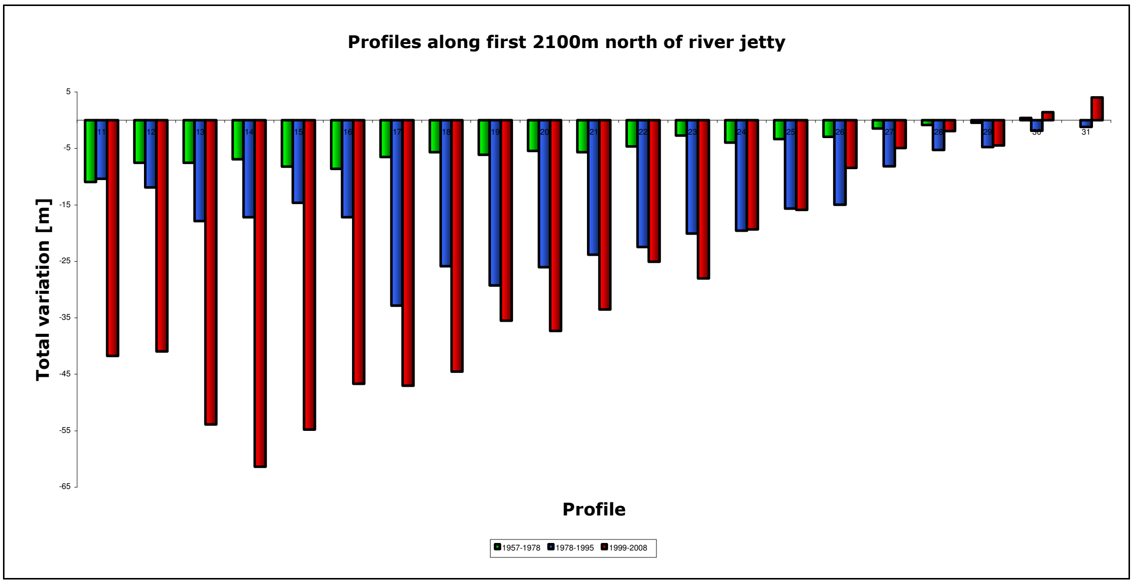


Figure IX - 7 Decrease in beach width over first 2100m north of river jetty during several time periods

IX.3 Location borrow pit

There are several possibilities for a borrow pit. A borrow pit in front of Praia Piçarras is not an option since the borrow pit will then be situated in the shallow nearshore. The sudden increase in depth will influence wave propagation or even wave breaking. This will eventually influence the beach profile by disturbing the littoral sediment transport.

A first possibility is creating a borrow pit in front of the coastline of Alegre beach. This is according to the plan of Prosul and is therefore indicated by "2007 Borrow Site" in Figure IX - 8. The beach of Alegre has also been nourished in 1999. A conclusion drawn from this information is that the beach of Alegre was eroding or stable, but not accreting. Making a borrow pit in front of Alegre beach will alter the wave induced currents and will lead to a transport of sand from the foreshore and nearshore into the borrow pit. This will lead to an increase of beach erosion. Therefore this location is not a good option. Another argument against the use of this borrow pit is the possibility of dredging fines, since the pit is located very close to the river mouth.

Another possibility is the use of the borrow pit used in 1999. In Figure IX - 8 the borrow pit used is indicated by '1998', since the dredging activities started in December 1998. Due to the position of the borrow pit in deep water, it is expected that it will not, or hardly, influence the local flow patterns and sediment transport. The borrow pit is located about 12 kilometers off the coastline.

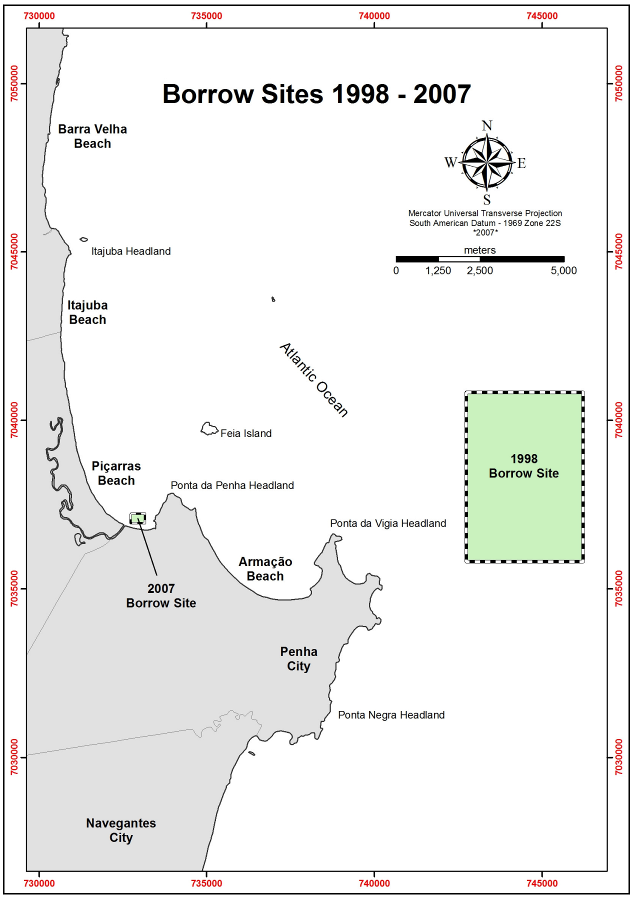


Figure IX - 8 Possible locations of the borrow pit [2]

Weighing the possible borrow sites with their consequences on flow patterns and occurring sediment transports, the borrow pit of 1999 will be used.

There are no data available on the sediment placed during the last nourishment in 1999 and therefore there are no data about the sediment present in the borrow pit.

In Appendix V it is concluded that the sediment available in the borrow pit used in 1999 is somewhat smaller than the sediment now present at Piçarras beach. In the same appendix an assumption was made about the sediment available in the borrow pit, being d_{n50} = 0.260mm.

IX.4 Desired beach width and slope

IX.4.1. Design principles: design and advanced fill

There are several ways to determine the desired beach width that has to be achieved by the nourishment. In this design the design and advanced fill are used, see Figure IX - 9.

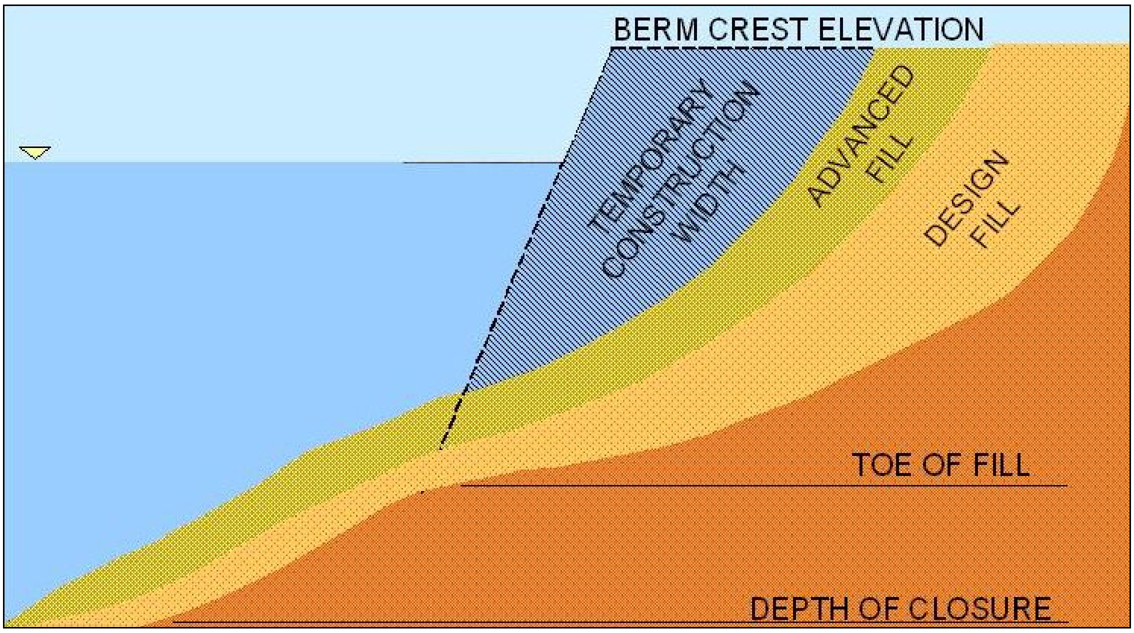


Figure IX - 9 Principle of design and advanced fill [5]

First a design fill is placed. At the same time the advanced fill is placed. While time passes, the advanced fill will erode. This is mainly due to the structural erosion, which made the nourishment necessary in the first place. The erosion rate after a nourishment is slightly higher than the pré-nourishment rate. This is due to the shift in beach orientation. Secondly the sand spreads out on the sides. The sand placed forms some sort of rectangular along the coasts. Waves will rework this sand body to make a smooth transition between the original and the nourished beach. This longshore spreading is visualised in Figure IX - 10. In this figure also the cross-shore redistribution is mentioned. This is the reshaping of the beach profile by waves since the sediment is placed with a slope equal to the angle of internal friction of the material. Of course this slope is too steep considering the wave action. Therefore a smoother profile will be formed, which is preferable for the beach tourists. As can be seen in Figure IX - 9, the beach width after construction will decrease due to this cross-shore redistribution.

For the design and advanced fill the economical optimum is said to be 175 to 250 m^3 per meter coastline [5]. Later on, calculated volumes will be compared to this standard, to get an indication of the number.

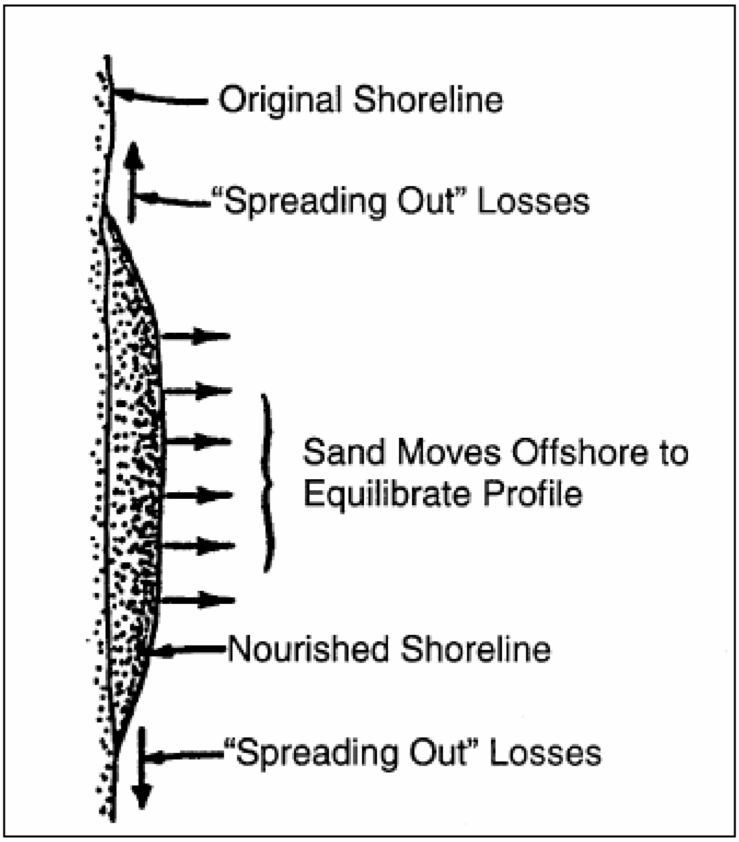


Figure IX - 10 Sediment losses due to longshore spreading and cross-shore redistribution [5]

Since there is no intervention with the causes of the erosion, the retreat of the coastline will continu. After the advanced fill has eroded, it is time for the first renourishment. If this design is applied correctly, the design fill will never be affected by erosion. Therefore the width of the beach plane established by the design fill will be the minimal beach width at all times.

As can be seen in Figure IX - 7, the erosion rate of Piçarras beach is a function of the orientation of the shoreline and changes along the coastline. Therefore the advanced fill will erode faster in the south. The renourishments should take place when the total volume of the advanced fill had eroded. It should be noted that most of the volume should be placed in the southern part of the nourished stretch. This way the beach width remains equal over the nourished stretch of beach.

IX.4.2. Determined width

The following factors play a role in determining the desired beach width:
- recreation on beach
- erosion rate on the area undergoing the most severe erosion

An engineering factor to consider is the buffer of sediment for storm events. There is not much data available about the nourishment in 1999. The profiles measured in 1999 show an average dry beach width of 66 meters. These profiles were measured by the local government. In Figure IX - 11 the width is compared to previous years.

The difference between dry beach width and beach plane width is visualised in Figure IX - 12. An average dry beach width of 66m means the waterline was on average 66m seaward of the end of the backshore. The width of the beach plane is less. It is the width of the horizontal stretch of beach. Locals say the width of the plane was 40m after construction.

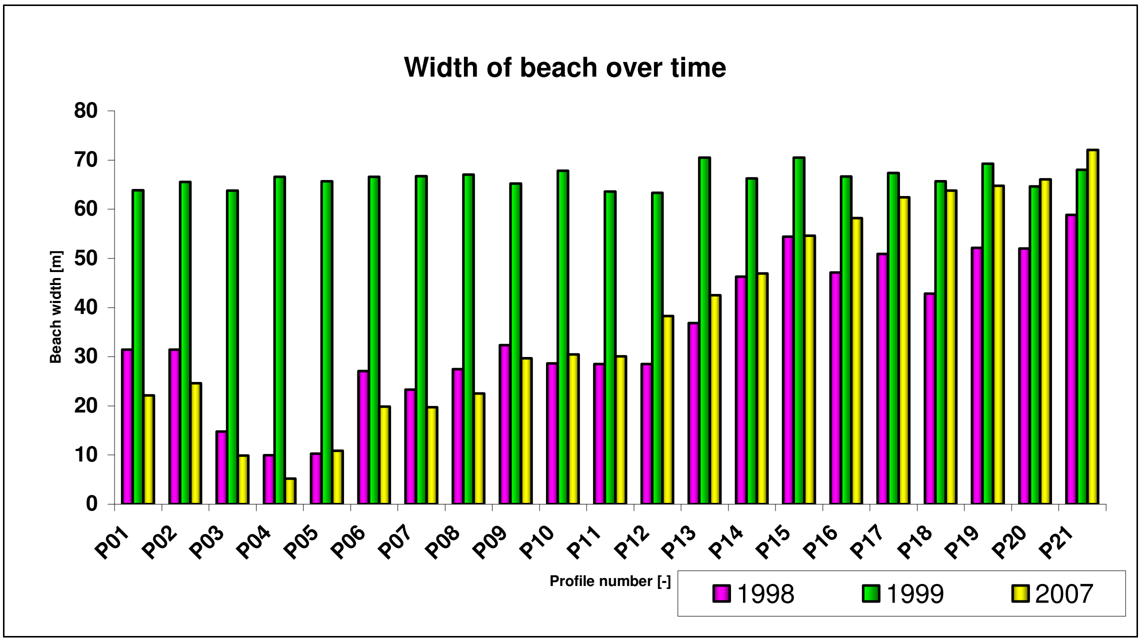


Figure IX - 11 Width of beach profiles 1 until 21 in 1998, 1999 and 2007 [2]

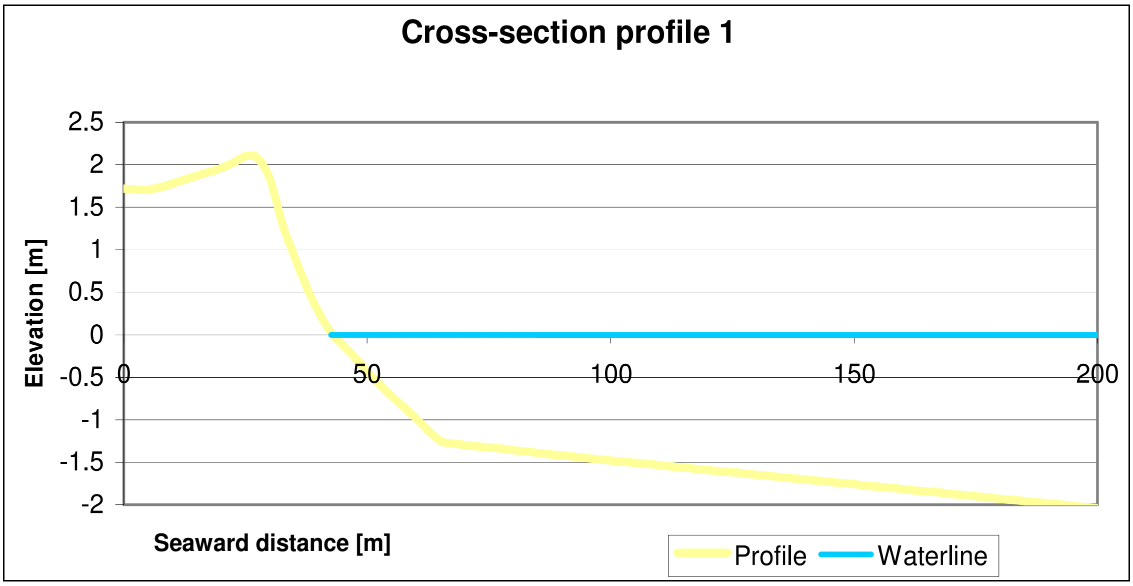


Figure IX - 12 Explanation beach plane width and dry beach width

Since the sediment that was placed in 1999 has almost completely disappeared on some spots, this width of the beach plane of 40m seems minimal for the new nourishment. Of course this depends on the re-nourishment schedule.

It is determined to have a minimal beach plane width of 35m at all times. This means the design fill after equilibration (the cross-shore redistribution) will provide a 35m wide beach plane. By placing the advance fill another 35m of beach plane will be added.

As said before, the intervals of renourishment are based on the lifetime of the advance fills. All data combined lead to a variation of the beach plane width between 35 and 70m with a renourishment interval of 10 years.

The height of the dry beach is also an important factor of the nourishment design, as it will be judged by all the beach visitors. It is important to keep the berm height at a high level, as it will reduce the wave run up and risk at flooding during periods of high water levels and extreme waves. A severe storm will cause a wind set-up of IBGE +1.0m. Applying a too high level however, is undesirable for recreation. If the berm is elevated too high above its level created by nature, scarping of the berm can occur and the beach could be dangerous for swimming. For these reasons, the berm of the beach will have a height of IBGE + 3.0m.

In Table IX - 1 the highest points of each of the profiles are shown, which shows that the berm at IBGE + 3.0m is a good average for the stretch of the nourished beach.

Berm height along Piçarras beach	
profile number	berm height [m]
01	2.22
02	2.80
03	2.56
04	1.59
05	2.44
06	2.44
07	2.79
08	3.02
09	2.96
10	2.81
11	3.14
12	3.17
13	3.37
14	3.43
15	3.51
16	3.61
17	3.86
18	3.71
19	3.83
20	3.70
21	3.39
22	3.42
23	3.94
24	3.83
25	3.88
26	3.43
Mean	3.19

Table IX - 1 Berm height per profile along Piçarras beach

From a recreational point of view the desired beach slope should not differ too much from the actual slope. The present slope is already quiet steep. If the beach becomes steeper, the wave energy will be dissipated in a narrower breaker zone, causing a rough area for swimmers.

The slope is determined by the prevailing wave conditions at the shore and by the sediment sizes available. The sediment size can be influenced by the nourishment. Since the sediment from the borrow pit is slightly finer than currently present, the slope will become a bit milder.

IX.5 Volume calculations

The next step in the design of the nourishment is the determination of the volume of sand to place on the beach. There are several ways to establish the volume that is needed using the required beach plane width.

A first estimate will be made using the method of translating profiles. This method assumes no difference between the currently present sediment sizes and the sediment sizes available in the borrow pit. Since this is not entirely true, the number will be calculated more exactly using Deans method of intersecting and non-intersecting profiles. The last method used is the Dutch method. The Vellinga scaling method will not be applied since the difference in sediment size of the native sand and the fill sand is too small.

Some data are similar for all methods, therefore they are presented in Table IX - 2.

General data for the nourishment design

profile number	d* [m]	new berm height [m]	profile width [m]
01	2.36	3.0	150
02	2.46	3.0	100
03	2.54	3.0	100
04	2.57	3.0	100
05	2.67	3.0	100
06	2.77	3.0	100
07	2.82	3.0	100
08	2.91	3.0	100
09	2.97	3.0	100
10	2.94	3.0	100
11	3.05	3.0	100
12	2.99	3.0	100
13	3.09	3.0	100
14	3.18	3.0	100
15	2.86	3.0	100
16	3.37	3.0	100
17	3.59	3.0	100
18	3.59	3.0	100
19	3.60	3.0	100
20	3.54	3.0	100
21	3.38	3.0	50

Table IX - 2 General data for the design of the nourishment

The results of all methods will be compared to the volume eroded in the past nine years, which is 395,000 m^3, see Appendix V, chapter 3. As said before, the sediment placed will redistribute in longshore and cross-shore direction and erode due to the structural erosion. The volume eroded in the past nine years is a very good criterium, since these processes are already discounted in the this number. The only difference with the new nourishment is the fact that a greater amount of sand will be placed. This will initially result in more erosion.

IX.6 Translating profiles

The first nourishment exists of two parts. These are called the design fill and the advance fill, like treated previously. The volumes calculated here will provide a beach width between 35 and 70 meters.

It is determined that the sand used for the nourishment will have approximately the same grain size distribution as the native sand. This means the sediments are compatible. When this is true, the method of translation can be used. This means that every element of the nourished profile will be displaced at the same distance seaward over the vertical active dimensions of the profile, see Figure IX - 13.

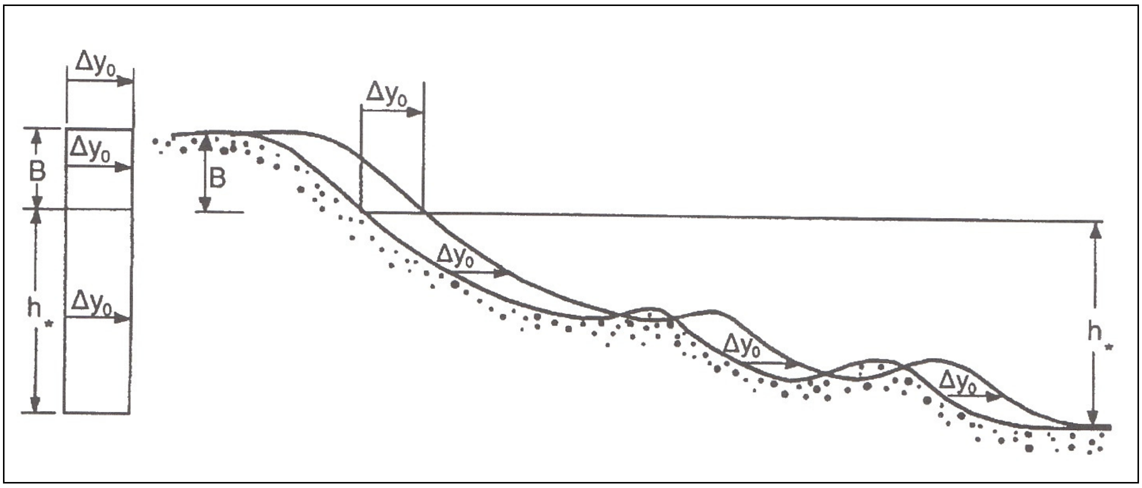


Figure IX - 13 Translating profiles [11]

Every element will be displaced over a maximum distance of 35 meters for the design fill and another 35 meters for the advanced fill. To calculate the volumes the following formula is used:

$$¥ = \Delta y_0 \times (d_* + B)$$

where

¥	=	volume to be placed [m^3]
Δy_0	=	translation distance [m]
d_*	=	depth of closure, deviates per profile [m]
B	=	berm height, 3.0m

When these volumes are calculated, additional volume is added to raise the level of the dry beach to IBGE + 3.0m. In Table IX - 3 the results are given per profile.

Nourish volumes per running meter beach for the method of translating profiles					
profile number	Δy0 design fill	Δy0 advanced fill	design fill [m3/m]	advance fill [m3/m]	first nourishment [m3/m]
01	25.2	35.0	144	188	332
02	22.2	35.0	127	191	318
03	35.0	35.0	247	194	441
04	35.0	35.0	292	195	487
05	35.0	35.0	243	198	441
06	35.0	35.0	233	202	435
07	31.7	35.0	185	204	389
08	29.7	35.0	177	207	384
09	30.2	35.0	181	209	390
10	35.0	35.0	225	208	433
11	30.4	35.0	184	212	396
12	28.4	35.0	170	210	380
13	24.9	35.0	152	213	365
14	25.4	35.0	157	216	373
15	26.5	35.0	155	205	360
16	23.5	35.0	150	223	373
17	19.8	35.0	130	231	361
18	22.1	35.0	145	231	376
19	25.0	35.0	165	231	396
20	24.9	35.0	163	229	392
21	22.5	35.0	144	223	367
Mean			180	210	390

Table IX - 3 Volumes to be nourished per running meter beach for the method of translating profiles

The volumes to heighten the beach and the volumes to widen the beach are present in the total nourishment volumes. It is divided in a first nourishment, which includes the design fill and the advanced fill, and a repeated nourishment, which is just the advanced fill. These are the total volumes over Piçarras beach.

Total nourish volumes for the method of translating profiles		
profile number	first nourishment [m3]	repeated nourishments [m3]
01	49,728	28,169
02	31,836	19,102
03	44,121	19,448
04	48,715	19,588
05	44,120	19,890
06	43,470	20,211
07	38,897	20,382
08	38,405	20,685
09	38,991	20,889
10	43,276	20,818
11	39,564	21,170
12	38,009	20,971
13	36,464	21,309
14	37,309	21,619
15	36,024	20,501
16	37,274	22,302
17	36,079	23,059
18	37,627	23,081
19	39,607	23,105
20	39,173	22,879
21	18,339	11,157
Total	817,029	440,333

Table IX - 4 Total nourish volumes for the method of translating profiles

The method of translating profiles results in 817,000m^3 over the first 21 profiles. The mean volume per running meter beach is 390m^3 for 70 meter dry beach width. This is a large nourishment, compared to the financial norm. The advanced fill is in range of the norm, so the later nourishments will be financially more attractive.

This theory of translating profiles is only valid until the closure depth. This volume estimation will therefore be relatively low. Volumes of sand dissapearing outside the closure depth, by wrong placement during construction or displacement by storms, will lead to relative big losses. There is no buffer of sand available to compensate for these losses.

It is quickly seen however, that this method leads to very large volumes. Comparing this volume with the calculated eroded volume of 395,000m^3 in nine years (Appendix V), this amount of 817,000m^3 is large for a width of 70 meters. Although the width of the new nourishment is 70 meters, compared to a minimal width of the previous nourishment of 45 meters, more than a doubling of the volume is not completely realistic.

IX.6.1. Equilibrium profiles

The second method is better than the previous method since it takes sediment sizes into account. The nourished sand will not totally translate the profile. But a new equilibrium profile will form, which could either be intersecting or non-intersecting, see Figure IX - 14.

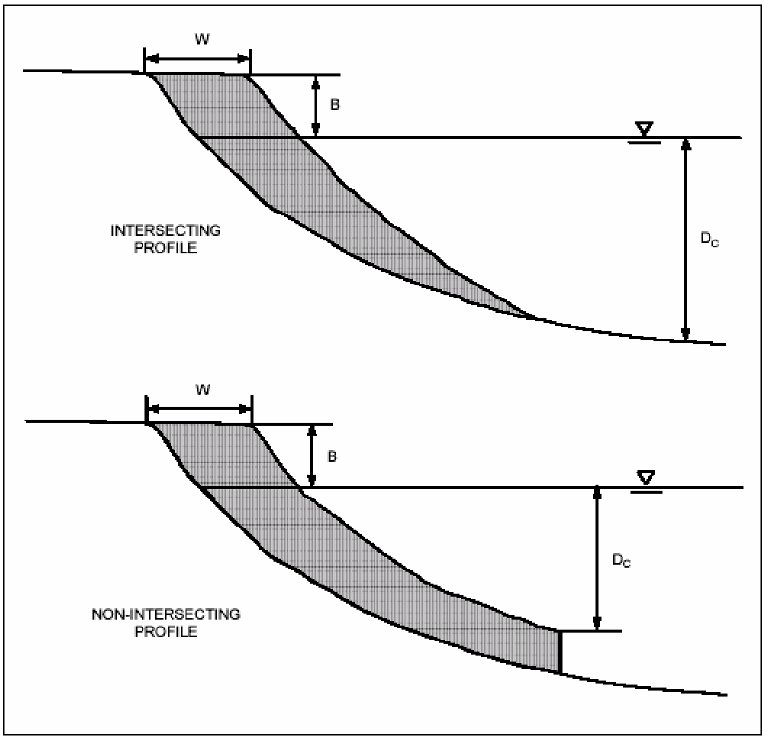


Figure IX - 14 Intersecting and non-intersecting profiles [11]

In appendix V it was determined that the sediment in the borrow pit will be compatible with or slightly finer than the native sand, i.e. the sand currently present, $\frac{A_f}{A_n} < 1$. This means that the equilibrium profile will be non-intersecting.

While determining the profile changes one should realise that storm waves at low water level can do more damage than waves combined with storm surge level. But since the tidal range is small at the bay of Piçarras (0.6m), this analysis will not have a great impact. Therefore it can be concluded that the scenarios calculated here are governing.

For a non-intersecting profile the next formula [11] goes:

$$\frac{¥}{\mathrm{B} \times \mathrm{W}^*} = \frac{\Delta y_0}{W^*} + \frac{3}{5} \times \frac{d_*}{B} \times \left(\left(\frac{\Delta y_0}{W^*} + \left(\frac{A_n}{A_f} \right)^{\frac{3}{2}} \right)^{\frac{5}{3}} - \left(\frac{A_n}{A_f} \right)^{\frac{3}{2}} \right)$$

Where

$¥$ = volume to be nourished [m^3]

B = berm height, 3.0m

W^* = reference offshore distance associated with a reference breaking depth, $W^* = \left(\frac{h_*}{A_n} \right)^{\frac{3}{2}}$

Δy_0 = translation distance [m]

d_* = closure depth [m]

A_n = 0.122, profile scale parameter native sand, determined by table 3.1 [11], using d=0.285mm

A_f = 0.117, profile scale parameter fill sand, determined by table 3.1, using d=0.260mm

With this formula the volumes are calculated for all 21 profiles. Here the volumes needed to raise the beach to IBGE + 3.0m are added. The results are given in Table IX - 5. In Table IX - 6 the total volumes to be nourished are presented.

Nourish volumes per running meter beach for the method of equilibrium profiles					
profile number	Δy_0 design fill	Δy_0 advanced fill	design fill [m3/m]	advance fill [m3/m]	first nourishment [m3/m]
01	25.2	35.0	157	207	365
02	22.2	35.0	140	211	351
03	35.0	35.0	268	215	483
04	35.0	35.0	313	216	529
05	35.0	35.0	264	220	484
06	35.0	35.0	255	224	479
07	31.7	35.0	206	226	432
08	29.7	35.0	197	230	427
09	30.2	35.0	202	233	434
10	35.0	35.0	248	232	480
11	30.4	35.0	205	236	442
12	28.4	35.0	190	234	424
13	24.9	35.0	170	238	408
14	25.4	35.0	177	242	419
15	26.5	35.0	173	228	401
16	23.5	35.0	171	250	421
17	19.8	35.0	152	260	412
18	22.1	35.0	168	261	429
19	25.0	35.0	189	261	450
20	24.9	35.0	186	258	444
21	22.5	35.0	164	251	415
Mean			200	235	435

Table IX - 5 Volumes to be nourished per running meter beach for the method of equilibrium profiles

Total nourish volumes for the method of equilibrium profiles		
profile number	first nourishment [m3]	repeated nourishments [m3]
01	54,724	31,115
02	35,121	21,117
03	48,264	21,466
04	52,892	21,580
05	48,430	22,000
06	47,914	22,402
07	43,209	22,645
08	42,731	23,013
09	43,443	23,266
10	47,991	23,158
11	44,162	23,616
12	42,396	23,368
13	40,826	23,788
14	41,860	24,178
15	40,087	22,790
16	42,109	25,050
17	41,208	26,038
18	42,875	26,068
19	45,014	26,100
20	44,432	25,801
21	20,738	12,533
Total	910,424	491,093

Table IX - 6 Total volumes to be nourished for the method of equilibrium profiles

Again the volume is quite high. The volume needed of 911,000m^3 is almost equal to the volume calculated with the theory of the translating profiles. This is logical, since the grain sizes of the native sand and the nourish sand are quite well compatible. But again this volume is relatively high compared to the erosded volume in the last nine years.

IX.6.2. Dutch method

The last method to be treated is the Dutch method. This method does not use the desired beach width but is based on the erosion rate of the past years.

First the rates of the structural erosion have to be determined by using data of the last 10 years. Using the average erosion rate of the last 9 years for all 21 profiles to be nourished, the erosion rate is -3.17m/yr. This is a lot higher than before the nourishment, when it was about -0.972m/yr. This is shown in Table IX - 7. The positive numbers are caused by the fact that the nourished volumes are taken into account.

Shoreline changes and eroded volumes over first stretch of Piçarras beach

year	shoreline change per year [m/yr]	eroded volume per year [m3/yr]
57-78 photo	-0.24	-1.24
57-95 photo	-0.42	-2.22
57-07 photo	-0.23	-1.19
78-95 photo	-0.97	-5.29
95-05 photo	0.38	2.29
98-99 profile	31.40	173.16
99-08 profile	-3.17	-15.99

Table IX - 7 Shoreline changes and eroded volumes over the first 21 profiles of Piçarras beach

The increase in erosion rate between 1978-1995 and 1999-2008 can be explained by the longshore spreading of the nourishment, but it could also indicate an increase in wave energy in the studied area. In the calculations for Piçarras beach the erosion rate after the nourishment is used, as it is the most recent data available.

Usually the Dutch method adds about 40% to account for sediment compatibility and longshore spreading. In this case this is not necessary since the sediment is compatible, as discussed before. Also the longshore spreading is already encounted in the erosion rate after the previous nourishment. The only difference with the previous nourishment is the fact that this design aims for a design life time of 10 years. This means the volumes will increase compared to nine years ago. Therefore processes such as the longshore spreading after construction will be higher than nine years ago. For these reasons, a longer life time and increased longshore spreading, 15% will be added to the erosion rate, leading to a new erosion rate of 3.65m/yr.

To calculate the volume from this erosion rate, the next formulas are used.

$$¥_{\text{yearly}} = \text{e.r.} \times \left(\text{d}_* + B\right)$$

Where

$¥_{\text{yearly}}$ = yearly volume needed [m^3/yr]

B = berm height, 3.0m

d_* = closure depth [m]

The erosion rate is not the average of 3.65m/yr, but varies per profile. This way the calculation will be more precise.

With this volume needed per year the total volume per running meter beach can be calculated:

$$¥_{\text{lifetime}} = ¥_{\text{yearly}} \times t$$

t = the desing lifetime, 10 year

The design lifetime is set to 10 years. This way the requirement of the beach width varying between 70 and 35 meters will be met. The desing fill provides about 35 meter beach and the advance fill, which will take place every 10 years, will provide the other 35 meter. So every 10 years a nourishment has to be done. This timeframe will provide enough time for the government to collect the money that is needed. The project expenses will be lower when using a repeating interval of 10 years in stead of 5 years, since the mobilisation costs will become a smaller part of the total costs.

The results of the Dutch method can be seen in Table IX - 8. The erosion rates shown are not yet raised with the 15%.

Nourish volumes per running meter beach for the Dutch method

profile number	erosion rate [m/yr]	design fill [m3/m]	advance fill [m3/m]	first nourishment [m3/m]
01	-5.22	322	322	644
02	-5.12	321	321	642
03	-6.74	429	429	858
04	-7.67	491	491	983
05	-6.85	447	447	893
06	-5.84	387	387	774
07	-5.87	393	393	787
08	-5.56	378	378	756
09	-4.44	305	305	610
10	-4.67	319	319	638
11	-4.19	291	291	583
12	-3.13	216	216	432
13	-3.50	245	245	490
14	-2.42	172	172	344
15	-1.99	134	134	268
16	-1.06	77	77	155
17	-0.62	47	47	93
18	-0.24	18	18	37
19	-0.56	42	42	85
20	0.18	0	0	0
21	0.51	0	0	0
Mean		240	240	480

Table IX - 8 Nourish volumes per running meter beach for the Dutch method

Profile 20 and 21 have a positive erosion rate which means the coast has been accreting at those cross-sections. Therefore the design and the advanced fill is taken to be zero.

On average there is 480m^3/m necessary to widen the beach between 35 and 70 meters so it will last 10 years. As treated before a financially attractive nourishment is between 175m^3/m and 250m^3/m. Therefore again the first nourishment will not be efficient, but the repeating nourishments will be.

Total nourish volumes for the Dutch method		
profile number	first nourishment [m3]	repeated nourishments [m3]
01	96,527	48,263
02	64,186	32,093
03	85,837	42,919
04	98,271	49,136
05	89,349	44,674
06	77,413	38,707
07	78,669	39,335
08	75,620	37,810
09	60,962	30,481
10	63,801	31,901
11	58,273	29,137
12	43,169	21,584
13	49,010	24,505
14	34,363	17,181
15	26,775	13,388
16	15,461	7,731
17	9,338	4,669
18	3,678	1,839
19	8,484	4,242
20	0	0
21	0	0
Total	1,039,186	519,593

Table IX - 9 Total nourish volumes for the Dutch method

The total amount of sand needed for the first nourishment is 1.040.000m^3. This is comparable to the volumes calculated with the previous two methods.

The volume for the repeated nourishments, 520.000m^3 seems correct since it is comparable to the volume of sand lost over the last nine years, which was established to be 395.000m^3.

The Dutch method requires placement of the sediment between LWL -1 meter and the dune foot. Since there is no dune foot, the upper level of the placement can be the end of the beach at IBGE + 3.0m. The lowest level of placement is IBGE -1.21m.

IX.7 Volume to be nourished

In Table IX - 10 the results of the previously treated methods are presented.

Comparison of calculation methods		
method	volume first nourishment [m3]	volume repeated nourishments [m3]
translating profiles	817,029	440,333
equilibrium profiles	910,424	491,093
dutch method	1,039,186	519,593

Table IX - 10 Comparison of volume calculation methods

It is obvious that all methods are within the same range. The Dutch method requires the largest volumes but is most reliable since it is based on actual observed numbers. The theories with equilibrium profiles assume the existance of these equilibria which are in this theory not really dependent on hydraulic boundary conditions.

Because the Dutch method has a higher reliability and less uncertainty, this method is chosen for the new nourishments. During the first nourishment 1.040.000m^3 of sand will be placed. By doing this, the beach will be 70 meters wide. The different widths and slopes of the beach can be seen in Figure IX - 15. The profile of June 2007 is coloured brown. The red line represents the design fill right after the placement. The advanced fill is indicated by the orange line. After some time, the beach slope will flatten due to wave action and an equilibrium will be reached. This is visualised by the white plane. The beach planform then has a width of 70m. After 10 years the advanced fill has eroded and only the design fill is still in place, the yellow plane. The first repetition of the advanced fill with be executed and again a cross-section indicated by the orange line will originate.

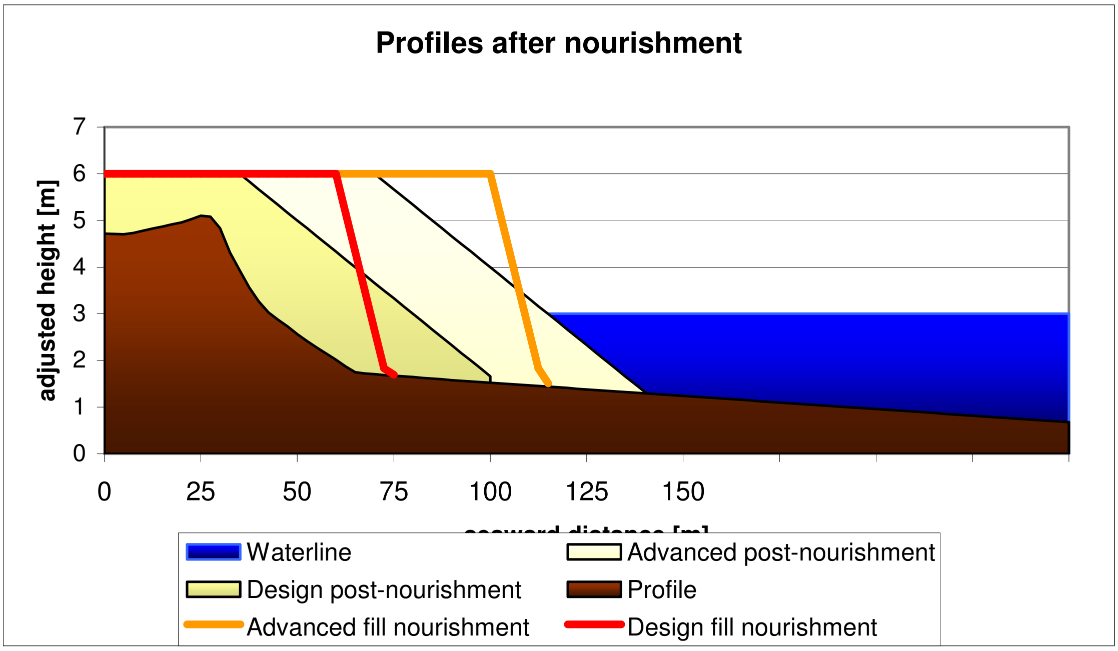


Figure IX - 15 Cross-sections of the beach in several stages of the nourishment plan

To make sure a situation like present in 2008 will not occur again, it is important to nourish before all the sand has been washed away. It is necessary to execute repeated nourishment with an interval of 10 years. With this interval there is always a sufficient wide beach and the costs of the repeated nourishments will be under control. A five year plan could lead to higher costs due to the mobilisation costs.

Table IX - 11 shows the nourishment scheme for the next 50 years.

Nourish plan for the next 50 years	
year	volume to nourish
2009	1,040,000
2019	520,000
2029	520,000
2039	520,000
2049	520,000
2059	520,000

Table IX - 11 Nourish plan for the next 50 years

The volumes of the repeating nourishment are lower than the volume of the first nourishment, since there will be a wider beach present. The beach width will be 70 meters at maximum in the years 2009, 2019, 2029, 2039, 2049 and 2059. The minimum beach width is on average 35 meters. There could locally be a smaller beach, since the erosion rates change per profile. As can be seen in Table IX - 8 the maximum erosion rate is -7.67m/yr. This would mean that the beach width of 70 meters would entirely disappear in 10 years. As said before the renourishment volumes have to be placed primarily in the southern part of the 2100m.

The numbers of the repeated nourishments could change due to changes in the erosion rates. It is therefore important to keep monitoring the beach. When more data is available, a more specific nourishment design can be made.

IX.8 Retaining structure

The design of the nourishment can be expanded with a retaining structure. A hard construction can be build when executing the first nourishment. This structure will help to keep the sand at the stretch of beach were it was initially placed. Several option are possible.

An example of a cross-shore retaining structure is visible in Figure IX - 16. The sand is kept in place by a submerged sill, which will also lead to a smaller sediment volume to be nourished.

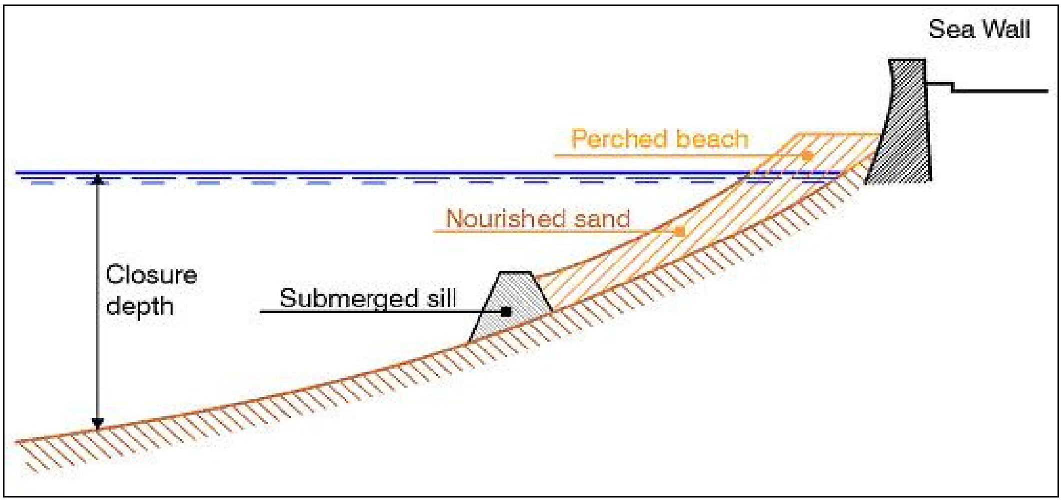


Figure IX - 16 Example of a perched beach; sediment of a nourishment are kept in place by a submerged sill [28]

To intervene in longshore transport a groyne would be an option, see Figure IX - 17. This will prevent the nourished sand to spread to the northern stretch of coastline, were no nourishment was performed. The jump in beach width will be kept in place by the groyne. The disadvantage of placing a groyne is the interruption in longshore transport. This means that downstream of the groyne the erosion will increase. This will only result in a displacement of the erosion problems.

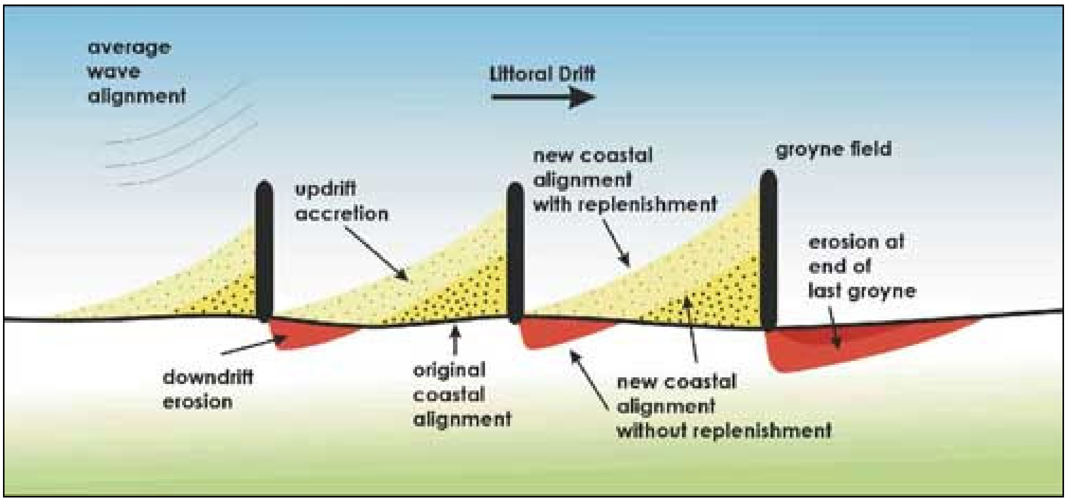


Figure IX - 17 Consequences of a groyne [9]

Another possibility to intervene in the longshore transport, is building a detached breakwater, see Figure IX - 18. Due to the breakwater the wave energy at the beach will decrease, which will lead to a decrease in erosion rate. Even some accretion in the shadowzone of the breakwater might occur. Just as the groyne, the transport will increase at the downdrift side of the structure, which will result in erosion.

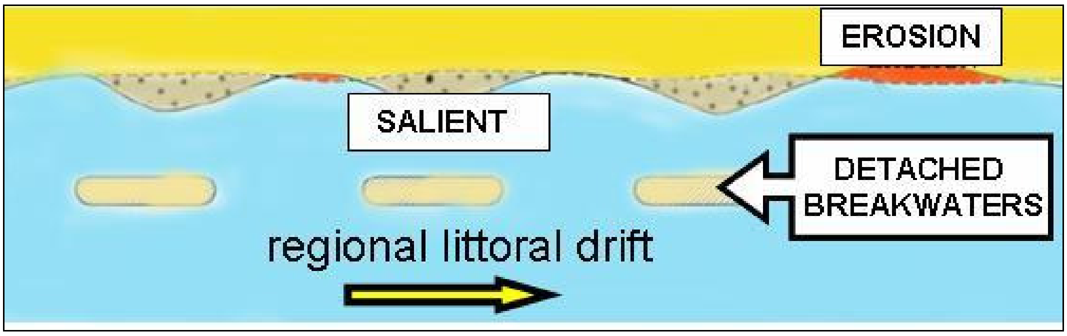


Figure IX - 18 Consequences of a detached breakwater [31]

Evaluating these alternatives, none of them seem suitable. Due to the lack of knowledge about the causes of the erosion, intervention with a solid structure could lead to unforeseen and unwelcome consequences.

IX.9 Project costs and execution

IX.9.1. Vessel type

A choice has to be made for one of two dominating types of dredging vessels to execute the nourishment at Piçarras beach. The first one is the cutter suction dredger (CSD), see Figure IX - 19.

Figure IX - 19 Image of a Cutter Suction Dredger

The CSD is a stationary dredger. It is a pontoon fitted at one end with a ladder that supports the suction pipe and on the other end with two spuds. The spuds are anchor poles that play an important role in anchoring the hull and moving it forward during the dredging process.

When dredging, the pontoon swings around the central spud (the working spud). During the sideward movement of the suction opening, a crown shaped cutter-head turns in front of the opening and cuts slices of soil into lumps that can enter the suction mouth. The sideward movement is controlled by two winches that are connected to anchors that are positioned on either side of the dredging area. When a cut is completed, the dredge is moved a little forward so that a new cut can be made. This forward step can be achieved by mounting the working spud on a hydraulically actuated spud carriage, or by alternately using the working spud and the auxiliary spud. The CSD has a productivity of up to 400,000m³ per week.

The second type of vessel that qualifies, is the trailing suction hopper dredger (TSHD), see Figure IX - 20.

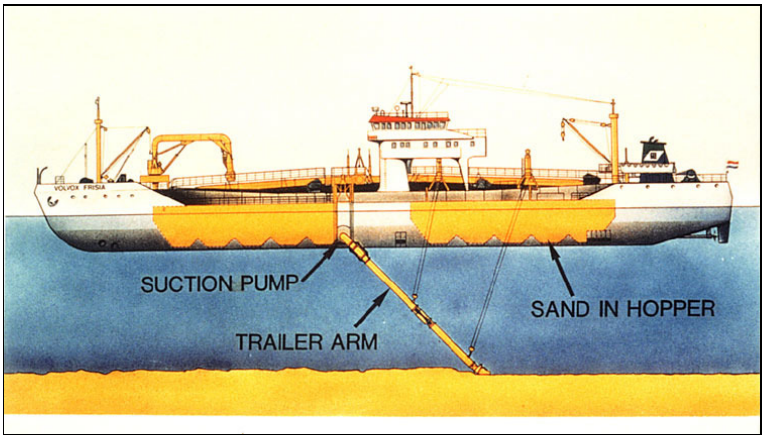


Figure IX - 20 Image of a Trailing Suction Hopper Dredger [8]

The TSHD is a seagoing vessel. When dredging it tows one or two suction pipes over the seabed. A draghead shaves thin layers of material from the bottom. Dredged material enters the suction pipe connected to the draghead. The other end of the pipe is connected to the hull of the vessel. By pumping action a mixture of sand and water is pumped into the hold of the ship, the hopper. When this hopper is filled with the mixture, it starts overflowing. The excess water flows overboard and the sediment remains largely in the hopper. Loading stops when the carrier capacity is reached (this either can be by volume or by tonnage). The load can be discharged either by dumping through bottom doors or by pumping ashore. The TSHD has a productivity of up to 1,000,000 m³ per week.

For this project the TSHD will be used based on the following benefits the TSHD has compared with stationary dredgers:

- High level of seaworthiness: The TSHD is a seaworthy vessel, because the suction tubes have several swivel connections and are suspended on swell-compensating hoisting lines, allowing work to proceed in wave and wind conditions.
- Mobile and independent operation: The vessel can sail on its own power to any location in the world and has the necessary supplies and the most important spare parts on board.
- High productivity in terms of both volume [m³] and area [m²]

IX.9.2. Execution time

Some important characteristics of a TSHD are important when calculating the execution time. In this study a standard size TSHD will be used.

hopper contents (sand)	11,000 (8,000)	m³
loading production	8,000	m³/hour (2 pipes)
pumping out production	4,000	m³/hour
sailing speed	25	km/h

Table IX - 12 Characteristics of the trailing suction hopper dredger used in this design

The amount of sand that has to be dredged for the first nourishment is 1,040,000 m³. The vessel has a draught of 10m. which does not allow the vessel to dump the sediment directly onto the beach. Therefore at approximately 2.5 km in front of the beach, the sediment will be transported further by pipelines. The borrow area is located approximately 10 km away from point where the transportation is taken over by the pipes. The time of a single working cycle of the vessel can be calculated.

pumping time	60	min
sailing full	30	min
pumping out time	120	min
sailing empty	30	min
total cycle time	**240**	**mins = 4 hr**

Table IX - 13 Calculation of cycle time of TSHD

A remark can be made about the sailing time, either full or empty. This is a rather rough approximation, since the turning time of the vessel is included, either from the borrow area on its way to the point where transport is taken over by pipelines and the other way around.

For optimal use the vessel will be deployed for 168 service hours per week (7 days per week, 24 hours per day). Some limiting factors have to be taken into account which prevent the vessel from operating.

service hours per week	168	hours
mechanical downtime (3%)	-5	hours
operational downtime (5%)	-8	hours
waves (3%)	-5	hours
operational hours per week	**150**	**hours**

Table IX - 14 Calculation of total operational time per week

Although the vessel is equipped with swell compensating parts, still a downtime due to waves is taken into account for real extreme conditions. This is not so much the downtime of the vessel, since the vessel can cope with waves up until 3 to 4m, but the transport of sediment though the pipelines to the beach which will be disrupted. Finally the weekly production and the execution time for the whole project can be calculated.

no. of cycles per week	37	
weekly production	296,000	m³
execution time	**3.6**	**weeks**

Table IX - 15 Calculation of execution time

IX.9.3. Production costs vessel

Several factors that influence the production costs of the nourishment are discussed in this paragraph.

<u>Depreciation, Interest, maintenance, repair</u>

depreciation and interest per week of 84 hours	€ 173,500
maintenance and repair per week of 84 hours	€ 70,250
total	**€ 243,750**

Table IX - 16 Depreciation-, interest-, maintenance- and repaircosts for the TSHD

These costs do not only concern the vessel, but also cover the additional wear due to sediment transport through the pipelines. An extra 15% is added to the expenses for maintenance and repair.

The values apply for a week consisting of 84 service hours. For this project a utilisation of 168 service hours is set, so an increasing factor M has to be applied, where it is assumed that 80% of depreciation and interest and the maintenance and repair is variable and proportional to the number of running hours.

So in case of a utilisation of 168 hours a week the factor M becomes:

$$M = 1 + 0.8 \times \frac{168 - 84}{84} = 1.8$$

The new costs follow consequently, see Table IX - 17.

depreciation and interest per week of 168 hours	€ 312,300
maintenance and repair per week of 168 hours	€ 126,450
total	**€ 438,750**

Table IX - 17 Total costs of depreciation, interest, maintenance and repair

A few remarks can be made about costs not included in maintenance and repair costs:

- not included are the costs for assemblation and dismantling, management and storage, special services and project oriented refit
- other factors that may increase the price for projects abroad are climate conditions, import duties, level of training of local personnel, local technical facilities and available equipment and the geographical location.

For a final proposal it is required to do further investigation on the above mentioned factors that may influence the costs. For this study the costs calculated so far will suffice since it is a preliminary proposal.

Crew expenses

The order of magnitude of costs per crewmember is as follows:

average costs per Dutch crewmember per week	€ 3,000
average costs per local crewmember per week	€ 1,000

Table IX - 18 Crew costs

For an extended crew structure is referred to the lecture notes Dredging Technology, especially for the case when partly local crew is hired for dredging projects outside Europe. In total 16 Dutch crewmembers and 13 local crewmembers will be on board, another 10 local crewmembers will be on the leave. Usually the number of crewmembers *on board* is used in calculating the weekly costs, which therefore do not include the costs for crew on the leave. The total weekly expenses for the crew on board can be calculated:

$$16 \times 3{,}000 + 13 \times 1{,}000 = 61{,}000 / week$$

Fuel and lubricants

Fuel expenses are calculated based on the engine consumption and the price per litre. The limiting factors (mechanical downtime, weather, waves etc.) that prevent the vessel from operating, as calculated in the previous paragraph, of course also influences the operational hours of the engine.

service hours per week	168	hours
downtime	-18	hours
operational hours per week	150	hours

Table IX - 19 Operational hours per week

The consumption of the chosen vessel is approximately 2 000 litres per hour, the average price for marine diesel is approximately €0.25 per litre.

Both values are obtained from the lecture notes Dredging Technology. An additional 10% of the price may be included for the costs for the lubricants.

$$1.1 \times (150 \times 2{,}000 \times 0.25) = 82{,}000 / week$$

<u>Insurance expenses</u>

The weekly insurance costs are defined as a percentage of the value norm of the vessel. The value norm of the applied vessel is € 53,500,000, the percentage is 0.07% and allows for the insurance in the event of damage as well. The weekly insurance expenses can be calculated:

$$0.00007 \times 53{,}500{,}000 = 37{,}000 / week$$

<u>Summary weekly production costs vessel</u>

depreciation and interest	€ 312,300
maintenance and repair	€ 126,450
crew	€ 61,000
fuel & lubricants	€ 82,500
insurance	€ 37,000
subtotal	**€619,250**
other expenses (10%)	€61,925
total	**€681,175**

Table IX - 20 Summary weekly production costs vessel

IX.9.4. Total expenses

<u>Weekly expenses</u>

production costs vessel	€681,175
staff on site	€ 25,000
pipe rent & installation	€ 50,000
subtotal	**€ 756,175**
profit/risk/general overhead (20% of subtotal)	€ 151,235
weekly total project expenses	**€ 907,410**

Table IX - 21 Weekly project expenses

Total project expenses
Assumed is that the dredging vessel has to mobilised from Europe and can sail in one week to the operation location and back again.

mobilisation (1 week)	€ 681,175
execution time 3.6 weeks x € 907,410	€ 3,266,676
demobilisation (1 week)	€ 681,175
TOTAL PROJECT EXPENSES	**€ 4,629,026**

Table IX - 22 Total project expenses

The costs in euro per dredged cubic meter of sand:

$$\frac{4{,}629{,}026}{1{,}040{,}000} = 4{,}45 / m^3$$

IX.9.5. Future expenses

The costs of 4.6 million euro represent the costs of the first nourishment to be executed. For future nourishments only 520,000m³ needs to be nourished, because these only concern the advanced fill. This will result in a decrease of the execution time.

mobilisation (1 week)	€ 681,175
execution time 1.8 weeks x € 907,410,-	€ 1,633,338
demobilisation (1 week)	€ 681,175
TOTAL PROJECT EXPENSES	**€ 2,995,688**

Table IX - 23 Total project expenses of future works

The costs in euro per dredged cubic meter of sand:

$$\frac{3{,}103{,}688}{520{,}000} = 5{,}76 / m^3$$

X. Evaluation

X.1 Preparation

X.1.1.Financial aspect

After we got the approval of doing a MSc-project in Brazil our first job was to raise sponsors which would create financial possibilities to make the trip. A list with potential interested companies was created. In each letter we tried to describe specifically what we knew about the company and why they could be interested in sponsoring our project based on their working area and based on shown interest in civil and/or hydraulic engineering students. We requested each company for a substantial amount of money, keeping in mind that they would probably not agree with this quantity, but would still donate enough to cover our budget. Later on we realised that this was not the best method to get the most out of it. Instead of requesting an amount of money we offered the company a few sponsor alternatives to give them some choice. For each alternative we clearly defined what we could offer the company in trade for a sponsorship of the project. Of course the more money the company would sponsor, the more we could offer like keeping the company up to date of (preliminary) project results, giving presentation at the company's office, sending a hardcopy of the report etc. In this way, companies can choose an alternative that fits best with their policy regarding sponsoring. It increases the chance that a company agrees with one of your proposals and consequently the chance that you can cover your budget.

Besides sponsors, it is also possible to request for funding at the TU Delft. The university offers possibilities to support students in the final phase of their study. Most of these funds support students who want to do a study related project, internship or thesis abroad. Each fund has its own target group with corresponding criteria. Students can only apply for one fund per project. Based on advice from previous Masterproject groups and with the help of International Office of the Faculty of Civil Engineering we applied successful for the STIR-fund.

X.1.2.Visa

Another aspect in the preparation was the application for our visa. This not only took us a lot of time (both in The Netherlands and Brazil), but also costed a significant amount of money. Fortunately we were informed by the project group of last year to start early with the application in order to receive the visa in time. Later on we realised that we, as Dutch citizens, are in a privileged situation since we only have to spend a lot of time filling in dozens of forms and paying a high but acceptable amount of money to finally receive our visa. The law here makes it a lot harder for foreigners to come to Holland than the other way around, concerning Brazil in this case.

X.2 In Brazil

In the beginning of our stay we were confronted with some cultural differences we had to get used to. At first this was the really warm welcome we got from our coordinators and Brazilian students. Everyone was willing to guide us in the neighbourhood and we were immediately invited to everyone's place and family. We liked this a lot, but are not used to this. In Europe we are not so open-minded to strangers as we call it. This could also be explained by the fact that the local coordinators and some students had experience with hosting Dutch students from the TU Delft, since we were not the first group there. Another major cultural difference which showed up was the fact that arriving too late on an appointment or postpone a deadline is quite common. The social character of the people is a very nice and respectable characteristic. Compared to Europeans they miss a business focused mentality.

Since our stay only took 8 weeks, it was necessary to spend our time efficiently and stick to our deadlines. Due to the local mentality this was not always possible, but in the end we considered it as very instructive to get used to habits of other cultures. In a worldwide focused business like coastal engineering, this is a very valuable experience. Another reason why we didn't stick to deadlines, was that more and more research into related subjects was stimulated and gladly performed by us.

X.2.1.Collection of data

The first goal during our stay in Brazil was to collect all available data which could be used to model Piçarras bay. Data was available from different sources and we started using these data assuming it was reliable and correct. Instead of verifying these data we implemented it directly in the project. After some time we discovered that several data were not useful in its original condition and some adjustments had to be made to make them applicable for our project. The work based on the original data that had been done up until this discovery, had to be done all over again. Although time was lost because of this, it was one of those instructive moments during this project which made us realise that you always have to verify the data before you use it for a project or study.

X.2.2.Modelling

The main objective of the project was to deliver a proposal for a decent nourishment. In order to do so, an investigation had to be made into the erosion processes. Beforehand a few software programs were picked to model these processes. This was SWAN for the wave modelling, SMC for the wave induced currents and erosion processes and Unibest (UB) for shoreline changes. However SWAN requires quite some programming knowledge and experience. Due to this the decision was made to switch to Delft3D (D3D) which offers a far more user-friendly interface. D3D exists of a few different modules which enable modelling of wave climates, but also modelling of flow and morphological changes of the beach, but also the generation and manipulation of bathymetries. Basically this would make the use of the programs mentioned before unnecessary. We found it reasonable to use only D3D for the modelling part to limit the loss of data as far as possible, which definitely occurs when using the output of one program as input for the next program.

The wave module appeared to give stable results, but the module which should provide flow computations was not working properly. For this module, a lot of input parameters had to be chosen arbitrarily. Much effort was put in obtaining realistic flow results, unfortunately without success. From this step we learned that if too many parameters are uncertain, it can be concluded immediately to quit using the program. We lost a significant amount of time in this phase of the project.

For further development it was decided to only use the wave module of D3D and to use the more simplistic software program SMC for modelling wave induced currents and UB for erosion processes. Knowing theoretically how to set up a model is not a guarantee for reliable results. Because of the lack of knowledge about the programs and the lack of experience using them we had to put a lot of effort creating the first simulations. This took a significant amount of time. Another reason why we lost time was that we did not stick to our objectives. The main objective was to design a nourishment based on modelling results. At this stage we were so into the modelling and were drifting away form our initial main objective, that the goals were re-evaluated. Together with professor Klein two possible objectives were analysed. Firstly the design of the nourishment and secondly modelling the current situation to investigate the causes of the erosion. Since we came to Brazil for a design project, it was decided to maintain the first goal. We certainly could not finish this in Brazil any more so some work was left for us in Delft, along with writing the entire report.

X.2.3.Communication

An important aspect in which we failed was communication. Because every person from the project group was busy with its own, separate task it is important to keep each other up to date. It appeared that everyone was so into his own subject, that sometimes one person didn't realise where another person was working at. We learned that you have to communicate about each others progress frequently, preferably at the beginning of a working day, in order to prevent double work, keep a good overview and work directly towards the formulated objectives.

X.2.4.Back in Delft

The project will be assessed for 11 ECTS. Converting this in time that has to be spend to the project this is approximately 2 months. We already spend a lot of time in the preparation of the project and off course during our stay in Brazil. We defined some clear deadlines for ourselves and agreed that we would stick to these deadlines in order to finalize the project soon. However writing a report of more than 2 months of work takes more time than one would expect. During the project we got a lot of undesired results: results that did not give a good representation of the reality. But poor results are results as well and still have to be included in the report. This way you show the work that already has been done and it could be possible to formulate recommendations for further investigation based on these inferior results.