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FEASIBILITY STUDY

Coastal erosion study Hoi An

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A feasibility study on coastal erosion problems in Hoi An, Viet Nam. Finding a solution for the erosion problem the city of Hoi An is affected by in the recent decades.
In cooperation with:

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Contents

Abstract

Witteveen+Bos
Department of Hydrodynamics and Morphology

A feasibility study to a solution to coastal erosion problems in Hoi An, Viet Nam

by Luc Ponsioen
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This report is the result of a 10 week internship at Witteveen+Bos of Luc Ponsioen and Hoang Thi Linh Giang. The focus of the internship was performing a feasibility study to a possible solution for the heavily eroding coast of Hoi An. The biggest challenge of this research was understanding the coastal system at Hoi An. Due to multiple external factors the situation along the coast is quite different compared to 'normal' situations. It appeared that current theories about longshore and cross-shore sediment transport do not seem to apply in the Hoi An situation. This makes it hard to predict the impact of hard structures such as breakwaters and groynes.

Chapter 1

Introduction

1.1 Problem definition

Within the last few decades the coastline at the Hoi An beaches in Vietnam has retreated so far that it is currently threatening the houses and beach resort at the beach. At multiple points the coastline is already further landwards than the resorts, causing this resorts to be located partly in the sea. Short term measures are required to prevent the beach resorts from disappearing in the sea. Part of the problem in this case is the Cu Lao Cham island about 15 km offshore. This island blocks and deforms the incoming waves causing unusual wave patterns at the Hoi An coast. This makes it very hard to describe the system along the coast.

1.2 Approach

In this feasibility study a few possible solutions for this major erosion problem are investigated, the focus is on the strip of coast from the river mouth until 7 km north of the Thu Bon river. In order to find a decent solution for the problem an extensive study has been done on the coastal development of the beach in the past 20 years.

Understanding the system

First the coastal system is studied and described in chapter 2. A minor stakeholder analysis is performed to get insight into a.o. the political system in Hoi An. This stakeholder analysis is presented in chapter 3. The stakeholder analysis should have been based on a field visit by Hoang Thi Linh Giang and Assoc.Prof. Mai Van Cong.

Unfortunately the field visit took place when the internship of Luc Ponsion was already over. Therefore the field visit report, as written by Hoang Thi Ling Giang, has been attached to this report as a side document.

Coastal development

The coastal development is studied extensively to find the main cause of the erosion. Since there is hardly any data of the coastal situation before 1995 the analysis of the coastal development is primarily based on the past 20 years. The coastal development is described in chapter 4.

Finding a solution

Multiple possible solutions are presented in chapter 5. The possible solutions are evaluated and finally a best solutions is picked and worked out in detail. Finally the advice including recommendations for future research towards the client are presented in chapter 6.

Chapter 2

System description

2.1 Introduction

The area of interest of this project is a 7 km strip of coast, north of the Thu Bon River. The area starts at the north side of the Thu Bon river mouth and stretches all the way up to 7 km north-west of the river mouth. This piece of coast has a slightly curved coastline and a lot of beach resorts have been built in the last few decades. In the last couple of years severe coastal erosion has been observed. The area of interest is demonstrated in figure 2.1

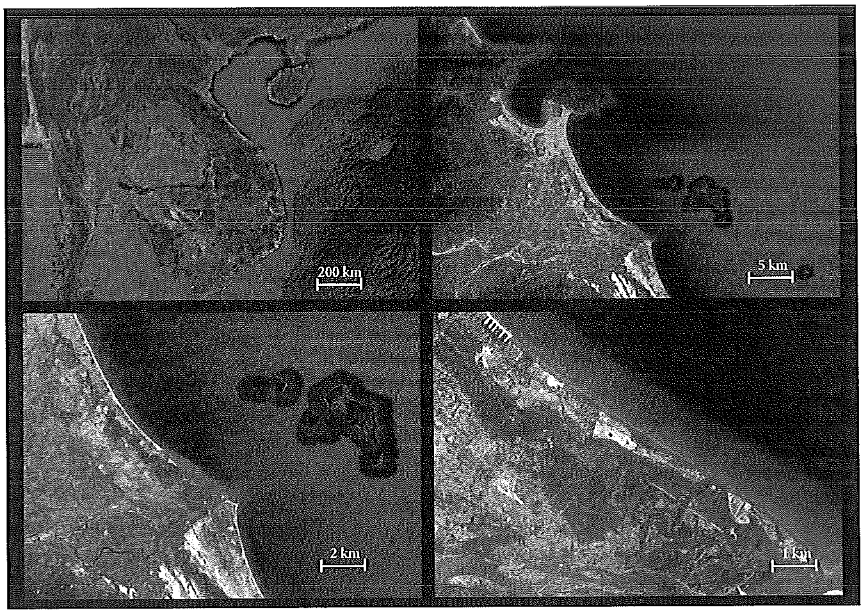


FIGURE 2.1: Overview of the Hoi An project site

2.2 Delta

Hoi An is characterized by a deltaic coastal profile. The area in and around the city clearly shows a pattern of meandering rivers that confluence and bifurcate constantly. Basically the whole area between Da Nang, 30 kilometres north of Hoi An, and Hoi An is part of the delta. The interesting part however is that there are only two spots where the rivers debouch in the sea, which are in Hoi An and in Da Nang.

2.2.1 Rivers in the Delta

The main river in the delta is the Thu Bon river. The Thu Bon river discharge is regulated by a dam upstream of the river. The reservoir attached to the dam is the Ho Thuy dien song Tranh reservoir which can be found about 65 km south-west of the city of Hoi An. Part of the song Vu Gia River also debouches in the Thu Bon River but the main part of this river flows towards Da Nang, 30 km north of Hoi An. The song Vu Gia River is a bifurcation of two smaller rivers, one of them is named the Buong River. The discharge of the Buong River is also regulated by an upstream dam located about 60 km west of Hoi An. The delta area and main rivers are indicated in figure 2.2.

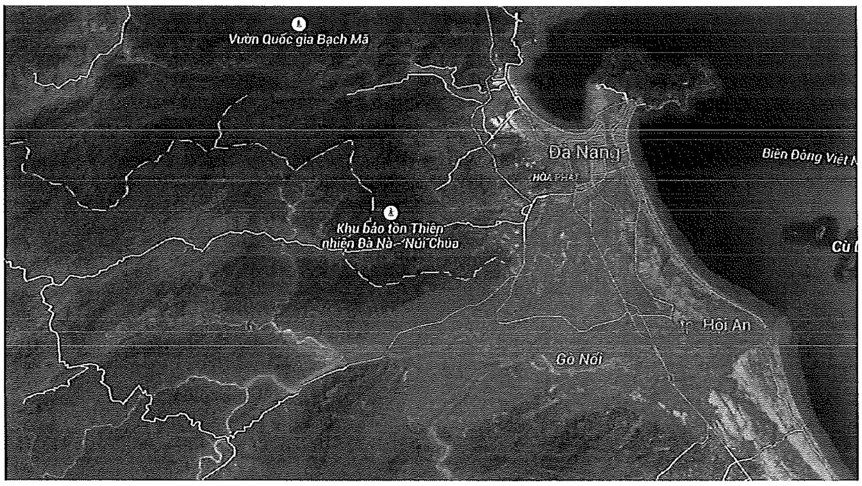


FIGURE 2.2: Overview of the delta area

2.2.2 Sediment transport

In the past century the sediment transport in the rivers in the delta area have changed severely. In the earlier decades of the 20th century the sediment transport increased due to deforestation and construction of roads on steep hill sides. The fact that the river has had a severe increase in sediment transport can be deduced from the presence of an offshore delta in front of the river mouth. In the last decade(s) the sediment transport however has decreased due to the construction of large hydropower dams and bank protection along the river [1].

The river transports an average of 460.000 tons/yr. However this number varies fairly in different years. For example in 1987 the sediment transport was 49.000 tons as in 1981 it was 1.800.000 tons [1]. This variation in sediment transport is important to bear in mind when performing calculations.

2.2.3 Hydro power plants

As mentioned earlier, some hydropower dams have been constructed in the basin area of the Thu Bon River. The construction of these dams already has a dramatic effect on the discharge and the sediment transport of the river. The current planning is to construct another 6 dams in the basin area. Although these dams are mainly constructed in the Vu Gia River basin they can still influence the discharge of the Thu Bon River. Since the discharge is more and more controlled by humans, an unnatural discharge and sediment transport pattern is therefore expected in the future.

2.3 Wind-, wave-, and flow patterns

Earlier this year a study on wind-, wave- and flow data in the gulf of Tonkin (in which Hoi An is located) is performed by Hyder, commissioned by Arcadis. Details on the data can be found in the report of this study, to get an idea of the main wind directions, wave heights- and directions and flow patterns in the gulf a brief summary of the collected data is given below.

2.3.1 Waves

The offshore wave- and wind conditions are obtained from ships' observations in the gulf. It appears that the dominant wave direction is south-west directed, so waves approaching the coast from the NE direction. During the monsoon season, September to January, the waves tend to approach the coast from a more NE direction and the intensity of the waves is higher. During the dry season the waves approach the coast from a more SE direction with a significant lower intensity. A wave rose for the average wave height and wave direction is given in the Hyder report, this rose is shown in figure 2.3.

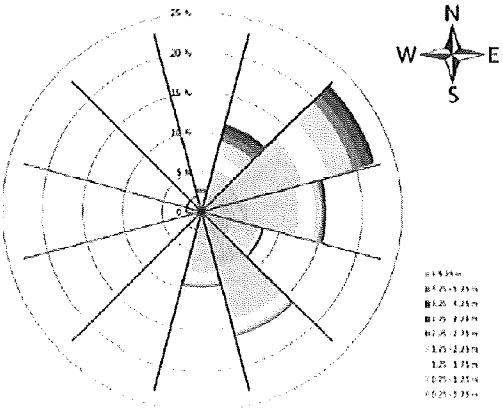


FIGURE 2.3: Wave rose of the yearly average wave height and direction

More wave data is obtained from wave recordings by Fugro and by ECMWF wave climates. These wave roses are shown in Appendix B in figures B.2, B.4 and B.6. The wave roses are also presented in figure ??

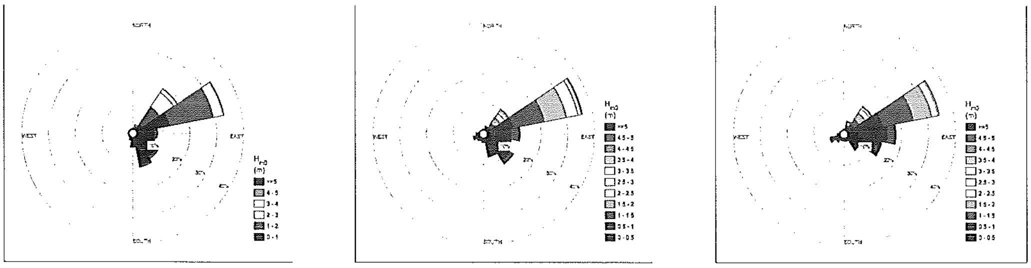


FIGURE 2.4: Wave roses for wave climates abtained from ECMWF data. The roses are shown for coordinates: lat15,75 lon108,75 (left); lat16,5 lon108,75 (middle); lat16,5 lon108 (right)

Significant wave height

The significant wave height of the system is derived from the wave climate as presented in table B.1 in Appendix B. Wave statistics from ECMWF are also shown in Appendix B, in figure B.1, figure B.3 and B.5. The locations of the recordings of the wave date from ECMWF are shown in figure 2.5. The different significant wave heights of the wave climates are presented in table ??. The table also shows the significant design wave height ($H_{s,d}$) for a 1/100 year storm. This will be the critical wave height for the design of the solution. Three different methods are used to determine the design wave height from the given wave climates: a Peak over Threshold analysis, a Gumbel distribution and a Weibull distribution. One can see that the results of the different approach methods to determine the design wave height do not differ too much.

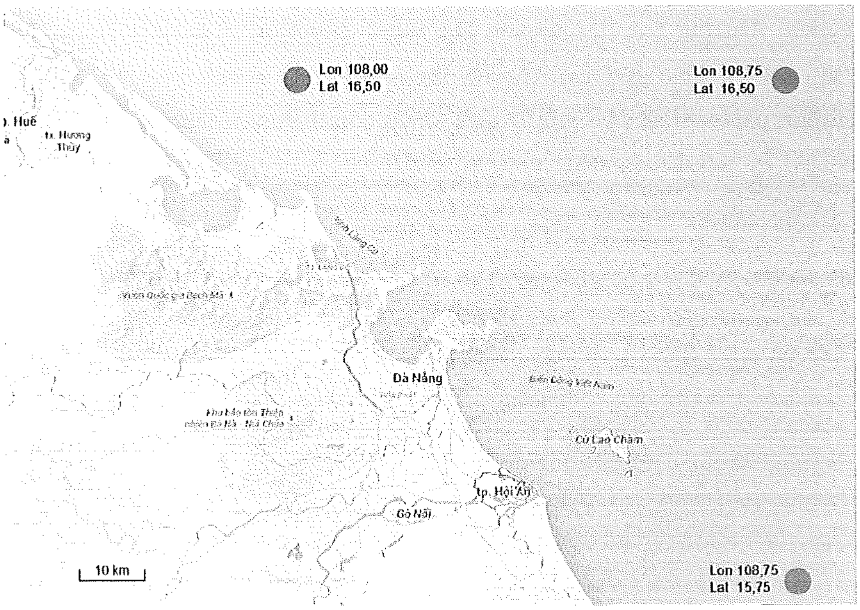


FIGURE 2.5: The locations of the recordings of the ECMWF data

According to wave theory $H_s = H_{1/3}$, which means the significant wave height is considered the average wave height of the top 1/3 of the waves in the wave climate as shown in figure B.1.

$$H_{1/3} = \frac{1}{1/N} \sum_{i=1}^{N/3} H_i \tag{2.1}$$

Using this theory one finds for the significant wave height a value of $H_s = 2,28$ [m] for the wave climate as presented in table B.1, this represents the wave climate about 100 km seawards of the Hoi An coast as recorded by Fugro. For the wave data as recorded by ECMWF the significant wave heights turn out to be $H_s = 1,98$ [m], $H_s = 1,87$ [m] and $H_s = 1,69$ [m]. The different significant wave heights are shown in table ??.

TABLE 2.1: Significant wave height for different wave climates

Wave data	Significant wave height Hs [m]	Peak over Threshold Hs,d [m]	Gumbel distribution Hs,d [m]	Weibull distribution Hs,d [m]
100 km offshore	2,28	8,68	8,66	8,66
Lon: 108,00; Lat: 16,50	1,69	5,84	5,83	5,90
Lon: 108,75, Lat: 16,50	1,87	6,27	6,43	5,96
Lon: 108,75; Lat: 15,75	1,98	6,39	6,36	6,21

2.3.2 Wind

The wind conditions follow the same pattern as the wave conditions; the dominant wave direction is from the NE direction. This condition is mainly found during the monsoon season. During the dry season the wind direction is mostly from the SE direction. A wind rose is also given in the Hyder report, the wind rose is shown in figure 2.6. The similar pattern for the wind- and wave conditions indicates that the waves are mainly caused by wind (sea-state waves), swell waves occur less.

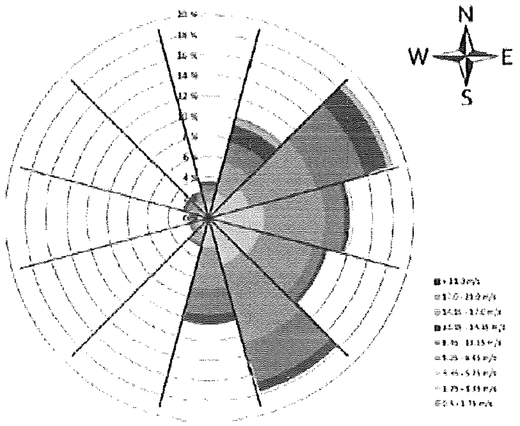


FIGURE 2.6: Wind rose of the yearly average wind speed and direction

2.3.3 Currents

Four main flow patterns are observed throughout the year. During the monsoon season, September to may, water enters the gulf westwards. In the period November-May there is also a N-NE directed flow along the Vietnam coast from Mui Da Nang as far as Hon Dau. This water is thought to be removed by a South and South Easterly-setting broad current through the middle of the gulf, but there is much variability. Between June and August the flow is variable but mainly in a counter-clockwise sense with S and SE sets predominating along the coast of Vietnam.

Interesting observations were done by the Hyder research team. It appears that there is a quite large offshore delta area in front of the river mouth; wave breaking was observed until 1 km offshore. Also, when moving southwards along the coast, larger waves were detected going further south. This is most probably caused by the presence of the Cu Lao Cham Island.

2.3.4 Tide

According to [2] the tidal range at Cu Lao Cham, the island in front of the Hoi An coast is 0,82 m. The amplitudes of the tidal components (K1, O1, M2 and S2) are demonstrated in table ??.

Tidal component	Amplitude
M_2	0,17
S_2	0,06
K_1	0,23
O_1	0,17
Tidal range	0,82

TABLE 2.2: Tidal components at Cu Lao Cham according to [2]

The form factor of the tide is determined by:

$$F = \frac{K_1 + O_1}{M_2 + S_2} \tag{2.2}$$

This leads to a form facto $F = 1,74$ which means the tide has a mixed, mainly diurnal character.

2.4 Morphology

A visual observation of the coastline would suggest that the coast around Hoi An is wave dominated. However this is hard to determine from visual observations. The Cu Lao Cham island, about 15 km offshore, causes unusual and rather complicated flow patterns at the Hoi An coast. The island is about 7 km long and 3 km wide and is located right in front of the mouth of the Thu Bon river. Therefore the Hoi An coast is not approached by standard swell waves, which makes it difficult to determine a flow pattern along the coast.

Due to the presence of the islands in front of the Thu Bon River mouth as well as sediment supply from the river the area seaward of the river mouth is relatively shallow. Water depths until the island are at most 20 meters.

2.4.1 Coastline retreat

Satellite images of the river mouth over the past 20 years show a significant retreat of the coastline at the north side of the river mouth. The images show that the coastline has retreated systematically in 20 years time. A huge retreat is visible between 1995 and 2000. This is probably caused by the storm of 1999 which caused a huge flood in the area.

At the southern side of the river mouth the coastline shows a less constant retreat. Overall, observed over 20 years, erosion is visible. But, this is not in a straight line; the retreat is more in an oscillatory way. Some years resulted in erosion, some years resulted in accretion. This might have something to do with the regulation of water discharge through the dams.

In the area north of the river mouth over a length of 4 km an expected amount of 60.000 m2 of land is lost every year. Currently, the coastline directly north of the river mouth is protected by means of various coastal structures. The loss of surface area does however continue but is more focussed in the area directly north of the river mouth as well as underwater where the profile continues to deepen.

More about the coastal retreat is written in chapter 4.

2.4.2 Beach profile

Some observations of the southern beach profile lead to the following conclusions:

- Steep cliffs on the beach or dune face indicate erosion;
- A relatively wide beach with a newly vegetated dune face indicates that the coast is accreting;
- A normal sized beach (width in the order of 50 m) and a dune face consisting of old vegetation and even trees indicate a stable beach section.

Especially at the north side of the mouth of the Thu Bon River, significant coastal erosion can be observed in the last decade(s). Several coastal protection works were executed in order to combat the erosion at the beach resorts. The coastal erosion has proceeded along the coastal sections without any protection (the sandy beach lies further landward than the protection works) and secondly, the protection works are damaged heavily at certain locations, which indicates that the erosion of the seabed in front of the coastal protection works has proceeded as well. These are clear signs of a significant sand deficit. From these observations it is also clear that coastal erosion is more severe on the north side than it is along the coastal stretch at the south side of the river mouth. This does however not guarantee that the severe coastline retreat that has been observed at the north side of the river mouth will not occur on the south side as well in due time.

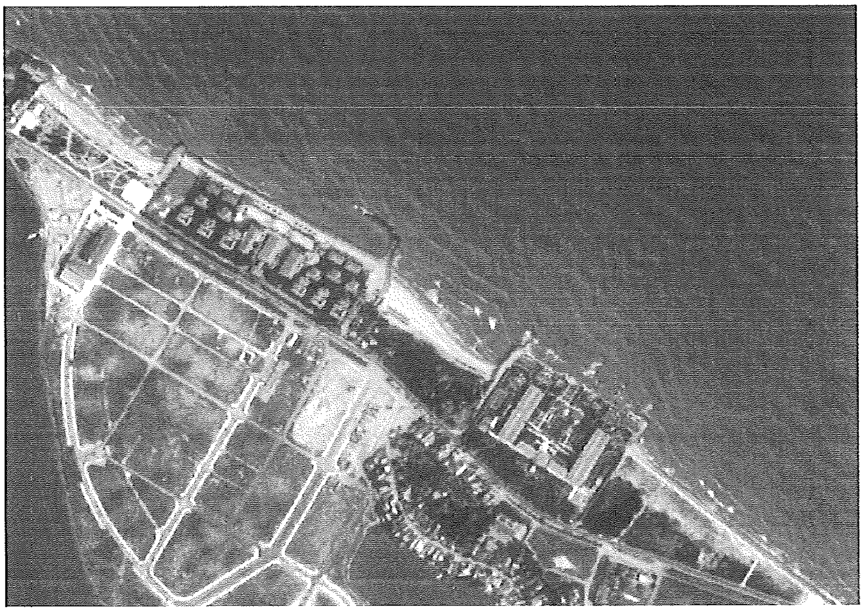


FIGURE 2.7: Severe beach erosion has occured at the north side of the river mouth

2.4.3 Measurements from Hyder report

In field measurements showed that the sediment along the coast southwards of the river mouth is fine sediment without silt. The river bank appears to consist of very fine sediment with occasionally black silt.

The conclusions of the Hyder report regarding the beach erosion are:

1. Less sediment is transported to the delta of the Thu Bôn River due to interference in the river (either construction of bank protections, operational hydropower dams or sediment mining). With that, a deficit of sediment occurs along the coast of the project site. This results in gradual erosion, starting near the river mouth;
2. The observed changes south and north of the river mouth are part of the natural (cyclic) dynamics of the river delta system. This results in some temporarily dry surface area loss south of the river and an even more progressive erosive trend north of the river;
3. Possible impacts of climate change such as:
    - Less sediment, transported to delta of the Thu Bôn River due to climate change (less discharge due to shift in rainfall and intensity);
    - Gradual erosion along the coast of the project site as a result of climate change (sea level rise);
    - Erosion along the coastline due to gradually changing wave climate;
    - More damage along the coast due to more frequent or more severe storm conditions.

Considering the location of the coastal erosion (mainly in the direct vicinity of the Thu Bôn River mouth), abovementioned causes 1 and 2 appear to be the most important causes of the observed coastal changes. Proof of effects from climate change (for example gradual erosion along the entire coastline due to sea level rise or changing hydraulic conditions) has not been found.

Chapter 3

Stakeholder analysis

Many different parties will have stakes in any kind of measures that are potentially taken at the Hoi An coast. In the Hoi An region 3 main stakeholder sections can be separated:

1. Government sector (representatives departments): Authorities of Hoi An city (units take care of the safety of public beaches and maintain shoreline stabilization in the name of public safety)
2. Local people: Fishermen, shop owners, farmers etc.
3. Business and Tourist sector: Most of the tourism sector along the coast is financed by private investors.

3.1 Government sector

Like always, the local government will have stakes in a construction project in their region. The Hoi An municipality has multiple departments that could have stakes in the project. The departments as mentioned below are in some way related to construction along the coast. Probably a lot of requests for permits need to be sent to different departments, which will take a lot of time.

- Provincial People's Committees
- People's Committee of Hoi An
- Department of Natural Resources and Environment
- Department of Agriculture and Rural Development

- Department of City management
- Department of Transport
- Department of construction
- Department of Internal affairs
- Department of financial and planning
- Department of Science and Technology of Quang Nam Province
- Construction and project management board

3.2 Local people sector

3.2.1 Fishery

Measures against erosion might have a negative influence on the local fishermen. The construction of, for instance, a breakwater to prevent or reduce erosion could change the local current in such a way that fishery becomes impossible. Beach nourishment could bring such an amount of sediment in suspension that the fish flee to different grounds, away from the reachable fishing grounds of the locals. Since most of the local fishermen fish in little boats in the river mouth or in the delta just offshore of the river mouth it is important to keep this fishing grounds intact.

Exact numbers are not known yet but visual inspection of satellite pictures of the Hoi An area show huge am ounts of smaller boats drifting in the docks. This suggests that a significant amount of the population depends on fishery. So the local fishermen are a party that should not be underestimated as a stakeholder.

3.2.2 Agriculture

The area around Cua Dai beach used to have quite some agricultural activity. When looking at older satellite pictures of the area some farmland is visible. In the recent year the urban development of the city and the construction of a lot of restaurants and beach resorts have suppressed the farmland. In the area closer to the city lot of farmland is still visible but in the area closer to the beach there is hardly any farmland left.

3.2.3 Aquaculture

Satellite pictures of Hoi An clearly show lots of fish- and shrimp-farms. Especially the area just behind the strip of land with the beach resorts contains many aquacultural companies. When certain measures are applied at the coast to prevent the erosion, it is important for the fish- and shrimp-farmers that a certain water quality is guaranteed so they can keep their business running. When for instance too much sediment is brought into suspension due to beach nourishment the water is less suitable for aquacultural usage. This of course affects the yield of the fish- and shrimp-farms.

3.3 Business and Tourism sector

3.3.1 Beach resort owners

A lot of beach resorts are visible when looking at satellite pictures from Google earth. In the 7 km north of the Thu Bon River 11 resorts directly on the beach were counted. Another 2 resorts appear to be under construction. Visual observation shows that a resort covers between 200 to 500 meter of beach. Especially the first 2 km of beach north of the river is almost entirely covered with beach resorts. There is hardly any beach visible anymore. Further north there are wider strips of beach visible. However these beaches are threatened by erosion as well. An overview of the number of resorts is visible in figure 3.1. The red circled resorts already exist, the blue circled are under construction.

The beach resort owners clearly have a big stake in the protection of the beaches. After all, what is a beach resort without a decent beach? Besides that, the resorts are threatened by the erosion as well. Some spots show severe erosion patterns. Sometimes so extreme that adjacent resort tend to disappear into the sea without serious measures against erosion. The resorts have taken personal measures against the erosion problems but when the erosion trend keeps holding on these measures will be just temporary. A good example of the personal measures the resorts have taken is demonstrated in figure 2.7. The resorts were build a few years ago on a rather wide beach but are currently threatened to be eaten by the sea. It is clear that the resorts would like to see their beaches recover in the original state.

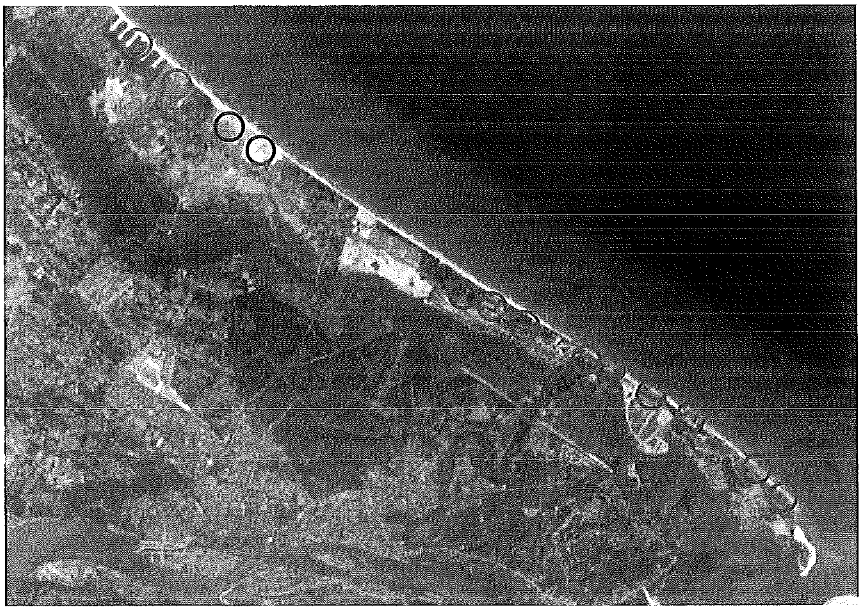


FIGURE 3.1: Beach resorts north of the river mouth. The red circled resorts already exist, the blue circled resorts are under construction.

Chapter 4

Coastal development

4.1 Recent coastline retreat

The coastline at Cua Dai, close to the old city of Hoi An, shows structural retreat in the last 20 years. In 1995 the coastline stretched several hundreds of meters further into the sea compared to the current situation. The 1995 situation is indicated with the red line in figure 4.2. The current situation is indicated with the white line. An interesting development during the years is the movement of the river mouth. The width of the mouth hasn't changed much but the location has. The river mouth is now more southwards and more landwards. Figure 4.3 indicates the same line but now with the situation as it was in 1995. One can clearly see that there used to be a nice wide beach but there is not much left of it.

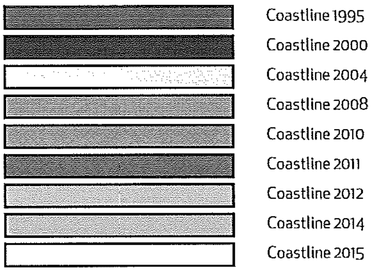


FIGURE 4.1: Legend of figures 4.2, 4.4 and 4.3

FIGURE 4.2: Coastline in 1995 (the red line) compared with the present situation (the white line)

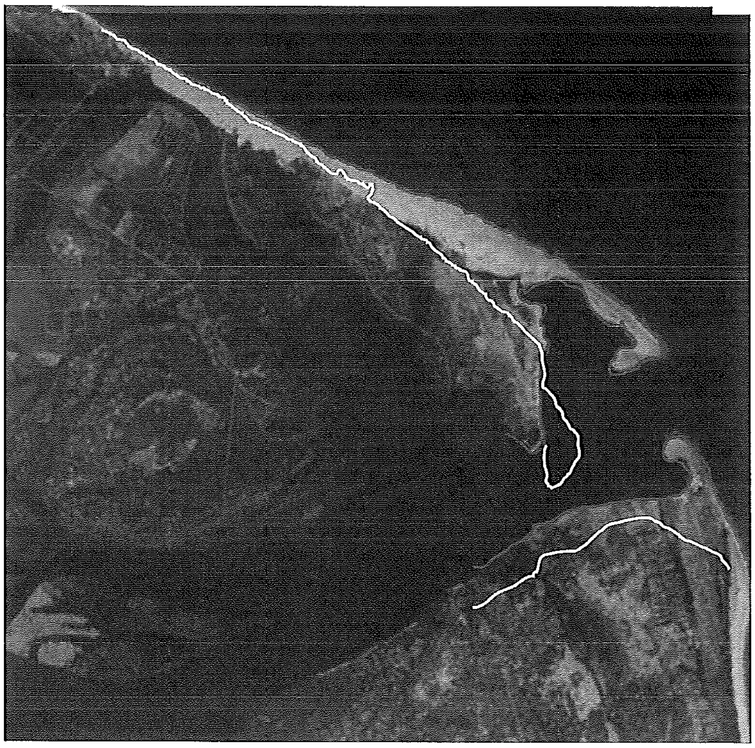


FIGURE 4.3: Coastline in 2015 (the white line) compared with the situation in 1995 (the red line)

Figure 4.2 and figure 4.3 also give a good impression of the urban development in the area. Especially along the shore lots of buildings have been built in the past 20 years. When the trend of coastal erosion continues all these buildings will eventually end up in the sea, which of course is something we want to prevent.

Estimations in section 'Surface loss' show between 600.000 and 700.000 m^2 of surface loss over a length of 4 km since the year 2000. This relates to an average coastline retreat of 10 to 12,5 m per year.

Figure 4.4 shows the development of the coastal retreat. The spit that is present in the 1995 line is already completely gone in the 2000 line. This is most likely due to the storm of 1999. This gigantic storm, combined with huge rainfalls caused a major flood in central Vietnam. The large discharge of the river and big waves spread the sediment in the spit over the rest of the coast creating a very wide beach. The yellow and the blue line show this nicely. However, in the period between 2000 and 2015 severe erosion occurred and the beaches almost completely flushed away. Most erosion took place in the area up until about 2 km north of the river mouth. A bit further north some accretion is visible between 2000 an 2004 but this was only temporary, after 2004 also the more northern parts suffered from erosion.

FIGURE 4.4: Coastline development between 1995 and 2015

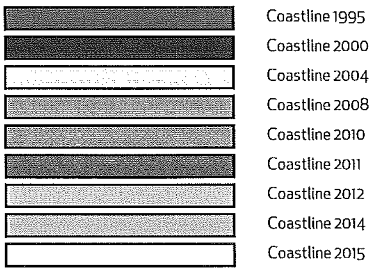


FIGURE 4.5: Legend of figures 4.2, 4.4 and 4.3

4.2 Earlier coastline development

Not much data is available about the development of the coastline before 1995. A few pictures of the overview of the Hoi An area are presented in figures A.20 to A.24. Especially the pictures of 1973 and 1990 are not particular high resolution pictures. Therefore it is hard to say something about the potential cyclic behavior of the coast. The pictures are simply not detailed enough to see this. Worthwhile noticing is the big spit that almost blocks the river entrance in the 1990 picture. The situation for 1973 and 1990 are also presented in figure ??.

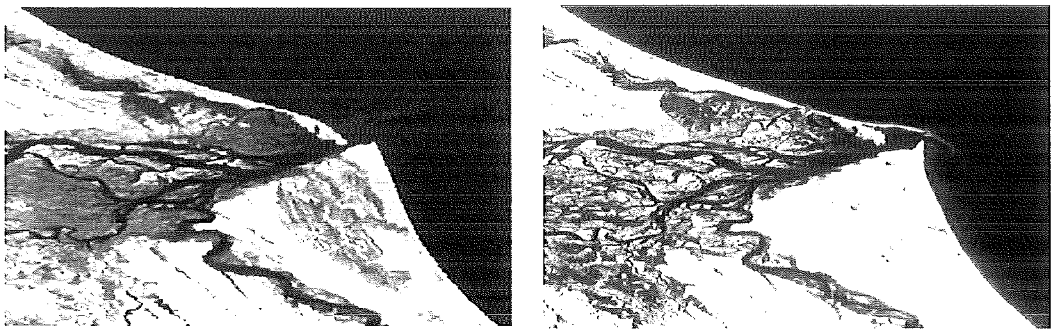


FIGURE 4.6: Overview of the Hoi An coastal area in 1973 (left) and 1990 (right)

Compared to the situation in 1990, the spit has already reduced a bit in 1995. In 2000 the spit was completely gone. Like mentioned before this is probably caused by the 1999 storm. Somewhere between 1973 and 1990 the spit started to develop and between 1990 and 1999 the spit length reduced again. It could also be that the spit was even bigger in the period between 1973 and 1990 but we cannot state this with any certainty due to lack of data.

Interestingly the spit growth is south-eastward directed. This is contradictory to the conclusion of section 'S-phi curve' that the net sediment transport is northward directed. It is possible that, since the coast is wave dominated, a certain period of higher sediment discharge of the river has caused the spit growth.

4.3 S-phi curve

An important tool to explain sediment transport is the so called S-phi curve. This curve sets out the angle of approach of the waves against the amount of sediment transport. A positive angle means in this case sediment transport in the direction of the positive alongshore coordinate. The positive alongshore coordinate is in this case the axis parallel to the shore to the right. So waves approaching the shore south-directed (about +30 degree to the coast) cause sediment transport to the right (positive direction in this case). A lot of research has been done, which led curve as shown in figure 4.7. It appears that the largest sediment transports are not found at the 45 degree point but at a somewhat smaller angle. This exact point depends on the situation. Zero transport occurs when the waves approach the shore perfectly parallel to the coastline.

Taken into account that most waves approach the shore coming from the NNE, NE and E direction the representative area on the S-phi curve is shown in figure 4.7. The circled area indicates roughly the expected wave induced sediment transport.

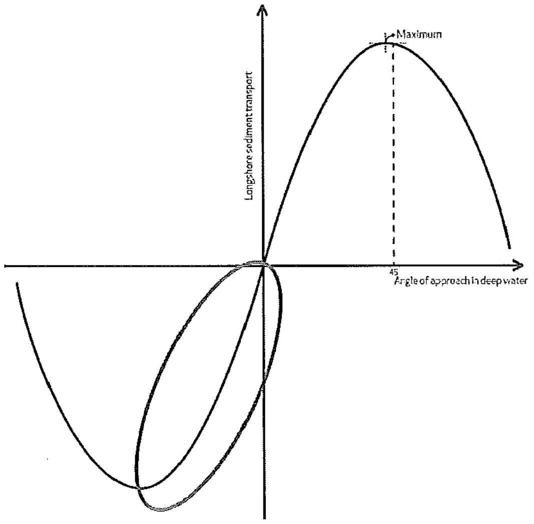


FIGURE 4.7: Longshore sediment transport (S) as a function of deep water approach angle (phi)

The dominant wave direction causes in this case sediment transport in de negative alongshore axis, this is demonstrated in figure 4.7. There is however quite a big side note with this drawing, namely the fact that the S-phi curve is mostly based on regular swell waves. The measured data at Hoi An indicate hardly any swell waves and much more sea state waves. The swell waves are blocked by the Cu Lao Cham island which makes the waves approaching the Hoi An coast irregular. The direction and wave height of swell waves do not vary a lot on short notice. That's what makes it relatively easy to predict the direction of sediment transport. When the waves become irregular, it is impossible to make a decent prediction of the sediment transport direction.

In the report [?] the sediment transport rates along the Hoi An shore are determined with the 1D modelling programme Unibest-CL and Unibest-LT. The sediment transport rates as mentioned in the report are indicated in figure 4.8. The sediment transport occurs mostly in the area between 50 and 200 meter from waterline.

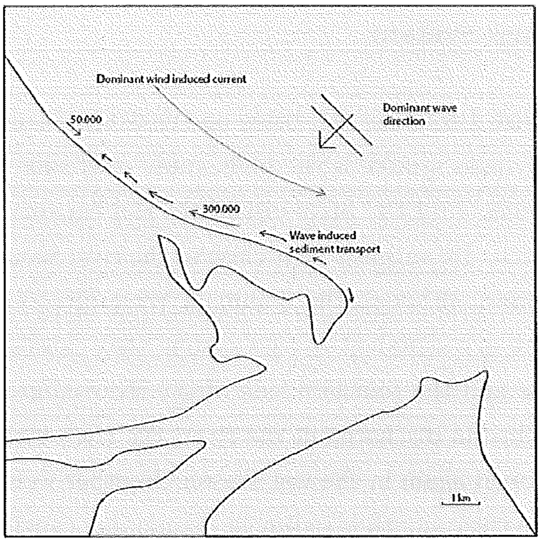


FIGURE 4.8: Sediment transport direction as caused by approaching swell waves. This is however probably not a representative picture for the real situation at Hoi An due to the presence of irregular waves. The amounts of sediment transport are indicated in m^3/y

4.4 Spit growth

The movement of the river mouth and therefore spit growth at the northern side of the mouth indicate sediment transport from the north [?]. Besides in the longshore direction, the spit also develops in the upstream direction of the river, it basically grows into the river. This is a good indication of a low discharge of the river. Spit growth is caused by a sudden interruption of the longshore sediment transport, for instance a sufficiently wide and deep river. The longshore sediment transport is interrupted and the sediment settles, leading to accretion. The fact that the spit growth is land inwards, or upstream river directed, indicates that the cross shore sediment transport rate caused by the waves is stronger than the sediment rate caused by the flow of the rivers. In other words, the waves 'push' the sediment in the river mouth.

In the 1995 line also spit growth is visible but far more seawards. This could be an indication that the discharge of the river used to be higher. The sediment rate of the river was higher than the sediment of the waves. The balance point between the sediment rate of the river and the waves was more seawards, therefore the river 'pushed' the sediment more seawards.

4.5 Surface loss

4.5.1 By-pass system

In a meeting with Prof.dr.ir. M. Stive on the 31th of august 2015 it became clear that most likely a by-pass system is the main cause of erosion on the northern beaches close to the river mouth. Prof.Dr. Stive visited the Hoi An area himself and is well acquainted with the situation. He suggests that close to the river mouth there is southward directed sediment transport although the dominant wave direction would suggest the opposite direction. There is a sediment bypass system that causes the northern side of the river mouth to erode and the southern side of the river mouth to accrete. Due to the large seasonal difference in discharge in the river, the river mouth accretes in the dry season and is flushed open again in the wet season. In other words, in the dry season the delta area around the river mouth is sediment demanding causing it to be filled with sediment from the north side. In the dry season this sediment is flushed away after which it eventually ends up on the south side. So basically a by-pass system is present at the Hoi An coast.The seasonal variability of the waves and river discharge make it hard to put an exact number on the amount of sediment that is by-passed. Prof.Dr. Stive estimated, by some basic calculations, the by pass system to be in the order of 75.000 to 100.000 m^3/y.

Prof.Dr. Stive states that the southern shore has an overall pattern of sedimentation due to the by-pass system. This is confirmed by calculations on the southern shore by Arcadis and Hyder [?]. The results of these calculations are shown in figure 4.9. The coastline as it was in 2000 was used as a reference line, the y-axis shows the increase or decrease of surface area. Notable is the sudden increase in surface on the southern side after 2000. This is probably caused by the 1999 flood that caused a huge sediment discharge in the river. Lots of this sediment settled on the tip of the southern shore after which natural processes flattened out the coastline again. The interesting part of this figure however is the 2010 to 2014 area. After 2010 the surface of the southern shore seems to remain more or less on its position while the northern shore surface keeps decreasing. Somehow about 100.000 m^3 of sediment seems to disappear within 4 years. Strikingly this is more or less the same as the reclaimed land area.

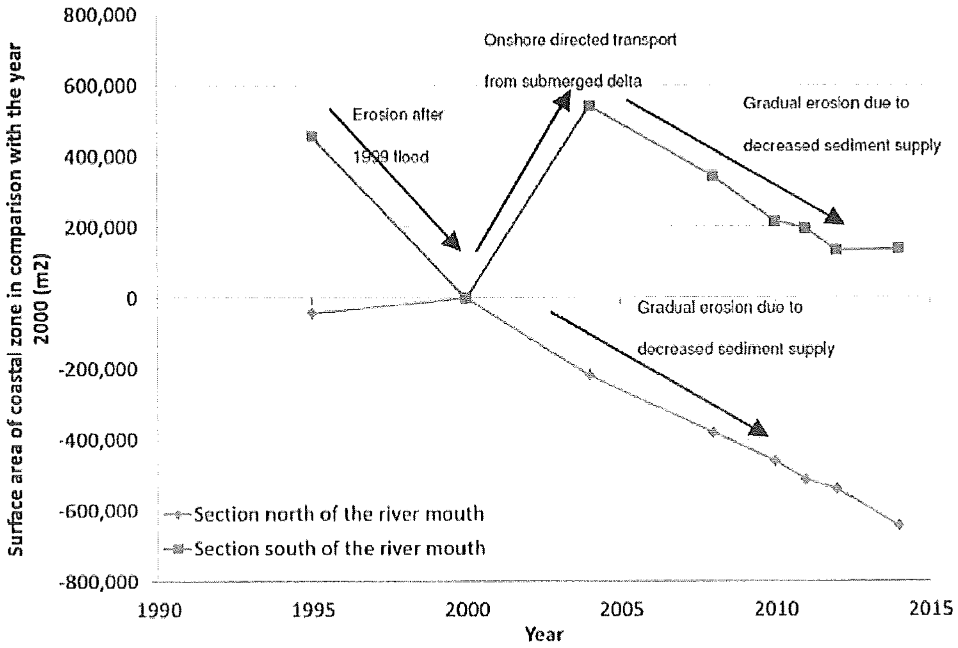


FIGURE 4.9: The development of the coastal areas north and south of the river mouth. Calculations done by Arcadis and Hyder [?]

4.5.2 Sediment budget calculation

To determine the amount of land surface that has disappeared due to the erosion processes a sediment budget calculation is performed. The surface of the eroded land is determined by setting a polygone in GoogleEarth that indicates two coastlines. In order to determine the different coastlines the history function of GoogleEarth is used as well as satellite pictures. GoogleEarth has a function that can measure the surface between these two lines. By doing so there is quite a big measuring error in the provided data but this was the only option available. The results of this sediment budget calculation are presented in figure 4.10. When this figure is compared with figure 4.9 [1] a comparable trend is visible. Borne in mind that the data is quite rough, there is ground to say that the figures follow a similar trend except for the period before 2000. In the figure as provided by Hyder a much bigger erosion and accretion peak is visible in the period between respectively 1995-2000 and 2000-2004. This is probably a deviation in measuring since the picture from which the 2000 coastline is provided (figure A.2) is very pixelated. The measuring error for the determination of the coastline therefore becomes in the order of 25-50 meters. The same holds for the determination of the 2008 and 2010 coastline, figures A.4 and A.5, although these pictures are sharper it remains difficult to determine the exact coastline in detail. For the 2004, 2011, 2012, 2014 and

2015 the history function of GoogleEarth can be used, which makes the position of the coastline more accurate.

The trend after 2004 is quite similar in both figures. Both show a decreasing surface over the years. However it is not what we expected to see. As mentioned in the section 'By-pass system' the current thought is that a by-pass system transports sediment from the northern towards the southern shore but this is not what is observed from the satellite pictures. There must be an other system that causes the southern shore to erode as well. According to Hyder this is caused by the decrease in sediment transport in the river over the years. But we do not have data to confirm this theory.

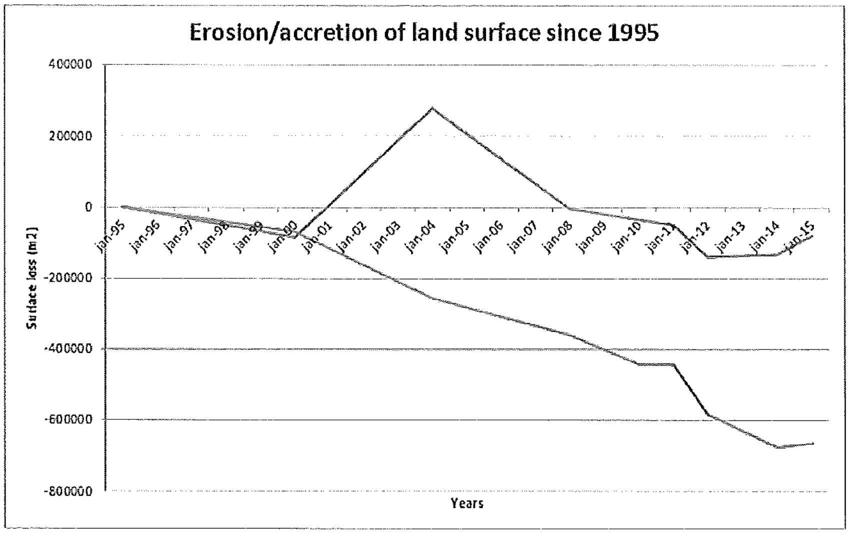


FIGURE 4.10: Surface loss or gainings of the northern (red line) and southern (blue line) coast.

An interesting discovery is made when the gradient of the blue line in figure 4.10 is plotted. This gradient indicates the average yearly surface loss over a certain period. These values are indicated in figure 4.11. A sudden peak is present around 2011. This sudden peak can be explained when the northern shore area is observed better. One can see that there has been a large land reclamation which started in 2010 and was finished in 2012.

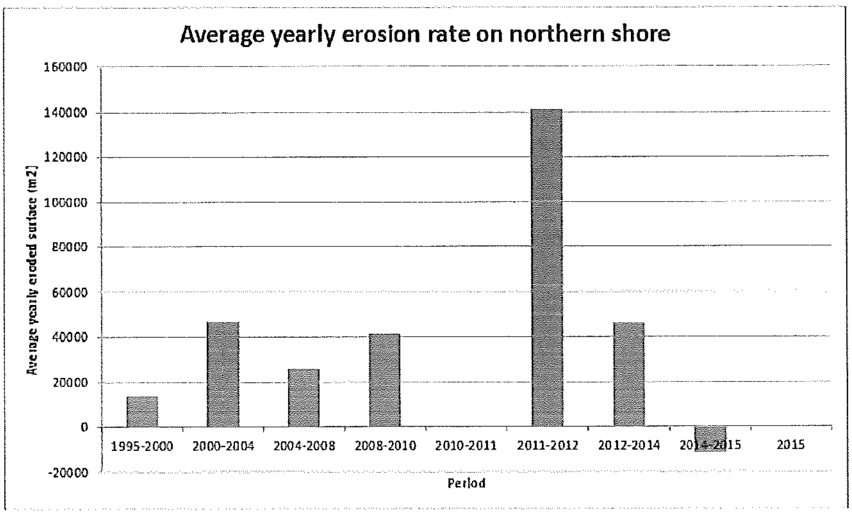


FIGURE 4.11: Average yearly erosion rates [m^2] at the norther coast.

Land reclamation

Satellite pictures of the coastal area show that severe land reclamation has taken place between 2010 and 2011. This is visible in figure 4.12 and 4.13. An area of about 35.000 m^2 worth of rice paddies and shrimp farms has been turned into land. The required sediment for this land reclamation is maybe taken from the Cua Dai beaches. In this case, this sped up the erosion process even more. The first signs of reclamation are visible in a picture of the situation in 2010. When a picture of 2011 is observed the total area has already been reclaimed.

A sudden removal of sediment brings the system further out of its equilibrium. The coastal area is a dynamic system which can be brought out of balance quite easily. The area from which the sediment is removed is most likely the end of the spit at the northern side of the river mouth. A large and wide strip of beach was visible on older satellite pictures that seemed to be unused and could therefore quite easily be removed without harming anybody. The fact that the sediment is removed from this area would be an explanation for the sudden coastline retreat at the end of the spit between 2011 and 2012. This is clearly visible in figure 4.4.

If the sediment from the beach was used for the purpose of land reclamation, this was not a wise thing to do. The removal of the sand has brought the system even further out of balance and it is not likely that the system will recover itself naturally. The sediment supply from the river probably keeps decreasing so the outer delta area will become even more sediment demanding.

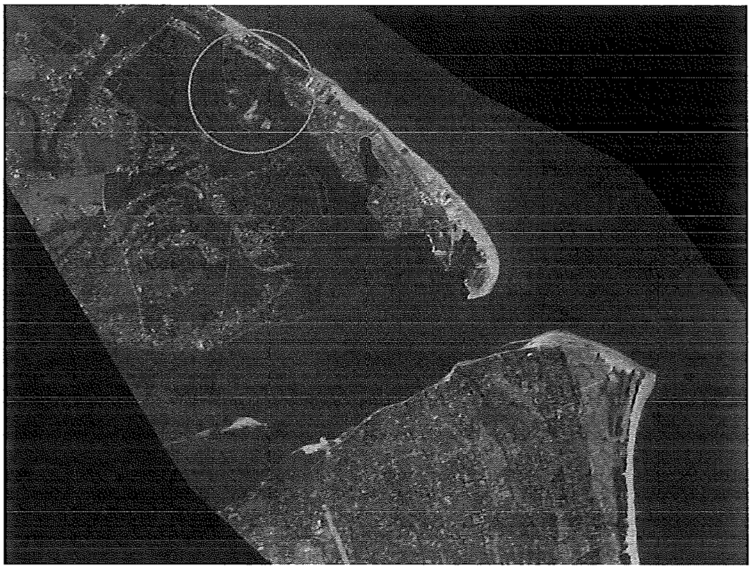


FIGURE 4.12: The first signs of the land reclamation are visible in 2010. The red circled area is the area to be reclaimed.

FIGURE 4.13: The land reclamations is almost finished in 2011. The red circled area is the reclaimed area.

4.6 Cross-shore transport

4.6.1 Cross-shore profile description

In figure 4.14 two cross-shore profiles along the coast are visible, one profile is measured about 2 km north of the river mouth and one in the area of 5 km north of the mouth. These two cross-shore profiles are quite different. It appears that close to the river mouth a flatter bed occurs in the first 250 meters down the waterline. Between 250 and 800 meters seawards the profile is more or less equal and after the 800 meter line the most northern profile shows a steeper line again. No bars seem to occur in front of the coast.

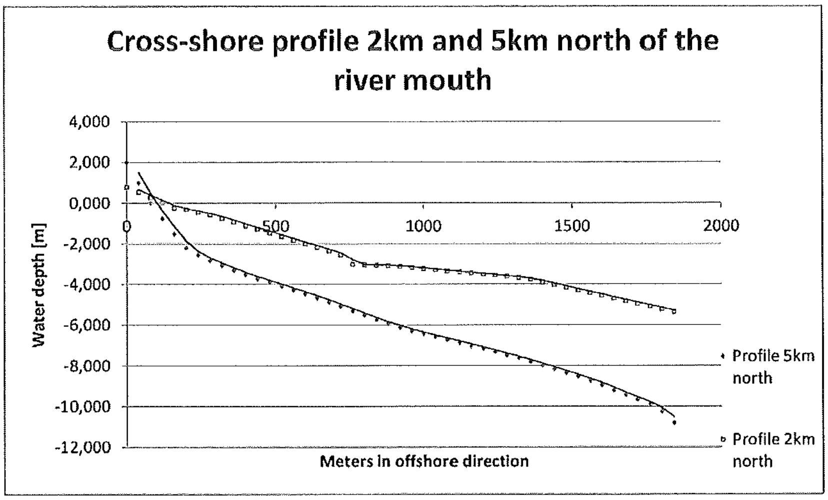


FIGURE 4.14: Cross-shore profile at around 2 km and around 5 km north of the river mouth

4.6.2 Equilibrium cross-shore profile

Dean approximation

On semi-empirical grounds Dean [Dean (1977)] developed a theory that describes an equilibrium situation of the cross-shore profile. The theory describes the development of the water depth over the width of the surf zone.

$$h(x') = A(x')^{2/3} \tag{4.1}$$

Here x' is the distance perpendicular to the coastline and A is the local shape factor. A is seen to vary from 0,079 to 0,398 $m^{1/3}$. The magnitude of A was empirically related to the fall velocity w_s.

$$A = 0,5w_s^{0,44} \tag{4.2}$$

On its turn the fall velocity is described by equation 4.3. The magnitude of w_s is determined iteratively.

$$w_s = \sqrt{\frac{4(s-1)gD}{3C_D}} \tag{4.3}$$

$$C_D = \frac{24}{D} \tag{4.4}$$

$$Re = \frac{w_s D}{\nu} \tag{4.5}$$

D is the grain size, ν the kinematic viscosity of the water, s is the relative density of the grain particles and g the gravitational force. It turns out that the fall velocity is 0,0082 m/s.

Null-point hypothesis

A more recent theory has changed the theory for the equilibrium profile slightly. The term involving gravity is reduced which causes coarser material to move onshore and finer material to move offshore. This seems to fit more to the reality. Profiles of coarser material are steeper than profiles of finer material, any sediment that finds itself on a profile that is 'too steep' moves seawards. This leads to a new null-point hypothesis as described in equation 4.6.

$$h(x') = \frac{(7,5w_s)^{2/3}}{g^{1/3}} x'^{2/3} \tag{4.6}$$

5km north of the river mouth

From the Hyder report [?] two different grain sizes were used. At some point one states that visual observation has shown a grain size of 200-250 μm while a few pages later the grain size is described as 'very fine sediment', which means around 100 μm. Both grain sizes are used in the calculations for the equilibrium profiles as described by Dean and the Null-point hypothesis. Both the Dean approximation and the Null-point hypothesis are presented for D50 = 100 μm and D50 = 200 μm in respectively figure 4.15 and 4.16. The figures clearly show that the cross-shore sediment transport in the most northern side of the project site is more or less in equilibrium for D50 = 100 μm. The cross-shore profile fits nicely between the Dean approximation and the Null-point hypothesis. For D50 = 200 μm the cross shore profile is too shallow and too gentle compared to the equilibrium profile. The coastal profile naturally strives towards an equilibrium which means sediment is transported offshore to get to this equilibrium. This could be an explanation for (part of) the erosion.

2km north of the river mouth

The cross-shore profile closer to the river mouth does not come close to the equilibrium profiles for both the grain sizes. The profile at 2 km north of the river is way too shallow and not steep enough to be in equilibrium. However, observations from Arcadis [?] have shown that quite a large outer delta is present around the river mouth. This outer delta could be the be the reason that the wide beach and shallow cross-shore profile have remained intact and resisted against the urge towards equilibrium. The great source of sediment, coming from the river, basically kept the wide beaches alive. In recent years the sediment discharge of the river has decreased severely, meaning that the source of sediment to remain the wide beaches intact has disappeared. Consequences are that the urge towards equilibrium has now taken over resulting in an eroding coast.

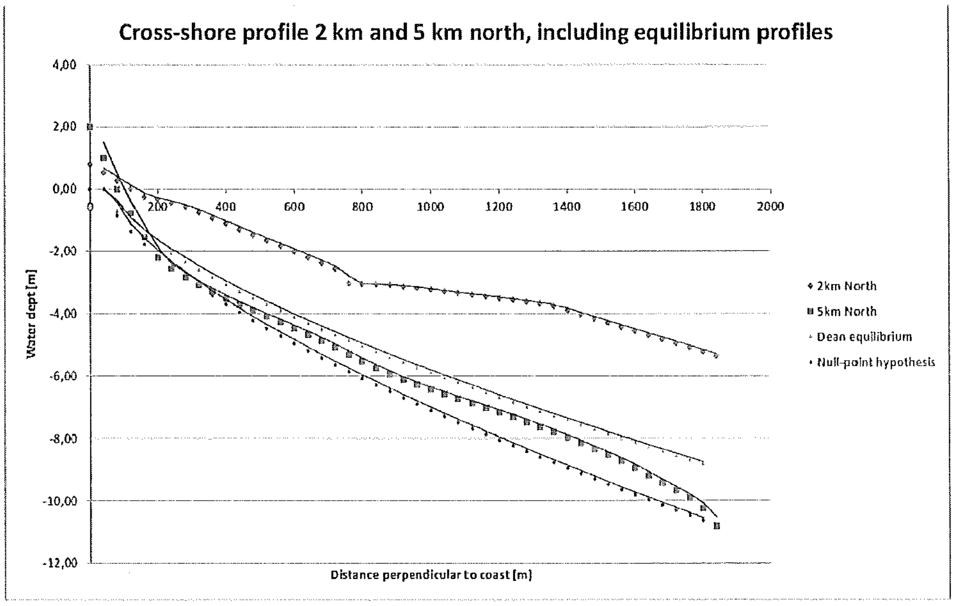


FIGURE 4.15: Cross section at 2km and 5km north of the river mouth including the Dean equilibrium and the Null-point hypothesis of the project site. With grain size d50 = 100 μm

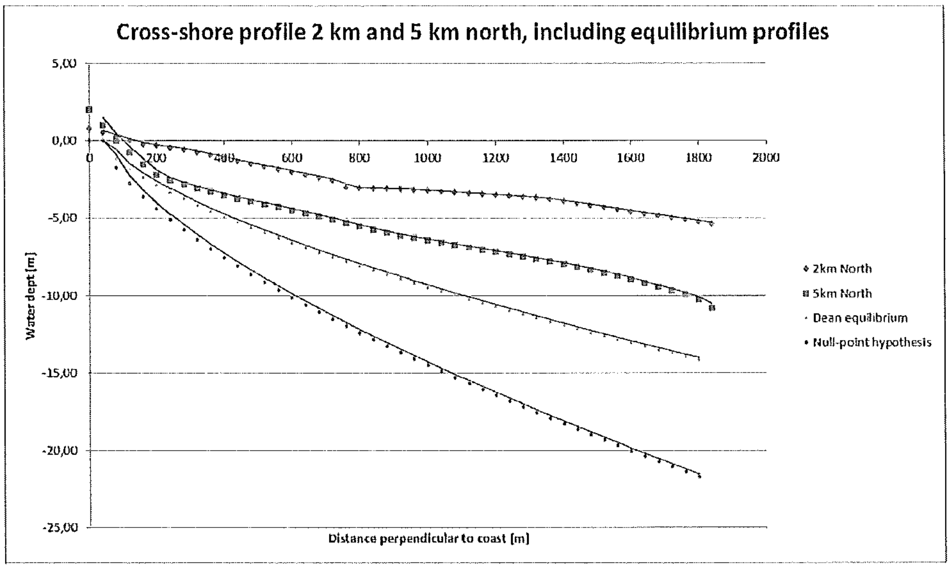


FIGURE 4.16: Cross section at 2km and 5km north of the river mouth including the Dean equilibrium and the Null-point hypothesis of the project site. With grain size d50 = 200 μm

4.7 Longshore sediment transport

For the determination of the longshore sediment direction GoogleEarth satellite pictures were observed, the pictures are shown in Appendix A.

4.7.1 Sediment transport direction

In pictures A.10 until A.14 it is clearly visible that the beach has eroded massively. About 100 to 120 meters of beach has flushed in just 11 years. At some spots the beach had retreated so far that the beach resorts are already located behind the waterline. Pictures A.15 until A.19 demonstrates that the coastline has already retreated to the road and starts to threaten this as well. This is clearly visible when putting the situation of 10-11-2004 and 15-3-2015 next to each other, as demonstrated in figure ??. Although the pictures look quite different, they are taken at exactly the same location. This indicates the huge amount of erosion that has taken place and also the enormous urban development in the past 11 years.

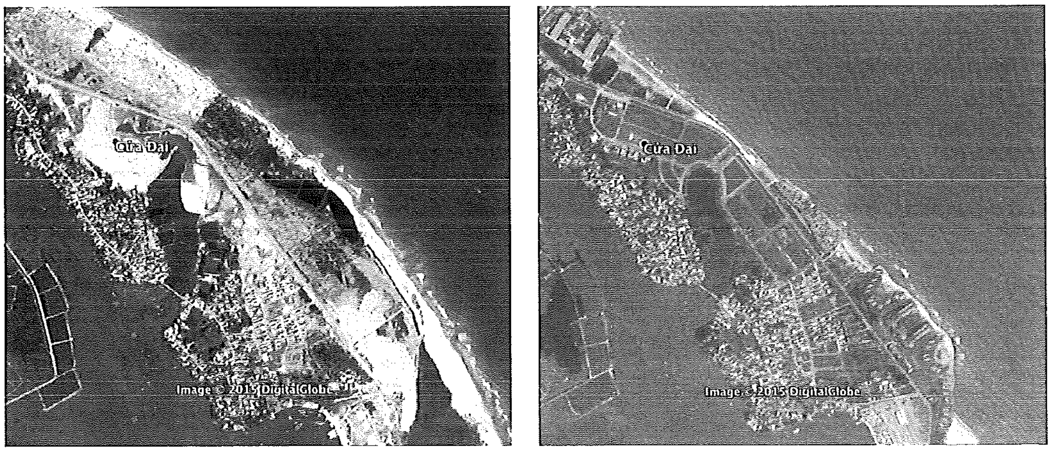


FIGURE 4.17: Situation just north of the river mouth on 10-11-2004 (left) and 15-3-2015 (right)

An important issue in this case is to determine where all this sediment is going to. Due to the complex wave pattern it is rather difficult to indicate a net sediment transport direction based on the waves. However, a study on the development of the coast in the recent history by means of visual observation of satellite pictures could tell us a lot about the direction of the sediment transport. Based on theory and personal experience an indication can be given of the amount of sediment transport.

The trend in the pictures indicates a north-west directed longshore sediment transport, i.e. to the left in the pictures. This is based on small details visible in the pictures.

Along earlier constructed breakwaters, jetties and groynes sedimentation occurs generally on the south (or right) side of the structures. On the north side of the structure some erosion patterns are visible which indicates a lee zone. Both the sedimentation on the south side and the lee zone on the north side indicate that the sediment transport is north directed. When looking again at the wave rose as demonstrated in figure 2.3 this is not a strange conclusion, a northward direction longshore sediment transport direction is also what would be expected in a situation where an island would not block the waves.

4.7.2 Longshore sediment transport quantities

CERC hand calculations

In order to determine the bulk longshore sediment transport quatities the CERC formula was used. These 'hand calculations' should give an idea of the amount of yearly averaged sediment transport along Cua Dai beach. The formula is defined as follows:

$$Q_L = K\left(\frac{\rho\sqrt{g}}{16\gamma_b(\rho_s-\rho)(1-n)}\right)H_{b,rms}^{5/2}sin(2\alpha_b) \tag{4.7}$$

With variables:
Q_L = Longshore sediment transport $[m^3/s]$
K = CERC coefficient according to CEM-US $K = 1,4e^{-2,5d_{50}}$
d_{50} = Average sediment diameter [mm]
$H_{b,rms}$ = Root-mean-squared wave height at breaker line [m] $H_{b,rms} = H_b/1,41$
α_b = Angle between wave orthogonal at breaking line and beach normal
γ_b = Breaker index (= 0,78)
ρ_s = Sediment density (= 2650 $[kg/m^3]$)
ρ = Water density (= 1025 $[kg/m^3]$)
n = Porosity (=0,4)
g = Gravity acceleration (= 9,81 m/s^2)

Q(-) is defined as sediment transport from south to north.
Q(+) is defined as sediment transport from north to south.

The results of the CERC calculations are presented in table 4.1. The calculations were performed for two cross sections along the coast. The gradient in longshore sediment transport rate indicates the amount of erosion or accretion. The two sections are indicated in figure 4.18.

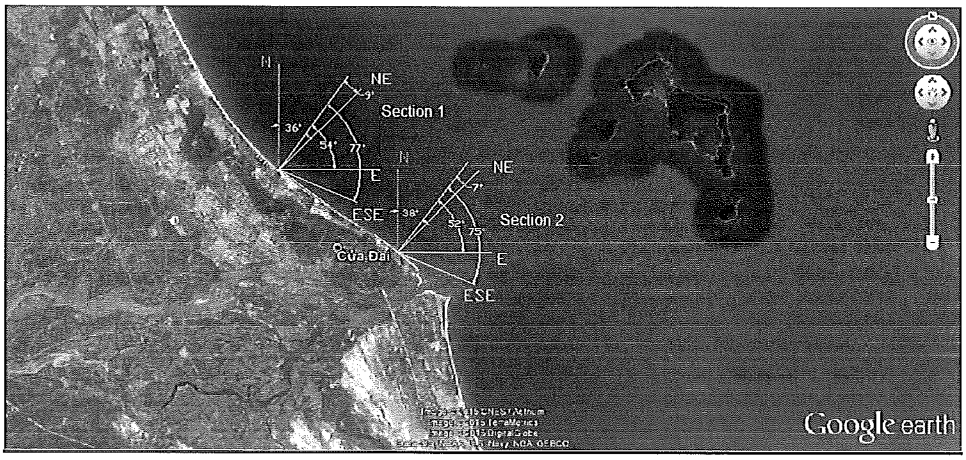


FIGURE 4.18: The different sections on which the CERC calculations were performed.

The calculations were split into two parts: a characteristic summer situation and a characteristic winter situation. In the summer period the waves are predominantly E and ESE directed waves. In the winter period the waves are predominantly N and NE directed waves.

TABLE 4.1: CERC calculation results

	Direction	N	NE	E	ESE
Longshore sediment transport across section (m3/y)	Section 1	25431.2	190309.6	259282.2	103299.8
	Section 2	26661.6	234865.6	266337.7	124911.5

In winter, there are two main wave direction N, NE that affect the coastline the most, this leads to the following results:

- The total amount of sediment transport in section 1: $Q = 25431.2 + 190309.6 = +215740.8(m^3/year)$
- The total amount of sediment transport in section 2: $Q = 26661.6 + 234865.6 = +261527.2(m^3/year)$

So amount of sediment transport from section 1 to section 2: +45786.37 (m3/year), indicating southward directed net sediment transport.

In summer, there are two main wave direction E, ESE that affect the coastline the most, this leads to the following results:

- The total amount of sediment transport in section 1: $Q = -259282.2 - 103299.8 = -362582(m^3/year)$

- The total amount of sediment transport in section 2: $Q = -266337.7 - 124911.5 = -391249.2(m^3/year)$

So amount of sediment transport from section 1 to section 2: -28667.2 (m3/year), indicating northward directed net sediment transport.

CoDeS calculations

The program CoDeS, developed by Deltares and Witteveen+Bos, is used to estimate the amount of sediment that is yearly transported along the Hoi An coast. This, however is not an exact representation of the reality since the calculations as performed by the program are based on offshore wave data. The influence of the local bathymetry, which also holds the Cu Lao Cham island, is not included. The results of the CoDeS calculations are presented in figures 4.19 and 4.21. A more zoomed in overview of the longshore sediment transport rate close to the river mouth is given in figures 4.20 and 4.22.

The results of the CoDeS calculations more or less match with the observations from the satellite pictures. The highest erosion rates occur where the longshore sediment transport gradient is the highest. At the satellite pictures the most erosion is visible in the area close to the river mouth. Indeed the gradient turns out to be the highest in that area. However, this doesn't match with the theory of a by-pass system which is thought to occur around the river mouth. Again, this is probably due to the effect of the Cu Lao Cham island, the impact of this offshor island is not taken into account in these CoDeS calculations.

Parameter	**Value**
Breaker index	0.78
Closure depth	6
Beach slope	0.011
Rho_s	2650
Rho_w	1014
Porosity	0.4

TABLE 4.2: Input parameters for the CoDeS model for longshore sediment transport rates.

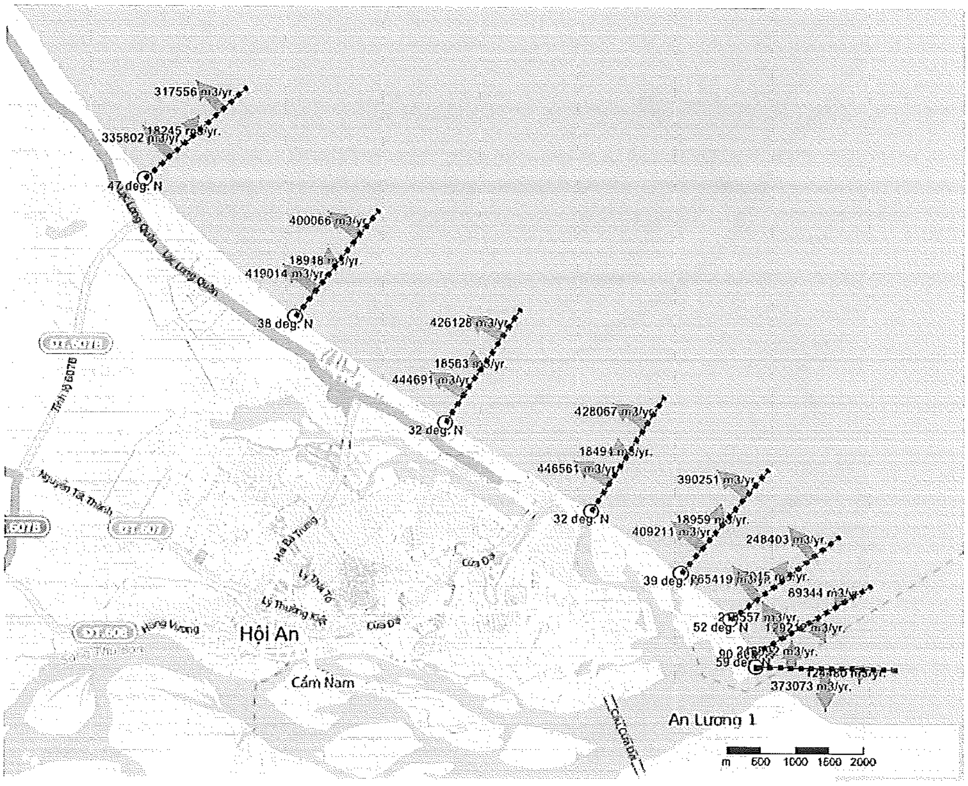


FIGURE 4.19: Overview of the yearly average longshore sediment transport rate along the Hoi An coast. With grain size d50 = 150 μm

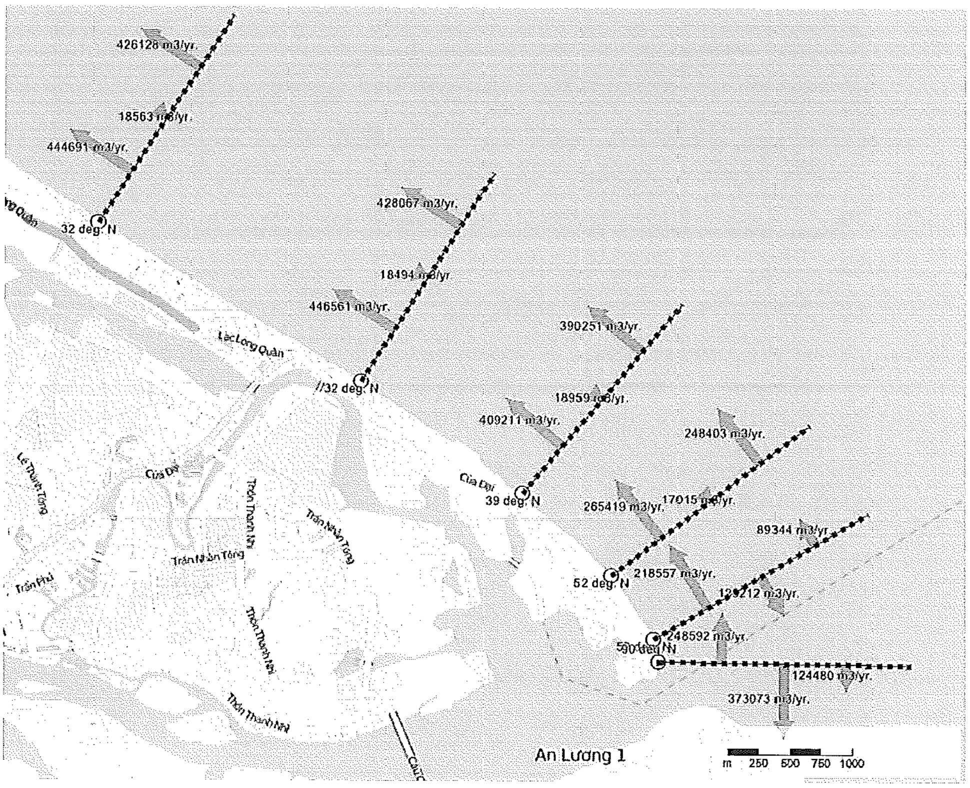


FIGURE 4.20: Overview of the yearly average longshore sediment transport north of the river mouth. With grain size d50 = 150 μm

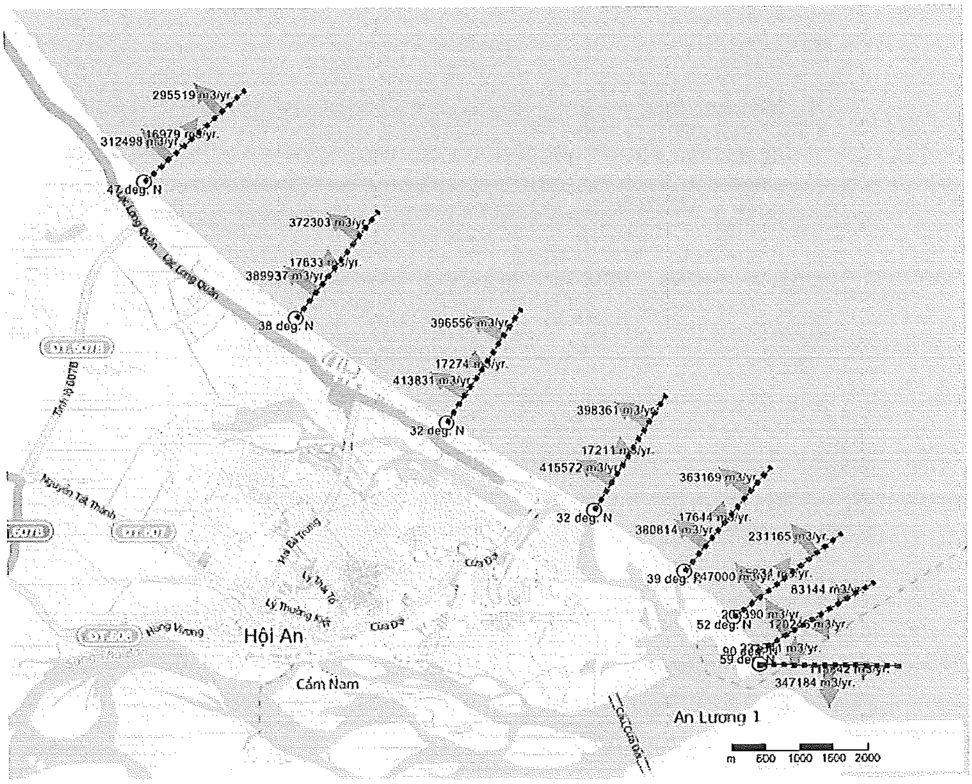


FIGURE 4.21: Overview of the yearly average longshore sediment transport rate along the Hoi An coast. With grain size d50 = 200 μm

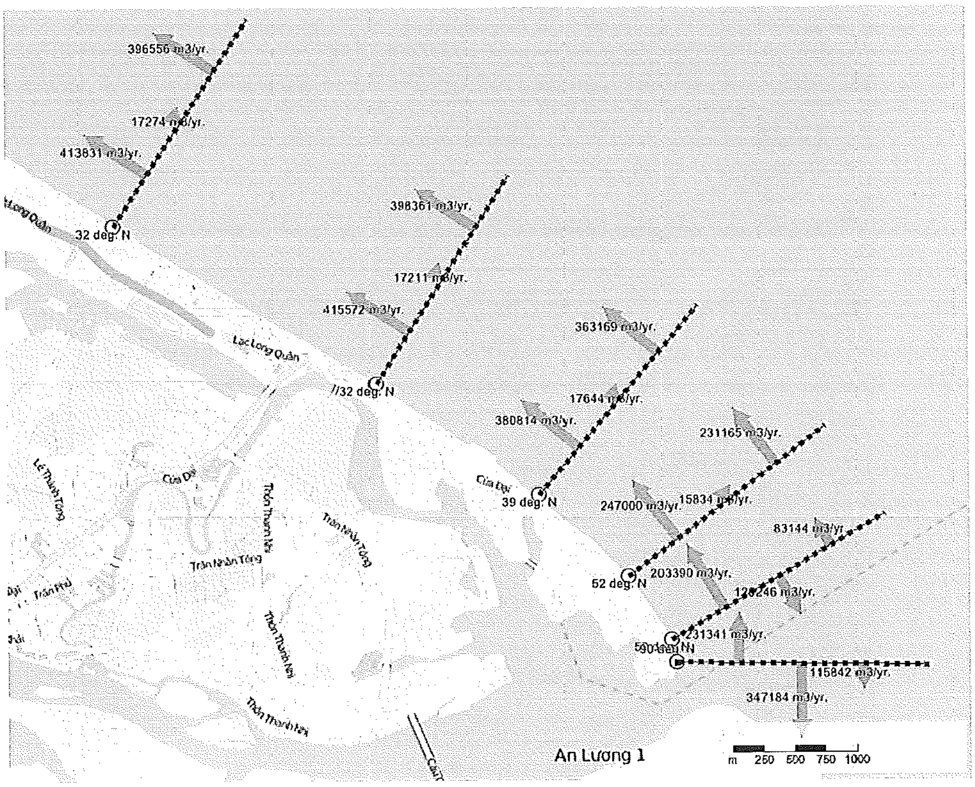


FIGURE 4.22: Overview of the yearly average longshore sediment transport north of the river mouth. With grain size d50 = 200 μm

4.8 More frequent storms

According to local people I've spoken in Hue, 50 km north of Hoi An. The climate in the area is changing. The monsoon used to be days and days of moderate rainfall, sometimes the rain lasted for several weeks. Nowadays the rain is shorter and more intense. Although it rained non-stop in the four days I was in the area and the rainfall wasn't that heavy, the locals told me this was a minor rain shower and it used to be a lot worse. That is, worse in the sense that the rainfall was longer. The more intense rains are often associated with heavy winds causing it to get an almost storm like character.

More frequent storms could also be a reason for the erosion problem. During a storm severe volumes of sand are transported from the beach towards the sea. The high water level and big waves stir the sand in the areas that are normally not touched by the water up and transport it more offshore. Natural cross-shore sediment transport processes transport the sediment particles back towards the beach but this is a slow going process. When the storms occur more frequent the beach hasn't got enough time to recover itself and the net result is erosion.

Heavier rainfalls also cause sudden high discharges of the river. Which in its case leads to more sediment transport towards the sea. This is actually a positive effect since it brings more sediment to the shore and therefore reduces the erosion process.

Chapter 5

Possible solutions

In this chapter five possible solutions will be described which will be evaluated later to find out which solution is probably best for the Hoi An case. A distinction will be made between the so called 'hard measures' and 'soft measures'.

5.1 Hard measures

Hard measures are solutions to the problem in which man made structures prevent any further erosion of the beach. There are many different ways to apply hard measures, depending on the problem. Roughly, the hard measures can be divided into two categories:

- Structures that influence the longshore sediment transport rate at all time, so both under normal and extreme weather conditions. Examples are: Groynes, Breakwaters (both attached and detached) and Dams .
- Structures that only influence the sediment transport in extreme weather conditions. Examples are: A seawall, Sea dike of Coastal revetment.

We are interested in a solution for a structural erosion problem and the restoration of the beach, therefore only the first type of hard measures are considered.

5.1.1 Variant 1: Breakwater

Description

Variant 1 is a classic solution for an erosion problem: a breakwater. The idea is simple, a breakwater is constructed with a length that exceeds the width of the surfzone. By far the most longshore sediment transport takes place in the surfzone and when this longshore transport is blocked the erosion problem should be fixed. Of course it is not that easy in practice, since the breakwater blocks the sediment transport the erosion downstream of the breakwater will be worse because the source of sediment is gone. A second thing is that a large breakwater will only work if the main cause of erosion is longshore sediment transport, when the main cause is cross-shore sediment transport the breakwater will have no function at all.

A breakwater will only be effective if there is little offshore directed cross-shore sediment transport. If there is large cross-shore transport the sediment that is captured by the breakwater will disappear again and the nett effect of the breakwater is zero.

Location

The longshore sediment transport at the Hoi An coast is northward directed. Since the breakwater is supposed to catch the sediment it should be placed on the downstream side of the coastal drift. In this case it means on the north side of the project site, so about 7 km north-west of the Tu Bon river mouth. In figure 5.1 the location is illustrated on a map of the Hoi An coast. The dark brown rectangle represents the breakwater, the yellow plane is an indication of the development of the coastline after construction. After how many years this situation occurs is not known yet in this stadium of the research. This will be explained later in this report.

Expected impact

Sedimentation will occur southwards of the breakwater and if the breakwater works properly the sedimentation continues all the way towards the river mouth. This is indicated with the yellow plane in figure 5.1. Whether the effect of the breakwater is noticeable all the way up to the river mouth or not should follow from some calculations or a model. It is quite important that the sedimentation is noticeable also close to the river mouth because this is the place where most erosion has taken place and therefore the largest desire for accretion is present. When this is not the case this solution is not

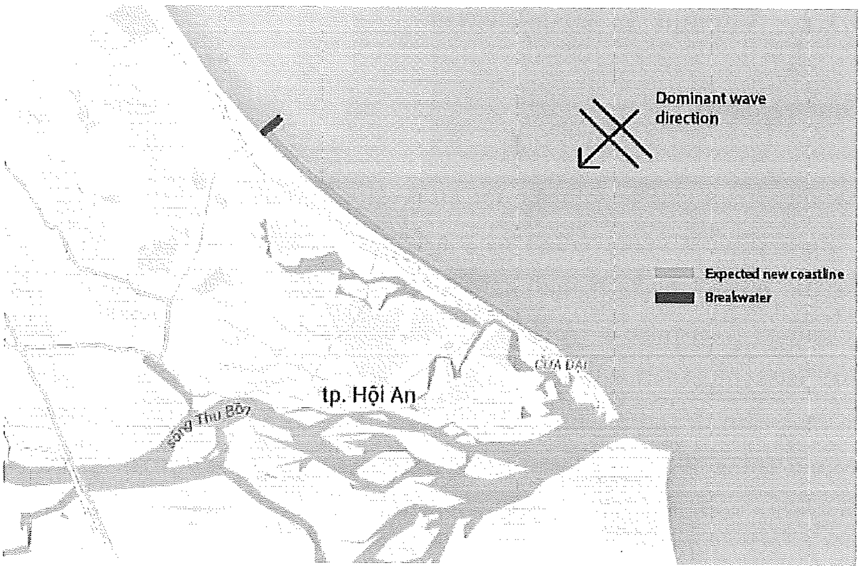


FIGURE 5.1: Variant 1: A breakwater constructed about 7 km north-west of the Tu Bon river mouth

sufficient and can be left out of the recommendation.

Down drift of the breakwater, at the lee side, erosion will occur. Which of course is not desirable, it will amplify the current problem. This taken into account as well as expectation that the effect of a large breakwater will probably never be noticeable all the way towards the river mouth makes this solution probably not the best solution. A second breakwater, placed halfway between the first breakwater and the river mouth, could be an option. However, also for this solution the expectations are that it will not function as it should.

5.1.2 Variant 2: Groynes

Description

Variant 2 is based on the same principle as variant 1, namely the catchment of longshore sediment transport due to a breakwater or jetty type of construction. The idea of variant 2 is to construct multiple small breakwaters, reaching roughly to about half of the surf zone at some distance from each other. These little breakwaters are called groynes and the space between two groynes can be seen as a compartment. Where in variant 1 the big breakwater is supposed to catch all the sediment, are the groynes in variant 2 meant to catch a little part of the littoral drift within each compartment. All together this should keep the coastline at least intact and at some places will cause accretion of the coastline. Also for the construction of groynes holds that the offshore directed cross-shore sediment transport should not be too large otherwise the effect of the groynes in the longshore direction is negligible.

Two main types of groynes can be distinguished:

1. **Impermeable, high-crested:** Crest levels above MSL + 1m. These types of groynes are used to keep the sand within the compartment between adjacent groynes. The shoreline between two groynes will develop until perpendicular to the dominant wave direction.
2. **Permeable, low-crested:** Crest levels between Mean Low Water and Mean High Water lines, such that the structure-induced eddy generation is reduced, at least at high tide. These groynes are generally used to slightly reduce littoral drift and to create a more regular shaped shoreline, and not the saw-tooth profile that occurs when using high-crested, permeable groynes.

Since we are not interested in a slight reduction of the littoral drift but want to expand the coastline and therefore need severe accretion the usage of permeable, low crested groynes is not an option. So the high crested, impermeable groynes will be evaluated. An indication of how the shoreline will look after some time after construction of the groynes is demonstrated in figure 5.2.

Location

The groynes will be constructed over the entire length of the project site, which means all the way until 7 km north west of the river mouth.

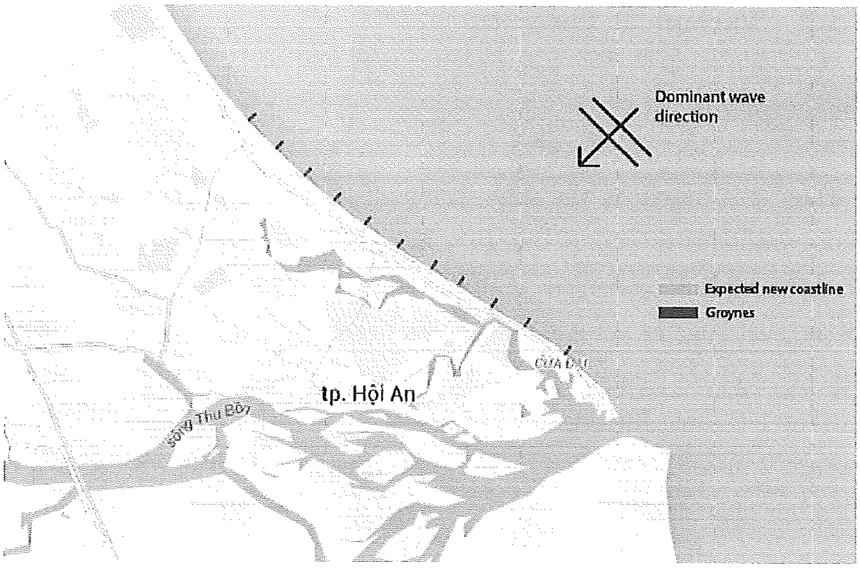


FIGURE 5.2: Variant 2: Multiple groynes will be constructed perpendicular to the coast

Impact groynes

The impact of the groynes on the down drift side will be less dramatic than the impact on the same area of the breakwater. Since the groynes only block part of the littoral drift the down drift side will not completely be closed of from sediment supply. But, as mentioned earlier, the sediment transport direction on the down drift side of the groynes changes in the south-east direction so the impact on the down drift side will probably not be significant.

5.1.3 Variant 3: Detached shore parallel offshore breakwaters

Description

In variant 3 detached breakwaters are constructed parallel to the shore. The breakwaters are not located attached to the shore but a hundred to few hundred meters offshore. The idea is to create a 'shadow zone' behind the breakwaters in which the wave height is reduced. Due to the reduced wave height in the shadow zone sedimentation can take place. Especially in areas with high cross-shore sediment rates the detached breakwaters can turn out to be very effective. A schematic impression of the offshore detached breakwaters is given in figure 5.3.

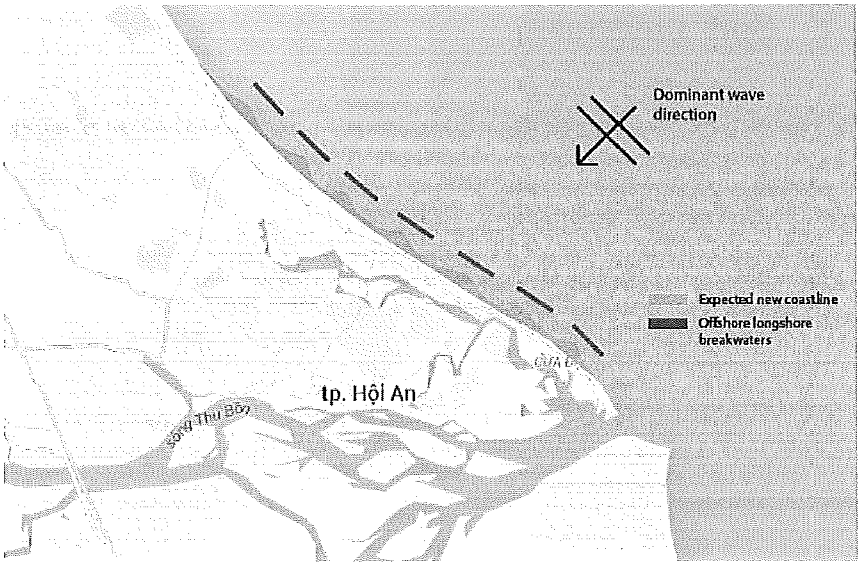


FIGURE 5.3: Variant 3: Multiple detached shore parallel offshore breakwaters will be constructed following the shoreline

Location

The detached breakwaters will be placed just outside the surf zone, which will be approximately 200 to 300 meters offshore, the exact distance is to be determined later. Multiple detached breakwaters will be constructed leaving gaps in between them. This is necessary in order to keep the shore relatively open and not completely close it off from waves and tide. It will cause a curved, wave-like shore pattern due to the many shadow zones that are created. In the shadow zones the sedimentation will be more and therefore the shore will also expand more.

Impact offshore detached breakwaters

In theory offshore detached breakwaters sound like a perfect solution for the problem. In practice however these kind of breakwaters have never proven to work in highly dynamic areas. Tests have been done at the eastern shore of Italy, an area with an even less dynamic system, and even there the impact of the offshore detached breakwaters was little. Based on this knowledge it does not seem like a good idea to apply this solution at the Hoi An coast.

5.2 Soft measures

For the so called soft measures no structures are required. The principle is to let nature do its job. For instance by a beach- or foreshore-nourishment up-drift of the longshore current, the natural sediment transport processes will distribute the sediment over the coast. A disadvantage of soft measures is that the natural erosion processes will continue and therefore measures should be repeated every few years.

5.2.1 Variant 4: (Beach) nourishment

Description

A simple way to restore the beach is by taking sediment from deeper water and dump it on the beach. When the sediment is dumped at the right spot the natural sediment transport divides the sediment over the rest of the beach. Another option is to divide it immediately over the coastline and therefore making the beach wider over the entire length. A detailed calculation or model is required to determine which option is best.

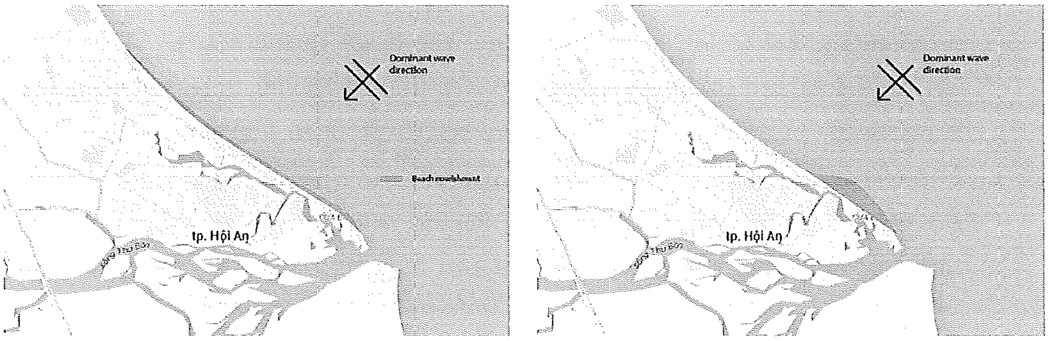


FIGURE 5.4: Beach nourishment at the Hoi An coast. The situation with nourishment over the entire coastline (left) and local nourishment (right) is depicted

Beach nourishment does not sound like an attractive solution for the problem since the source of the problem is not tackled. But it is a relatively cheap solution and could therefore be interesting. Of course, when the yearly sediment transport rates are too high and beach nourishment should be repeated every year a hard measure could be more efficient to apply.

Nourishment is done by dredging companies, the transport of the sediment from the deeper sea towards the beach can be done in different ways of which the following are the most common:

- By trailing suction hopper dredgers. The sediment is dredged offshore by the hoppers. When the boat is filled with sediment it is transported towards the coast where it can be placed on the beach by rainbowing (spraying the sediment from the front of the ship on the beach) or by a pipeline that can be attached to the boat.
- By cutter suction dredgers. This is less common when dredging on sea. The sediment is dredged by drifting platters with a big cutter attached to it. The sediment is cut loose by the cutters and via big pumps and a pipeline transported directly towards the beach.

Location

Like mentioned before there are two options to apply beach- or foreshore nourishment:

- Nourishment over the entire coastline. This type of nourishment has immediately the required result: the coastline moves seawards and therefore the beach becomes wider. However, since severe amounts of sediment transport rates occur at the Hoi An shore, the beach might erode again very quickly.
- Nourishment at one certain spot. When applying this type of nourishment the required result is not immediately visible. The sediment will be dumped at one particular spot and not over the entire beach. The natural sediment transport processes divide the sediment over the coast i.e. if the sediment is dumped at the right spot. This solution could maybe lead to a conflict between the beach resorts since the resorts around the nourishment place longer benefit the wider beach.

Which kind of nourishment is to be applied depends strongly on the local cross- and longshore sediment transport rates. Due to the complex flow patterns around the river mouth one cannot tell with the current knowledge which of the two solutions would be the best. It could however be stated that it is clear that the system is seriously short in sand. A solution for the shortage of sand is simply bringing sand back into the system. Therefore applying (beach) nourishment is simple but effective short term solution for the problem.

Impact nourishment

By applying nourishment the original coastline of for instance the year 2000 or 2004 can be brought back. This of course also means the original erosion pattern will occur again. When the nourishment is performed at the right spot this is no problem since the sediment is divided along the coast by natural processes. On the northern shore there is northward transport in the more northern area and southward transport in the area closer to the river mouth. The ideal spot to drop the nourishment would be at the point where the transport changes from northward to southward so the sediment is nicely divided in two directions. The problem at Hoi An is to determine where this ideal spot will be. Due to seasonal variation of the wind- and wave direction the longshore current changes during the year. This also means the turning point moves during the year. A detailed wave- and flow model is required to determine the cross- and longshore currents along the coast. By doing so the location of a sand-engine kind of nourishment can be determined. Until this model study is performed the best advise is currently to just restore the original coastline by nourishing the entire area.

The amount of surface loss since 1995 is indicated in table 5.1. One can see that there is quite a difference in restoring the coastline to the 2000 situation or restoring it to the 2004 situation. The major difference is because of the extremely wide beach just north of the river mouth at the 2000 situation. One can almost state that this beach is unnecessarily wide. Therefore it is probably better to restore the coastline towards the 2004 situation. This will be cheaper and basically the same goal is reached, namely creating a wider beach and preventing the coastline to retreat any further.

TABLE 5.1: Average and total surface loss since 1995

Surface loss (m^2)			
Measuring point	Total since 1995	Required to restore coastline	Average yearly
1995	0	664284	13851
2000	69254	595030	46728
2004	256168	408116	25893
2008	359742	304542	41277
2010	442296	221988	-313
2011	441983	222301	141335
2012	583318	80967	46216
2014	675751	-11466	-11466
2015	664284	0	0

Required amount of sediment for restoration of coastline

The required amount of sediment in order to restore the coastline is determined by the cross-shore profile. In figure 4.14 a cross shore profile as measured in 2009 is presented. When this profile is used one finds roughly a bottom slope of 1/50. Depending on the level of increase above mean sea level this leads to the amounts of required sediment as presented in table 5.2.

TABLE 5.2: Required amount of sediment to restore the coastline towards the 2004 situation.

Increase level above MSL [m]	Required amount of sediment [m^3]
0,5	816233
1,0	1020291
1,5	1224349
2,0	1428407

5.2.2 Variant 5: Set-back line

In coastal erosion cases the problem of threatening by the sea can be solved by a so called Setback line. By adopting the Setback Line concept, there should be sufficient reserve seaward of the Setback Line for long term coastal development and a more robust soft defense, such as a vegetated dune area, for protecting private homes and other properties against the effects of extreme storm events. Defining a setback line is appropriate only for cases where minor coastline fluctuations are expected to occur in the coming 50 years. The Setback line can be determined with a 2D modelling computer program like Unibest, Delft3D or XBeach. These program are able to estimate the location of the coastline in the, for instance, future 10, 20 or 50 years.

In the Hoi An case a Setback Line can probably not be applied because too many houses and beach resorts are already built in the area close to the sea. The Setback Line would probably be placed behind these buildings, which makes it useless since the area that should be reserved is already overbuild.

Chapter 6

Conclusion and recommendation

6.1 Evaluation possible solutions

Like mentioned before in this report it remains hard to understand the coastal dynamic situation along the Hoi An coast. With basic theories we cannot explain what we observe in reality. There are too many contradictions in what we observe to say with any certainty what the sediment transport directions and sediment transport rates are. In order to say something about these aspects a higher detailed model is required. Unfortunately there was not enough time available in this internship to set up such a model.

Along the Hoi An coast several local hard measures have been applied in order to stop the erosion. Non of them seem to work as they should. This is not strange since it is impossible to make a decent design for such a structure without knowing what's exactly happening around the location of the structure. There is proof that structures like groynes and offshore detached breakwaters work. However, those are situations in which the system is less dynamic than the Hoi An situation. In a more dynamic system like the Adriatic Sea the effect of the local hard measures has proven to be not so good. The system at Hoi An is even more dynamic than the Adriatic sea so the expectation is that they will work even less in this case. Therefore building more structures along the Hoi An coast would in the current situation probably be a waste of money. There is simply not enough ground to base the design of such a structure on.

What we do know is that the entire system is short of sand. A basic best solution for this problem is to supply the system with sand. We believe that the only way to tackle the erosion problem is to get the entire system back into balance. Since we do not expect the system to recover itself in a natural way the only way to get it back in balance is by applying a severe nourishment.

6.2 Conclusion

Research has been done on the Hoi An coastal area for the sake of making a preliminary design of a solution the coastal erosion problems in the area. Due to the complex morphological situation around the Hoi An area it appeared to be difficult to determine the currents and sediment transport directions. Therefore the impact of hard structures cannot be predicted. Based on experience with local erosion preventing structures in less dynamic environments the advise is to not use them. Structures that have been built along the coast seem to work very poorly and building more of them would only be a waste of money. The problem should be solved by looking at the bigger picture and not looking at local solutions. The system is sand demanding and currently the only solution to prevent further erosion is to supply the system with sand. Therefore variant 4: '(Beach) nourishment' is presented as the best solution for the current erosion problems. When the 2004 coastline is restored by nourishing, the beach should be restored and the buildings on the beach are safe. Depending on the desired level of the beach above mean sea level between 800.000 and 1.400.000 m^3 of sand is required. When the erosion will continue as it currently does the beaches are safe for at least the next 10 years.

6.3 Recommendation

More detailed modeling

In order to get better insight in the flow patterns along the coast a more detailed model is required. For the sake of this model a grid with the morphology of the Hoi An coast including the Cu Lao Cham island is created. Using a program like SWAN or Delft3D it should be possible to set up a model that calculates the flow lines along the coast and could therefore give an explanation for the erosion problems. Unfortunately there was not enough time available within this internship to complete this model. It is highly recommended to finish this model to understand the erosion problems better.

Stakeholder analysis

The stakeholder analysis as presented in this report could be more elaborate. On beforehand the idea was to plan a site visit where a.o. the research with the objective of a stakeholder analysis could be performed. Unfortunately this site visit could not be planned within the time frame of this internship leading to a less elaborate stakeholder analysis.

Field visit

A visit of the project site will give a better insight in the history of the coastline. Interviewing local people about this issue could be useful to find out if the erosion problem is a problem from the last 20 years only or a problem that has occurred before. We do not know much about the history of the coast before 1995. 20 years is not a long period on coastal development scale and it could very well be that the current erosion pattern is part of a fluctuating system.

The data of the morphology along the coast is currently 6 years old. Since the coastal system is highly dynamic this data is not up to date anymore. In a field visit some measurements can be done to determine the current cross-shore profile. When this data is compared to the morphological data of 2009 a lot can be said about the short time development of the coast.

A field visit could also be very useful to see with own eyes what is actually happening around the coast to get more feeling for the situation.

Appendix A

Beach erosion pictures

A.1 Pictures used to determine the coastline retreat

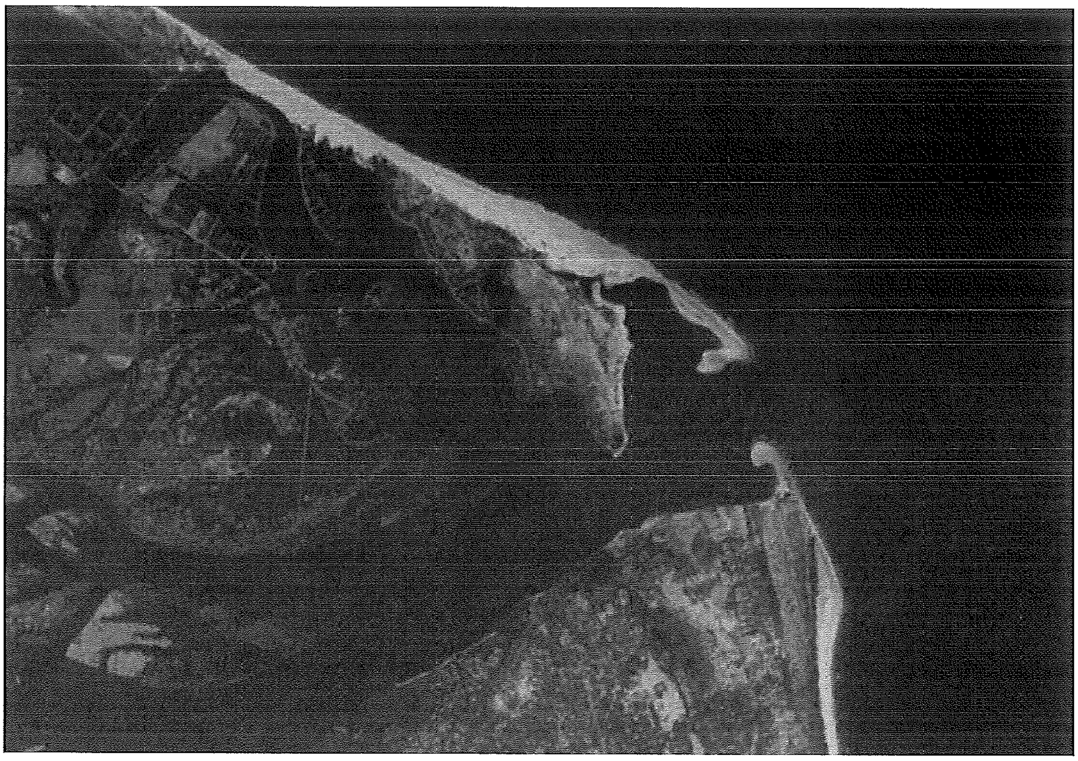


FIGURE A.1: Hoi An coastline 1995

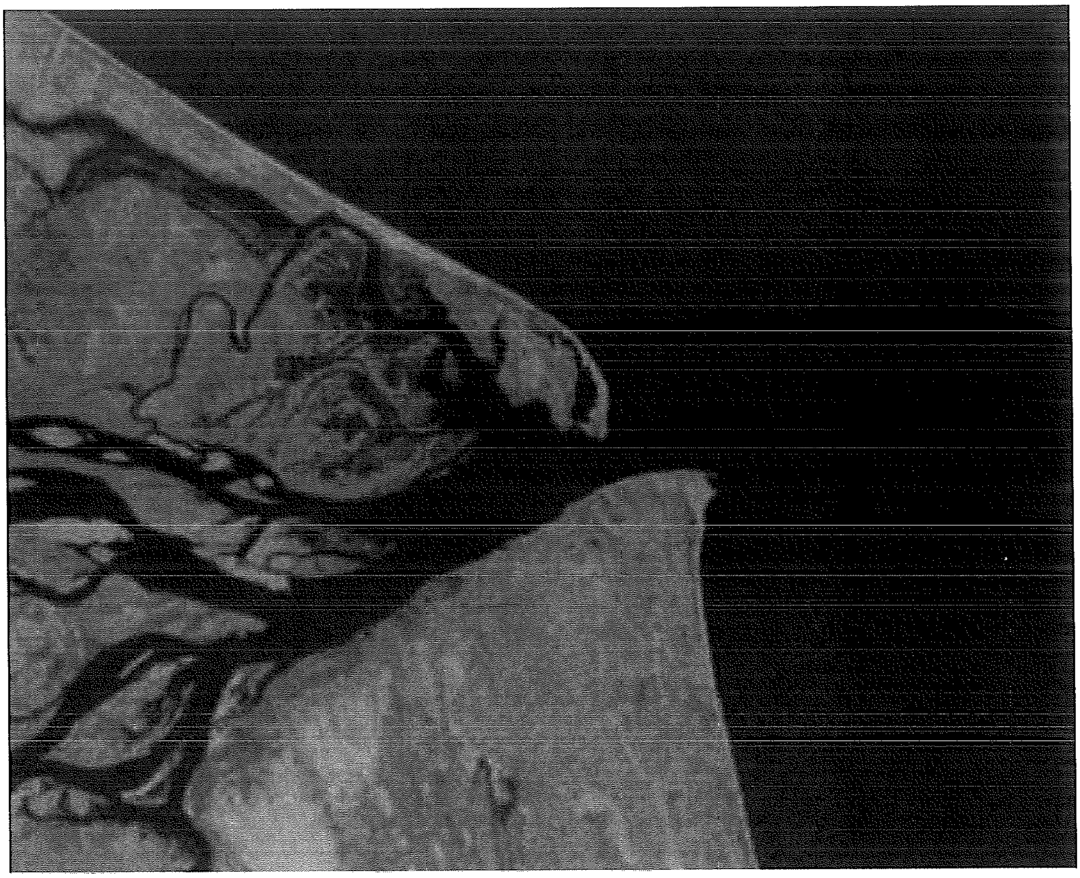


Figure A.2: Hoi An coastline 2000

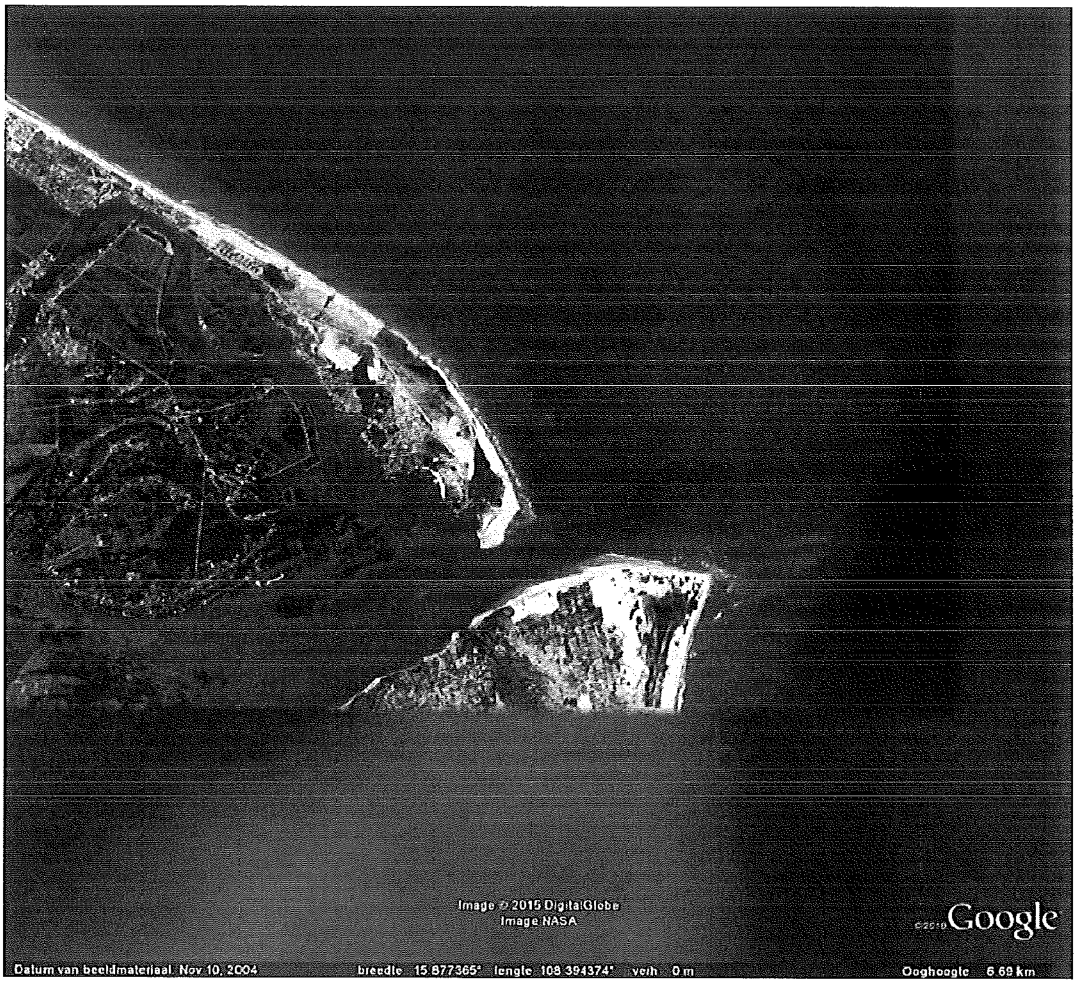


FIGURE A.3: Hoi An coastline 2004

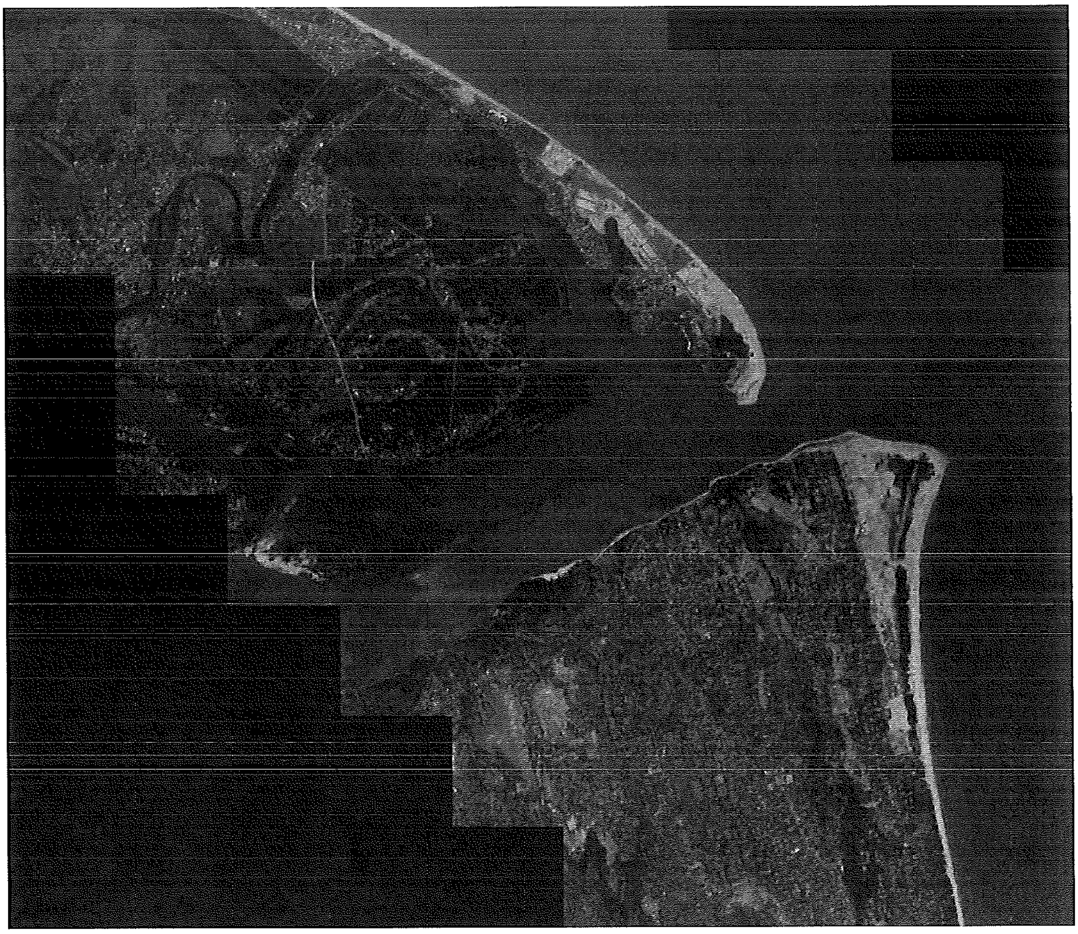


FIGURE A.4: Hoi An coastline 2008

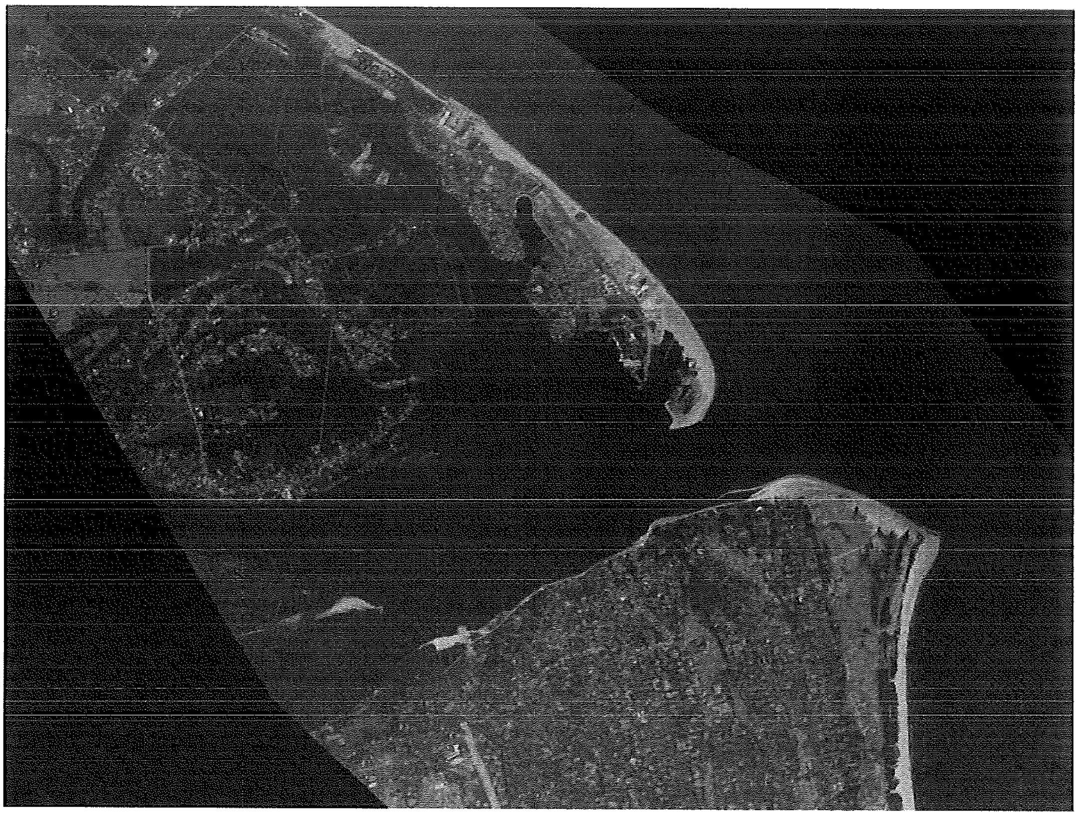


FIGURE A.5: Hoi An coastline 2010

FIGURE A.6: Hoi An coastline 2011

FIGURE A.7: Hoi An coastline 2012

FIGURE A.8: Hoi An coastline 2014

Figure A.9: Hoi An coastline 2015

A.2 Erosion at the area 3-4 km north of the river mouth

FIGURE A.10: A Hoi An beach resort, situation 10-11-2004

FIGURE A.11: A Hoi An beach resort, situation 8-4-2011

FIGURE A.12: A Hoi An beach resort, situation 10-4-2012

FIGURE A.13: A Hoi An beach resort, situation 1-3-2014

FIGURE A.14: A Hoi An beach resort, situation 15-3-2015

A.3 Erosion at the area 2-3 km north of the river mouth

FIGURE A.15: A Hoi An beach resort, situation 10-11-2004

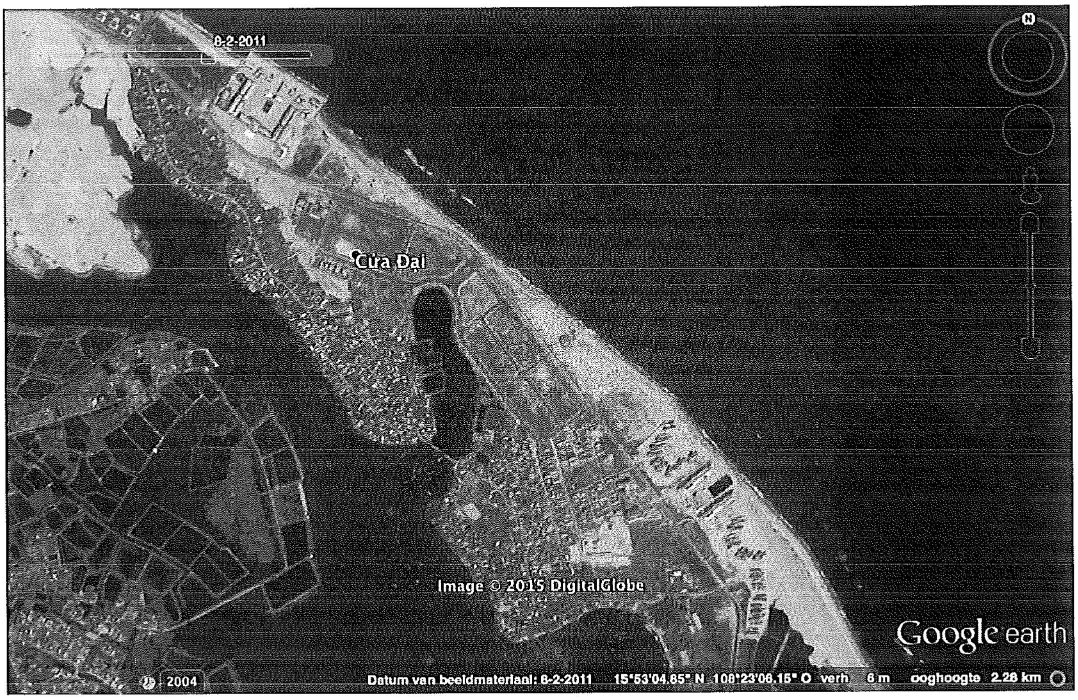


FIGURE A.16: A Hoi An beach resort, situation 8-2-2011

FIGURE A.17: A Hoi An beach resort, situation 10-4-2012

FIGURE A.18: A Hoi An beach resort, situation 1-3-2014

FIGURE A.19: A Hoi An beach resort, situation 15-3-2015

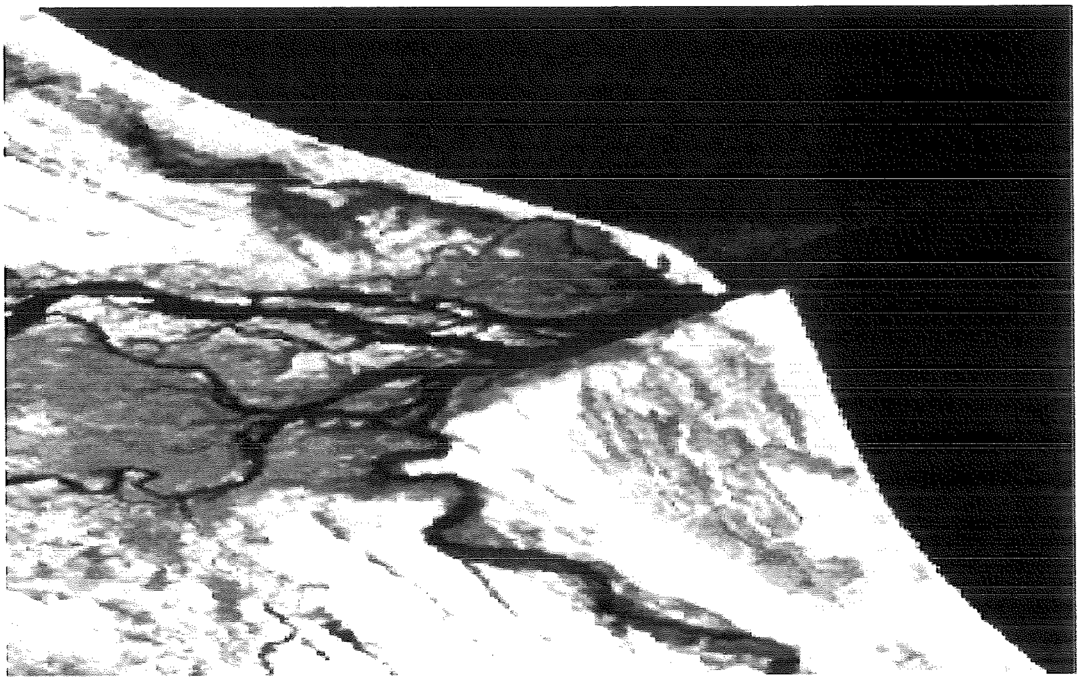


FIGURE A.20: Overview of the Hoi An coastline in 1973

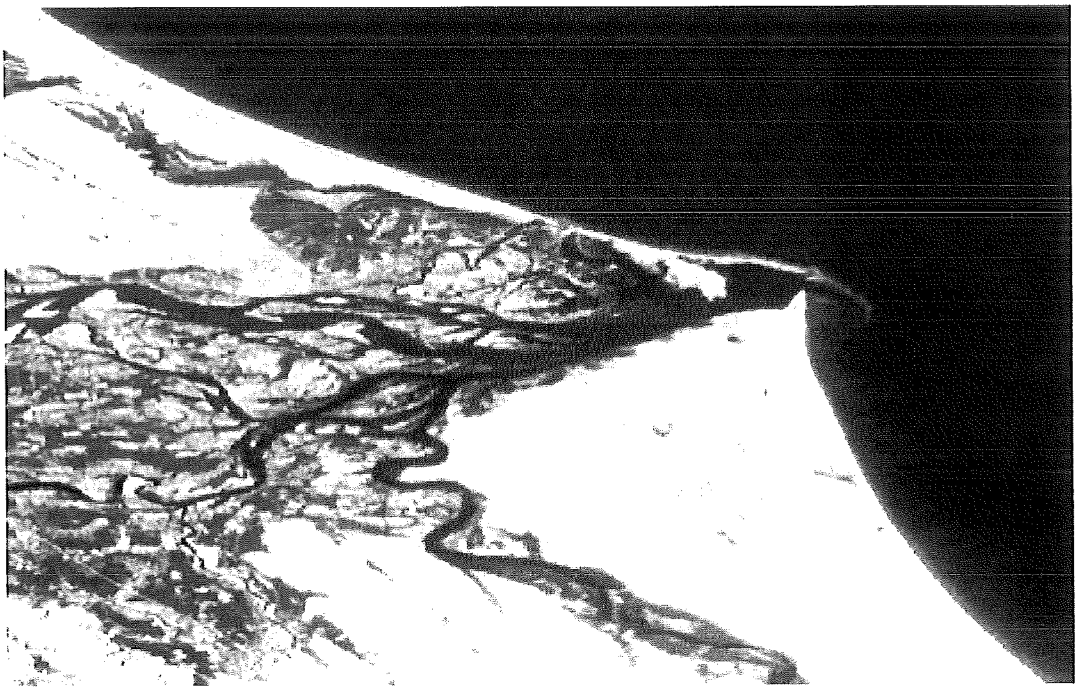


FIGURE A.21: Overview of the Hoi An coastline in 1990

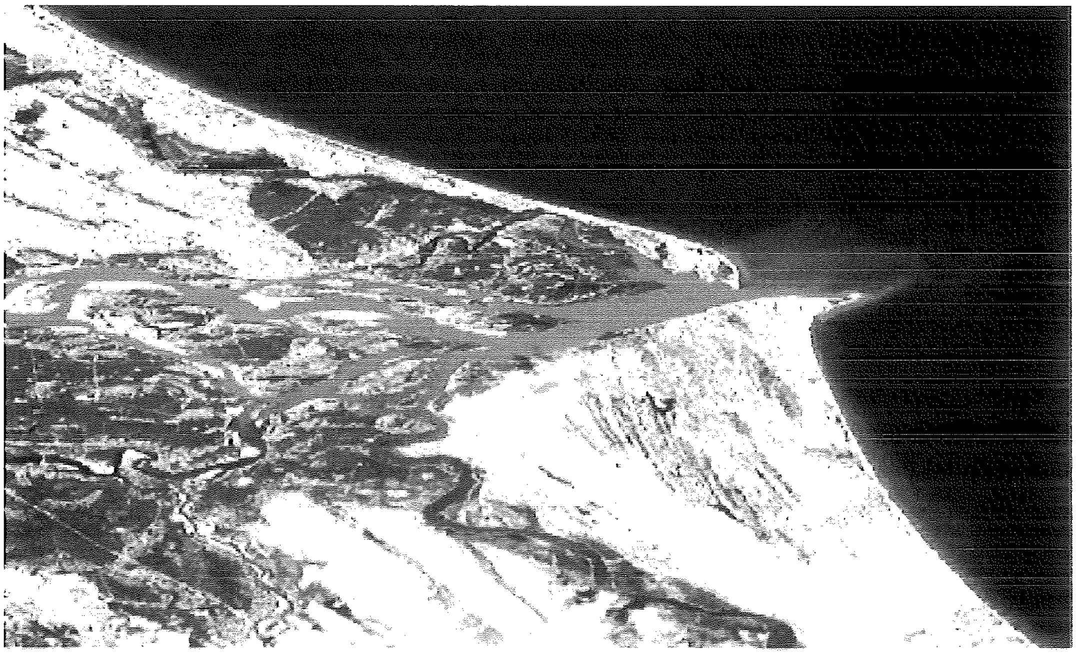


FIGURE A.22: Overview of the Hoi An coastline in 2001

FIGURE A.23: Overview of the Hoi An coastline in 2007

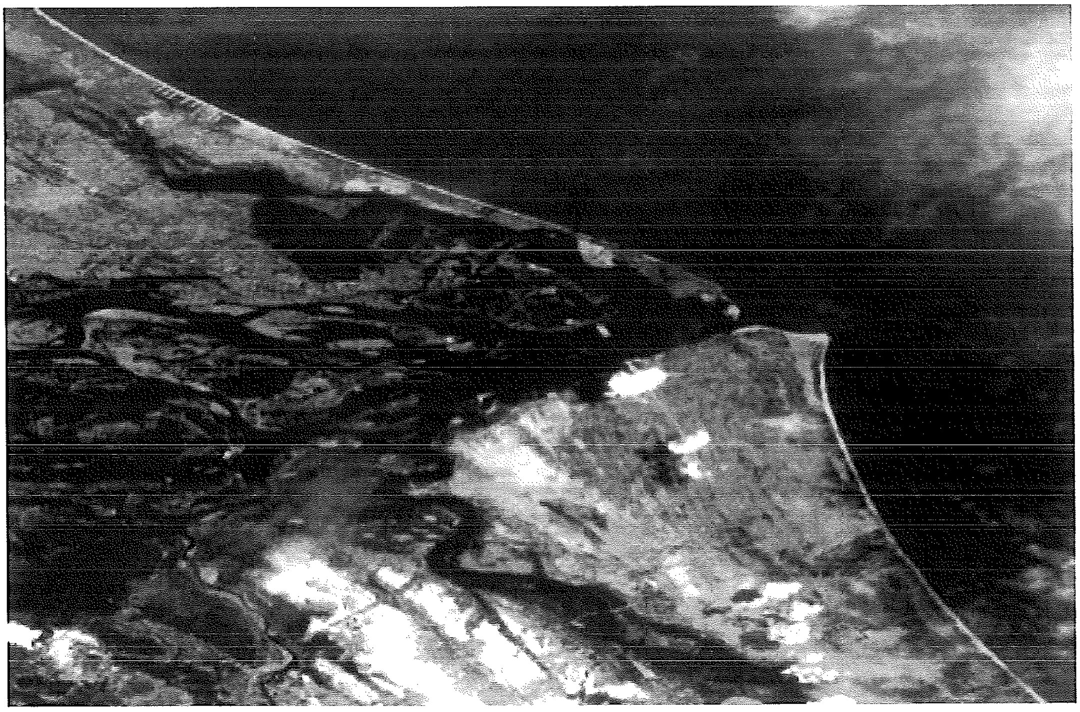


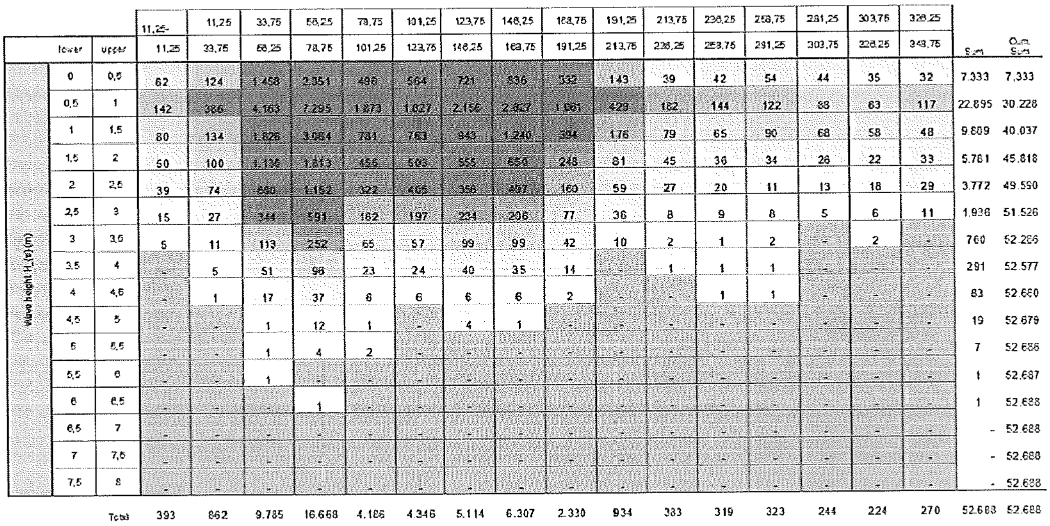
FIGURE A.24: Overview of the Hoi An coastline in 2013

Appendix B

Data

TABLE B.1: Wave climate 100 km offshore of the Hoi An coast. The data is obtained between 01/01/1996 and 31 / 12/2005 by Fugro. Witch significant wave height $H_s = 2.28[m]$

	0 - 30	30 - 60	60 - 90	90 - 120	120 - 150	150 - 180	180 - 210	210 - 240	240 - 270	270 - 300	300 - 330	330 - 360	Total
0.0- 0.5	3	18	163	182	173	158	49	2	0	1	8	4	761
0.5- 1.0	31	645	2085	771	821	1408	407	13	7	9	13	9	6219
1.0- 1.5	55	997	1376	242	296	352	158	20	8	4	5	10	3523
1.5- 2.0	47	916	413	5	16	30	27	7	6	1	1	12	1481
2.0- 2.5	34	896	181	3	4	7	1	1	1	0	0	16	1144
2.5- 3.0	30	564	63	5	1	5	0	0	0	0	1	13	682
3.0- 3.5	12	335	38	2	0	0	0	0	0	0	0	1	388
3.5- 4.0	10	178	16	0	0	0	0	0	0	0	0	2	206
4.0- 4.5	7	99	2	1	0	0	0	0	0	0	0	0	109
4.5- 5.0	7	56	2	0	0	0	0	0	0	0	0	0	65
5.0- 5.5	0	24	0	0	0	0	0	0	0	0	0	1	25
5.5- 6.0	1	3	0	0	0	0	0	0	0	0	0	0	4
6.0 - 6.5	1	1	0	0	0	0	0	0	0	0	0	0	2
6.5 - 7.0	0	0	1	0	0	0	0	0	0	0	0	0	1
7.0 - 7.5	0	0	0	0	0	0	0	0	0	0	0	0	0
7.5 - 8.0	0	2	0	0	0	0	0	0	0	0	0	0	2
Total	238	4734	4340	1211	1311	1960	642	43	22	15	28	68	14612



	lower	upper	11,25- 11,25	11,25 33,75	33,75 56,25	56,25 78,75	78,75 101,25	101,25 123,75	123,75 146,25	146,25 168,75	168,75 191,25	191,25 213,75	213,75 236,25	236,25 258,75	258,75 281,25	281,25 303,75	303,75 326,25	326,25 348,75	Sum	Cum. Sum
Wave height H_(s)(m)	0	0,5	62	124	1.458	2.351	496	564	721	836	332	143	39	42	54	44	35	32	7.333	7.333
	0,5	1	142	386	4.163	7.295	1.873	1.827	2.156	2.827	1.061	429	182	144	122	83	63	117	22.895	30.228
	1	1,5	80	134	1.826	3.084	781	763	943	1.240	394	176	79	65	90	68	58	48	9.809	40.037
	1,5	2	50	100	1.130	1.813	455	503	555	650	248	81	45	36	34	26	22	33	5.781	45.818
	2	2,5	39	74	680	1.152	322	405	356	407	160	59	27	20	11	13	18	29	3.772	49.590
	2,5	3	15	27	344	591	162	197	234	206	77	36	8	9	8	5	6	11	1.936	51.526
	3	3,5	5	11	113	252	65	57	99	99	42	10	2	1	2	-	2	-	760	52.286
	3,5	4	-	5	51	96	23	24	40	35	14	-	1	1	1	-	-	-	291	52.577
	4	4,5	-	1	17	37	6	6	6	6	2	-	-	1	1	-	-	-	83	52.660
	4,5	5	-	-	1	12	1	-	4	1	-	-	-	-	-	-	-	-	19	52.679
	5	5,5	-	-	1	4	2	-	-	-	-	-	-	-	-	-	-	-	7	52.686
	5,5	6	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	52.687
	6	6,5	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	1	52.688
	6,5	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	52.688
	7	7,5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	52.688
	7,5	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	52.688
		Total	393	862	9.785	16.668	4.186	4.346	5.114	6.307	2.330	934	383	319	323	244	224	270	52.688	52.688

FIGURE B.1: Wave climate at coordinates Lon: 108,75 lat: 15,75. With significant wave height $H_s = 1,98[m]$

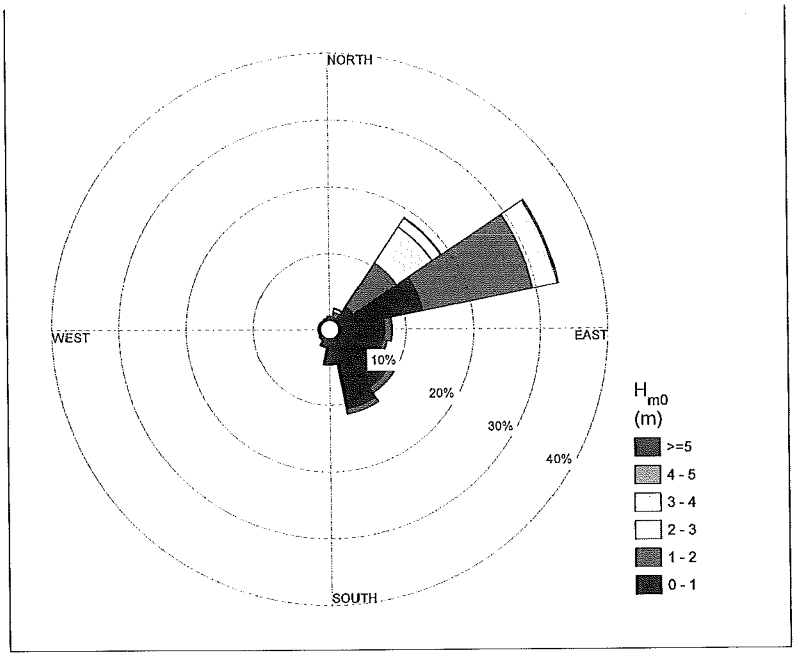
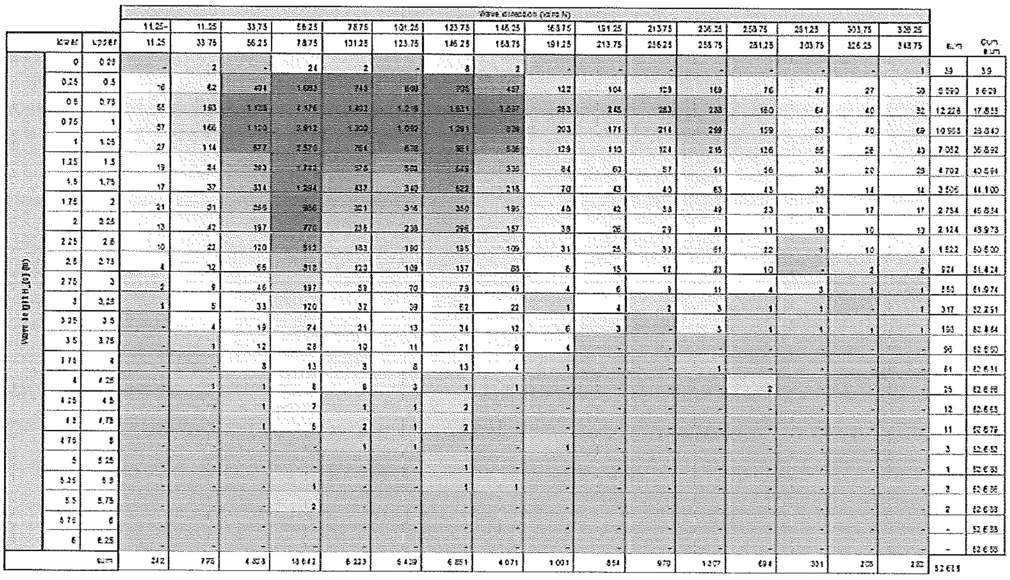


FIGURE B.2: Wave rose of the wave climate at coordinates Lon: 108,75 lat: 15,75. With significant wave height $H_s = 1,98[m]$



Wave height H_m0 (m)		Wave direction (deg N)																	
		11.25-	11.25	33.75	56.25	78.75	101.25	123.75	146.25	168.75	191.25	213.75	236.25	258.75	281.25	303.75	326.25		
lower	upper	11.25	33.75	56.25	78.75	101.25	123.75	146.25	168.75	191.25	213.75	236.25	258.75	281.25	303.75	326.25	348.75	sum	Cum. sum
0	0.25	-	2	-	21	2	-	8	2	-	-	-	-	-	-	-	1	39	39
0.25	0.5	16	62	491	1.093	743	698	976	457	122	104	129	169	76	47	27	33	5 590	5 629
0.5	0.75	55	193	1.128	4.376	1.402	1.216	1.631	1.037	253	245	283	238	160	64	40	32	12 226	17 855
0.75	1	57	166	1.120	3.912	1.320	1.092	1.291	838	203	171	211	299	159	63	40	69	10 985	28 840
1	1.25	27	114	677	2.570	784	678	951	536	129	110	124	215	126	55	28	43	7 052	35 892
1.25	1.5	19	84	393	1.722	978	592	643	335	84	60	57	91	56	34	20	23	4 702	40 594
1.5	1.75	17	37	331	1.294	437	342	622	215	70	43	40	63	43	20	14	12	3 506	44 100
1.75	2	21	51	296	986	321	316	350	195	46	42	38	49	23	12	17	17	2 734	46 834
2	2.25	13	42	197	776	235	238	296	157	38	26	29	41	11	10	10	10	2 124	48 958
2.25	2.5	10	22	120	512	183	190	195	109	31	25	33	41	22	1	10	8	1 522	50 480
2.5	2.75	4	12	65	318	123	109	137	63	6	15	12	23	10	-	2	2	924	51 404
2.75	3	2	9	46	197	53	70	79	49	4	6	9	11	4	3	1	1	550	51 954
3	3.25	1	5	33	120	37	39	62	22	1	4	2	3	1	1	-	1	317	52 271
3.25	3.5	-	4	19	74	21	13	34	12	6	3	-	3	1	1	1	1	193	52 464
3.5	3.75	-	1	12	28	10	11	21	9	4	-	-	-	-	-	-	-	96	52 560
3.75	4	-	-	3	13	3	8	13	4	1	-	-	1	-	-	-	-	51	52 611
4	4.25	-	1	1	8	6	3	1	1	-	-	-	-	2	-	-	-	25	52 636
4.25	4.5	-	-	1	7	1	1	2	-	-	-	-	-	-	-	-	-	12	52 648
4.5	4.75	-	-	1	5	2	1	2	-	-	-	-	-	-	-	-	-	11	52 659
4.75	5	-	-	-	-	1	1	-	-	1	-	-	-	-	-	-	-	3	52 662
5	5.25	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1	52 663
5.25	5.5	-	-	-	1	-	-	1	1	-	-	-	-	-	-	-	-	3	52 666
5.5	5.75	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	2	52 668
5.75	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	52 668
6	6.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	52 668
	sum	242	775	4 808	18 642	6 223	5 439	6 851	4 071	1 001	854	979	1 357	694	301	205	282	52 615	

FIGURE B.3: Wave climate at coordinates Lon: 108,75 lat: 16,50. With significant wave height $H_s = 1,87[m]$

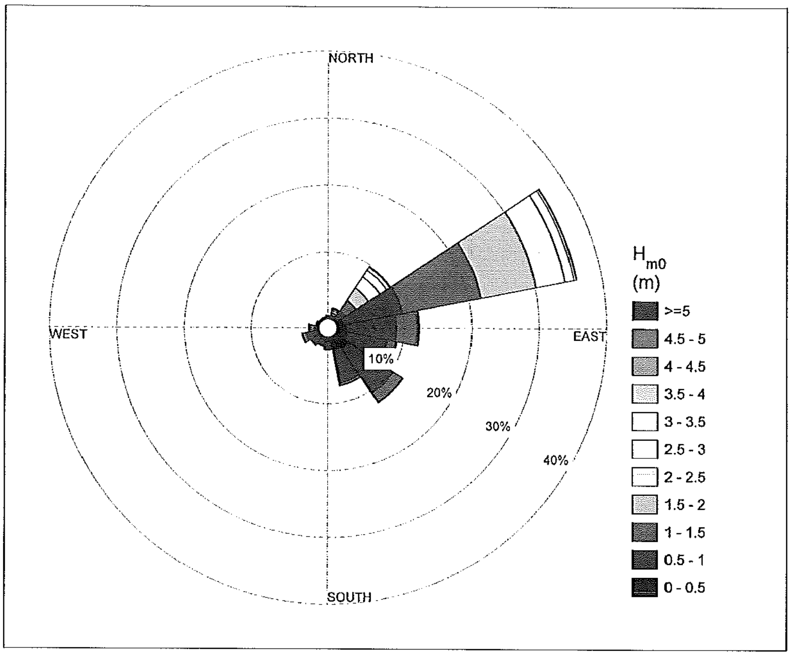
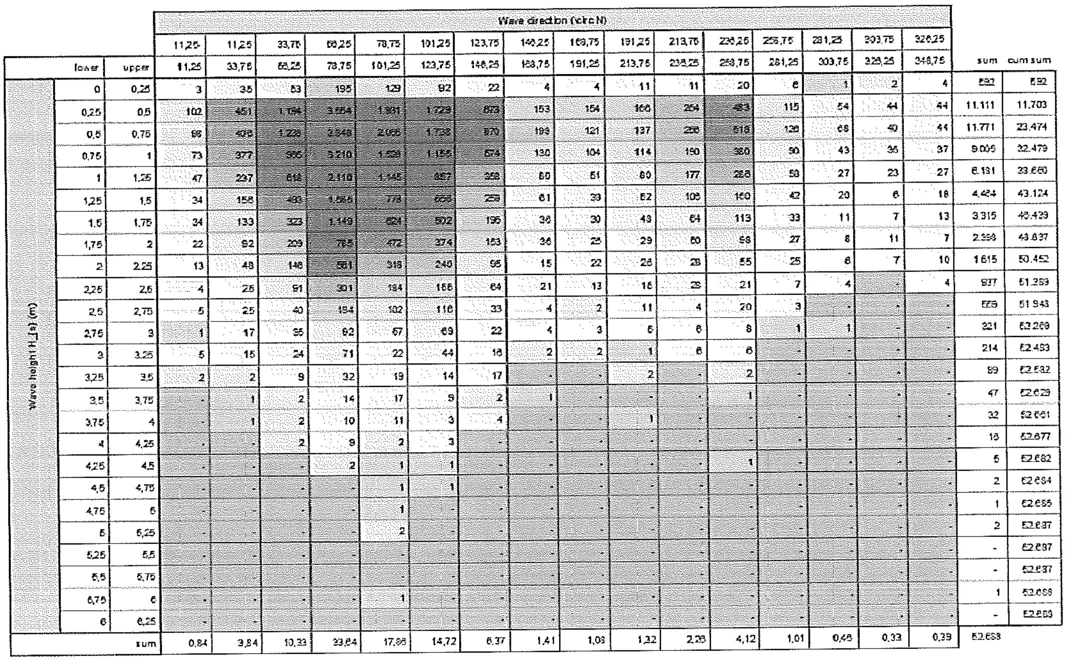


FIGURE B.4: Wave rose of the wave climate at coordinates Lon: 108,75 lat: 16,50. With significant wave height $H_s = 1,87[m]$



			Wave direction (°drc N)																
			11,25-	11,25	33,75	56,25	78,75	101,25	123,75	146,25	168,75	191,25	213,75	236,25	258,75	281,25	303,75	326,25		
	lower	upper	11,25	33,75	56,25	78,75	101,25	123,75	146,25	168,75	191,25	213,75	236,25	258,75	281,25	303,75	326,25	348,75	sum	cum sum
Wave height H_(s) (m)	0	0,25	3	35	53	195	129	92	22	4	4	11	11	20	6	1	2	4	592	592
	0,25	0,5	102	451	1.194	3.554	1.931	1.729	673	153	154	166	254	483	115	54	44	44	11.111	11.703
	0,5	0,75	98	476	1.228	2.848	2.065	1.738	870	193	121	137	256	518	128	68	40	44	11.771	23.474
	0,75	1	73	377	965	3.210	1.529	1.156	674	130	104	114	150	380	90	43	36	37	9.005	32.479
	1	1,25	47	237	618	2.110	1.145	857	358	80	51	80	177	228	58	27	23	27	6.181	38.660
	1,25	1,5	34	158	493	1.565	778	656	259	61	39	62	108	160	42	20	6	18	4.464	43.124
	1,5	1,75	34	133	323	1.149	624	502	195	36	30	43	64	113	33	11	7	13	3.315	46.439
	1,75	2	22	92	209	785	472	374	153	36	25	29	50	58	27	8	11	7	2.398	48.837
	2	2,25	13	48	148	561	318	240	95	15	22	26	28	55	25	6	7	10	1.615	50.452
	2,25	2,5	4	25	91	301	184	156	64	21	13	16	29	21	7	4	-	4	937	51.389
	2,5	2,75	5	25	40	194	102	116	33	4	2	11	4	20	3	-	-	-	559	51.948
	2,75	3	1	17	35	82	67	69	22	4	3	5	6	8	1	1	-	-	321	52.269
	3	3,25	5	15	24	71	22	44	16	2	2	1	6	6	-	-	-	-	214	52.483
	3,25	3,5	2	2	9	32	19	14	17	-	-	2	-	2	-	-	-	-	99	52.582
	3,5	3,75	-	1	2	14	17	9	2	1	-	-	-	1	-	-	-	-	47	52.629
	3,75	4	-	1	2	10	11	3	4	-	-	1	-	-	-	-	-	-	32	52.661
	4	4,25	-	-	2	9	2	3	-	-	-	-	-	-	-	-	-	-	16	52.677
	4,25	4,5	-	-	-	2	1	1	-	-	-	-	-	1	-	-	-	-	5	52.682
	4,5	4,75	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	2	52.684
	4,75	5	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1	52.685
	5	5,25	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	2	52.687
	5,25	5,5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	52.687
	5,5	5,75	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	52.687
	5,75	6	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	1	52.688
	6	6,25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	52.688
		sum	0,84	3,84	10,33	23,64	17,98	14,72	6,37	1,41	1,08	1,32	2,28	4,12	1,01	0,48	0,33	0,39	52.688	

FIGURE B.5: Wave climate at coordinates Lon: 108,00 lat: 16,50. With significant wave height $H_s = 1.69[m]$

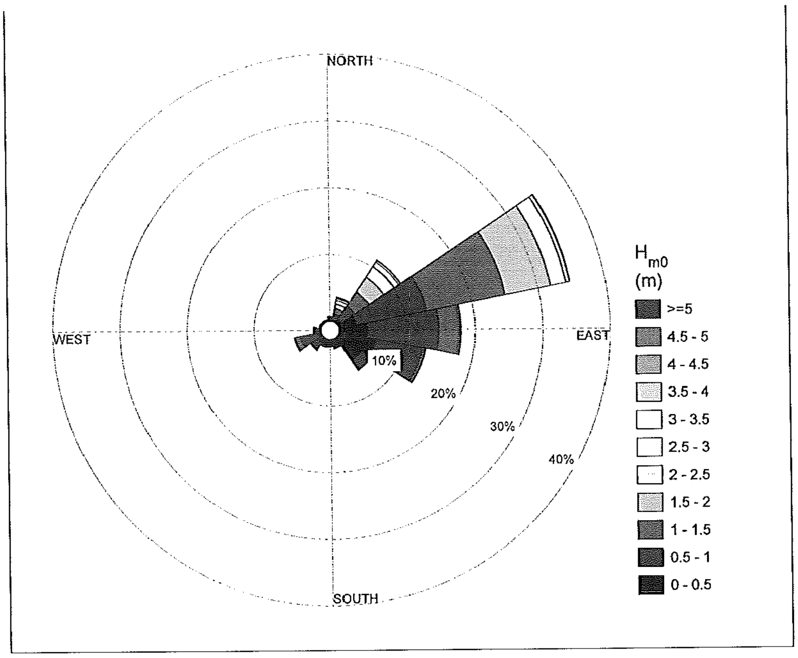
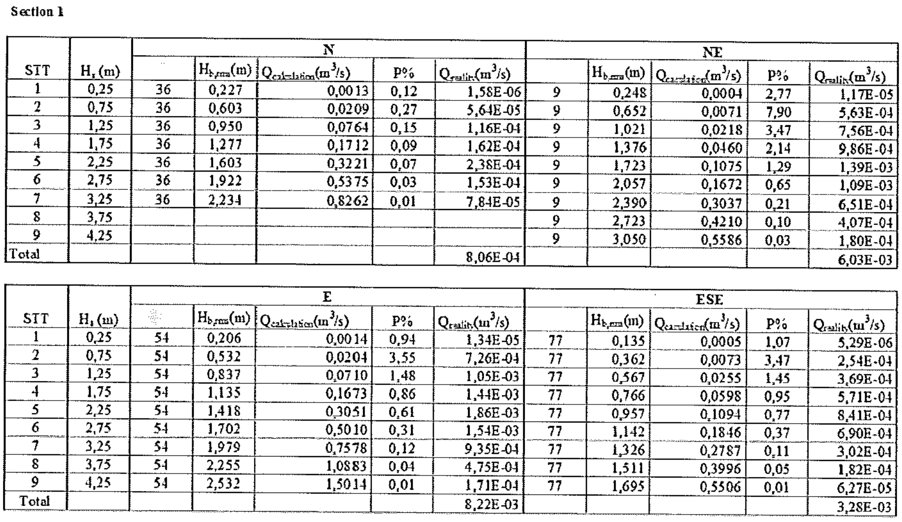


FIGURE B.6: Wave rose of the wave climate at coordinates Lon: 108,00 lat: 16,50. With significant wave height $H_s = 1.69[m]$

Appendix C

Calculations

In this appendix the results of several calculations are presented.

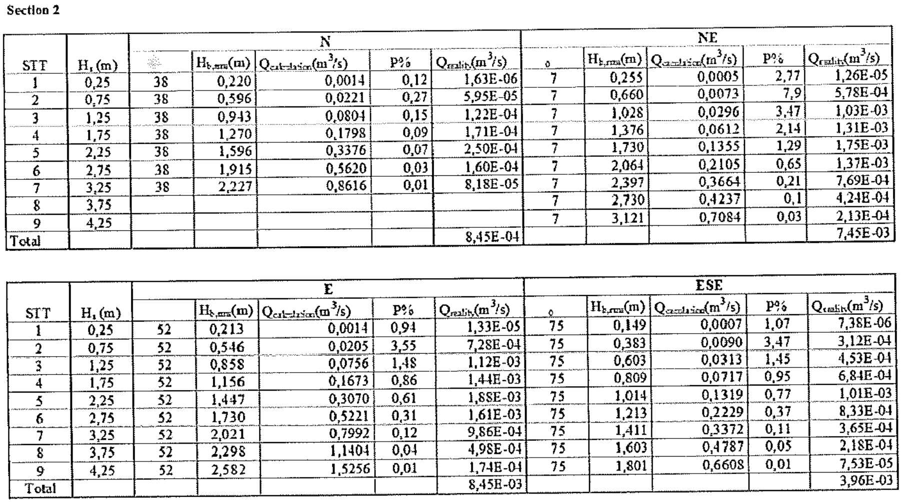


Section 1

STT	H_s (m)	N					NE				
			$H_{b,rms}$(m)	$Q_{calculation}$(m^3/s)	P%	$Q_{reality}$(m^3/s)		$H_{b,rms}$(m)	$Q_{calculation}$(m^3/s)	P%	$Q_{reality}$(m^3/s)
1	0,25	36	0,227	0,0013	0,12	1,58E-06	9	0,248	0,0004	2,77	1,17E-05
2	0,75	36	0,603	0,0209	0,27	5,64E-05	9	0,652	0,0071	7,90	5,63E-04
3	1,25	36	0,950	0,0764	0,15	1,16E-04	9	1,021	0,0218	3,47	7,56E-04
4	1,75	36	1,277	0,1712	0,09	1,62E-04	9	1,376	0,0460	2,14	9,86E-04
5	2,25	36	1,603	0,3221	0,07	2,38E-04	9	1,723	0,1075	1,29	1,39E-03
6	2,75	36	1,922	0,5375	0,03	1,53E-04	9	2,057	0,1672	0,65	1,09E-03
7	3,25	36	2,234	0,8262	0,01	7,84E-05	9	2,390	0,3037	0,21	6,51E-04
8	3,75						9	2,723	0,4210	0,10	4,07E-04
9	4,25						9	3,050	0,5586	0,03	1,80E-04
Total						8,06E-04					6,03E-03

STT	H_s (m)	E					ESE				
			$H_{b,rms}$(m)	$Q_{calculation}$(m^3/s)	P%	$Q_{reality}$(m^3/s)		$H_{b,rms}$(m)	$Q_{calculation}$(m^3/s)	P%	$Q_{reality}$(m^3/s)
1	0,25	54	0,206	0,0014	0,94	1,34E-05	77	0,135	0,0005	1,07	5,29E-06
2	0,75	54	0,532	0,0204	3,55	7,26E-04	77	0,362	0,0073	3,47	2,54E-04
3	1,25	54	0,837	0,0710	1,48	1,05E-03	77	0,567	0,0255	1,45	3,69E-04
4	1,75	54	1,135	0,1673	0,86	1,44E-03	77	0,766	0,0598	0,95	5,71E-04
5	2,25	54	1,418	0,3051	0,61	1,86E-03	77	0,957	0,1094	0,77	8,41E-04
6	2,75	54	1,702	0,5010	0,31	1,54E-03	77	1,142	0,1846	0,37	6,90E-04
7	3,25	54	1,979	0,7578	0,12	9,35E-04	77	1,326	0,2787	0,11	3,02E-04
8	3,75	54	2,255	1,0883	0,04	4,75E-04	77	1,511	0,3996	0,05	1,82E-04
9	4,25	54	2,532	1,5014	0,01	1,71E-04	77	1,695	0,5506	0,01	6,27E-05
Total						8,22E-03					3,28E-03

FIGURE C.1: Table with the results of the CERC calculations for longshore sediment transport rates for section 1. The numbers are in m^3/s



Section 2

STT	H_s (m)	N					NE				
			$H_{b,rms}$(m)	$Q_{calculation}$(m^3/s)	P%	$Q_{reality}$(m^3/s)	o	$H_{b,rms}$(m)	$Q_{calculation}$(m^3/s)	P%	$Q_{reality}$(m^3/s)
1	0,25	38	0,220	0,0014	0,12	1,63E-06	7	0,255	0,0005	2,77	1,26E-05
2	0,75	38	0,596	0,0221	0,27	5,95E-05	7	0,660	0,0073	7,9	5,78E-04
3	1,25	38	0,943	0,0804	0,15	1,22E-04	7	1,028	0,0296	3,47	1,03E-03
4	1,75	38	1,270	0,1798	0,09	1,71E-04	7	1,376	0,0612	2,14	1,31E-03
5	2,25	38	1,596	0,3376	0,07	2,50E-04	7	1,730	0,1355	1,29	1,75E-03
6	2,75	38	1,915	0,5620	0,03	1,60E-04	7	2,064	0,2105	0,65	1,37E-03
7	3,25	38	2,227	0,8616	0,01	8,18E-05	7	2,397	0,3664	0,21	7,69E-04
8	3,75						7	2,730	0,4237	0,1	4,24E-04
9	4,25						7	3,121	0,7084	0,03	2,13E-04
Total						8,45E-04					7,45E-03

STT	H_s (m)	E					ESE				
			$H_{b,rms}$(m)	$Q_{calculation}$(m^3/s)	P%	$Q_{reality}$(m^3/s)	o	$H_{b,rms}$(m)	$Q_{calculation}$(m^3/s)	P%	$Q_{reality}$(m^3/s)
1	0,25	52	0,213	0,0014	0,94	1,33E-05	75	0,149	0,0007	1,07	7,38E-06
2	0,75	52	0,546	0,0205	3,55	7,28E-04	75	0,383	0,0090	3,47	3,12E-04
3	1,25	52	0,858	0,0756	1,48	1,12E-03	75	0,603	0,0313	1,45	4,53E-04
4	1,75	52	1,156	0,1673	0,86	1,44E-03	75	0,809	0,0717	0,95	6,84E-04
5	2,25	52	1,447	0,3070	0,61	1,88E-03	75	1,014	0,1319	0,77	1,01E-03
6	2,75	52	1,730	0,5221	0,31	1,61E-03	75	1,213	0,2229	0,37	8,33E-04
7	3,25	52	2,021	0,7992	0,12	9,86E-04	75	1,411	0,3372	0,11	3,65E-04
8	3,75	52	2,298	1,1404	0,04	4,98E-04	75	1,603	0,4787	0,05	2,18E-04
9	4,25	52	2,582	1,5256	0,01	1,74E-04	75	1,801	0,6608	0,01	7,53E-05
Total						8,45E-03					3,96E-03

FIGURE C.2: Table with the results of the CERC calculations for longshore sediment transport rates for section 2. The numbers are in m^3/s

Bibliography

[1] Martijn Onderwater and Ian Benton. Hoi an south development limited. Technical report, Hyder Consulting Limited & Arcadis, January 2015.

[2] Tien Nghiem Lam. *Hydrodynamics and Morphodynamics of a seasonally forced tidal inlet system.* PhD thesis, Delft University of Technology, 2009.

List of Figures

List of Tables