# Coastal erosion Hoi An

## Multidisciplinary project

Delft University of Technology

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Challenge the future

# Multidisciplinary project

*Coastal erosion along Hoi An beach*


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# Table of Contents


Table of Contents ..... ii
Acknowledgements ..... iv
Summary ..... v
1. Introduction ..... 1
2. Problem definition ..... 2
2.1 Problem description ..... 2
2.2 Project goal ..... 3
2.3 System boundaries ..... 3
3. Hoi An coastal system ..... 5
3.1 Evolution of the coast ..... 5
3.2 River influence ..... 7
3.3 Shoreline movements ..... 8
4. Stakeholder analysis ..... 11
4.1 Problems and goals ..... 11
4.2 Power interest diagram ..... 13
5. Reasons for shoreline retreat ..... 14
5.1 Human impacts ..... 14
5.2 Natural causes ..... 15
5.3 Natural variation ..... 16
5.4 Hypotheses ..... 17
6. Solutions ..... 19
6.1 Strategy to deal with coastal erosion ..... 19
6.2 Solution requirements ..... 19
6.3 Results of analysis of possible measures ..... 21
6.4 Three alternatives ..... 22
6.5 Nourishment strategy ..... 24
6.6 Quick solutions ..... 25
6.7 Beach policy ..... 25
7. Conclusion and recommendations ..... 28
7.1 Conclusion ..... 28
7.2 Recommendations ..... 29
References ..... 31
List of figures ..... 37
A. Area ..... 40
A.1 Vietnam and Hoi An ..... 40
A.2 Study area ..... 42
A.3 Cham Island protected area ..... 43

A.4 Coastal erosion problems in Vietnam ........ 44
A.5 Legal aspects ........ 45
B. Stakeholders ........ 47
B.1 Interviews ........ 47
B.2 Interviews conclusion ........ 63
B.3 Stakeholder problem statements and goal trees ........ 64
B.4 Estimation of hotel values ........ 73
C. Coastal system ........ 74
C.1 Bruun Rule ........ 74
C.2 CERC formula ........ 75
C.3 Bathymetry ........ 76
C.4 Wave climate ........ 77
C.5 Tide ........ 78
C.6 Sand Balance ........ 79
C.7 Erosion rate estimates ........ 80
D. Estimates of river sediment supply ........ 81
E. Research into reasons for shoreline retreat ........ 86
E.1 Human impacts ........ 86
E.2 Natural causes ........ 92
E.3 Natural variation ........ 95
F. Currently applied solutions ........ 104
F.1 Applied solutions ........ 104
F.2 Failure of seawalls and revetments ........ 109
G. Erosion prevention possibilities ........ 113
G.1 Systematic criteria and option finding ........ 113
G.2 Hard versus soft measures ........ 117
G.3 Possible measures ........ 118
G.4 Multi criteria analysis ........ 123
H. Main alternatives + nourishment strategy ........ 126
H.1 Large sand nourishment ........ 126
H.2 Medium nourishment + groynes ........ 128
H.3 Small nourishment + revetment ........ 134
H.4 Nourishment strategy ........ 139
H.5 Beach policy ........ 143
I. Measurements ........ 147
I.1 Measurement stick ........ 147
I.2 Thu Bon river observations ........ 149
I.3 Sediment samples analysis ........ 150

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# Summary


Severe erosion of Cua Dai Beach, with its many resorts, hotels and restaurants, has become a huge issue for Hoi An. The shoreline variation became problematic since the construction of the first buildings along the beach and currently it is costly to adapt to the retreating coastline. To overcome the current problems, the goal of this project is to present three economic and technical durable options which are supported by the community and will recreate Cua Dai Beach.

The coastal system around Cua Dai Beach extends from Tam Ky until Danang and includes Cham Island. Cham increases the complexity by blocking certain wave directions and influencing sediment movements. Satellites have recorded large changes in the coastline in the past decades, from an onshore migrating sand bank to the formation of a spit and its erosion. Two dominant wave climates are identified causing a net northward directed sediment transport.

There are several contributors to the recent erosion rate: sea level rise (5%), increasing storms (5-25%), sand mining (40-80%), dam construction (5%) and natural variation (10-50%). The following were excluded as significant reasons for the current erosion: changes in watershed, deforestation, land subsidence due to groundwater extraction, tectonic subsidence, changes in near shore underwater conditions and sediment blockage by hydropower dams, although the latter could be of influence in the future. To explain the current erosion rate three hypotheses are presented. The first hypothesis focuses on the increasing amount of storms in combination with a reduced river supply, the second hypothesis has the decrease of the sediment supply from the river as sole main cause and the third hypothesis considers natural variation in combination with a reduced river supply. All hypotheses account for erosion due to sea level rise. The hypotheses differ in predictions of the future erosion. With the first hypothesis it is uncertain if the current erosion will increase or decrease, with the second there is continued erosion at the current rate while the third is likely to see a continued erosion at a reduced rate.

To halt structural erosion without shifting the drawbacks only combinations with sand nourishments followed from the multi criteria analysis as feasible options. Therefore three nourishment alternatives are suggested to restore Cua Dai beach, whereby a high attractiveness of a certain alternative is considered highly important. The costs of the solutions are between yearly costs of €1.3 and €2.1 million when averaged over a twenty year period. The first alternative, a large beach nourishment without extra structures, has the advantage of combining well with current measures and having an attractive wide beach. The disadvantages are that it needs a large initial investment and the solution is feels less safe. As second alternative a medium sand nourishment with groynes as sediment retaining structures is suggested. The advantages of this alternative are that the beach in front of the resorts is easily maintained and a smaller beach width is needed between the groynes to deal with the structural erosion. The disadvantages are that constructing multiple stone groynes in combination with a sand nourishment is costly. A small sand nourishment combined with a revetment is suggested as third alternative. It has the advantage of giving a good protection against incidental storm erosion. In addition, it creates a safer feeling for the local people and also a part of such a revetment is already present. However, some disadvantages are that the beach might not always be present after a storm and that the movement of tourists and other people onto the beach is less fluent.

To execute any of the current solutions the most financially attractive source location for sand with properties comparable to the current beach sand has to be found. Possible locations are in front of the mouth and further offshore. Furthermore, more data about the local currents and waves is preferred for making a reliable model that predicts the effects of sand nourishments. Until that moment, small nourishments should be used as maintenance solutions to prevent further problems. All options and maintenance solutions should be combined with a proper beach management to make the implementation of future solutions possible and to prevent future expense for protecting buildings that are built to close to the shore.

# 1. Introduction

Almost all coasts in the world are retreating. Causes are amongst others the rising sea level and increasing storms. However, the erosion rates at Hoi An, Vietnam over the last few years are alarming and are not likely to be explained by the above phenomena alone. Hoi An is a coastal city lying at the mouth of the Thu Bon river and has around 120,000 inhabitants. In the last twenty years large resorts were built along the famous Cua Dai Beach to provide luxury accommodations for tourists. And now this beach experiences severe erosion.

Although erosion itself does not have to be problematic, it becomes so when money is invested close to the sea and it is difficult to adapt to the retreating shoreline. Furthermore, the beach has changed to such an extent that tourism rates are decreasing. Being one of the most important sectors for Hoi An, the erosion has far reaching consequences. In order to deal with this issue, the total system has to be understood. What is causing the erosion? What problems are created by it? What is the preferred future situation? This study is conducted to answer these questions and to present options to deal with this urgent matter.

The coastal system and its disturbances that are causing the erosion need to be analysed to find the problem. Several causes exist for a landward moving shoreline, which are also applicable to Hoi An. In this study the possible reasons are investigated and quantified in order of magnitudes on their contribution to the erosion rate. This is however one side of the story. If actions needs to be taken, it is important to know what the actions are required to achieve. Interviews with resort managers and questionnaires for the local community will provide a good understanding of the effects of the shoreline retreat on Hoi An. This interview results in so called social problems. Combined with the technical problems, these translates into requirements for solutions. Three alternatives will be reached that fit the boundaries and wishes of the region and are able to bring back Hoi An on the map as popular holiday destination.

The main report consists of an concise overview of the total work that is done in the eight weeks of this study. It starts with a more elaborate problem definition than is given here and the goal that is set for this project in Chapter 2. After that, the social problems, dilemmas and influences of the different stakeholders engaged in the current erosion issue are presented in Chapter 3. The next chapter, chapter 4, describes the coastal system of Hoi An. Amongst others, it shows how the coast has evolved over the past 40 years and how the current shape can be explained by coastal engineering theory. Chapter 5 follows by showing the reasons for shoreline retreat. Although data is limited, it is possible to estimate the influence of different mechanisms on the rate of erosion. Here are also three hypotheses given that can explain the current shoreline movements. Future measures have to counter these hypotheses and fit the requirements that are presented in Chapter 6. Chapter 6 also elaborates on the three alternatives and gives advice for the implementation of the solution in together with a coastal management strategy to prevent similar problems in the future. The main report ends with a conclusion and recommendations for further research.

# 2. Problem definition

This chapter describes why the current situation is problematic and what goal is set for the project. It includes the future perspectives of the Hoi An area and how these affect the problem definition. Furthermore, the research is focussed between certain boundaries, which are also given in this chapter.

## 2.1 Problem description

Figure 2.1 - Erosion problems in Hoi An

Over the last decade Cua Dai Beach at Hoi An has been eroding to an extent that Cua Dai Beach is no longer present and now shore adjacent buildings are threatened. The southern end of Cua Dai Beach has changed substantially and the northern stretch is eroding at an average of 12 m/year (see Chapter 3 for the exact evolution of the coast).  The problem of erosion is twofaced. One side is the threatening of the buildings. Figure 2.2 shows Cua Dai Beach and the large number of hotels and resorts along it. The amount of investments along the beach and their proximity to the sea makes the erosion a large problem. The other side is the loss of an attractive landmark for tourism which reduces the income of the city.

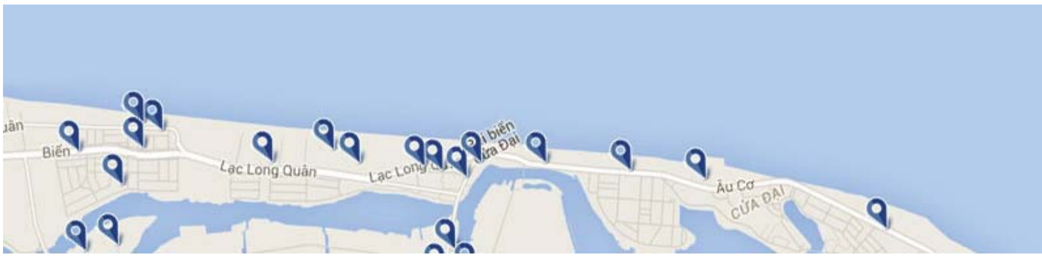



Figure 2.2 - Hotels and resorts at Cua Dai Beach (Booking.com, 2015)

Hoi An lives on tourism. With 64% of the total municipal revenue it is their main source of income and without tourism there is not much left of the city in its current form (hoian-tourism.com, 2013). In 2013 tourism in the Quang Nam province accounted for 3.6 trillion VND or €170 million, which was equal to 10% of the gross provincial product (Vietnam News, 2013). In 2007 Hoi An itself earned revenue from tourism worth VND 950 million or €40 million (UNESCO, 2008). Most tourism in the province is based in, or originates from, Hoi An.  The news of the eroding coast is spreading around the world and the amount of tourists that is visiting Hoi An is already decreasing. This affects the resorts, but also the local inhabitants whose business has shifted to tourism as well. The high amount of tailors, restaurants and homestays cannot survive with a declining rate of tourists (Vietnam News, 2013).

In the future the problem can also occur in other Hoi An areas; in 2012 a bridge is constructed from Hoi An towards the land south of the river. With the beach on the southern side of the river mouth still present, it can be expected that resorts and tourism will settle to this part of the area as well. Although there are no problems with this prospect yet, similar mistakes as for Cua Dai Beach might be made: too much investments too close to the sea. Another perspective Hoi An has to deal with in the future is the changing climate. In the next decades the sea level will rise due to climate change, according to ASEC Consultants sea level rise nearby Hoi An will be 5 mm/year (ASEC Consultants, 2014). In their prediction a quarter of the area of Hoi An will be regularly flooded by the year 2020. Furthermore, typhoons are shifting south and the number arriving at the coast of Vietnam is increasing (DiGregorio, 2015). The increasing amount of typhoons or tropical storms is leading to more extreme wave conditions that can lead to more erosion.

## 2.2 Project goal

The following project goal is defined:

*Presenting at least three economic and technical durable options which are supported by the Hoi An community to recreate the famous Cua Dai Beach.*

The recreation of Cua Dai Beach is necessary to keep the amount of tourists high and to maintain the economy of the Hoi An community and resorts. Important parts of this goal are that the options that will be provided in the end are both economic and technical durable. This implies that only realistic alternatives will be designed which have the possibility of being implemented in Hoi An. Furthermore, the options should be carried by the whole community: local beach users, resorts, fishermen, et cetera. This will set certain boundaries, but will eventually provide better options. Furthermore, avoidance of shifting the problems to adjacent areas is important. The problem is not solved when it is shifted to another place.

To achieve the project goal the following questions have to be answered during the project:

- What does the coastal system in Hoi An look like?
- What are the reasons for shoreline retreat?
- What problems is the erosion causing?
- What are the stakeholders needs and wishes for the future?
- What are the requirements for solutions?
- How to make the options durable?

## 2.3 System boundaries

The boundaries of the system in which the study is conducted are here defined in two stages. First following the size of a province and then following the size level of a town.

### 2.3.1 Provincial level

At the size of a province, the coastal stretch north of Hoi An has a natural boundary at the peninsula near Danang. In the south, the system is similarly bounded. The bounding of the influence is based on the expectancy that those particular points will act as a barrier for sediment. Seawards, the sphere of influence includes the Cham Island for two reasons. First, the island has influence on the wave directions and wave refraction at Hoi An. Second, tourism to the island is likely to rise and decline with the tourism at Hoi An. Another important factor is the Thu Bon river, which flows into the area of interest and carries sediment. The river course has changed in history, but currently the main catchment area for rainfall and sediment of the Thu Bon river is depicted on the left side of Figure 2.3.

Since funds for projects are allocated by the provinces, it is quite important that a shy 12 kilometres north of Hoi An lies the bordering town of Danang, which is a municipality with the status of a province. A province mostly solves its own problems in Vietnam and thus projects will be checked to be beneficial within its own borders. Any fix for Hoi An or Danang would be taken on independently and a local fix which shifts the problem outside its own area is sometimes accepted. This current project does not follow the provincial boundary strictly. If there would be expected effects on the Danang coastal stretch, those will be qualitatively checked as well.

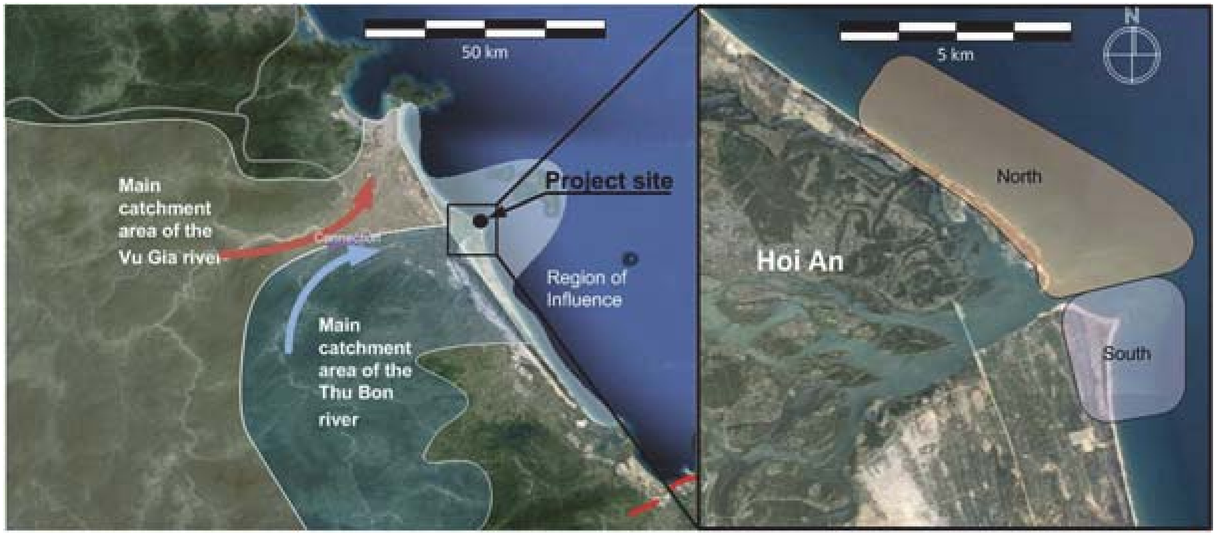



**Figure 2.3 - System boundaries at provincial level (left) and city level (right)**

To summarize the left side of Figure 2.3: in the sphere of influence is the town of Hoi An, the Cham Island, the mouth of the Thu Bon river and the coastal stretch to the points where alongshore sediment transport is expected to be bounded.

### 2.3.2 City level

This report focuses on two smaller areas which together comprise the system, see right side of Figure 2.3. The north part of the system has its inland boundary at the inland river that divides the Cua Dai Beach strip from the city. The south part has its boundary 400 meters inward from the 2015 coastline.

Seawards the system stretches on average around 3 kilometres. It is bounded by the water depth of 18 meters. This water level is the boundary, because from here on the sea bottom is horizontal for a significant stretch (See Appendix C.3 Bathymetry map Hoi An). Two parts in this system have been chosen, because the north part will be treated differently than the south part. This affects what coastal changes are acceptable and is the result from the fact that less invested money has been invested in the south part of the system. The city itself or sand bars landwards of the mouth, fall outside of the system boundaries. At this level of scope, the river will be seen as a supply input parameter for any estimations in the system area.

# 3. Hoi An coastal system

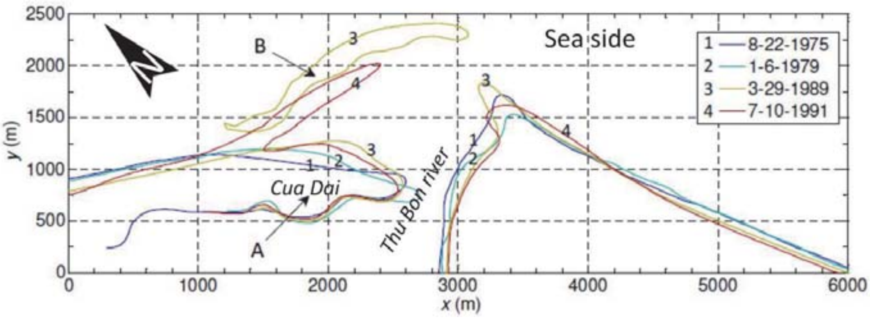
This chapter elaborates on the coastal system around Hoi An. It starts with a description of how the coast has evolved since 1975, using Landsat images to show the movements of the shoreline. After this, the influence of the Thu Bon river on the coastal system is given, together with an estimate of the sediment discharge. Furthermore, some theory about erosion is given. This chapter concludes with a sand balance of the area in front of the coast.

## 3.1 Evolution of the coast

The river mouth of Hoi An has seen much morphological activity in the past. Landsat images were analysed by Hoang, Tanaka, Viet & Duy (2015) to study this activity. Starting from 1975 several changes can be observed. The spit on which Cua Dai beach is situated was relatively small in 1975. It began to widen due to a large sand bank that migrated to the shore and merged with it between 1979 and 1991(see Figure 3.1A). Between 1991 and 2007 the coast featured two spits (see Figure 3.1B). Spit B was the remainder of the sand bank and continued to merge with the coast. Meanwhile on the right side of the river, the sandbank migrates to the right. An outcrop formed on this side between 1995 and 2002. From 2003 to now this outcrop has been eroding quite fast while still migrating to the right (see Figure 3.1C). In the same period erosion can be observed along the whole length of the spit left of the river. In the observed period the cumulative changes are: a spit that has first accreted after 1975 and then eroded back by 2015 to about the same size as it was in 1975; erosion along the left part of the spit; a river migrating right (southward) and a changing shape right (south) of the river.

**(A)**

*Approaching and merging sand bank*




**(B)**

*Double spit formation*

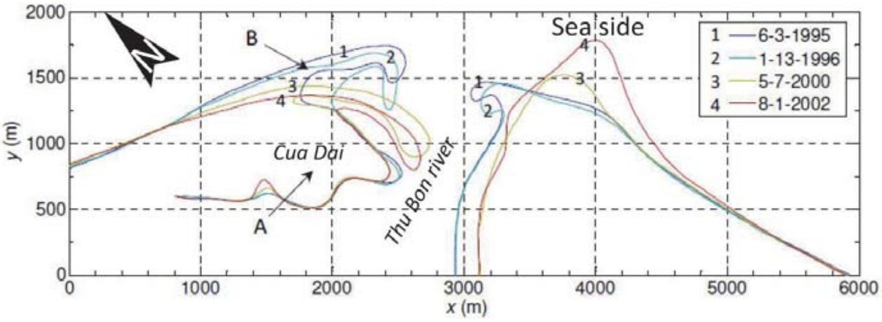
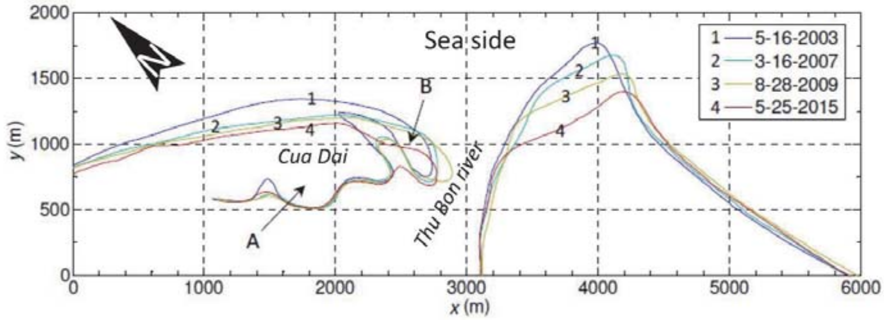



**Figure 3.1 - Evolution of the Hoi An coast based on Landsat images (Hoang, Tanaka, Viet, & Duy, 2015)**

**(C)**

*Overall erosion*




**(D)**

*Overview*

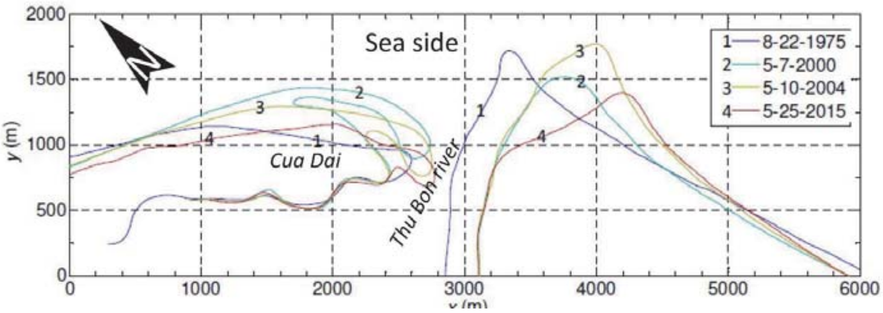
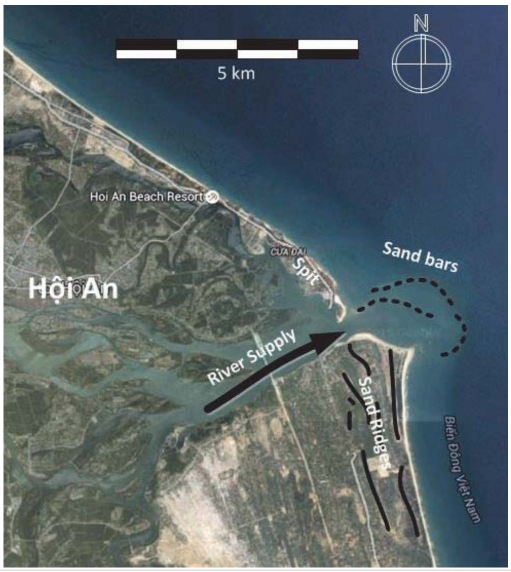



Figure 3.1 - Evolution of the Hoi An coast based on Landsat images (Hoang, Tanaka, Viet, & Duy, 2015)

Coasts form the transition between the sea and land. Their appearance can vary widely depending on the circumstances. However they can be classified by comparing the influence of waves, tides and river supply, see Figure 3.3 (Boyd, Dalrymple, & Zaitlin, 1992). This classification helps to link the appearance of the coast to the dominant processes. For example a delta stretching in all directions indicates a large river supply and relatively low wave and tidal power. In the case of Hoi An, the wedge shape south of the river is typical of a wave-dominated coast (Boyd, Dalrymple, & Zaitlin, 1992), see Figure 3.3. The sand ridges show this section of the coast has been prograding, meaning that the shoreline has moved seawards. Based on the appearance of the coast the Hoi An estuary can be expected to have large influence from waves and river supply and to be affected less by tides. Figure 3.1 shows net erosion in the last 10 years rather than accretion. Clearly the coast is not prograding any longer. From the three components that shape the delta, one must have changed to cause a shift from prograding to transgression, meaning a landward moving shore. It is estimated that the yearly erosion is 12 m/year, leading to a yearly erosion of Cua Dai Beach of 240,000 $m^3$. This is based on Appendix C.7.

Figure 3.2 - Coastal features of the beach at > Hoi An (Edited map from Google maps)



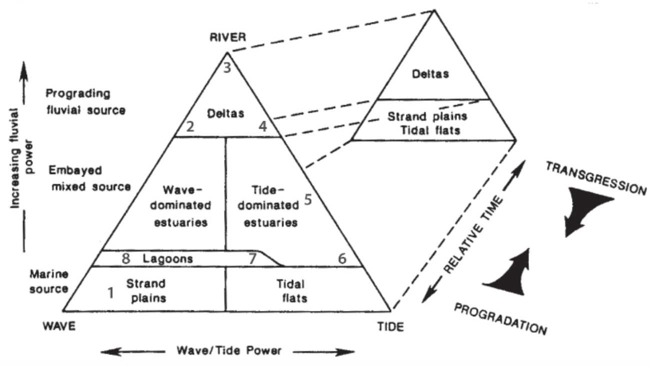




Figure 3.3 - Coast classification (Boyd, Dalrymple, & Zaitlin, 1992)

## 3.2 River influence

The Vu Gia – Thu Bon river system is one of the largest river systems in central Vietnam and covers a large part of the Quang Nam Province. Both rivers originate in the high mountains on the west side of Vietnam and flow into the East Sea through Dai (Hoi An) and Han (Danang), see Figure 3.4. The average annual discharge of Thu Bon River is about 327m$^3$/s. However, the flow regime in the river has a large seasonally fluctuation. The flow during the flood season is 62-69% of the annual volume, with 26-31% occurring in the peak month November (Long, Tung, & Huy, 2013). These flash floods carry enormous amounts of sediment down the river, which is transported to the river mouth area. The sediment supply from the river basin to the river mouth area is a sediment source for the advancement of the river delta shoreline. To determine if a decrease of the sediment supply of the Thu Bon River to the shoreline might influence the coastal erosion of Cua Dai Beach the amount of this sediment transport to the river mouth is estimated with three different methods. For the complete calculation with these methods, see Appendix D. All sediment estimates are given in Table 3.1 below.

Figure 3.4 - River network of the Vu Gia – Thu Bon basins (Long, Tung, & Huy, 2013)

Table 3.1 - The three different sediment estimates

| Estimate based on: | Estimated Sediment Transport (m$^3$/y) |
|---|---|
| Catchment area | 600,000 |
| Bed slope | 440,000 |
| Sediment concentration | 390,000 |

The orders of magnitude of the three different methods are comparable and the results give realistic values. However, the results differ quite a lot from each other and all have its own remarks. The first method, based on the relationship between specific sediment yield and catchment area gives a comparable river in Japan. However, the climate in Japan differs from the climate in Vietnam. In addition the amount of extreme rainfall events occurring at the catchment areas of both rivers might differ and there might be different ways of erosion occurring in the watersheds of the rivers. These situations probably cause different amounts of particles flushing into the river. For the second method, the bed slope and dominant discharge are used and usually such a formula can be used for approximations. The method is usually applied at river sections with uniform cross section along the whole length of the section and the system is defined as a closed system without lateral inflow. The sections used for this method are non-uniform and there probably is lateral inflow in each section. Also because there is a lack of discharge data, the same discharge value is used for each section. With the third method, the discharge and sediment concentration for each month are defined and multiplied with each other. This means the discharge and sediment concentration per month are averaged over the whole river stretch.

In conclusion, no comparison between the reliability of each method is needed. Each method can be seen as a reliable approximation of the sediment supply with its own remarks. For further calculations in this report the most extreme value is considered to determine how big the influence of the reduction of the sediment supply of the Thu Bon River is.

## 3.3 Shoreline movements

In paragraph 3.1, the evolution of the coast over the recent decades is described. This paragraph zooms in on the erosion and accretion theory. After this, it is explained why the coastline looks as it does now. Furthermore, it shows the way of sediment transport along the coast and this paragraph finishes with a finding about an increased amount of sand offshore.

### 3.3.1 Erosion and accretion theory

In the section 3.1 Evolution of the coast, it was explained that the tides, waves and river supply are major influences of the coast. However, the mechanisms behind it were not discussed. In this section the erosion and accretion patterns will be assessed by looking at the wave driven sediment transport. The capacity for wave driven sediment transport can be approximated by the CERC formula, which is showed in detail in Appendix C.2.

The along-shore sediment transport is dependent on both wave height and angle of incidence with the coast. Transport of sediment itself does not cause erosion or accretion, but gradients in transport do. If more sediment is transported into a section of the coast than is transported out of it, accretion has taken place and the coast grows in offshore direction. If more sediment is transported out of a section of the coast than is transported into it erosion has occurred and the coast retreats. Changes in the coastline occur when the alongshore sediment transport is not constant. This transport changes when waves break at different angles along the shore or when the wave heights are different, assuming there is no difference in sediment characteristics along-shore. If wave heights decrease in along-shore direction accretion is expected, while if wave heights increase in alongshore direction erosion can be expected. Another consequence of these relations is that an alongshore uniform wave climate with a low angle of incidence will strive to create a straight coast smoothing out any humps created by for example rivers.

### 3.3.2 Coastline formation Hoi An

The shape of the coastline of Hoi An can partially be explained by looking at the long shore sediment transport by the waves. Figure 3.5 shows schematically the influence of normally incident waves on a river mouth. Eventhough the wave climate at Hoi An is not normally incident the combination of the milder southern summer waves and the high nothern winter waves can add up to a similar effect. As sediments settle at the river mouth they create an outcrop. The waves at this outcrop will break at an angle and hence induce a sediment transport away from the outcrop. The result is a wedge shape. This shape can be observed south of the river mouth of Hoi An, see Figure 3.2. The rate at which the delta can grow depends on the sediment supply. If the supply becomes insufficient, as might have become the case in Hoi An, the waves will transport sediment away from the river mouth to the sides and flatten out the coastline and thus there will be erosion around the river mouth and accretion on the sides.

The north part does not form a wedge shape but features a spit instead. Waves breaking in front of the coast at an angle generate a longshore current that is interupted by the river outflow. This reduces the sediment transport rate and thus accretion occurs at the updrift side. Downdrift the waves regain their strength and the transport rate increases leading to erosion downdrift. The result is a spit slowly migrating in the direction of the longshore current. The spit at Hoi An has likely been formed by the same mechanism.  The appearance of both a spit and wedge at the coast is quite rare and indicates that the dominant wave climate might be varying spatially. The reason for the variation in wave climate is likely to be Cham Island.

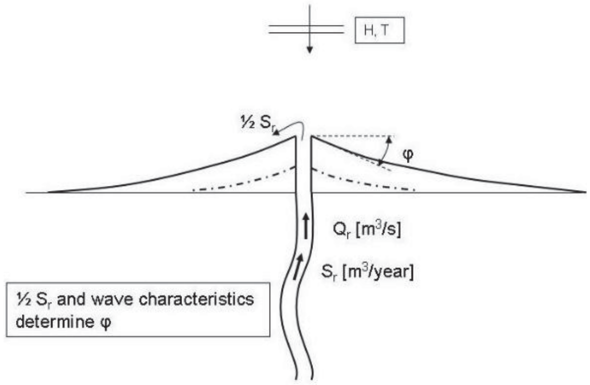



Figure 3.5 - Developments of a deltaic coastline with normally incident waves (Bosboom & Stive, 2015)

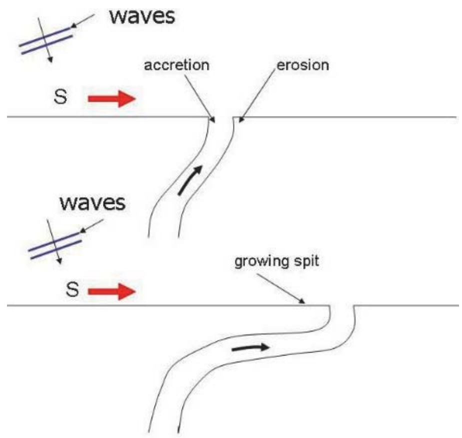



Figure 3.6 - Spit formation at a river mouth (Bosboom & Stive, 2015)

### 3.3.3 Net sediment transport directions according to Professor Stive

It is known that the transport has seasonal components as high winter waves come from the north while the rest of the year waves tend to come from the south (see appendix C.4). First calculations neglecting the influence of Cham island suggest a southward transport of 20,000 $m^3$/year, northward transport of 340,000 $m^3$/year and net northward transport in the order of 320,000 $m^3$/year with a gradient to the north of approximately 100 $m^2$/year along Cua Dai beach (Ponsioen, 2015).

Professor Stive estimated the directions of the sediment transport based on the geographic characteristics of the Hoi An delta. Sediment supplied by the river is dumped in the outer delta and forms a source for sediment. This river supply, in terms of discharge and suspended sediment, is highly variable. Most sediment is supplied in the wet period (August to December) when river run off is higher. From Figure 3.7, both a net northwards and net southwards directed sediment transport can be noted. In the area north of the river, a certain divergence point is assumed where the net sediment transport is zero. From this point, the net sediment transport is directed to the north and to the south. The multiple sediment transport directions suggest that Cham Island is affecting the dominant wave climate (for instance by shoaling, refraction and diffraction of waves) differently for different sections of Cua Dai Beach.  South of the divergence point, the net sediment transport is directed southwards. A bypass of sediment around the outer delta is assumed where it continues along the beach south of the river. The areas where erosion and accretion have been observed are marked with different colours.


Figure 3.7 - Estimated sediment transport directions by Professor Stive (Stive, 2015)

### 3.3.4 Seasonal erosion and accretion

The cross-shore profile of the beach responds differently during calm periods with normal wave conditions (dry season) and during storm events with stronger wave conditions (wet seasons), which results in a seasonal behaviour of the profile as shown in Figure 3.8. In the stronger wave conditions, the storm surge level is high and the waves can reach the upper shoreface and impacts it. Consequently, an avalanching process takes place where sand is eroded from the dunes and falls down to the lower shoreface. These sandbars are then transported offshore by a strong undertow. In the milder wave conditions, the wider berm of the beach is rebuild again since these offshore bars move onshore and finally attach to the shore (List & Farris, 1999).

This principle shows that the material which has been eroded from the beach is not lost permanently. After the wet season, the beach is (partly) restored by this mechanism. Similarly, the high winter waves in Hoi An will cause temporary erosion of the beach and dune front that would be restored by the calmer summer waves if there were no structural erosion present.

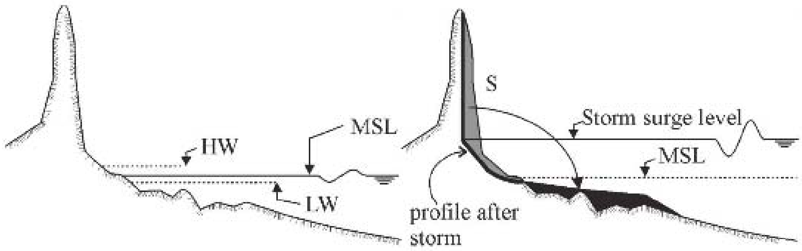



Figure 3.8 - Left: profile during dry (calm) season. Right: during wet (rough) season (Bosboom & Stive, 2015)

### 3.3.5 Sand balance

From three years, 1965, 2001 and 2014, the bathymetry is shown in Figure 3.9. In the figure there are depth contour lines for 5, 10 and 15 meters. Based on this picture the volume of sand above the 15 m depth line can be calculated for each year, which is showed in Appendix C.6.

Normally when erosion takes place, there is sand transported along the shore to a place where accretion takes place or into a sink located in a delta. However, as is calculated from the bathymetry from (Tanaka, Hoang, & Viet, 2016) depicted in Figure 3.9, this might not have been the case at Hoi An. The sand in the assumed outer delta has increased with 25.3 million cubic meters in the years from 2001 to 2004. This would normally coincide with accretion at the shore and a good explanation why this is not the case is still pending. In recent history, 30 years ago, it is seen that a sand bank emerged in this outer delta. The accretion in the outer delta might lead up to another sand bank emerging and the current erosion might be part of natural variation. Or another mechanism might be present. In both cases the data should be checked and confirmed since a rise of 25.3 million cubic meters dwarfs the present erosion in size (240,000 $m^3$/year loss versus a 2,000,000 $m^3$/year gain).

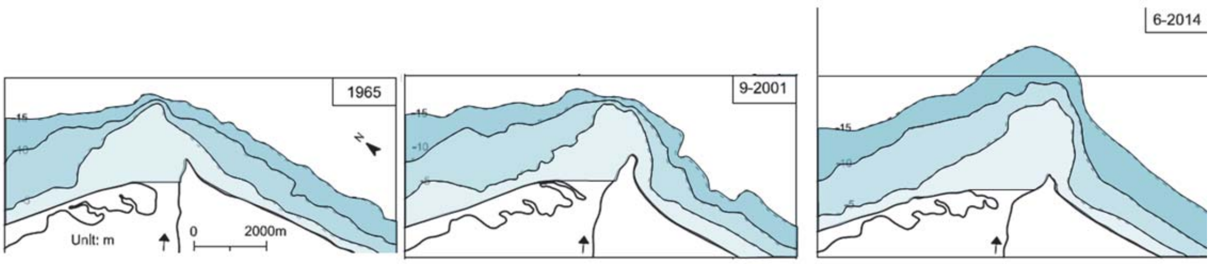



Figure 3.9 - Contoured areas, based on (Tanaka, Hoang, & Viet, 2016)

# 4. Stakeholder analysis

In Hoi An the coastal erosion at the Cua Dai beach has a multitude of stakeholders. For example resort owners, locals and government bodies. The stakeholders that are involved in this problem are presented in this chapter with their goals, dilemmas and their influence on a solution.

## 4.1 Problems and goals

The stakeholders are analysed using problem statements and goal trees. These are derived from the results of interviews and questionnaires or common sense when this was not possible. The full analysis can be found in Appendix B. Stakeholders. In this chapter a concise overview of the stakeholders' problems, dilemmas and goals related to the beach erosion at Hoi An is given. It shows how every stakeholder is involved in the problem and why it is difficult to find easy solutions.

**National government**

The National government is the highest administrative body of the Vietnamese state and is called the National Assembly. They control the local governments of the provinces and give orders to those provincial governments (Ronald J. Cima, 1987). The goal of a national government is to strive for the best for their country's inhabitants. However, there is the dilemma of the national government not to favour one province above others, otherwise it would be easy to get enough resources available for the coastal erosion problem.

**Local government of the Quang Nam Province**

The city of Hoi An is of economic importance for the Quang Nam Province. The economy of the whole province has financial benefits of the touristic city of Hoi An. Due to that the provincial government also wants Hoi An to have an attractive beach. However, recreating the beach is not easy. The sand mining and hydropower dams in the rivers might be (partly) responsible for the coastal erosion, but those are also important sources of income for the province and industries that should not be hampered too much. The province has also a large influence on the solution since any large coastal intervention in Vietnam is normally paid for by the province. The province of Quang Nam already disbursed VND 54 billion or €2.3 million in 2012 for a dike at Cua Dai Beach. (ThanhNienNews, 2014)

**Local government of Hoi An**

The city of Hoi An is a provincial city according to the political structure of Vietnam and is under the direct authority of the provincial government. One of the major problems the local government of Hoi An has to deal with nowadays is the coastal erosion of the Cua Dai Beach. Extreme erosion can damage the city, both structural and economic wise. The dilemma that exists here is the amount of money available to solve this. The coastal erosion is not the only issue that needs to be financed and the budget is finite. The expected income from the beach is estimated on €3.6 million a year, as explained in B.4 Estimation of hotel values. An investment which is lower than this amount will be profitable for the city.

**Citizens living from the beach in Hoi An**

A wide beach is part of the protection of the city. Next to that, the tourists who visit the city will create incomes for the citizens of Hoi An, when the beaches disappear there will be less tourists and so on less income for the citizens. These citizens are for example restaurant and bar owners, bicycle keepers, fishermen and life guards. The wish of the citizens for keeping their jobs is clear, but the problem is that these people do not have a lot of power to urge the government to implement effective solutions for their future and are therefore dependent on how the beach tourism is evolving now.

**Resort managers**
Nowadays the resorts at Cua Dai Beach are very important to attract tourists to the city and the beaches of Hoi An. Wide and beautiful beaches have a direct value for the hotels and resorts located at the beaches, but it is noticed that the amount of tourists is already decreasing. The resort managers can be classified in two parts: those at Cua Dai Beach and affected by the erosion or those at north of where the erosion is currently taking place. The current problems fits the latter in the future too. The wish of the resorts at Cua Dai Beach is to get the original beach back to counteract the reducing amount of beach tourists. The dilemma here is that a government program and cooperation between the resorts on the whole stretch is needed to be effective. This is not the case yet and seen as a hurdle by several resorts.

Financial contribution
Beach hotel owners could be financial contributors to a solution as well. It is in their best interest to protect their investment by investing a little more. For example two resorts were investing "several hundred billion dong" (Tre, 2014) which is equivalent to tens of millions in Euros. If such an investment can be more profitable by paying (partly) for the coastal defences this is a smart investment. However coastal measures are mostly only useful when it is done for an area as whole and this would ask for a rare cooperation of different investors with different ideas. Also the prison dilemma is in effect as every solution helps everyone, also the ones who were not paying their part. So it is for an individual hotel owner the most profitable to not pay, but for the whole group of hotel owners it would be best if everyone pays.

**Building industry**
One of the main industries of Vietnam is their building industry. The Vietnamese infrastructure development triggers a great demand for sand and concrete. This demand has been increasing significantly over the past years (StoxResearch, 2015). The building industry in Vietnam uses a lot of sand mined at several rivers in the country. A wish from the building industry is to acquire enough materials to build with, but the dilemma is that they want to buy it at low costs, otherwise other sources than the rivers were possibilities to get the right materials.

**Sand miners**
The building industry mentioned above uses sand that is mined from the Vietnamese rivers as the Thu Bon river, which might have negative effects on the rate of coastal erosion Sand miners operating for the building industry want to mine the sand from sources where it is easy and cheap to extract. Although this is already prohibited without license, it still occurs. However, when it can be proved that this sand mining is affecting the erosion, this might lead to extra control in the future. This is the dilemma that sand miners have to deal with to maintain a profitable business in the years to come.

**Tourists**
Tourists have the wish for a nice beach, but not only for themselves, also for the environment and local community. Tourists are flexible and can therefore always shift to a place that matches their interests more. However, if the wider beach can be achieved, they would like to see more cheap and public space instead of resort owned beaches. This is the dilemma here, because a public beach would imply that the government has to invest in it. Currently, it is unclear whether this funding will ever come and when.

## 4.2 Power interest diagram

In the following power versus interest diagram the stakeholders are ranked on their interest and possible influence in the issue, see Figure 4.1. The most important stakeholders are those with high interest and high power to make changes and therefore require the most attention when implementing a possible solution.

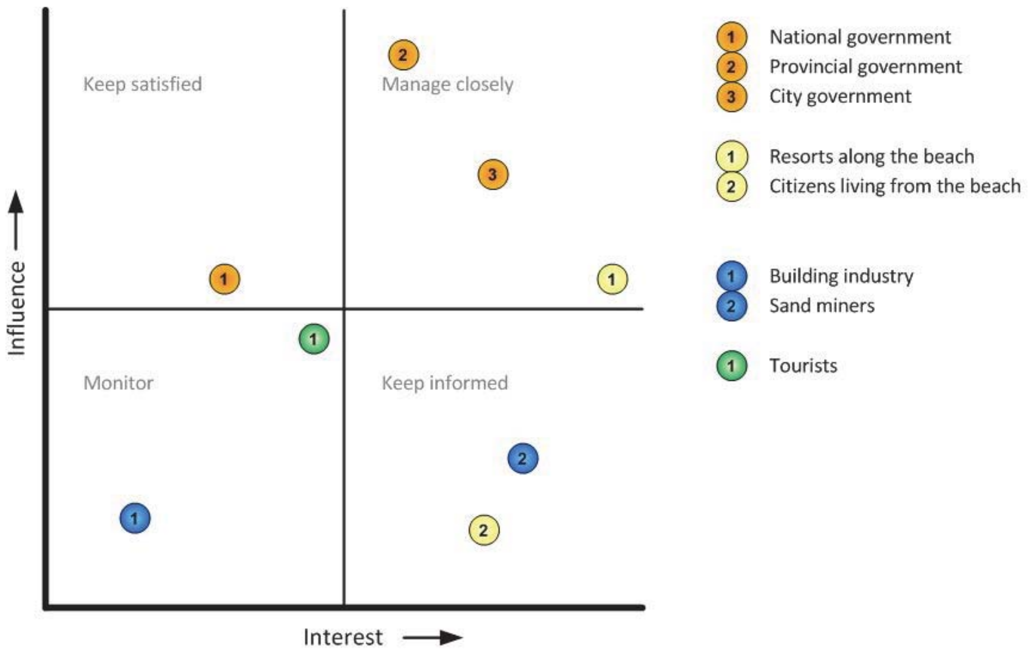



Figure 4.1 - Power versus interest diagram

# 5. Reasons for shoreline retreat

The severe erosion at Cua Dai Beach might not be caused by one factor, but by a combination of factors. In this chapter, the possible causes are described and quantified with an order of magnitude. How these number are derived is given in Appendix Research into reasons for shoreline retreat. This chapter facilitates in giving an overview of the possible causes and concludes with three hypotheses that would explain the erosion.

## 5.1 Human impacts

Changes in the coastal and river system can be induced by humans and their possible actions which give cause for erosion are given in this paragraph. Two factors have influence on the erosion are sand mining and dam construction upstream on the Thu Bon river. Three factors can be excluded as being a reason for the erosion. These are human changes in the watershed, land subsidence due to water extraction and land reclamation for the bridge construction.

### 5.1.1 Sand mining ______ Order of magnitude: 5m/year

One of the sediment sources for the coastal area in the system area is the Thu Bon River, this river takes sediment from inland areas to transport it to the ebb tidal delta in front of the Cua Dai inlet and after that it will be distributed along the coast. The impact of sand mining in the upper part of the river differs from the impact of sand mining in the lower part of the river. When sand is mined in the upper part of the river it does not change the total sediment transport in the river to the shoreline because the loss in sediment due to the extraction is compensated by the degradation of the river bed.

In the lower part of the river the effect of sand mining changes the sediment transport to the coast. When sediment is extracted, the river bed at the same location will erode to compensate for the sediment loss. This will cause a lowering  reduction of the flow velocity (water level stays the same) and thus a lowering of the sediment discharge to the shoreline. Based on one daytime observation, the amount of sand mining is roughly estimated on 100,000 $m^3$ sand per year. With a sediment transport rate of 400,000 to 600,000 $m^3$ per year this is a reduction of 25%. Using an order of magnitude for the erosion this would be around 5m/year shoreline retreat.

### 5.1.2 Dam construction ______ Order of magnitude: 0.5m/year

Possible coastal erosion by sediment blockage by hydropower dams requires the blocking of a sediment rich part of the rivers catchments area and will influence the area downstream of the dam first. It is unlikely that the sediment blockage by the dams is influencing the erosion at the mouth of Hoi An, because the erosion started before the current hydropower dam in the Thu Bon river was constructed. It is also constructed far upstream in the watershed, relatively limiting the amount of sediment that will be trapped.

However, a different flow regime will change the yearly transport capacity of the river and this will influence the amount of sediment arriving at the mouth of the river. Using an assumption of the reservoir capacity, the yearly transport would have declined for approximately 3% since the placement of the dam. This reduction in dominant flow has an influence on the erosion rate of about 0.5m per year.

### 5.1.3 Excluded possibilities

For the changes in the watershed, a new river connection between the Thu Bon and Vu Gia rivers and deforestation are the main factors that have a high influence on the amount of sediment transported by the river. However, it turned out that the river connection and deforestation would increase the sediment supply instead of decrease it. Relative sea level rise due to water extraction related to land subsidence could be another cause for erosion, but groundwater extraction in Central Vietnam is very low (WEPA, 2015). It is however a problem for, for example, the Mekong Delta in South Vietnam. The last excluded reason for the erosion is an area of reclaimed land in the Thu Bon river. This area was made to build the bridge crossing the river and could have changed the river outflow direction. However, the erosion was already taking place before this land was reclaimed and therefore do not match together.

## 5.2 Natural causes

Also possible natural causes for the erosion exist. One natural cause that is affecting the erosion is climate change. Sea level rise and the increasing rate of storms are contributing to the erosion. Natural causes that are excluded are tectonic subsidence and changes in near shore conditions.

### 5.2.1 Sea level rise — Order of magnitude: 0.5m/year

Sea level rise is a well-known driver for coastal retreat. The sea level rise at Hoi An has been around 4mm/year for the last 50 years (ISPonre Vietnam, 2009) and expected to rise 6mm/year (Ministry of Natural Resources and Environment, 2009). Following the Bruun Rule (see Appendix C.1 Bruun Rule) the shoreline retreats due to the an adaption of the bed. Sand from the shore is transported to the near shore to form the same bed slope as before the sea level rise. Erosion or more precise, shoreline retreat, is expected to be taking place at a rate of half a meter per year when not taking river supply into account.

### 5.2.2 Increasing amount of storms — Order of magnitude: 2.5m/year

Another effect of a changing climate that can impact the coastal balance and cause erosion is the increasing amount of storms. As explained in Chapter 3.3.4 Seasonal erosion and accretion, during storm conditions sediment is transported seawards. Normally this in balance with the return of sediment during calmer conditions. However when there is an increasing frequency and/or intensity of the storm the loss of sediment can be partly permanent. Due to the warmer air at the equator and therefore larger temperature differences between equator and poles, heavier storms will form with more extreme wave conditions (ISPonre Vietnam, 2009). This process is already going on, when looking at the increasing rate of typhoons hitting Vietnam. Using the amount of sediment displacement by a large storm and the increase in storms, this leads to an rough estimation of 2.5m per year of erosion.

### 5.2.3 Excluded possibilities

Excluded natural causes are tectonic subsidence and changes in near shore conditions. Since erosion is occurring along almost the total coast of Vietnam, you might suspect a common cause.

One of the reasons for the erosion could be tectonic movements, which can lead to relative sea level rise compared to Vietnam's shore and therefore erode the coast However, Hoi An is not located near a colliding edge of earth plates and also the vertical movements are relatively slow compared to other contributors of coastal erosion.

Near shore underwater conditions like morphology and water depth influence the local wave climate. If larger waves can meet the shore, more erosion compared to the past will happen. Some changes are seen for in the near shore conditions, for example the increased amount of sand offshore, as given in Chapter 3.3.5 Sand balance. However, possible effects of this change would be in favour of accretion instead of erosion.

## 5.3 Natural variation

The shape of most coastlines is dynamic. The coast can move landwards in one decade and move seawards in the next. Also the natural yearly amount and intensity of storms varies. This paragraph gives three possible forms of variation that could explain the erosion without influence of humans or changing external factors.

### 5.3.1 Storm variation — Order of magnitude: 35m for $^{1}/_{5}$ year storm; 120m for $^{1}/_{50}$ year storm

Averaged over one or several years a constant cross-shore profile can be expected as extreme conditions and mild conditions average out over long period. Depending on the wave conditions the profile shifts over the year due to heavier wave attack during storms. This is the cause of the variation in the profile and makes for a temporary loss of sand of the beach. With modelling of the Hoi An cross-shore profile and wave data, erosion rates can be found for certain return periods of storms. The effect of typhoons on the beach can be devastating over a large width of the beach moving a lot of sand to the foreshore. The empirical calculation suggests 120 m of beach impacted by it and 79.5 $m^3$/m of sand displaced. Lesser storms with a return period of four to five years or longer can cause sand to move to the foreshore. The calculation suggests 35 m of beach is affected and 10.6 $m^3$/m sand displaced. For these storms the problem is rather limited if there is sufficient beach to compensate the temporary loss, which is currently not the case due to the construction of the resorts.

### 5.3.2 Sand bar moving onshore — Order of magnitude: 60m in total

In 1989 a sandbar was observed approaching the coast of Hoi An, which is already described at Chapter 3.1 Evolution of the coast. The volume of sand carried by the sand bar to the coast can be approximated from the Landsat images. With this calculation the volume of sand amounts to 1,370,000 $m^3$ or 1.37 million cubic meters. The assumption is that 90% of this volume, 1,230,000 $m^3$, was added to Cua Dai beach. Cua Dai beach has a length of about 3 km and with an assumed active depth of 5 m it is calculated that the beach widened by such a nourishment with about 60 m. Last years the natural equilibrium is recovering and that could be the reasons why there is a lot of erosion these years.

### 5.1.1 Sediment streaming due to river outflow variation — Order of magnitude: 5m/year

Another natural cause for the erosion might be the movements of the Thu Bon river mouth and in which direction most of the sediment is flowing when it reaches the sea. This would explain the sand bar that is visible in 1989 in a different way. Namely, as part of the ebb tidal delta above sea level, formed by sediment from the river. The hypothesis here is that the major outflow direction of the Thu Bon river has shifted from northwards to southwards in about 30 years, while the amount of accretion at the spit was influenced by the sandbank in front of it.

At some point in time, probably around 1990, the shape of the spit has changed so much that the easiest outflow direction began turning southwards. The erosion by waves on the sand bank started overruling the accretion by sediment supply and the sand bank and spit were getting smaller.

Much slower rates of erosion compared to those at the end of the dynamic spit are occurring now at Cua Dai Beach. To quantify the influence of the change in river outflow direction is difficult. The along-shore transport of sediment that distributes the sediment along the coast is for a large part based on waves and winds. Using the outflow direction of the river it is estimated that the sediment supply to the north side of the river mouth has decreased in the order of 100 000 $m^3$. Similar to the effect of sand mining this again leads to an order of magnitude for erosion of 5m per year.

## 5.4 Hypotheses

In this paragraph three hypotheses are presented which are able to cause the witnessed shoreline retreat at Cua Dai Beach. Each hypothesis focuses around a main driver of the erosion and several secondary drivers. The hypotheses should be able to partly explain the following observations:

- Shoreline retreat of 12m/year from 2004-2015
- Over a stretch of 4000m (resulting in ~240,000 $m^3$/year)
- An increase of foreshore sand amount of 25,000,000$m^3$ between 2001-2014

### 5.4.1 Hypothesis 1:Relatively large increase in the rough wave conditions

The increasing amount of storms approaching or impacting the coast of Central Vietnam have, according to this hypothesis, the largest impact on the coastal erosion. These storms are formed due to the changing climate and the amount of it is increasing. Storm waves transport sand offshore and due to the fact that when there are no or too few mild waves to bring the waves back it will not or in too little amounts be transported back to the beach. The main driver of this first hypothesis is the increasing amount of storms. Secondary drivers are the reduction of sediment supply, which is relatively large compared to the other secondary drivers. These are the sea level rise and the natural variation of the shoreline movement. This is shown in Figure 5.1.

The fact that the amount of sand lying in the foreshore is increasing supports this hypothesis and that would suggest this hypothesis might be true. In addition it is proven that the amount of storms has been increasing in the past several years. One of the things that is contradicting this hypothesis is that the erosion along the coast is not uniform, close to the mouth the erosion is more severe than further away from the mouth.

Continued erosion takes place only when the storm conditions continue to rise, it is unsure how the rough conditions will continue to develop and therefore future predictions are unsure for this hypothesis

### 5.4.2 Hypothesis 2: Relatively large sediment supply reduction of the river

Several factors like sand mining, the dam in the river and changes in the watershed of the river influence the sediment transport of the Thu Bon River to the shoreline. The sand mining has the largest impact on the amount of sediment transported to the shoreline. The dam in the river also reduces the sediment transport, however with a smaller amount. Furthermore, the changes in the watershed do not give a reduction of the sediment transport in the river. According to this hypothesis the river sediment supply is experiencing a higher decrease than with the other two hypotheses, causing more coastal erosion compared to the other two. This hypothesis involves a river sediment reduction as main driver for the erosion problem. The secondary drivers are the sea level rise, increasing storms and the natural variation as shown in Figure 5.1.

As mentioned before in this report the erosion close to the Thu Bon river estuary is a lot more than the erosion further away from this inlet. This would suggest that the reduction of the river sediment supply is dropping and causing the erosion at this river mouth. However the increasing amount of sediment at the foreshore is contradicting the suggestion that the sediment supply reduction is influencing the erosion. This suggests that the river is supplying enough sediment to not cause any erosion.

This hypothesis will see continued erosion in the future, even when sand mining is reduced in the first years to first decades no change is going to occur in the sediment discharge of the river. The river first has to restore to its former bed levels.

### 5.4.3 Hypothesis 3: Relatively large natural cyclic shoreline movement

The biggest factor of the coastal erosion in this hypothesis is the natural variation, which contains the natural variation of the river mouth in the southward direction and the moving sandbars in the foreshore. According to this hypothesis, the direction of the sediment flow from the river mouth has been moving southward in the past several years due to natural processes and the situation of nowadays is almost the same as several years ago when there was a sandbar as part of the coast, causing a lot of sand loss at the beach. Also the multiple yearly storm variation is causing a natural cyclic shoreline movement.

This third hypothesis involves the natural variation of the shoreline movement as the main driver for coastal erosion. The secondary drivers are the reduction of sediment supply which has a relatively large order of magnitude compared to the other secondary drivers which are sea level rise and the increasing amount of storms. Figure 5.1 shows the orders of magnitude of all the drivers of this hypothesis.

A contradicting point of this hypothesis is that there are no data that show that there is a cyclic sand bar and it might also be a non-cyclic sand bar, indicating that it might not be a natural cyclic shoreline movement. However, what is supporting this hypothesis is again the increasing amount of sand in the foreshore.

This hypothesis is likely to see a reduced erosion in the future since the sand from the foreshore will not continue to accrete in the foreshore but will be moved to the coast.

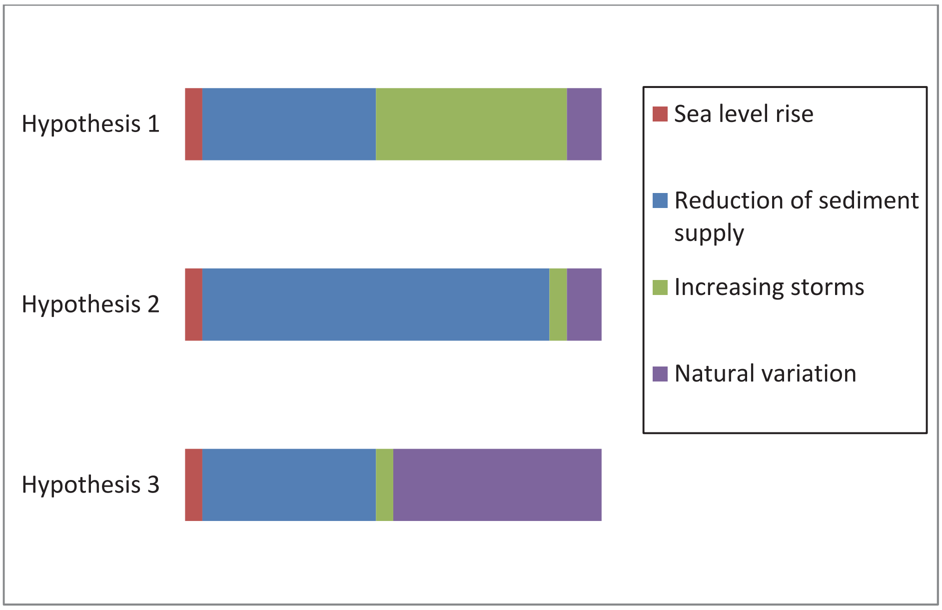



Figure 5.1 - Order of magnitude of the influence of main and secondary drivers of the three hypotheses

# 6. Solutions

With the problems known, this chapter looks into solutions. This chapter starts with three possible strategies from which one is chosen. After that, the requirements for alternatives are given, which are based on an systematic approach of stakeholder analysis. After analysis of possible measures, the three most promising are further worked out. This chapter concludes with some quick solutions, that can be used to overcome the problems until a permanent solution will be implemented.

## 6.1 Strategy to deal with coastal erosion

Three options are available when confronted with an erosion problem: take no action, relocate endangered structures, or take positive action to halt the erosion. All are described below, after which one is chosen as best strategy.

**Possible strategies**

*Option 1: No action*. It is an option to undertake no action when confronted with coastal erosion. If only undeveloped land or inexpensive structures are threatened it is more profitable to accept the losses than to invest in measures. It is also a good reference point from which to evaluate other measures.

*Option 2: Relocation*. To prevent damages by coastal erosion, the relocation of endangered structures can be considered. This can be done either by moving them to a different location or further away from the water. Moving a building is a costly operation and will be ineffective if it is not moved back far enough. Therefore, it is required to know the current erosion rate (m/year) and the likelihood that this erosion rate will continue or alter in the future.

*Option 3*: Positive action to halt erosion. If the invested money along the shoreline is large and if relocation of this property is difficult, it is often preferred to take action to prevent further erosion. Protection measures can be installed both as a temporary and as a long term solution. This option is often cheaper and much more convenient than relocation.

**Chosen strategy**

At Cua Dai beach the money invested at the location makes the no action or relocation option unwanted. Also considering the amount of local people living from the beach, makes the first two options not a social and economic feasible option. Therefore this chapter continues with finding the right positive action to undertake to prevent unwanted coastal erosion.

## 6.2 Solution requirements

Numerous options are possible to stop the erosion. The Hoi An situation makes certain options more advantageous than others. A systematic approach is used to translate the goals of the stakeholders into requirements, which is described in Appendix G.1 Systematic criteria and option finding. Two important loops in the system are found here.

The first loop shows the vicious circle between the declining tourism due to the reducing beach attractiveness, this leads to economic damage to the resorts, which results in a lower budget for measures and a lower rate of the implementation of measures. The implementation of measures is positively related to beach recovery, so if no measures will be implemented the beach will further deteriorate, reducing the beach width and attractiveness of the beach even further, leading to a further decline in tourism. To mitigate effects of economic damage this circle needs to be broken by a suitable alternative.

The second loop is smaller and starts with structural damage due to the erosion, leading again to economic damage to resorts, a reducing budget for measures and a decline in the implementation of measures, reducing the coastal flood protection even further, leading to more structural and economic damage. This is another vicious circle that will go on until the resorts run out of resources to repair itself, if it is not broken by an alternative. The current paragraph elaborates on the final requirements which are given below.

1. *High protection of buildings*

   The protection of buildings against the erosion is a requirement that is shared by several stakeholders and therefore important. Furthermore, an alternative that can limit or take away the structural damage to buildings will break the vicious circle.

2. *High attractiveness*

   The attractiveness of the coast is very important to make sure the tourists keep coming (back) to Hoi An. If the given alternatives can make the beach attractive again and maintain it like that, the other vicious circle will be broken. Attractiveness is here not only the beach width, but also the distance to the beach, the costs of beach visit and the safety of the swimming water.

3. *Low costs*

   The costs of measures is always important. Somebody has to pay for it and likes to achieve the highest value for the lowest price. If the tourists are not willing to pay for a beach visit, the costs of measures have to be divided amongst other parties. Measures will be implemented sooner if the costs are low and the two described loops can be broken before it is too late.

4. *Long lifetime*

   Currently, mostly temporary measures are used that hardly survive one storm season, due to the lack of funding. Measures with a long lifetime can form a more permanent protection. It turned out that cooperation to one single solution is difficult. When measures have a long lifetime, it saves the effort of consult that would be needed every several years with more temporary measures.

5. *High speed of effectiveness*

   The current state of erosion is severe and at some locations not much of the beach is left. Furthermore, some buildings have already collapsed due to the erosion. A solution that shows results fast is important here. It reassures flood protection, but would also maintain or perhaps increase the rate of tourism again.

6. *No shifting of problems to adjacent areas*

   An important criterion is that measures may not shift the problems to others in the area than the local users and resorts in Hoi An. Currently the resorts are protecting their own property with hard structures, that keep shifting the erosion northwards. To deal with the problem effectively, this may not be the case for the permanent solution.

7. *High safety*

   Part of the attractiveness is the safety of staying at the beach and swimming there as well as the safety of the resorts. Solutions that do not pay attention to one of these kinds of safety should be avoided, since this would further reduce the reputation of Hoi An.

8. *Combines well with current measures*

   Action needs to be taken fast, to break the loop of declining tourism and structural damage before it is too late. The possibility for alternatives to combine with the current measures will lead to implementation of this new measures more easy.

9. *No bad influence on other industries*

   The final requirement for alternatives is that they should not affect other industries than tourism in a bad way. Industries like sand mining and hydropower generation are important money-makers for the province and Vietnam as nation and cannot be hampered.

## 6.3 Results of analysis of possible measures

This paragraph concludes into the three most promising measures. Those three measures will be considered and elaborated in more detailed in the next paragraph. All current applied measures and other possible measures are ranked in a multicriteria analysis, all of which is given in which are given in Appendix F and G.3. The results are the following:

- The highest ranked measure was sand nourishment. It scores very well on all requirements that were given in the previous paragraph. Furthermore, it is very flexible to cope with future changes. Its drawbacks are that there is no reduction in the yearly variation and people might still feel unsafe. It is also a periodic measure, with a lifetime of around 5 years.
- The measure that was tied in second place was a submerged breakwater. This one scores quite average on all measures and in such a way has no large drawbacks. It can recreate some beach, but it will still shift the problem to the area without breakwaters.
- The other measure tied in second place was the concrete revetment measure. It scored very well on almost every criteria, except for two criteria of which the attractiveness has a very large influence on the overall result. A concrete revetment does not have a great appeal for most tourist. When a beach is expected, concrete is a bit disappointing. The measure does not bring the beach back at all. It also shifts the problem to downdrift areas since it does not solve the erosion, but only diverts it. The revetment only protects against incidental erosion caused by storms. In the end it will fail by undermining of the construction.

Sand nourishment scored a 91/100 points and the concrete revetment and breakwater only 66/100. Further designing the latter two would be needless, since they would never outscore the sand nourishment. They do however have some benefits compared to nourishment alone. Therefore, the following three most promising alternatives are all based on sand nourishment, whether or not combined with other measures.

The first alternative as seen in Figure 6.1 is only the use of sand nourishment. This is very promising, but needs a lot of sand to retain the beach and give adequate storm safety. The second alternative makes use of sand nourishment in combination with sand retaining structures like (submerged) breakwaters or groynes. This way the sand nourishment has an increased lifespan and there is some reduced wave action for possible swimming benefits. It also needs way less nourishment than the first alternative Third the alternative focuses on storm safety. The basis is again sand nourishment to battle the structural erosion, but this option needs a relative small amount of sand since storm protection comes from a concrete revetment. There is still an adequate beach in the calm season but after a heavy storm the beach needs a small nourishment to return.

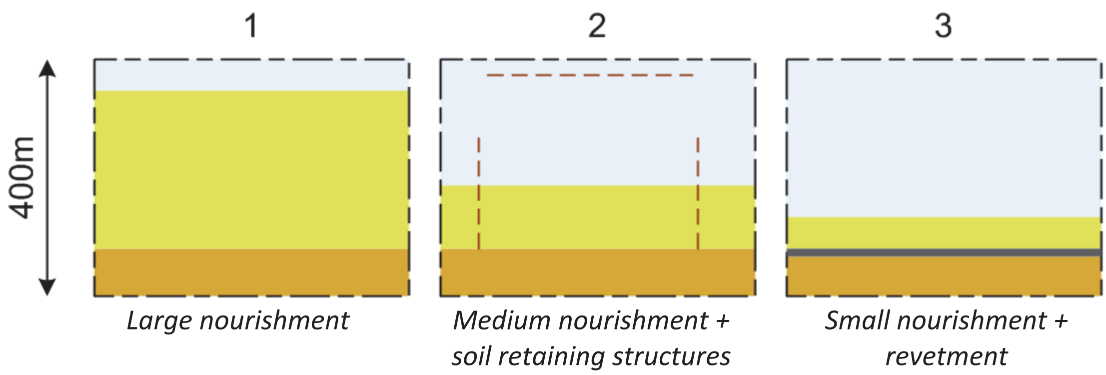



Figure 6.1 - Three alternatives

## 6.4 Three alternatives

This chapter describes the idea behind the three chosen alternatives and shows their (dis)advantages relative to each other. A more detailed explanation about the alternatives such as sketch designs, costs and effects on the coastline are given in Appendix H.1 to H.3. Furthermore, several benefits and downsides exist for using nourishment. These are given in Appendix G.2 Hard versus soft measures.

### 6.4.1 Large sand nourishment

The first alternative is a wide sand nourishment along the entire beach. Taking into account the incidental erosion caused by storms and the structural erosion, the sand nourishment has to create a 180m wide Cua Dai Beach. This is similar to as it was several years ago. To keep the width sufficient at all times a nourishment interval of 5 years is needed. At the southern part of the stretch more sand has eroded than further north, meaning that more sand has to be nourished more close to the river mouth. However, most resorts already have a hard structure protecting their property. Due to this, the beach in front the resorts can be less than 180m. On average the resorts are located 40m more seaward than the current shoreline, meaning that 140m of extra beach will be created here. Relative to the other three alternatives, a large sand nourishment has the following advantages:

Figure 6.2 - Coastline impression with large nourishment

- It combines well with current measures.
- The beach width is larger due to the protective function of it.

It shows also some disadvantages compared to the other alternatives:
- A relatively large initial investment is needed due to much larger beach width to nourish.
- Such a solution is a less visible decisive solution and creates a less safer feeling to the local people compared to hard structures.
- The large natural variation of the coastline will continue.

The net present value of the cost for the coming twenty years of this option is €37.8 million or VND 950 billion.

### 6.4.2 Medium sand nourishment with retaining structures

Figure 6.3 - Coastline impression with medium nourishment + groynes

As soil retaining structures, groynes are chosen over breakwaters. Although breakwaters as single measure score better, groynes are a good combination with a nourishment. In this alternative a set of 145m long groynes will be placed to protect the Cua Dai beach and several hotels from further erosion. Once protected the beaches between the groynes can be restored to a width of 60m by a sand nourishment. Besides the recreation of a beach, nourishment would accomplish to other issues: mitigate the erosion induced by the groynes on adjacent areas and compensate for the structural erosion in the future.

The beaches in between the groynes can be restored with a single large nourishment that would require little maintenance, as only storms are strong enough to move some sand out of the system and induce erosion of these beaches. These beaches would adapt to the dominant wave directions, leading to a saw tooth shape shoreline.

The combination with groynes has the following advantages:

- The beach in front of the resorts is easily restored by a large initial nourishment, with sand partly trapped between the groynes.
- Groynes reduce the longshore movement of the sand, meaning that a smaller beach width is needed between the groynes to deal with the structural erosion.

Compared to the other alternatives, is also has its disadvantages:

- Constructing multiple stone groynes is costly, especially when combining them with a sand nourishment of a large volume.
- A row of groynes only protects that particular area where they are placed. An erosion pattern will develop in the unprotected area beyond the outer groyne, due to the partial reduction in alongshore sediment transport. This pattern will always develop, no matter how many groynes will be constructed. A suitable location has to be found to allow for this erosion.
- Near the groynes is an less safe location for swimmers

The net present value of the cost for the coming twenty years of this option is €41.0 million or VND 1025 billion.

### 6.4.3 Small sand nourishment with revetment

Figure 6.4 - Coastline impression with small nourishment + revetment

The third alternative is a combination of a revetment and sand nourishment. The revetments deal with the task of storm protection of present buildings by preventing incidental erosion. The nourishment creates a beach for tourists and prevents the structural erosion and undermining of the toe of the revetments. Currently, two revetments are already in place along Cua Dai Beach. For this option, only another revetment has to be placed along the part that is now temporary protected by sandbags and other provisional methods. There is also no need for revetments along the beaches between two beach resorts. The protecting structures of the resorts act as groynes and prevent the shoreline from moving too far inland.

At the location where normally no wave action is present the revetment can be constructed as a stair structure, to make it easier for people to get to the beach. For the land side of the new revetment there are two options: keep it mostly as it is now, or change it into a boulevard.

There are several advantages, but also disadvantages to this alternative. Both will be described below. The advantages are the following:

- Due to the combination of nourishment and a revetment, this alternative offers a good protection against the incidental erosion caused by the high waves during storms. And since it is a concrete structure, it also feels safer.
- Compared to the other two alternatives, less initial nourishment is needed here. The storm protection is covered by the revetment, not by extra nourishment.
- A revetment is already present along a large stretch of Cua Dai Beach.

As with all options, there are some disadvantages to this alternative. Which are:

- The beach might not always be present. After the storm season, the sand can move offshore to such an extent that the sand level lies beneath the water surface, until the sand is brought back onshore by calmer waves or a next nourishment is carried out. This can hamper the tourism.
- Compared to full beach nourishment or the use of groynes, the movement to the beach is less fluent due to the revetment.

The net present value of the cost for the coming twenty years of this options is €23.9 million or VND 595 billion.

## 6.5 Nourishment strategy

There are several possibilities to choose from, when the decision for nourishment is made. This paragraph is a summary of Appendix H.5 and shows advises for the source of sand, the cross-shore location of nourishment and the interval between nourishments.

### 6.5.1 Source of sand

Since the shortest distance makes it the cheapest adequate supply the river deposit before the mouth is advised as source. Furthermore, the sand has the same properties as the beach sand (following from the sand sample analysis in Appendix I.3) The distance to the nearest sediment reservoir is one of the largest factors determining the price per cubic meter of sand (M. Marchand, 2012) This source is however not yet confirmed to be available with sufficient bathymetry charts.

The second best source is further offshore dredging. It is not yet certain where to find suitable mining locations. However it is known that the depth at those locations is around 80 meters and the distance is larger and subsequently the costs rise.

### 6.5.2 Cross shore location of nourishment

The use of shoreface nourishment is advised, since the costs are lower than the costs of a direct beach nourishment. When a limited amount of cubic meters from a nearby source is available, a combination with a beach nourishment should be considered since this nourishment type requires a reduced amount of sand.

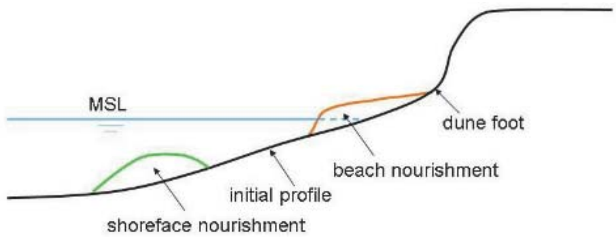


Figure 6.5 - Cross shore location of nourishment

### 6.5.3 Interval time of beach nourishment

Following from Figure 6.6 the most cost efficient maintenance strategy is nourishing every 2 years. Although nourishing every 5 years is around the same costs and this option has some advantages, it is not advised to start with an large initial nourishment as first nourishment in an area without experience with previous nourishments. For the first nourishment an interval of 2 years is advised and when additional research is done a 5 year interval can be used.

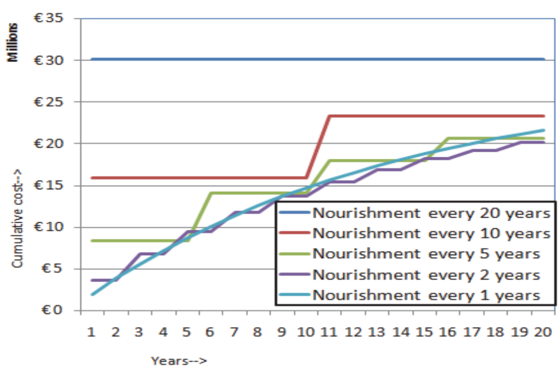


Figure 6.6 - Nourishment interval strategy

### 6.5.4 Longshore location of nourishment

Due to the costs it is advised to nourish the coast at nourishment points every 200 meters and use natural spreading by waves. Not distributing it by land based moving equipment reduces the costs. The coastline will smoothen itself when the distance between the nourishment points is not too large.

## 6.6 Quick solutions

While enough data and influence is being compiled to support and implement a final solution, the problem continues. This paragraphs shows two quick solutions that could be used to limit the problems until an alternative is constructed. Following from the multi-criteria analysis in Appendix G.4 in combination with their absolute costs, the following options are practical solutions to reduce the erosion temporarily.

### 6.6.1 To prevent the erosion from moving northwards

As explained in the previous sections structural erosion can only be stopped by a nourishment of the beach. Currently all measures move the erosion northwards and the beach that is marked red in Figure 6.7 is eroding heavily, based on observation of January 2016. To prevent the damage moving northwards the not used dunes, depicted with yellow, could be gradually flattened and used for nourishment to maintain the coast line and thus prevent further erosion north of this side. The amount of 160,000 m3 is only adequate for 2/3 year of nourishment. It does halt the erosion fully and is well combined with any future nourishment. Moreover, since the location is directly adjacent to the beach the cost are very low. Although dunes are normally used as sea defence against storms, this is not the case here. The dunes next to this stretch are already removed for resorts. However, future possibilities for coastal protection are diminished if this option is chosen.

Figure 6.7 - Dune fix

### 6.6.2 To prevent erosion locally

Quick (temporary) protection should only be applied at locations where buildings are threatened by the erosion. Other stretches should be left unprotected to not move the erosion northwards. To prevent the erosion locally geotextile sandbags are most effective, which allow for a steeper slope. Long geotextile bags can be used for retaining sand locally, by placing them as breakwaters or short groynes. The sand bags and groyne variant with a length of two long geotextile bags is depicted in Figure 6.8.

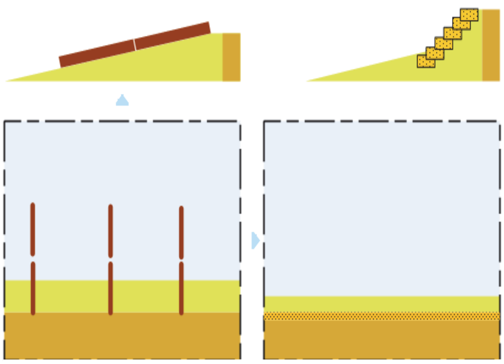


Figure 6.8 - Quick local fix

## 6.7 Beach policy

An effective policy and management of the coastal zone will mitigate or prevent similar problems induced by erosion in the future. Coastal zone management is a broad subject that can be applied on a large scale, but here it will be used on a few kilometres to set up a strategy for the preservation of the Cua Dai area (first part) and the stretch of beach south of the Thu Bon River (second part). Citing from Thia-Eng (2015), chairman of the East Asian Seas Partnership Council, coastal zone management can be used to reach the following four goals: maintaining the coastal resource systems, reducing resource-use conflicts, maintaining the environment and facilitating in multi-sectoral development.

Which resources are available and possible conflicts that can arise over this are given in Appendix H.4. This paragraph gives a concise overview of the designed strategies.

### 6.7.1 Cua Dai Beach

At the time the location for the first hotel or resort along Cua Dai Beach was defined, the designers were not aware of the future coastline variations at the defined location. For years most resorts, hotels and restaurants were built too close to the coastline, if you take the natural coastline variation in mind. One of the most important suggestions to facilitate the progress of multi-sectoral development is to construct any future building or structure far enough from the coastline. This way there will be no erosion issues threatening the resorts, hotels or restaurant along the beach.

Due to climate change there is erosion following from sea level rise and next to that, more tropical storms are hitting Cua Dai Beach. Therefore it is advised to build behind the dunes when present, to have the possibility for extra nourishments in the future and to have enough palm trees and vegetation in front of the buildings. Dunes protect against high storm surges, palm trees and other vegetation might protect against damage due to the wind and the extra nourishment protects against structural erosion damage.

When translating the above strategy into a policy, the following zoning map can be used. It shows a nourished Cua Dai Beach area, divided into a red and a green zone. The red zone stretches from the start of the nourished beach towards 300 meter into the sea. This can be seen as a 'no build' zone, to create space for the natural movements of the beach zone, prevent erosion related problems in the future and adapt to climate change. It stretches into the sea to also forbid the construction of private structures that might limit the longshore transport. Also the sandy part of the end of the spit is a prohibited zone to build on, since this is still a dynamic part of the beach. The green zone is free to build. Although this zone includes the dune zone, most of the dunes have already been removed for the construction of buildings and cannot contribute anymore to the natural nourishment of the beach system.

Figure 6.9 - Zoning Cua Dai Beach

Another important issue these days is that a large amount of licenses are provided to allow the construction of hotels, resorts and restaurants. According to the interviews with resort managers, the amount of tourists has been decreasing last years while more hotels and restaurants have opened their doors. While individual people could make more money, Hoi An as a whole gains more with fully used hotels and open beach parts instead of half full hotels without any public beach. This would reduce the total amount of tourists. Therefore the amount of hotels, resorts and restaurants should depend on the amount of tourists coming to and staying in Hoi An. This way all participants in the sector living from tourism can durable sustain themselves. On the long run this will create a more attractive Hoi An, without empty catering facilities.

Furthermore, a balance between the beach use by fishermen, resorts, restaurants and nature will arise to give everybody and everything enough space to flourish. It is advised not to provide any extra licenses for this stretch of coast to prevent possible conflicts.

### 6.7.2 Southern stretch

The following advice of the development of the area south of the Thu Bon river follows from the preferences that coastal erosion should not require any adaption measures. The suggested coastal zone management foresees future changes and adapt its land use policy to it.

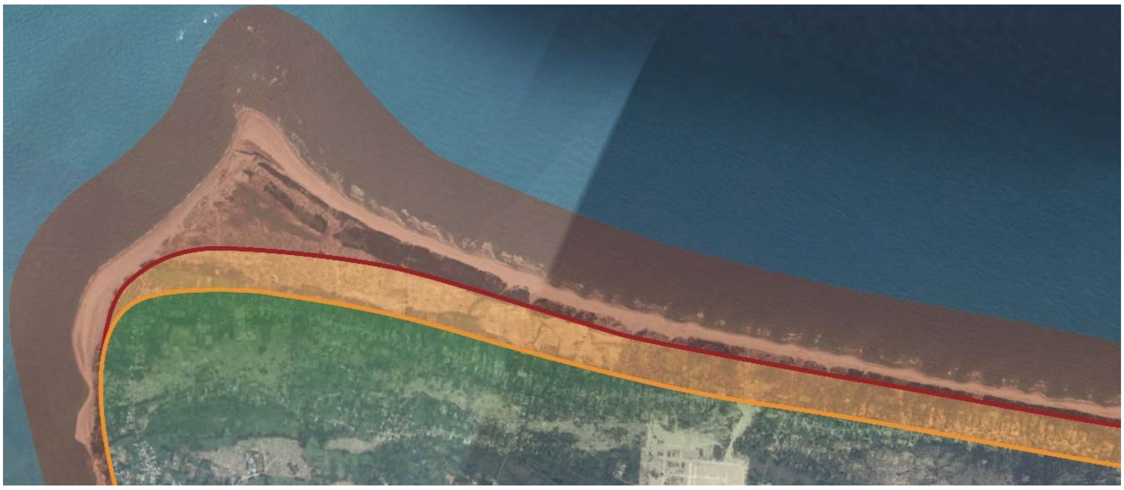


Figure 6.10 - Zoning south of Thu Bon river

The zoning map depicted in Figure 6.10 should be followed. A large part of the bulge next to the river mouth is a prohibited zone to build in. Looking at the recent history (see Chapter 3.1) it is clear that this is a highly dynamic part of the coast. Building here and close to the rest of the beach gives a high chance of lost value in the future, as can currently be seen at Cua Dai Beach.

Between the red zone surrounding the beach and the green zone, a yellow zone is present at this side of the river mouth. Most of the natural beach and dune system is still intact and it is advised to keep it that way. Dunes are an effective soft structure to prevent flooding . Following this policy, building in the yellow zone is only allowed if it is the only possible location for a structure that contributes to the regional development. In this zone agriculture or similar usage should be applied with the knowledge that is not a permanent usage. The green zone is a zone where building is allowed with no restriction since no problems are expected in the coming decades.

In Figure 6.11 the current cross section situation is depicted at the top and a possible future situation placed under it. If erosion would take place, all structures that are built in the green zone would still be safe.

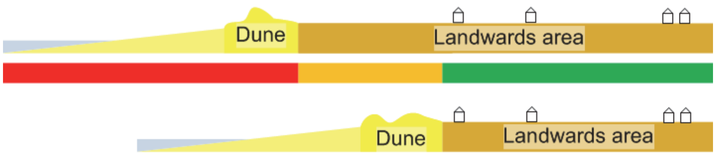



Figure 6.11 - Cross section with adaption profile

# 7. Conclusion and recommendations

This last chapter finalises the report by presenting the main conclusions and recommendations for further research. The latter provides options that would further develop strategies and predict the effects of sand nourishment.

## 7.1 Conclusion

The project started with the following goal:

*Presenting at least three economic and technical durable options which are supported by the Hoi An community to recreate the famous Cua Dai Beach.*

Before being able to present durable options, it was necessary to know what the reasons for the erosion are, what problems they are causing and finding out what needs to be solved or what effects need to be mitigated.

It became clear that several factors are causing the shoreline retreat of 12m/year at Cua Dai Beach. Although not enough data is present yet to proof their precise quantitative influence, order of magnitudes are given to the impact of these factors on the current erosion rate and translated here into percentages of contribution. A steady factor is sea level rise, which accounts for 5% of the total erosion rate. Another consequence of the global changing climate is the increased amount and intensity of storms reaching Hoi An, which contributes to 5-25%. Human contributions are the reduction of sediment supply caused by the construction of the hydropower dam in the Thu Bon river amounts to 5% and sand mining in this river to 40-80%. As can be seen, sand mining has a relative large influence. There is also some natural variation present, accounting for 10-50% of the erosion rate. Other factors are after research excluded as possible reasons for erosion at Hoi An.

The wide ranges in possible contributions are translated into three hypotheses that would explain the current shoreline movements. The first hypothesis is based on the increasing storms as main contributor. The second hypothesis explains the erosion by the reduction in sediment supply from the river. The last hypothesis interprets the shoreline retreat with natural variation as the main reason. The other factors are secondary contributors in these hypotheses. Robust solutions were needed that would be able to deal with each of the hypotheses.

Three alternatives are designed while keeping the wide range of factors that cause the erosion and the requirements for solutions based on interviews in mind. The most important requirements are that the options may not shift the problems to adjacent areas and that they have a high attractiveness. Hoi An has to remain an attractive destination for tourists, since this is the main source of income for the local community. This implies that doing nothing or relocation of the existing buildings are not the right way, social and economic wise, to deal with the problem. Furthermore, based on the first requirement, the use of solely hard structures along the coast was not an option. Hard structures do not stop the structural erosion and keeps shifting the erosion in downdrift direction. Restoring the sediment supply turned out to be a difficult solution and which takes effect only after several decades. This lead to the conclusion that sand nourishment, whether or not in combination with other structures, is the only suitable option in Hoi An.

The alternatives do not take away the causes of erosion. The external causes of climate change and natural variation cannot be diminished, at most be steered in a way that would reduce their effects. Increasing the sediment supply seems a viable option, but would create other negative effects.

The three alternatives counteract the effects of the mechanisms that contribute to the coastal retreat by nourishing the beach. Which alternative suits the situation and budget the best is up to the Hoi An's and Quang Nam policy makers. All alternatives are expected to give a net profit to the city with the averaged cost/year being below income/year.

After the beach has returned, with a width depending on the alternative that will be chosen, it is important to have a strategy to manage the beach use. If not, the same problems of losing properties that were built to close to the sea can arise again in the future. A zoning policy can be used to keep structures out of certain areas that are prone to erosion after, for example, a storm. A similar policy should be made for the stretch south of the Thu Bon river mouth. Although this area is not used intensively, due to the recently constructed bridge the land has become easier accessible for tourism and related construction activities. Also extra care has to be taken for the amount of licenses that will be provided for the construction and opening of hotels, resorts and restaurants. The tourism sector has to grow in the same pace as the amount of visitors coming to Hoi An. This way all participants in the sector living from tourism can sustain themselves. On the long run this will create a more attractive Hoi An, without empty resorts and restaurants. Furthermore, a balance between the beach use by fishermen, resorts, restaurants and nature will arise to give everybody and everything enough space to flourish.

## 7.2 Recommendations

This project does not yet result in a solution for Cua Dai Beach that can be implemented straight away. To achieve this status, there is one issue that should definitely be researched and three others that are preferably researched. Of the three preferred research options all are advised to be conducted even after the initial nourishment has been placed. This research can be used to further develop and enhance future maintenance strategies and better predict and mitigate adverse effects.

### 7.2.1 Fieldwork near the source location of sediment

More detailed bathymetry data and analysis should be made for the foreshore sand balance. A confirmation of the sand balance described in section 4.3.5 would mean that a cheap recycling of the sand could take place right away. The data is however inconsistent with what was expected. If this data is proved to be incorrect, other sources in the area should be checked for availability. Only the area relatively close to the shore is expected to be feasible as a source location, based on the sediment analysis undertaken in this project, which is given in Appendix I.3. A new fieldwork should focus on finding sand with similar properties as the beach sand at Cua Dai.

### 7.2.2 Research into wave shielding (local wave data)

Research of the wave climate close to Hoi An should be done to take the influence of shielding by the Cham Islands into account. At least two, yearlong, wave measurements located halfway between Cham and Hoi An are needed to measure wave height, period and direction. One in front of Cua Dai Beach and one more to the south. It is more preferred to collect such data at multiple locations to determine the complex wave movements behind the islands. Also preferred is the data of a longer time period to take multiyear variation into account, but one year is the bare minimum to make more reliable quantitative models or predictions. This research would focus on longshore sediment transport for different coastal stretches and on how Cham shields different beach stretches from different waves.

### 7.2.3 Research into the current and future river sediment supply

A more detailed analysis of the Thu Bon River is recommended to make a more reliable approximation of the sediment transport to the Cua Dai inlet, since the decrease in sediment supply from the river is one of the main factors contributing to the present coastal erosion. The estimation methods used as described in Section 3.2 could use improvement.

Together with the acquirement of more data, software like SOBEK-RE or Delft3D are suggested to make a more detailed model of the Thu Bon River.

The water level and discharge at multiple locations would be needed for such a model. Especially data of just upstream and downstream of the connections between the Vu Gia and Thu Bon river are needed. When modelling the Thu Bon river in more detail (with enough data points and at the right locations)the effects of sand extraction in the middle and lower stretch of the river could be determined. Also its effect on the sediment output into the coastal system could be found. A research into this topic could result, next to a better sediment input estimate for coastal models, into a better understanding of the river system and its problems like floods and bank erosion.

### 7.2.4 Delft 3D model for the coastal zone

With a Delft 3D model the currents and sediment transport patterns can be simulated in more detail. While more simplified models can give good estimates, Delft 3D can simulate in more detail the complicated interactions in and around the river mouth, which is a crucial part in understanding the dynamics of this coastal system. Another part of the problem is the complicated bathymetry that can influence the wave climate to a great extent. More simplified programs usually assume a longshore uniform profile which is not present in Hoi An, due to shallow areas south of Cham Island. The calibrated model can be used to better assess the impact and effectiveness of structures and nourishments near the river mouth.

For a Delft 3D model a multitude of data is needed and therefore can only be undertaken if some of the other research suggestions are conducted as well:

- Wave data and currents: this follows from section 7.2.2.
- Bathymetry: adequate data is present, but has to be confirmed or improved if possible.
- More reliable sediment supply: could follow from section 7.2.3.
- Bed type data: this project provides adequate rough data, however more locations with each a reliable analysis of the bed soil is preferred.

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# List of figures

**Figures**


*Figure 2.1 - Erosion problems in Hoi An* --- 2
*Figure 2.2 - Hotels and resorts at Cua Dai Beach (Booking.com, 2015)* --- 2
*Figure 2.3 - System boundaries at provincial level (left) and city level (right)* --- 4
*Figure 3.1 - Evolution of the Hoi An coast based on Landsat images (Hoang, Tanaka, Viet, & Duy, 2015)* --- 6
*Figure 3.2 - Coastal features of the beach at > Hoi An (Edited map from Google maps)* --- 6
*Figure 3.3 - Coast classification (Boyd, Dalrymple, & Zaitlin, 1992)* --- 6
*Figure 3.4 - River network of the Vu Gia – Thu Bon basins (Long, Tung, & Huy, 2013)* --- 7
*Figure 3.5 - Developments of a deltaic coastline with normally incident waves (Bosboom & Stive, 2015)* --- 9
*Figure 3.6 - Spit formation at a river mouth (Bosboom & Stive, 2015)* --- 9
*Figure 3.7 - Estimated sediment transport directions by Professor Stive (Stive, 2015)* --- 9
*Figure 3.8 - Left: profile during dry (calm) season. Right: during wet (rough) season (Bosboom & Stive, 2015)* - 10
*Figure 3.9 - Contoured areas, based on (Tanaka, Hoang, & Viet, 2016)* --- 10
*Figure 4.1 - Power versus interest diagram* --- 13
*Figure 5.1 - Order of magnitude of the influence of main and secondary drivers of the three hypotheses* --- 18
*Figure 6.1 - Three alternatives* --- 21
*Figure 6.2 - Coastline impression with large nourishment* --- 22
*Figure 6.3 - Coastline impression with medium nourishment + groynes* --- 22
*Figure 6.4 - Coastline impression with small nourishment + revetment* --- 23
*Figure 6.5 - Cross shore location of nourishment* --- 24
*Figure 6.6 - Nourishment interval strategy* --- 24
*Figure 6.7 - Dune fix* --- 25
*Figure 6.8 - Quick local fix* --- 25
*Figure 6.9 - Zoning Cua Dai Beach* --- 26
*Figure 6.10 - Zoning south of Thu Bon river* --- 27
*Figure 6.11 - Cross section with adaption profile* --- 27
*Figure A.1 - Vietnam overview (JohoMaps, 2015)* --- 40
*Figure A.2 - Map of Hoi An* --- 40
*Figure A.3 - Cua Dai Beach (Vietnam heritage tours, 2015)* --- 41
*Figure A.4 - Cua Dai Beach resorts (Vietnam discovery, 2015)* --- 41
*Figure A.5 - Study area province* --- 42
*Figure A.6 - Hoi An Biosphere zones (Thao, 2015)* --- 43
*Figure A.7 - Cham Island Marine protected area* --- 44
*Figure B.1 - Goal tree national government* --- 65
*Figure B.2 - Goal tree provincial government* --- 66
*Figure B.3 - Goal tree city government* --- 67
*Figure B.4 - Goal tree citizens of Hoi An living from the beach* --- 68
*Figure B.5 - Goal tree resort managers* --- 69
*Figure B.6 - Goal tree building industry* --- 70
*Figure B.7 - Goal tree sand miners* --- 71
*Figure B.8 - Goal tree tourists* --- 72
*Figure C.1 - The Bruun rule explained visually (Bosboom & Stive, 2015)* --- 75
*Figure C.2 - Map bathymetry East Sea / South China Sea near Hoi An (U.S. Army Map Service, 1984)* --- 76
*Figure C.3 - Wave compass of the offshore wave climate of Hoi An (ARGOSS, 2015)* --- 77
*Figure C.4 - Histogram of the offshore wave climate of Hoi An (ARGOSS, 2015)* --- 77
*Figure C.5 - Tide chart Hoi An (Tide-forecast, 2016)* --- 78
*Figure C.6 - Bathymetry and cross-shore sand balance* --- 79
*Figure C.7 - Erosion schematisation* --- 80
*Figure D.1 - Estimation of sediment supply by comparable catchment area (Viet & Tanaka, 2015)* --- 81
*Figure D.2 - River section used for the calculations* --- 84
*Figure E.1 - River connections between the Vu Gia River and Thu Bon River distributing discharge* --- 87
*Figure E.2 - Exploitable groundwater in Billion $m^3$/year( National Water Sector profile, 2002)* --- 88
*Figure E.3 - Sediment balance of a river segment (Mangor, 2008)* --- 88

*Figure E.4 - Initial deformation and propagation of a trench towards the downstream end of the river* ---------- 89
*Figure E.5 - Sand mining on Thu Bon river* ---------- 90
*Figure E.6 - Hydropower dams in theThu Bon river (ADB, MONRE, EVN, MOIT, Quang Nam DONRE, 2008)* ----- 91
*Figure E.7 - Narrowing by reclamation for the building of the Cua Dai Bridge* ---------- 92
*Figure E.8 - Earth plates (JohoMaps, 2015)* ---------- 93
*Figure E.9 - Shoreline change due to increased rough conditions* ---------- 94
*Figure E.10 - Considered cross-shore profile. (Chang, 2015)* ---------- 96
*Figure E.11 - Data fitted to the Bruun profile from Figure E.10* ---------- 96
*Figure E.12 - DUROS+ result for 1/50 year typhoon conditions* ---------- 97
*Figure E.13 - Hss and Tp fittings* ---------- 99
*Figure E.14 - DUROS+ result for 1/5 year conditions* ---------- 100
*Figure E.15 - Observed sandbar in in 1989. Adapted on data from (Hoang, Tanaka, Viet, & Duy, 2015)* ---------- 100
*Figure E.16 - Coastline variation between 1975 and 1991 (Hoang, Tanaka, Viet, & Duy, 2015)* ---------- 101
*Figure E.17 - Coastline variation between 1975 and 2015 (Hoang, Tanaka, Viet, & Duy, 2015)* ---------- 102
*Figure E.18 - Direction of sediment outflow from the river* ---------- 103
*Figure F.1 - Locations of coastal protection measures along Cua Dai Beach* ---------- 104
*Figure F.2 - Man looking down at failure of the improvised sandbags* ---------- 104
*Figure F.3 - Geotextile sand bags along a* ---------- 105
*Figure F.4 - Schematic cross-section of sand bag revetment* ---------- 105
*Figure F.5 - Breakwater in front of Victoria resort* ---------- 106
*Figure F.6 - Long geotextile bags as core of a permanent breakwater (Ten Cate, 2015)* ---------- 106
*Figure F.7 - L-shaped breakwater at Golden Sands resort* ---------- 106
*Figure F.8 - Concrete revetment* ---------- 107
*Figure F.9 - Schematic cross section of concrete revetment.* ---------- 107
*Figure F.10 - Collapsed Hoi An Hideaway resort* ---------- 108
*Figure F.11 - Schematic cross section of seawall.* ---------- 108
*Figure F.12 - Casuarina equisetifolia located on spit* ---------- 109
*Figure F.13 - Staggered pattern in planting vegetation* ---------- 109
*Figure F.14 - Current failed sea wall in Hoi An* ---------- 109
*Figure F.15 - Failure mechanisms. Seaward overturning (left) toe scour and rotation(right)* ---------- 110
*Figure F.16 - Typical bottom scour profiles for fine (left) and coarse material (right)* ---------- 111
*Figure F.17 - Ground water flow through toe cylinder (Hoop, 2006)* ---------- 111
*Figure F.18 - Downward profile changes with an infinitely long revetment* ---------- 112
*Figure F.19 - Landward migrating profile when a finite revetment is considered* ---------- 112
*Figure G.1 - Causal diagram* ---------- 116
*Figure H.1 - Nourishment width of different coastal sections* ---------- 127
*Figure H.2 - Basic design of alternative* ---------- 128
*Figure H.3 - Expected erosion and accretion next to a groyne.* ---------- 129
*Figure H.4 - Current rock revetments* ---------- 131
*Figure H.5 - Effect of the groyne field without nourishments* ---------- 132
*Figure H.6 - Dimensions and stacking of the long geotextile bags for the trial groynes* ---------- 133
*Figure H.7 - Location of revetments* ---------- 134
*Figure H.8 - Beach width* ---------- 136
*Figure H.9 - Shifting of erosion* ---------- 136
*Figure H.10 - Visual overview of different beach/bed levels* ---------- 137
*Figure H.11 - Revetment surface* ---------- 137
*Figure H.12 - Stairs example* ---------- 137
*Figure H.13 - Top view with new beach with revetment* ---------- 138
*Figure H.14 - Top view and impression of boulevard (Verkeersbureausinfo.nl, 2014)* ---------- 138
*Figure H.15 - Land classification* ---------- 139
*Figure H.16 - Sand sources* ---------- 140
*Figure H.17 - Cross shore location of nourishment* ---------- 141
*Figure H.18 - Nourishment interval strategy* ---------- 142
*Figure H.19 - Longshore nourishment locations* ---------- 142
*Figure H.20 - Focus points of nourishments* ---------- 143
*Figure H.21 - Difference in resources (Google Earth, 2015)* ---------- 145
*Figure I.1 - Photo series of measurement stick* ---------- 147

*Figure I.2 - Graph indicating the length of the stick as function of time* ---------- 148
*Figure I.3 - Graph indicating the relative vertical beach change as function of time* ---------- 148
*Figure I.4 - Observations map* ---------- 149
*Figure I.5 - Fieldwork river observation* ---------- 149
*Figure I.6 - Sand mining example* ---------- 149
*Figure I.7 - Locations of the sediment samples* ---------- 150
*Figure I.8 - Sieves* ---------- 150
*Figure I.9 - Gradation of soil by dry sieving method* ---------- 151
*Figure I.10 - Grain size distribution curve (Verruijt, 2012)* ---------- 151
*Figure I.11 - Grain size distributions of beach samples* ---------- 153
*Figure I.12 - Grain size distributions of sea samples compared to beach sand* ---------- 153
*Figure I.13 - Research locations seabed East Sea / South China Sea* ---------- 154

## Tables

*Table 3.1 - The three different sediment estimates* ---------- 7
*Table B.1 - Tax income Hoi An from hotels Cua Dai Beach* ---------- 73
*Table C.1 - Sand balance calculation* ---------- 79
*Table C.2 - Table summary of used data for erosion* ---------- 80
*Table D.1 - Sediment discharge river sections* ---------- 83
*Table D.2 - Sediment discharge calculation with formula of Gray and Simoes* ---------- 85
*Table E.1 - Sediment reduction due to dam* ---------- 91
*Table E.2 - Wave height calculation* ---------- 98
*Table E.3 - Wave period calculation* ---------- 98
*Table E.4 - Extrapolation of Hss and Tp for longer return periods based on measured data from (hải, 2010)* ---- 99
*Table G.1 - Weight of different criteria* ---------- 123
*Table G.2 - Currently used measures* ---------- 124
*Table G.3 - Other possible measures* ---------- 124
*Table H.1 - Total needed beach width* ---------- 126
*Table H.2 - Total nourishment widths of different parts of Cua Dai Beach* ---------- 127
*Table H.3 - Required stone sizes ($D_{n50}$) for the groynes indicated for different return periods* ---------- 131
*Table H.4 - Measured stone sizes at Victoria and Golden Sand resort, categorized* ---------- 131
*Table H.5 - Reference projects* ---------- 134
*Table H.6 - Sand sources overview* ---------- 140
*Table I.1 - Weekly measurements of the stick length at Cua Dai beach, Hoi An.* ---------- 147
*Table I.2 - Classification of soils (Verruijt, 2012)* ---------- 151
*Table I.3 - Grain Size Distribution Curve Results* ---------- 152

# A. Area

In this appendix some extra information about the area is given. It starts with a short introduction about Vietnam and its recent history. After this, the area around Hoi An will be described in more detail to give some background information of the Hoi An area. In paragraph A.2 there is elaborated on the study area, after which the regulations related to the Cham Islands are given. In the next paragraph an overview of coastal erosion problems in Vietnam is given. This chapter ends with some legal aspects relevant for this project.

## A.1 Vietnam and Hoi An

Vietnam is a Southeast Asian country with a relatively long coastline. As a reference: its coastline stretches as far as the coast from Denmark to Portugal with an area comparable to Germany (Thia-Eng, 2015). With a population of more than 90 million people Vietnam is in the top 15 of the world's most populated countries with a GDP of 1,902 dollar per capita (Landenwijzer Vietnam, 2014). The GDP is fairly low at the moment, but with a sustained 6% expected growth for the coming years it is expected to improve in the future. While having multiple religions, in the recent centuries there have been no religious tensions in the country. Most practiced religions are Buddhism and Catholicism.


Figure A.1 - Vietnam overview (JohoMaps, 2015)

In the whole of Vietnam there is a communist system with a one-party state since the country was unified in 1975. While still having a communist party system, more and more capitalistic ideas are allowed to support economic growth in the country. There are 58 provinces in Vietnam and five municipalities with the same status as a province. While there is a subdivision in smaller, more local partitions, the provinces have an important part in the decision making and funds allocation (Provinces of Vietnam, 2015).

Hoi An is a coastal city lying at the mouth of the Thu Bon River. It is part of the province of Quang Nam and has around 120,000 inhabitants. It used to be an important port in the middle of Vietnam and with it came wealth to the city. This might be partly due to the fact that Hoi An is translated in English as "peaceful meeting place". When the French got the exclusive trading rights to Danang, a city 50 km to the north of Hoi An, and when siltation of the harbour of Hoi An started, the town stopped to be important. This was around the end of the 18th century (Visit Hoi An, 2015). Due to this decline in importance the city stayed quite the same until now. Even during the Vietnam war the town survived quite well. Partly because both sides wanted it so (UNESCO, 2008).


Figure A.2 - Map of Hoi An

In 1999 UNESCO declared the old town of Hoi An to be a 'World Heritage Site' (UNESCO, 2008). This increased the amount of tourism to Hoi An substantially while also the amount of tourism in the whole of Vietnam rose. The amount of international visitors to Vietnam increased from 1.8 Million in 1999 to 7.9 million in 2014 (Ministry of Culture, Sports & Tourism, 2014). Hoi An and its inhabitants' wealth increased with it. In the last twenty years beach hotels were built near the famous Cua Dai beach to provide luxury resorts for tourists. In both pictures below the new touristic situation is depicted, but it is showing the difference in beach use. More small investment based, flexible venders use the beach, whereas beach resorts require a large investment to start with by building permanent structures.

**Figure A.3 - Cua Dai Beach (Vietnam heritage tours, 2015)**

**Figure A.4 - Cua Dai Beach resorts (Vietnam discovery, 2015)**

## A.2 Study area

Landwards of Hoi An a large river system (the Vu Gia and Thu Bon rivers) is present, which originates in the high mountains on the east side of the Truong Son Mountain Range and flows out into the sea through the Hoi An and Danang river mouths. The Thu Bon river is the one important for the Hoi An coast with respect to sediment and discharge. The average annual discharge of the Thu Bon river is $327m^3/s$(Viet & al.,2014). In the wet season, the wave direction is from the south and the discharge of the river is high, which causes the sediment in the river to be washed seawards. As a result, a large amount of sediment is deposited at the outside of the estuary. The river acts as a sediment source in the wet season, which increases the volume of the ebb tidal delta. In the dry season, the wave direction is from the north and the discharge of the river is very limited. During this time, the more severe wave climate has a large effect on the development of the coastal stretch.

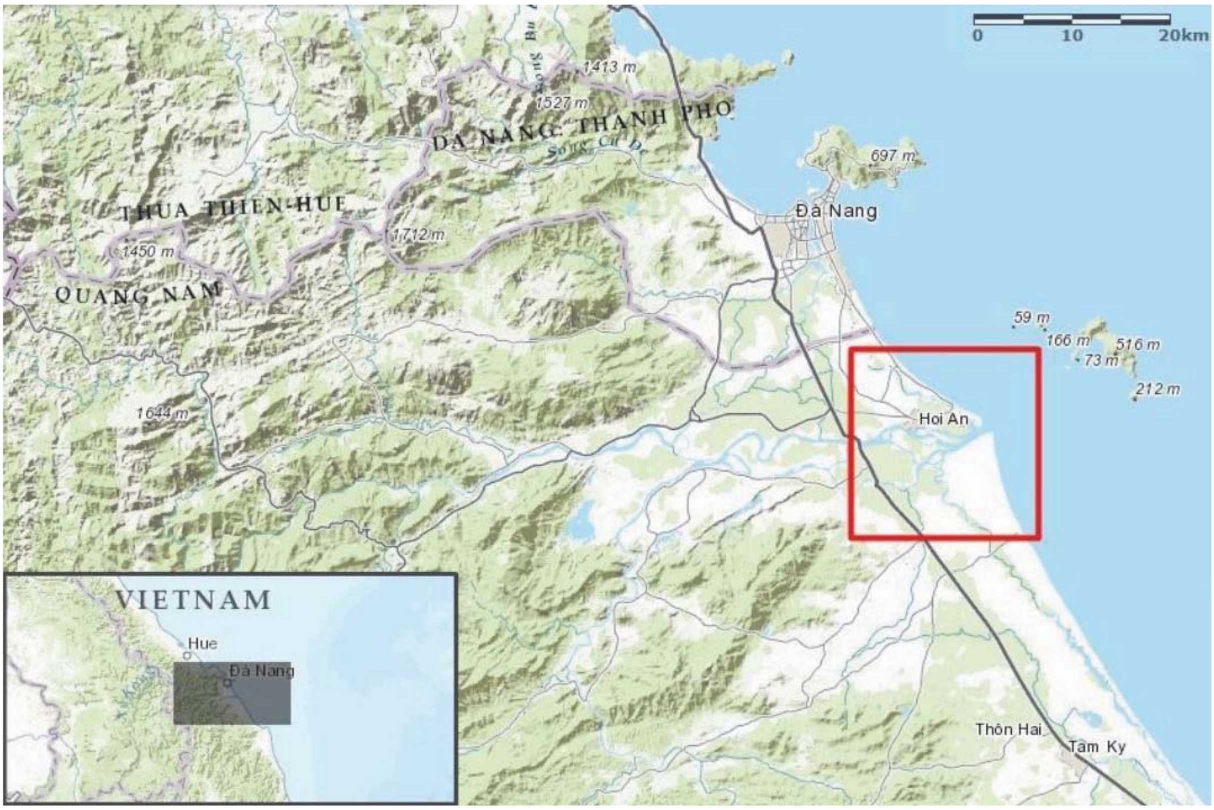



Figure A.5 - Study area province

If we zoom in at Hoi An, we find a more detailed overview of our study area. It consists of the beaches north of the Thu Bon river mouth which have a length of approximately 4 km. Presently, this coastal stretch is rapidly developing into a high class tourist resort area. The shape of the delta might give us some information about the sediment flow patterns in the study area. A spit is formed just north of the Thu Bon river estuary, which indicates the flow should be towards the river inlet. On the south side of the river, a wave dominated coast is observed, which has a rather smooth shoreline with well-developed beaches and dunes. In general, the shape is symmetrically cuspate. Based on the study of Viet &al. (2014), it can be seen that the tip of this sandy coast has been migrated further to the south.

In front of Hoi An lies Cham Island, which in fact is a group of one large island and seven smaller ones. The distance to the coast is 16km and 19km to the town of Hoi An. Probably due to Cham Island, the flow pattern in front of the whole coastal stretch changes in such a way that a different shape is observed at either side of the river estuary.

## A.3 Cham Island protected area

The old town of Hoi An has carried the name of World Heritage site since 1999. And due to the cities' relationship with the estuary and harmony with nature the area of Hoi An is designated as World Biosphere Reserve in 2009 (UNESCO, Cu Lao Cham - Hoi An, 2009). Biosphere Reserves are divided into three zones: a core zone, buffer zone and transition zone. The core zone is a strictly protected ecosystem. The buffer zone surrounds the core area and is used for activities that benefit scientific research, education and monitoring. The transition zone of the reserve allows the most activities with sustainable economic and human development (UNESCO, Biosphere Reserves, n.d.). How the zones are distributed in the Hoi An Biosphere Reserve is given in the picture below. The Cham Islands form the core area of the reserve. The old town of Hoi An together with the surrounding sea forms the buffer zone. The transition zones lies north of Hoi An.

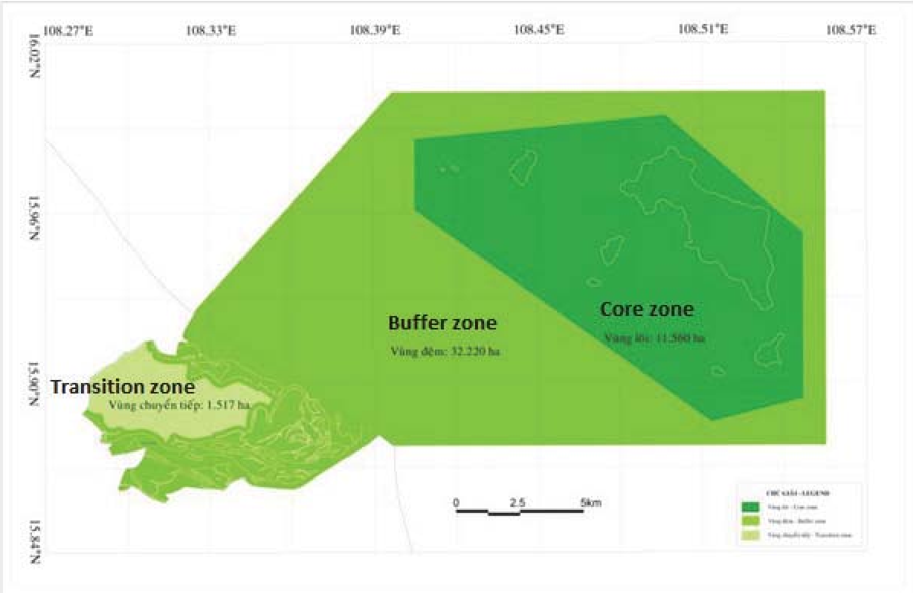



**Figure A.6 - Hoi An Biosphere zones (Thao, 2015)**

The core zone, formed by the Cham Islands, is also a Marine Protection Area. This zone was created for the 'conservation of its marine resources and biodiversity' and improvement of the local livelihood (Management of Cham Islands, 2014). The area is again divided into different zones, depicted in the following map. There are several strictly protected core zones, given with the red areas. The conservation of the coral reef ecosystem makes any kinds of visiting prohibited. This implies the collecting of coral and samples, but also excursions, swimming or other forms of tourism. A large part of the island's coast forms tourism development zones. Touristic activities are concentrated in this area to provide income for the local people. Other important zones are the rehabilitation zones. The activities in these zones focus on the recovering of ecosystems. It might therefore be possible that part of these areas become protected core zones in the future (Nhung, 2010).

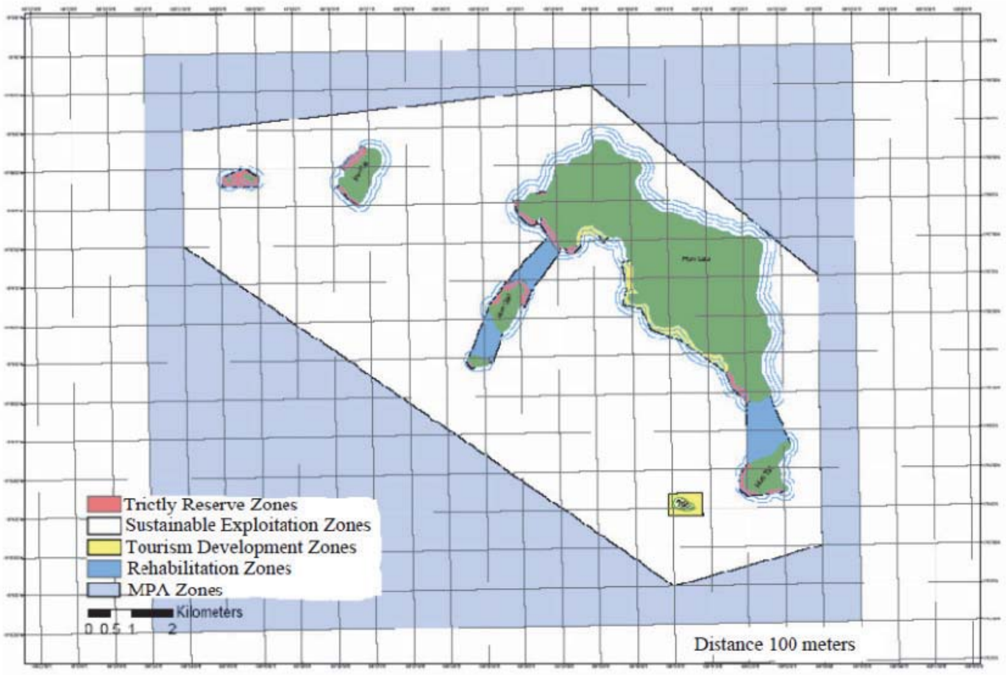



Figure A.7 - Cham Island Marine protected area

## A.4 Coastal erosion problems in Vietnam

Vietnam has a 3,260km long coast, with on average every 20km a river mouth (Cat & al., n.d.). Coastal erosion is not a problem unique for Hoi An. On multiple locations along the Vietnamese coast, erosion occurs, differing in intensity and causes. In this part, an overview of similar problems to the Hoi An erosion is given.

**North Vietnam**

Most north in Vietnam lies the Quang Ninh region. Due to the topography, erosion is only occurring on short sections. Furthermore this region is sheltered against waves by the mainland of China and the Chinese island of Hainan. However, the other large part of the northern region is dominated by the Red River delta, of which long coastal sections in the southern part are eroding.

The problems in this region are caused by a complex play of erosion and sedimentation near river mouths. Near the river mouth, sediment can settle with a high rate, while further from the mouth severe erosion occurs. Typhoons, causing high wave action, are destroying the beaches after which the longshore currents can redistribute the sediment over a long stretch of coasts. This causes erosion in on region and sedimentation in another. The construction of dams further limits the sediment supply and increasing the erosion rate. For the Dinh Vu region, the cause of erosion is the subsidence of the estuary in combination with sea level rise due to climate change. The actions of waves and tide are not in equilibrium with the current beach profile and are therefore reshaping it.

**Central Vietnam**

All coastal provinces in the Central region of Vietnam are dealing with coastal erosion (Cat & al., n.d.). The rivers in this region are short and carry a low sediment content, while the sea has relatively the highest wave energy. In the Quang Nam province alone, in which Hoi An is located, eighteen coastal sections are eroding. On the total 1765km long stretch from Thanh Hoa region south of Hanoi to Binh Thuan region a little north of Ho Chi Minh City, 392 km of the coast is eroding. The rates at which erosion occurs differs. The more irregular shaped coasts with bays and peninsulas are eroding at a lower rate. Most strong erosion occurs on convex sandy coasts, who face more wind and wave directions than concave coasts. 43% of the central Vietnamese coast erodes with a rate of 15-30m per year, of which some regions are dealing with over 100m per year (Cat & al., n.d.).

Although the process of erosion is different per location, it can be said that the overall rate of erosion is still increasing, especially since 1990.

Quang Ngai province, located south of the Quang Nam province, is eroding with the highest intensity of all regions along the central coast. A total length of 60km is eroding and despite of reinforcing measures, erosion still continues. Revetments, piling, protective walls and tree plants are unsuccessful in stopping it. Until the cause of erosion is not found, the preventive measures are not efficient. Different causes for erosion in this part of Vietnam including Hoi An can exist, which are further specified in Chapter 5or Appendix E.

**South Vietnam**
Based on surveys and maps, no erosion took place before 1940 in the southern coastal areas. Since 1960 erosion became a common problem here and since 1995 it has been causing serious problems. Not only a disappearing beach is problematic, also the threatening of residential areas, increased floods and saline intrusion are affecting human lives and economic development (Thao, 2014).

Also in this part of the country, the rate and intensity of the erosion differs per location. One of the provinces with severe erosion is the province of Ho Chi Minh City. The construction of a dam is one of the reasons for a sediment deficit and increasing erosion rate. The province located more south is also dealing with a reduced sediment supply, this time caused by the construction of irrigation and flood channels. Also the destruction of mangrove forests, which used to protect the coast from extreme wave actions, is a local reason for erosion.

## A.5 Legal aspects

### A.5.1 Land ownership

According to the Vietnamese Law on Land, an individual cannot own a piece of land. Article 5.1 from the Law on Land No. 13-2003-QH11 about ownership of land states: ‘Land belongs to the entire people with the State as the representative owner’, meaning that land is a collective good in Vietnam and the Vietnamese State is the administrative owner on behalf of the people. However, the State can allocate or lease a piece of land to an individual or entity. The duration of this right to use the land and the purpose for which the land has to be used is determined by the State, following from the land zoning and planning.

After being allocated a piece of land, the land user receives a so called ‘land use right (LUR) certificate’. This LUR is granted by the People’s Committee on provincial or district level, depending on the type of land use and user. The district People’s Committee is allowed to grant LUR certificates to domestic or overseas Vietnamese and for residential use only. The provincial level has the authority to also allocate land to religious and foreign entities. (Binh, 2011)

Although you cannot own land, with a LUR certificate you have several rights to have control over your land. Besides using it, there are rights to get a mortgage and lease or sub-lease it to another party. The piece of land can also be transferred together with the certificate for the specific duration and purpose. However, each type of land user has different rights. Vietnamese citizens have more land use rights than overseas Vietnamese or foreigners and differences exist between foreigners with diplomatic functions or without.

Compared to Vietnamese, the rights to lease a land as foreigner are very limited. Until recently the same was the case for the ability to buy a house in Vietnam as foreigner. In July 2015 the Law on Housing No. 65/2014/QH13 was taken into action, which increased the possibilities. With this new law, foreign organisations and individuals have the same right to own houses as domestic Vietnamese citizens. However, the amount is limited to 250 separate houses in the same area and 30% of the apartments in an apartment building. (Tung & Hien, 2014)

### A.5.2. Coastal management

**By law**

Coastal management in Vietnam is approached through several levels of governmental agencies. On the highest level, ministries are responsible for making policies for their sector and implementing them. The most relevant ministries for coastal related issues are the Ministry of Resources and Environment and the Ministry of Agriculture, Rural Development and Planning. The first one is responsible for environmental monitoring and maintaining the quality of water resources. The second ministry's tasks are water quantity management, flood protection and coastal defence. Furthermore, the Ministry of Planning and Investment is responsible for the financing and spatial planning of infrastructure at the coast (Thang, n.d.). The policies of the ministries are implemented per province by the People's Committee, who are in turn responsible for the development of their own province.

The Law on Environmental Protection No. 55/2014/QH13 is important for developments in the coastal zone. This law provides the rights, duties and obligations of governmental bodies, organizations or individuals who are engaged in the task of environmental protection. It is important that all protection measures are in line with the planning for land use, which is made at national level. This planning is based on an assessment of the current environmental status and the zoning of the environment and land use. The actions on provincial level must be aligned with this national planning. This provincial planning should also be made in consult with district level People's Committee and relevant agencies and organisations.

**In practice**

Although a lot of regulation exists for coastal management, in practice it does not always work out well. According to research by Dennis Eucker, integrated coastal approaches are often unsuccessful in Vietnam due to incomplete communication and favouring of certain sectoral interests (Eucker, 2008). Also certain aspects of coastal management are difficult to understand, making it even harder to get an integrated approach. Furthermore, the distribution of power can be uneven and the decision making is often top-down rather than by partnership on local levels. According to the same research, local communities in Vietnam often feel undermined by authorities with limited interests. Stated in the Law on Land, the coastal zone is managed by the state and the use of it should fit the national planning. In practice it can translate into people being able to exploit resources wherever they like.

As said before, several ministries are responsible for the coastal zone. All of them have to be consulted for major changes in the coastal zone, making it a resource consuming process. Unfortunately, a single party for coastal coordination does not exist and the cooperation between the different ministries is not always that well. The above makes it difficult for citizens to participate in coastal matters and results in a gap between political and social interests.

# B. Stakeholders

This appendix gives the extensive stakeholder analysis. It starts with all the answers to the interviews and questionnaires, which is summarized in the second paragraph. After this, each stakeholder is analysed using problem statements and goal trees. One other component is added to this appendix, which is an estimation of the value of the hotels along Cua Dai Beach.

## B.1 Interviews

In Hoi An, several resort managers, tourists and locals are interviewed to gain insights in the current problem and how they feel about it. This part of the appendix shows the raw data that is required with it.

### B.1.1. Resorts

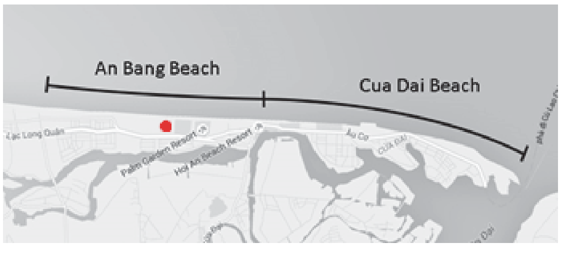
**Victoria Hoi An Beach Resort and Spa**

| | |
|---|---|
| Interviewee | General Manager, Frenchman who has lived here for 20 years |
| Resort location | At Cua Dai Beach, dealing with heavy erosion |
| Date | 2 December 2015 |


On request of the interviewee this interview is left out of the report.

**Boutique Hotel**

| | |
|---|---|
| Interviewee | Front Office Manager, Vietnamese |
| Resort location | north of Cua Dai Beach/An Bang Beach, where there is a beach left |
| Date | 2December 2015 |



1. How did the coastal erosion impact the hotel in terms of price of the room and the amount of guests?
*Currently we have no worries about beach erosion. We have had no erosion since the opening in 2009.*

2. Do/did you organise activities on the beach, if yes, which one?
*Not much, only sun bathing. No activities like water sports.*
3. Do you think the beach will be different in 10 years?
*In 10 years, I don't know. But I expect that in 5 years the beach will still be the same. We are not along the eroding Cua Dai Beach, but another one. Maybe there will be erosion, but we don't know.*

4. Why did you choose this location for the resort?
*This location was chosen because the rest was already occupied.*

5. The resorts along Cua Dai Beach all have their own solution. How do you feel about that?
*The locals nor the government has the right solution yet. The government is working on a project and if needed we might follow that.*
*The best way is to involve the government to carry on the project. I understand that others wanted to protect their own property first. But the best way is via the government.*

6. Is the current situation good enough or is more beach necessary?
*There are less tourists at Cua Dai Beach, I think some will come to us then. So we have a bit of an advantage from the erosion.*

**Muong Thanh HoiAn Hotel**

| | |
|---|---|
| Interviewee | Entertainment Manager, born in Hoi An (difficult to communicate with) |
| Resort location | at Cua Dai Beach, but on landside of the Au Co road |
| Date | 2December 2015 |


1. When has this hotel been built?
*Last year. It is open for eleven months now.*

2. Do you organise activities on the beach?
*Yes, food bars, water sports. Everyone want activities at the beach. But now there are no activities, because the weather is not good: high water, waves and wind.*

3. Last 30 years there has been a lot of sand disappearing from the beach. Who have tried to solve it and were they successful?
*Due to high water and wind, the sand is disappearing. But the government comes around for a project now.*

4. Have you already tried something to protect the beach?
*We have no project yet, and also no plans for doing a project. We have two public beaches nearby: Cua Dai Beach and in front of the hotel. Also, our hotel is far away from the beach, so there is no need for protection like a rock wall.*

5. Will the hotel be doing better in the future?
*Yes, why not? It is a new hotel.*

6. Is the current beach enough?
*Everybody wants more beach. To play football, water sports, and other activities.*

**Hoi An Beach Resort**

| | |
|---|---|
| Interviewee | General Manager, Vietnamese |
| Resort location | At Cua Dai Beach, but on landside of the Au Co road |
| Date | 3 December 2015 |


1. How did the coastal erosion impact the hotel in terms of price of the room and the amount of guests?
*Both reduced due to the erosion. The major erosion occurred around October 2014 and scared tourists to come to Cua Dai Beach. Less guests are coming to Hoi An Beach Resort and the guests who are coming to the resort want a beautiful beach which isn't there, so the resort has to compensate for that. We give a discount of approximately 10% or 20% for a room at the seaside and also the tourists who are visiting the resort try to get a discount when they see the beach is almost gone. The beach in front of the resort at the other side of the road belongs to Hoi An Beach Resort.*

2. Do/did you organise activities on the beach, if yes, which one?
*Before the erosion when it was a wide beach a lot of sport activities were organised. Sport activities like volleyball, jet skiing, kayaking and also other water sports. Now the beach is almost gone and there is nearly no area to organise these activities. The resort organises only the kayaking and has a bar with drinks and food still left and added some romantic activities.*

3. Last 30 years there has been a lot of sand disappearing from the beach. Who have tried to solve it and were they successful?
*The past 30 years the beach was wide and beautiful. Last year, 2014, there was severe erosion and the beach has retreated a lot. The provincial government organised several meetings and conferences about the beach erosion last year, but it was too late.*

4. Have you tried something to protect the beach? What kind, when and alone or in collaboration?
*Before the storm season this year a lot of sandbags were placed on a talud to protect the beach against more erosion. The plan to place those sandbags is from the government, however it is not so successful. The storm, wind and waves still affect the sand bags and the sand beneath it, some sand bags are sinking. Many people and resorts including the local people are requesting the cities and provincial government to do something and rescue the beach. The reason for the talud with sandbags is that people who want to swim still can go down when the water is save to swim.*

5. Why did you choose this location for the resort?
*The Hoi An Beach Resort is opened at the 15th of August 2000. The location of this resort is at a point where the river meets the ocean and that is the main reason of choosing this location. The slogan of the resort has to do with that: "An oasis of the peace where the river meets the ocean".*

6. What is your expectation of the future of the resort and the beach?
*The waves created by the storm are still a threat for the beach and the resorts located along the beach. We are scared for the storm which takes sand away from the beach and damages the protection of sandbags. We hope the erosion will no longer affect the beach so the resort will have a beautiful and wide beach where we can organise many activities.*

7. Do you think the beach will be different in 10 years?
*If the cities and provincial government has no good solution within 10 years the beach will attack the resort and the erosion will be a threat for the resort. The road in between the resort and the beach will not hold the erosion, it will then also disappear due to the beach erosion.*

8. Which solution do you think is the best solution?
*The beach has to be as wide as possible, because guests want a wide beach to do activities on the beach and to walk slowly into the sea.*

*The offshore breakwater is the best solution because it breaks the waves and makes the waves smaller and less strong. In addition the local people could also use the beach behind an offshore breakwater. However the gaps in between those breakwaters should be as narrow as possible.*

*A groyne has a negative effect on the landscape and due to the fact that it is build out of rocks it is not safe to swim nearby a groyne.*

*When a revetment is applied as beach protection there is no beach anymore so that is also no working solution.*

*The sand nourishment could work, but since it only brings sand back to the beach and does not give any protection to the beach it might not be a working solution. Furthermore, the extraction of sand at the sea bottom isn't safe for the environment.*

9. Is the current situation good enough or is a beach necessary?
*It is very valuable to have a beach and the situation when the beach was wide and beautiful should come back.*

We told about the interview with the general manager of Victoria Beach Resort and according to the general manager of Hoi An Beach Resort the opinion to collaborate as much as possible is the right opinion.

*Everyone should collaborate as much as possible and the government should listen to the opinion of the hotel and resort owners and of the local people, the support of the community is very important. Local people can collaborate, however their budget is limited and so on their influence on a working solution is also limited. The government should invite coastal experts from abroad who know what to do.*

*There are many reasons of the coastal erosion like the decrease of sand and mud from upstream. Too many people and resorts are extracting too large amounts of sand and mud from the river. Local people take sand from the river which is actually forbidden and the local people do not protect the environment with their actions.*

**Sunrise hotel**

| | |
|---|---|
| Interviewee | General Manager, German |
| Resort location | At Cua Dai Beach, dealing with heavy erosion |
| Date | 14 December 2015 |


On request of the interviewee this interview is left out of the report.

**Other resorts**

Other resorts that could not be interviewed, but are sometimes referred to in this report are the following:


AgriBank Resort


Palm Garden Resort

Indochine Hotel

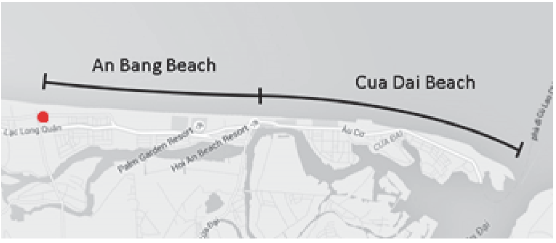
Golden Sand Resorts and Spa

### B.1.2. Tourists

Interviewed during the three sunny days of 9, 10 and 11 December 2015.

**#1**

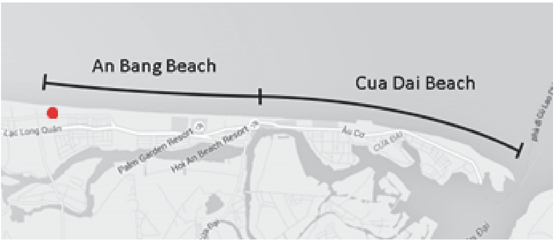
Gender Male
Age 30
Nationality German




1. How long are you staying in Hoi An? *4 days*
2. Did you choose to stay in Hoi An for its beach? *No, for the old town*
3. Why do you go to the beach? *Relax, to swim*
4. How often do you go to the beach in Hoi An? *2-3 days during my stay*
5. How much time do you spend on the beach, on average, when you are there? *A few hours*
6. If you go to the beach in Hoi An, to which beach do you go more often? *An Bang Beach*
7. Did you know Cua Dai Beach was eroding? *No*
8. Do you care about the beach erosion at Cua Dai Beach? *No, because I didn't know about it until now*
9. What would make you go to Cua Dai beach more often? *If the sea was easier accessible; if the whole beach was accessible to the public and not owned by hotels and/or resorts*

**#2**

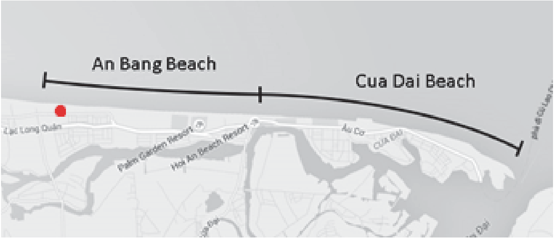
Gender Male
Age 30
Nationality Ireland




1. How long are you staying in Hoi An? *3 days*
2. Did you choose to stay in Hoi An for its beach? *No*
3. Why do you go to the beach? *Relax, do sports*
4. How often do you go to the beach in Hoi An? *Less than every week*
5. How much time do you spend on the beach, on average, when you are there? *A few hours*
6. If you go to the beach in Hoi An, to which beach do you go more often? *N/A, only one day*
7. Did you know Cua Dai Beach was eroding? *No*
8. Do you care about the beach erosion at Cua Dai Beach? *Yes, because we need to sustain our natural resources and counteract mass tourism.*
9. What would make you go to Cua Dai beach more often? *If the whole beach was accessible to the public and not owned by hotels and/or resorts; when there is the possibility for kite surfing*

**#3**

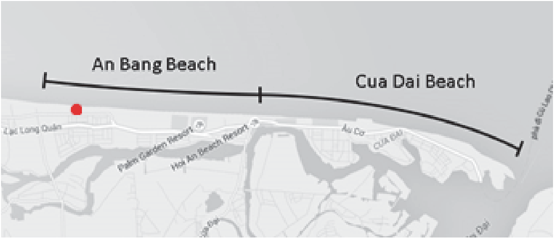
| | |
|---|---|
| Gender | Male |
| Age | 73 |
| Nationality | Sweed |




1. How long are you staying in Hoi An? *5 nights*
2. Did you choose to stay in Hoi An for its beach? *Yes, mostly*
3. Why do you go to the beach? *Relax, running*
4. How often do you go to the beach in Hoi An? *Every day the sun shines*
5. How much time do you spend on the beach, on average, when you are there? *4 hours*
6. If you go to the beach in Hoi An, to which beach do you go more often? *An Bang Beach, I think it is part of our hotel.*
7. Did you know Cua Dai Beach was eroding? *No*
8. Do you care about the beach erosion at Cua Dai Beach? *Yes, it might effect this place too.*
9. What would make you go to Cua Dai beach more often? *If it was less crowded*

**#4**

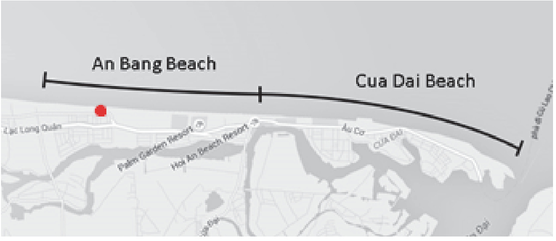
| | |
|---|---|
| Gender | Male |
| Age | 40 |
| Nationality | German |




1. How long are you staying in Hoi An? *3 days*
2. Did you choose to stay in Hoi An for its beach? *Yes, but also for the old city of Hoi An*
3. Why do you go to the beach? *Relax*
4. How often do you go to the beach in Hoi An? *Once*
5. How much time do you spend on the beach, on average, when you are there? *A few hours*
6. If you go to the beach in Hoi An, to which beach do you go more often? *An Bang Beach*
7. Did you know Cua Dai Beach was eroding? *Yes*
8. Do you care about the beach erosion at Cua Dai Beach? *Yes, because I generally care about the environment. But I only stay here for a short holiday.*
9. What would make you go to Cua Dai beach more often? *If the beach was wider and larger; if the sea was easier accessible*

**#5**

| | |
|---|---|
| Gender | Male |
| Age | 24 |
| Nationality | Australian |

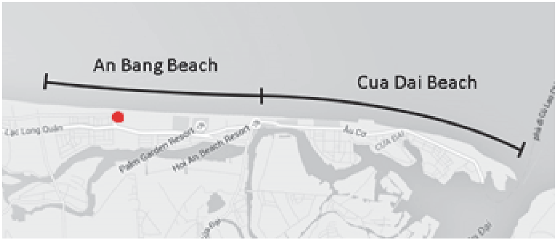



1. How long are you staying in Hoi An? *2 days*
2. Did you choose to stay in Hoi An for its beach? *Yes, but also for old town*
3. Why do you go to the beach? *Relax, to swim*
4. How often do you go to the beach in Hoi An? *Every day that I am here*

5. How much time do you spend on the beach, on average, when you are there? *Half a day*
6. If you go to the beach in Hoi An, to which beach do you go more often? *An Bang Beach*
7. Did you know Cua Dai Beach was eroding? *Yes*
8. Do you care about the beach erosion at Cua Dai Beach? *Yes, because it affects a lot of people*
9. What would make you go to Cua Dai beach more often? *If the whole beach was accessible to the public and not owned by hotels and/or resorts*

**#6**

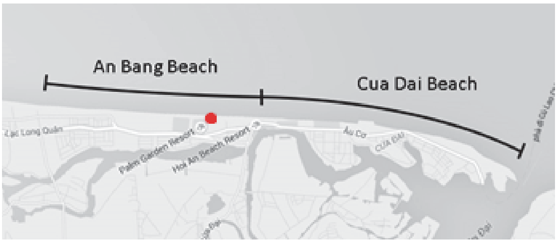
Gender Male
Age 19
Nationality German




1. How long are you staying in Hoi An? -
2. Did you choose to stay in Hoi An for its beach? *Yes, but also for the town*
3. Why do you go to the beach? *Meet people, relax, do sports, to swim*
4. How often do you go to the beach in Hoi An? *Almost every day*
5. How much time do you spend on the beach, on average, when you are there? *Half a day*
6. If you go to the beach in Hoi An, to which beach do you go more often? *An Bang Beach*
7. Did you know Cua Dai Beach was eroding? *No*
8. Do you care about the beach erosion at Cua Dai Beach? *Yes, but I've never heard about it*
9. What would make you go to Cua Dai beach more often? *If the beach was wider and larger; if the sea was easier accessible; if the whole beach was accessible to the public and not owned by hotels and/or resorts; if there were more activities*

**#7**

Gender Male
Age 24
Nationality Australian




1. How long are you staying in Hoi An? *6 days*
2. Did you choose to stay in Hoi An for its beach? *Yes, but also for motorbike riding and tailored clothes*
3. Why do you go to the beach? *Relax*
4. How often do you go to the beach in Hoi An? *Every day it isn't raining*
5. How much time do you spend on the beach, on average, when you are there? *A few hours*
6. If you go to the beach in Hoi An, to which beach do you go more often? *An Bang Beach*
7. Did you know Cua Dai Beach was eroding? *No*
8. Do you care about the beach erosion at Cua Dai Beach? *Yes, if the beach is eroded it is difficult for people to enjoy the beach*
9. What would make you go to Cua Dai beach more often? *If the beach was wider and larger; if the sea was easier accessible; if the whole beach was accessible to the public and not owned by hotels and/or resorts*

**#8**

Gender Male
Age 60
Nationality UK


1. How long are you staying in Hoi An? 2 *days*
2. Did you choose to stay in Hoi An for its beach? *No, for the old town*
3. Why do you go to the beach? *Relax*
4. How often do you go to the beach in Hoi An? *Almost every day I am here*
5. How much time do you spend on the beach, on average, when you are there? *Less than an hour*
6. If you go to the beach in Hoi An, to which beach do you go more often? *An Bang Beach*
7. Did you know Cua Dai Beach was eroding? *No*
8. Do you care about the beach erosion at Cua Dai Beach? *Yes, because I am an environmentalist*
9. What would make you go to Cua Dai beach more often? *If the whole beach was accessible to the public and not owned by hotels and/or resorts*

**#9**

Gender Female
Age 59
Nationality Canadian


1. How long are you staying in Hoi An? 4 *days*
2. Did you choose to stay in Hoi An for its beach? *Yes, but also for sightseeing*
3. Why do you go to the beach? *Relax*
4. How often do you go to the beach in Hoi An? *Less than every week*
5. How much time do you spend on the beach, on average, when you are there? *Less than an hour*
6. If you go to the beach in Hoi An, to which beach do you go more often? *No favourite yet*
7. Did you know Cua Dai Beach was eroding? *No*
8. Do you care about the beach erosion at Cua Dai Beach? *Yes*
9. What would make you go to Cua Dai beach more often? *If the beach was wider and larger*

**#10**

Gender Female
Age 30
Nationality USA


1. How long are you staying in Hoi An? 2 *days*
2. Did you choose to stay in Hoi An for its beach? *No, tourist locations*
3. Why do you go to the beach? *Meet people, relax, do sports*
4. How often do you go to the beach in Hoi An? *Almost every day I am here*

5. How much time do you spend on the beach, on average, when you are there? *A few hours*
6. If you go to the beach in Hoi An, to which beach do you go more often? *Cua Dai Beach*
7. Did you know Cua Dai Beach was eroding? *No*
8. Do you care about the beach erosion at Cua Dai Beach? *Yes, because the beaches are beautiful*
9. What would make you go to Cua Dai beach more often? *If the beach was wider and larger; if the whole beach was accessible to the public and not owned by hotels and/or resorts*

**#11**

Gender Female
Age 35
Nationality USA


1. How long are you staying in Hoi An? *3 days*
2. Did you choose to stay in Hoi An for its beach? *Yes, but also for its location on our travels going south*
3. Why do you go to the beach? *Meet people, relax, do sports*
4. How often do you go to the beach in Hoi An? *Once in three days*
5. How much time do you spend on the beach, on average, when you are there? *A few hours*
6. If you go to the beach in Hoi An, to which beach do you go more often? *Cua Dai Beach*
7. Did you know Cua Dai Beach was eroding? *No*
8. Do you care about the beach erosion at Cua Dai Beach? *No, because I was unaware*
9. What would make you go to Cua Dai beach more often? *If there were more activities*

**#12**

Gender Male
Age 38
Nationality German


1. How long are you staying in Hoi An? *5 days*
2. Did you choose to stay in Hoi An for its beach? *Yes, but also for our hotel (Mường Thanh Resort), surroundings and it is quiet*
3. Why do you go to the beach? *Relax*
4. How often do you go to the beach in Hoi An? *Every day it is not raining*
5. How much time do you spend on the beach, on average, when you are there? *Half a day*
6. If you go to the beach in Hoi An, to which beach do you go more often? *Cua Dai Beach*
7. Did you know Cua Dai Beach was eroding? *No*
8. Do you care about the beach erosion at Cua Dai Beach? *Yes, because if the erosion is leading to failure, something has to be done.*
9. What would make you go to Cua Dai beach more often? – *I already go there every day*

**#13**

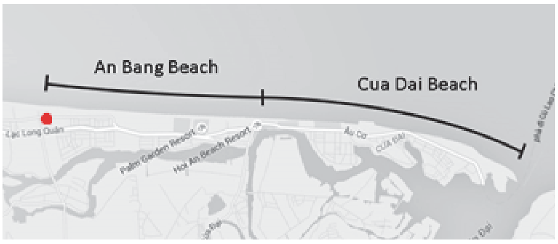
| | |
|---|---|
| Gender | Female |
| Age | 28 |
| Nationality | Belgian |


1. How long are you staying in Hoi An? *3 days*
2. Did you choose to stay in Hoi An for its beach? *No, for the city and its culture*
3. Why do you go to the beach? *Relax, nature*
4. How often do you go to the beach in Hoi An? *Almost every day we are here*
5. How much time do you spend on the beach, on average, when you are there? *A few hours*
6. If you go to the beach in Hoi An, to which beach do you go more often? *An Bang Beach*
7. Did you know Cua Dai Beach was eroding? *No*
8. Do you care about the beach erosion at Cua Dai Beach? *Yes, because the situation is problematic and there is need for a permanent solution*
9. What would make you go to Cua Dai beach more often? *If the beach was wider and larger; if the whole beach was accessible to the public and not owned by hotels and/or resorts; if there were no extra costs for i.e. parking of bicycles.*

### B.1.3. Restaurant/bars interviews

**#1**

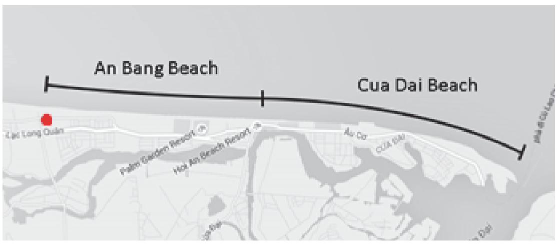
| | |
|---|---|
| Restaurant/bar name | Quănchiến Restaurant |
| Gender | Male |
| Age | 50 |
| Nationality | Vietnamese |




1. Do you live in Hoi An? *Yes, I have lived in Hoi an for 50 years*
2. Did the erosion at Cua Dai Beach affect your business in terms of sales? *Yes*
3. Do you care about the beach erosion at Cua Dai Beach? *Yes, because I sell food at the beach*
4. What would make the Cua Dai Beach more attractive? *If the beach was wider and larger*
5. Have you taken any action to deal with the beach erosion at Cua Dai Beach? *Yes, building the sea dike, piling*

**#2**

| | |
|---|---|
| Restaurant/bar name | Donut stall |
| Gender | Male |
| Age | 41 |
| Nationality | Vietnamese |

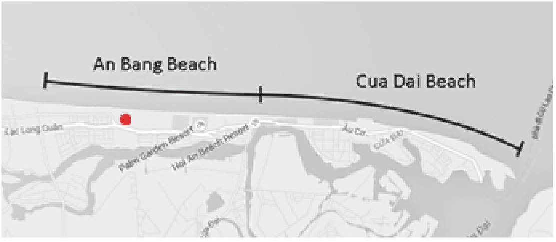



1. Do you live in Hoi An? *Yes, I have lived in Hoi an for 41 years*
2. Did the erosion at Cua Dai Beach affect your business in terms of sales? -
3. Do you care about the beach erosion at Cua Dai Beach? *Yes, because it affects the economic activities of local people. And the landscape and civilization of the ancient city.*

4. What would make the Cua Dai Beach more attractive? *If the beach was wider and larger; if there were more activities; if the whole beach was accessible to the public and not owned by hotels and/or resorts*
5. Have you taken any action to deal with the beach erosion at Cua Dai Beach? *I gave a hand to contribute to a better community.*

**#3**

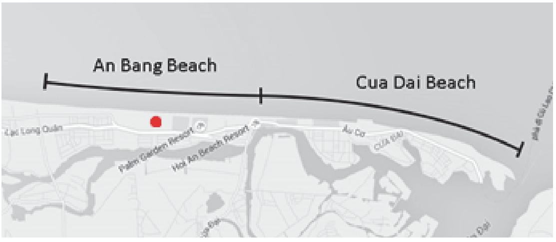
| | |
|---|---|
| Restaurant/bar name | Hidden |
| Gender | Female |
| Age | 32 |
| Nationality | Vietnamese |




1. Do you live in Hoi An? *Yes, I have lived in Hoi an for 32 years*
2. Did the erosion at Cua Dai Beach affect your business in terms of sales? *No*
3. Do you care about the beach erosion at Cua Dai Beach? *Yes, I would like to keep the coastline so that more tourists will travel to Hoi An. It is a place that tourists can visit to relax and sunbathe*
4. What would make the Cua Dai Beach more attractive? *If the whole beach was accessible to the public and not owned by hotels and/or resorts*
5. Have you taken any action to deal with the beach erosion at Cua Dai Beach? *Yes*
*My family has lived in Hoi An for more than 100 years. The erosion and the amount of resorts are reducing the amount of tourists that come to Hoi An.*

**#4**

| | |
|---|---|
| Restaurant/bar name | Restaurant Family |
| Gender | Male |
| Age | 30 |
| Nationality | Vietnamese |




1. Do you live in Hoi An? *Yes, I have lived in Hoi An for 30 years*
2. Did the erosion at Cua Dai Beach affect your business in terms of sales? *Yes*
3. Do you care about the beach erosion at Cua Dai Beach? *Yes, because it reduce our economy. The tourist sector will no longer be.*
4. What would make the Cua Dai Beach more attractive? *If the beach was wider and larger; if there were more activities.*
*There should be investments from different clients, as well as governmental level organizations.*
5. Have you taken any action to deal with the beach erosion at Cua Dai Beach? *Yes*
*I have joined activities as building the sea dike, helping everyone carrying soil to the beach and protecting the sea environment (water resource, keep the beach clean)*

*I would like to see that more foreigners will come, like you, and talk to us, fishermen and other people along the beach to help, together.*

**#5**

Restaurant/bar name  Hoa Hung
Gender  Female
Age  18
Nationality  Vietnamese


1. Do you live in Hoi An? *Yes, I have lived in Hoi An for 18 years*
2. Did the erosion at Cua Dai Beach affect your business in terms of sales? *Yes, tourists don't want to visit us because there is no beach. As a result, we are hit in our economic activities.*
3. Do you care about the beach erosion at Cua Dai Beach? *Yes, it impacts our job and we might lose our job.*
4. What would make the Cua Dai Beach more attractive? *If the beach was wider and larger; If there were more activities*
5. Have you taken any action to deal with the beach erosion at Cua Dai Beach? *Yes, I made sand bags to preserve the beach in front of my restaurant. I hope the government has policies to overcome the process of erosion in an effective way.*

**#6**

Street saleswoman

Restaurant/bar name  -
Gender  Female
Age  64
Nationality  Vietnamese


1. Do you live in Hoi An? *Yes, I have lived in Hoi An for 50 years*
2. Did the erosion at Cua Dai Beach affect your business in terms of sales? *Yes*
3. Do you care about the beach erosion at Cua Dai Beach? *Yes, because the erosion is impacting our job. We might lose our job.*
4. What would make the Cua Dai Beach more attractive? -
5. Have you taken any action to deal with the beach erosion at Cua Dai Beach? *I helped making sand bags, but they will break after a long time. I really hope that the government will pay attention and help us with our economic activities.*

**#7**

Restaurant/bar name  Restaurant Minh Vinh
Gender  Male
Age  62
Nationality  Vietnamese


1. Do you live in Hoi An? *Yes, I have lived in Hoi An for 62 years*
2. Did the erosion at Cua Dai Beach affect your business in terms of sales? *Yes, less tourists come because the Cua Dai Beach is eroding. As a result, the economic activities of my restaurant are declining.*

3. Do you care about the beach erosion at Cua Dai Beach? *Yes, in this eroding situation I worry about the sales of my restaurant.*
4. What would make the Cua Dai Beach more attractive? *If the beach was wider and larger; if there were more activities*
5. Have you taken any action to deal with the beach erosion at Cua Dai Beach? *Yes, making sand bags, planting trees. I also built a temporary embankment to keep the beach attractive to tourists.*

**#8**

| | |
|---|---|
| Restaurant/bar name | Restaurant VyQuynh |
| Gender | Female |
| Age | 36 |
| Nationality | Vietnamese |

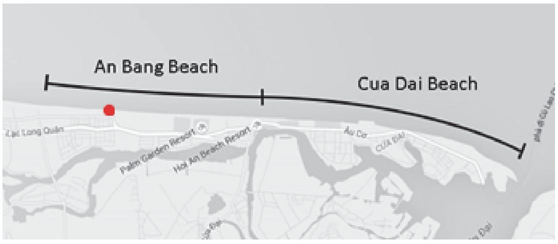

1. Do you live in Hoi An? *Yes, I have lived in Hoi An for 36 years*
2. Did the erosion at Cua Dai Beach affect your business in terms of sales? *Yes*
3. Do you care about the beach erosion at Cua Dai Beach? *Yes, because the erosion of the beach affects a lot of people from Hoi An or people that work here.*
4. What would make the Cua Dai Beach more attractive? *If the beach was wider and larger*
5. Have you taken any action to deal with the beach erosion at Cua Dai Beach? *Yes, I encourage local people to help restaurants near the beach to prevent erosion, with hopefully a reducing rate of erosion. I hope Cua Dai Beach will no longer erode and I wish that all governmental level organisations have a solution to improve the state of the beach.*

### B.1.4. Other locals

**Fishermen**

Hobby fisherman

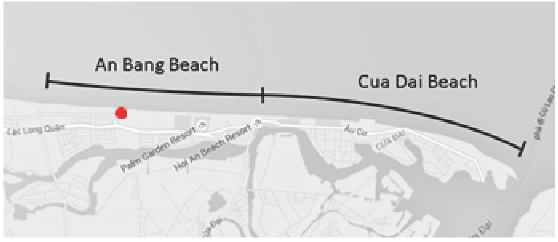
| | |
|---|---|
| Gender | Male |
| Nationality | Vietnamese |
| Age | 23 |




1. Do you live in Hoi An? *Yes, I have lived in Hoi An for 6 years*
2. How often do you go to the beach? *Once per week*
3. How much time do you spend on the beach when you are there? *A few hours*
4. If you use the beach in Hoi An, which beach do you use more often? *Cua Dai Beach*
5. Did you know Cua Dai Beach was eroding? *Yes*
6. Do you care about the beach erosion at Cua Dai Beach? *Yes, because Cua Dai Beach is eroding*
7. Do you think the disappearing of the beach has an impact on your job? *It will influence the ancient city of Hoi An.*
8. What would make you go to Cua Dai beach more often? *If the beach is made larger and bigger, it will be more attractive for tourists to come to Hoi An.*

**Life guard**

| | |
|---|---|
| Gender | Male |
| Nationality | Vietnamese |
| Age | 75 |




1. Do you live in Hoi An? *Yes, I have lived in Hoi An for 50 years*
2. How often do you go to the beach? *Almost every day*
3. How much time do you spend on the beach when you are there? *Almost the whole day*
4. If you use the beach in Hoi An, which beach do you use more often? *An Bang Beach*
5. Did you know Cua Dai Beach was eroding? *Yes*
6. Do you care about the beach erosion at Cua Dai Beach? *Yes, because it attacks our life.*
7. Do you think the disappearing of the beach has an impact on your job? -
8. What would make you go to Cua Dai beach more often? *We would like to keep a beach that is large and beautiful.*

**Bicycle keeper Cua Dai Beach**

| | |
|---|---|
| Gender | Male |
| Nationality | Vietnamese |
| Age | 30 |


1. Do you live in Hoi An? *Yes, I have lived in Hoi An for 30 years*
2. Did the erosion at Cua Dai Beach affect your business in terms of sales? *Yes*
3. Do you care about the beach erosion at Cua Dai Beach? *The number of tourists going to the beach has decreased significantly. I worry every day about my country and that it will not be again as it was before the erosion of the beach started.*
4. What would make the Cua Dai Beach more attractive? *If the whole beach was accessible to the public and not owned by hotels and/or resorts*
5. Have you taken any action to deal with the beach erosion at Cua Dai Beach? *Yes, urging the government to invest money in building an embankment.*

## B.2 Interviews conclusion

Using the interviews, the following line can be drawn for the opinions of tourists and local people. The diversity among resort managers makes it hard to conclude it in one common story.

### B.2.1. Tourists

Since the tourists are responsible for a large part of the income of Hoi An, it is important to know what they expect from the beach. Tourists on both Cua Dai as An Bang Beach were given a questionnaire to get to know this. It is remarkable that most of the tourists at An Bang Beach did not know about the erosion at Cua Dai Beach. Most of them are only staying for a couple of days in Hoi An. It could be that this is a winter season phenomenon, where most tourists are travelling through Vietnam or other countries in Asia and not staying at the same spot for too long. When they visit Hoi An, it was often not only for the beach, but also for its old town. Reasons to go to the beach are mostly relaxing and swimming.

Most of them would therefore like to see a wider beach with a sea that is easy accessible and also more public beach. Also more activities is often mentioned as a wish for a better beach.

However, despite not knowing about the erosion by a lot of tourists, most of them do care about it, for various reasons. The tourists at An Bang Beach did not care about themselves, since they found a proper beach, but worried about the environment or the local people. Beaches are seen as a beautiful thing that need to be preserved. Tourists that are interviewed at Cua Dai Beach worry more about the effects of failure. In short, the tourists do not worry about the beach for individual reasons; they can always move somewhere else. However, they do care about the effect on the environment and the local community and therefore wish for a large and sustainable beach.

### B.2.2. Locals

Different kinds of local people from Hoi An are making a benefit out of the beach and its related tourism. For the purpose of this project the restaurant and bars along or near the beach, sales(wo)men, bicycle keepers, life guards and fishermen are given a questionnaire. This helped to understand the value of the beach and how the erosion is affecting those living from the beach. Both the stakeholders on the severely eroded Cua Dai Beach as the An Bang Beach, where there is still a beach left, were visited. It can be noticed from the questionnaires that both areas worry about the erosion, even though the erosion has not reached all of them yet.

The restaurant and bars along An Bang Beach worry about the future of tourism in Hoi An, because of the erosion at Cua Dai. Tourism is one of their most important sources of income. A reducing amount of visitors would seriously affect their businesses. They also care about those situated along Cua Dai Beach. They care much about the whole community and therefore most of them have helped in a way to influence the beach erosion. This could be by manual labour, as filling sand bags and making the temporary embankments at CuaDai , but also by urging the government to do something about it.

The restaurant and bars and others living from the beach in the Cua Dai area are affected by the beach erosion. It has reduced the amount of tourists, which is their main source of income. This makes them worry about the future of their current jobs. Therefore almost all of them helped in constructing the primitive beach protections. They wish that the government will soon come up with effective countermeasures and to help them sustain their current financial activities.

The stakeholders on both An Bang as Cua Dai Beach agree on the requirement for a wider and larger beach. Even those who still have a decent beach left. Another opinion that is often shared is the wish for more public space on the beach instead of stretches owned by beach resorts.

## B.3 Stakeholder problem statements and goal trees

Stakeholders are analysed in this appendix using problem statements and goal trees. These are derived from the results of interviews and questionnaires or common sense when this was not possible. Each stakeholder chapter exists in a current state and has a desire to change its (future) situation. This is called the gap. The gap makes up the first clause of an actor specific problem statement. The reason an actor is not already in its desired state is the dilemma. The dilemma makes up the second clause of the problem statement. It can also be viewed a trade-off between the desired state and a negative drawback. Together, the gap and dilemma make a complete problem statement that describes the issues the stakeholder is dealing with. These issues can be made visible in so called goal trees. Goal trees are used to identify the main goals of different actors and to list their desires and dilemmas (drawn from the problem statements) as sub-goals. Lower levels of goal trees represent the abstract concepts of the sub-goals with several criteria. This bottom row of the goal tree serves to make all the goals more concrete and measurable and therefore include units. Both methods of analysis are described by (Haan & Heer, 2012) in their book ‘Solving Complex Problems’ and used for the following stakeholders.

**National government**

The National government is the highest administrative body of the Vietnamese state and is called the National Assembly. They control the local governments of the provinces and give orders to those provincial governments (Cima, 1987). There is a Budget Law in Vietnam, however the distribution of revenues between different levels of governments are not fixed by that law. The National Assembly sets the sharing rates for the distribution of the budget over the different levels of governments for each period of three to five years (Hien, 2005). There is no direct influence of the National Assembly on the coastal erosion of Cua Dai Beach however the Ministry of Resources and Environment is responsible for the coastal affairs and the Ministry of Agriculture, Rural Development and Planning is responsible for the coastal protection.

The goal of a national government is to strive for the best for their country's inhabitants. Vietnam is currently developing fast and it has the possibility to improve the living standards of the Vietnamese people. To make the goal more specific, the focus is on the people along the coast and their problems with coastal erosion. However, provinces play a large role in the policy implementation. It is the dilemma of the national government not to favour one province above others, otherwise it would be easy to get enough resources available for the coastal erosion problem. The problem statement of the national government is therefore the following:

*How to improve living standards along the coast for the Vietnamese people, without favouring one province?*

The wish and dilemma of the national government are put in the goal tree, see Figure B.1. Good living standards with respect to living along the coast are further specified in a high income and a high safety against water. The latter can be further broken down in a low amount of erosion and low amount of flooding, which can be measured in units.

The dilemma that makes it hard to fulfil the wish is the necessity for equal treatment of provinces. Breaking this goal down into measurable goals follows in the goal of similar allocation of funds and few to none legislation exemptions. All these goals follow from the top goal of a high welfare of the nation.

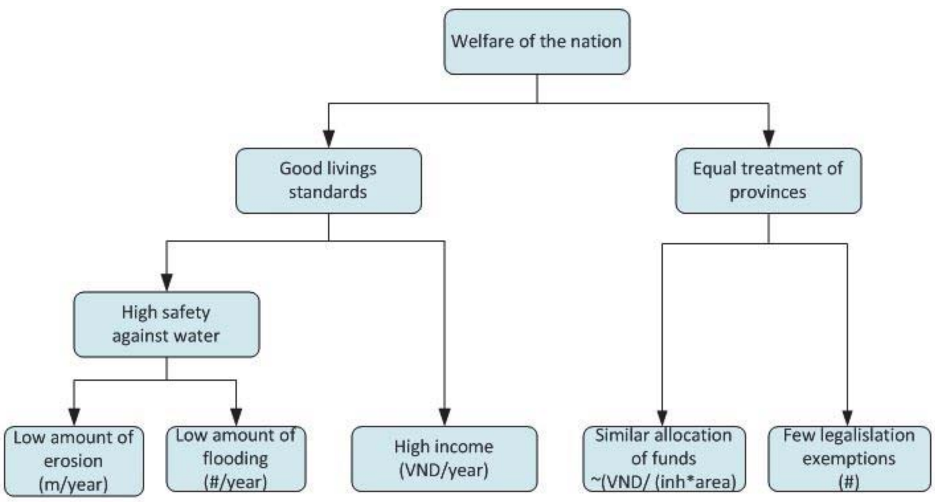



Figure B.1 - Goal tree national government

**Local government of the Quang Nam Province**

The city of Hoi An is of economic importance for the Quang Nam Province. The economy of the whole province has financial benefits of the touristic city of Hoi An, due to that the provincial government also wants Hoi An to have a nice and wide beach. According to Article 26.3 of Law On Land No. 13-2003-QH11, the Provincial People's Committee should approve the land use zoning and planning of the People's Committee of the city Hoi An. In addition, the provincial People's Council has to decide at which rates the revenues will be distributed over the lower levels (Hien, 2005). The income for the local government is generated with revenues from several taxes and fees.

As said before, provinces and their People's Committee play a large role in the daily management of the country and they are greatly responsible for what happens in their province. The provincial People's Council can decide the amount of budget they give to the provincial city of Hoi An. A current problem in the Quang Nam Province is the coastal erosion. However, solving this is not easy. The sand mining and hydropower dams in the rivers might be (partly) responsible for the coastal erosion, but those are important sources of income for the province and industries that cannot be hampered too much. The problem for Quang Nam province is therefore the following:

*How to prevent damage due to erosion at the Quang Nam Province, without hampering industries?*

The damage due to erosion can be broken down into structural and economical damage to hotels/resorts and homes, as can be seen in the goal tree, see Figure B.2. Furthermore, economic damage due to erosion to the Cham Islands and to the rest of the province, should be low. The prevention of hampering industries is translated into the goal of blooming industries. The measure for this is the income due to industries and the growth rate of this sector.

Similar to the national government, this goals should be achieved to benefit the welfare of the region, in this case the Quang Nam province.

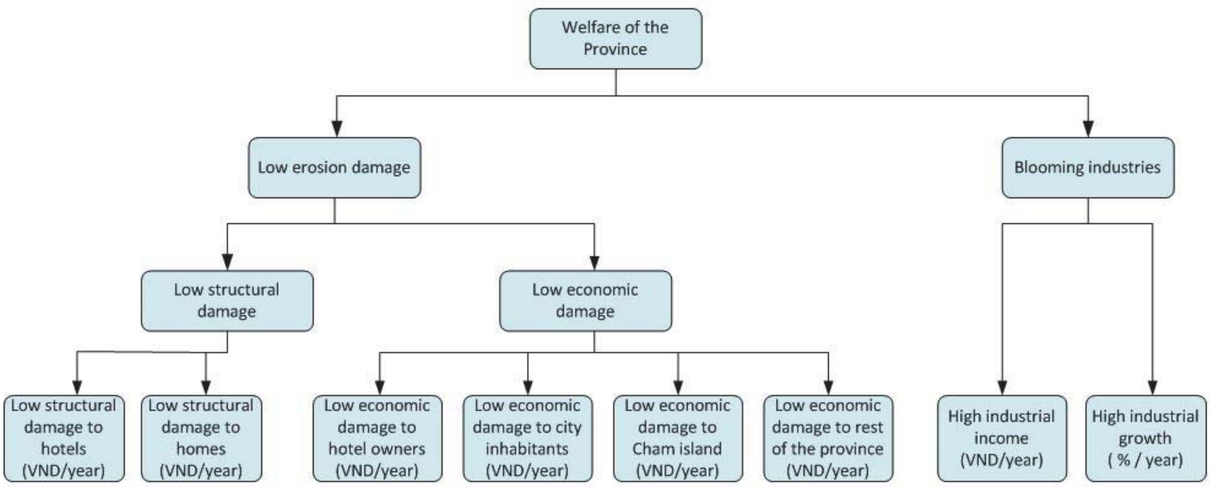



**Figure B.2 - Goal tree provincial government**

**Local government of Hoi An**

The city of Hoi An is a provincial city according to the political structure of Vietnam and is under the direct authority of the provincial government. It has a People's Council as the daily government of the city and a People's Committee as its executive hand. The People's Council is a democratically elected council and is defined as the local representative organ of state power. The People's Committee is the administrative local organ of the state and is responsible for the resolutions of the People's Council and as well as implementing state documents from higher authorities. The People's Council consists of people who are nominated by the Communist Party or self-nominated. So not only party-members have a seat in the Provincial City Council.

Provincial cities, like Hoi An, may use contributions from organizations and individuals for investment in infrastructure and other constructions in its own city. The revenues which are in its totality assigned to the local governments include the land and housing taxes and the tourist taxes (Hien, 2005).According to Article 25.3 of Law On Land No. 13-2003-QH11, the People's committee of provinces and cities under central authority is responsible for the land use zoning.

One of the major problems the local government of Hoi An has to deal with nowadays is the coastal erosion of the Cua Dai Beach. Extreme erosion can damage the city, both structural and economic wise. The dilemma that exists here is the amount of money available to solve this. The coastal erosion is not the only issue that needs to be financed and the budget is finite. This leads to the following problem statement:

*How to prevent damage due to coastal erosion at Cua Dai Beach, without losing budget for other matters?*

The low erosion damage can again be split up in structural and economic damage to hotels/resorts and homes, comparable to the province, but now only applicable to damage in Hoi An. The dilemma of limited budget is translated into the goal of efficient spending. This means that a sufficient part should go to deal with the erosion problems, but leaves enough budget for other city matters. All in all, this should lead to an increased welfare of the city.

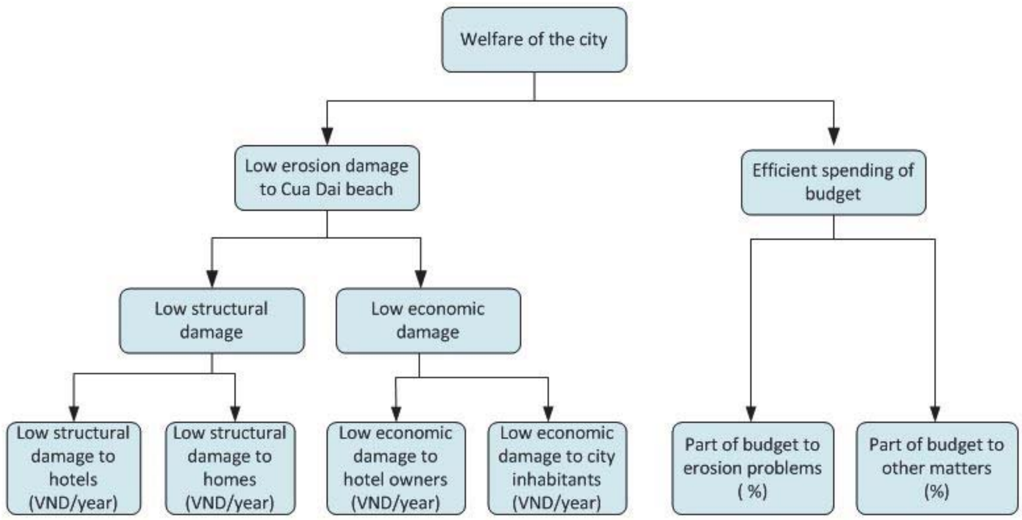



Figure B.3 - Goal tree city government

**Citizens living from the beach in Hoi An**

A wide beach is part of the protection of the city. When there is severe erosion of the coast and the erosion continues until it reaches the borders of the city, the erosion will deteriorate the historic valuable buildings and houses. Next to that, the tourists who visit the city will create incomes for the citizens of Hoi An, when the beaches disappear there will be less tourists and so on less income for the citizens.

Several citizens of Hoi An gain their incomes from the beach and its related tourism. These citizens are for example restaurant and bar owners, bicycle keepers, fishermen and life guards. Especially the restaurants owners along the beach are attached to their location. It will not be easy to let the location go and search for a new source of income, when the beach is eroding. It is crucial for them that the beach tourism keeps existing, as followed from the interviews. However, the problem is that these people do not have a lot of power to urge the government to implement effective solutions for their future and are therefore dependent on how the beach tourism is evolving now. The citizens are therefore dealing with the following issue:

*How to keep jobs on the beach, without any power to stop the erosion?*

The vague goal of enough jobs on the beach can be broken down in the sub-goals of having a high density of restaurant, bars and other beach related job opportunities along the coast. The goal of having the power to stop the erosion is translated into the power to adapt to the problem. Together they contribute to the goal of self-reliance.

The adaptation power is broken down into the flexibility to move, financial power and government support. The flexibility to move depends on the amount of own investments in a fixed location over the income the citizens make. The less investment in a fixed location, the easier it is to move to another place to exploit the business. Another important goal for power is the financial possibility to control the erosion. Again this is related to the yearly income. When the percentage of the cost of mitigation measures over yearly income is low, the citizens have more financial power to deal with it. A last factor of power is the support of the government. With funding from the government and shared wishes with the government, more can be done to control the situation.

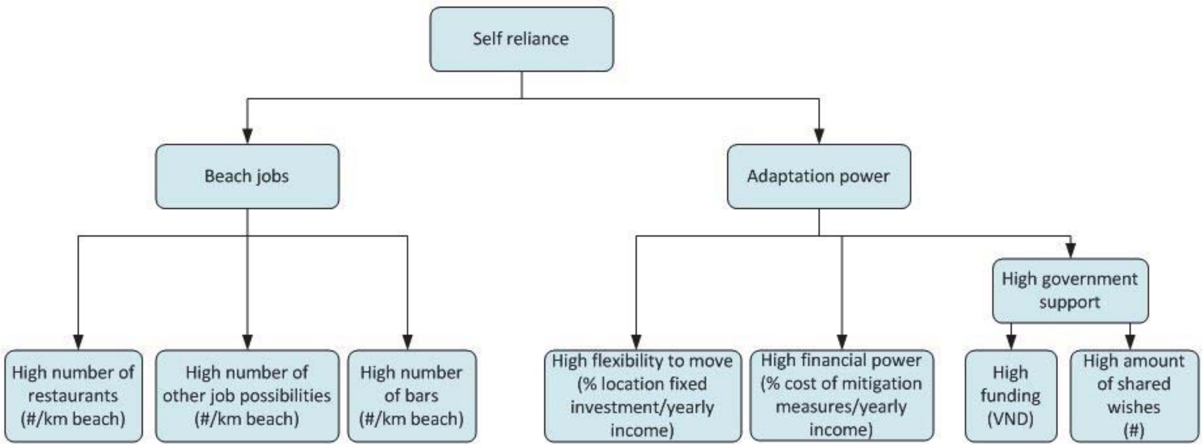



Figure B.4 - Goal tree citizens of Hoi An living from the beach

**Resort managers**
Nowadays the resorts at Cua Dai Beach are very important to attract tourists to the city and the beaches of Hoi An. Wide and beautiful beaches have a direct value for the hotels and resorts located at the beaches. Next to that, such beaches have also an indirect value for the hotels in the centre of the city of Hoi An because also those hotel visitors want to use the beaches. This means the beaches are of great importance for the resort managers.

The resort managers can be classified in two parts: those at Cua Dai Beach and affected by the erosion or those at An Bang Beach. The problem statement fits the latter in the future too. Those at An Bang Beach are either not aware of the problem yet or also fear the erosion. However, without action the erosion will eventually reach their resort as well.

The wish of the resorts at Cua Dai Beach is to get the original beach back to counteract the reducing amount of beach tourists. The dilemma here is that a government program and cooperation between the resorts on the whole stretch is needed to be effective. This is not the case yet and seen as a hurdle by several resorts, as followed from the interviews. The problem can therefore be summarized in the following statement:

*How to get the original beach back, while cooperation is difficult?*

A large goal tree is needed to specify these wish and dilemma. The original, nice beach means that a certain width of beach is required. Also the small distance to the sea from the rooms of the resort is an important measurement for this goal. Also the presence of coconut trees was seen as an important contributor to the appearance of the beach. Together with affordable rooms this makes an attractive resort. The other side of the tree focuses on the dilemma: the cooperation. Cooperation here means cooperation with the government, but also with other resorts in Hoi An. Shared wishes is a measure for cooperation, and also the funding from the government and meetings with other resorts are benchmarks for cooperation. Eventually, the fulfilment of these goal should lead to lasting tourism.

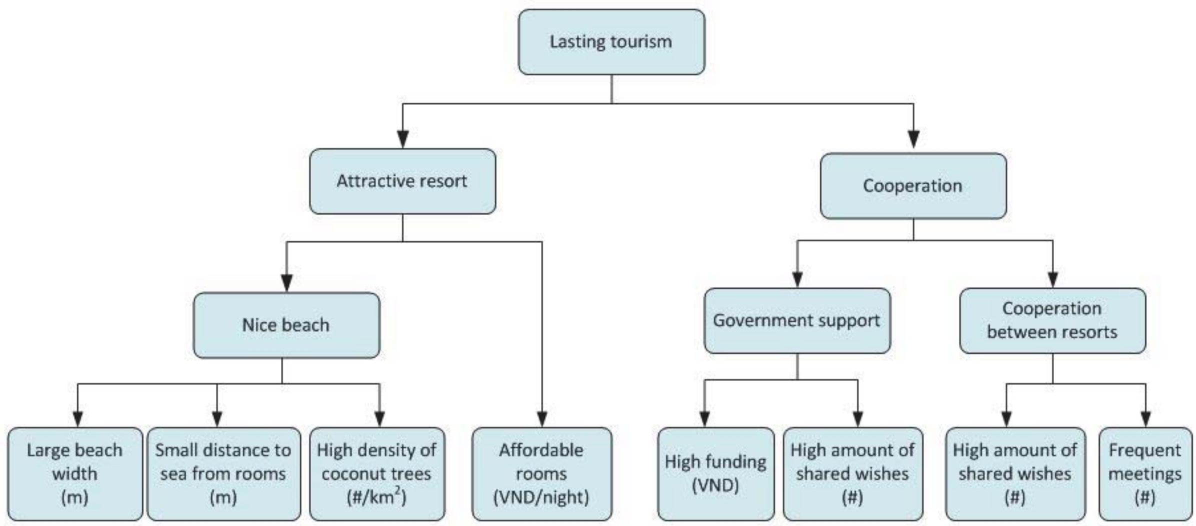



**Figure B.5 - Goal tree resort managers**

**Building industry**
One of the main industries of Vietnam is their building industry. The Vietnamese infrastructure development triggers a great demand for sand and concrete. This demand has been increasing significantly over the past years (StoxResearch, 2015). The building industry in Vietnam uses a lot of sand mined at several rivers in the country.

Mining sand from rivers for selling it to other countries or domestic use like the elevation of a highway is done repeatedly and this is financially attractive for the country. The Quang Nam Province is one of the dominant regions in Vietnam for the extraction of sand (Lynch, 2014). One of the main sources for this useful sand is the estuary nearby Hoi An, the Thu Bon Basin. The mining of this sand might have a negative effect on the Cua Dai Beach. It could be the case that due to this extraction there is less sand supplied to the coast and this might cause more erosion of the beaches.

A wish from the building industry is to acquire enough materials to build with, but the dilemma is that they want to buy it at low costs, otherwise other sources than the rivers were possibilities to get the right materials. The problem is clear from the following sentence:

*How to get enough buildings materials for construction, at low costs?*

The main goal of the building industry for having a high availability of building materials at low costs is the profit that can be made with respect to the purchasing of the materials. A high availability of materials means a high amount of sand available, but also the availability of other materials, like steel and gravel. The wish for low costs can also be broken down in these two types of material classes.

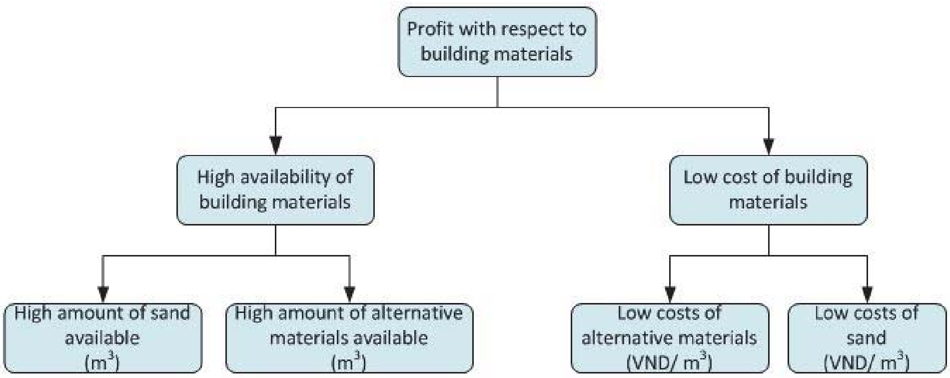



Figure B.6 - Goal tree building industry

**Sand miners**

The building industry mentioned above uses sand that is mined from the Vietnamese rivers, which might have negative effects on the rate of coastal erosion. Several sand mining activities take place in the rivers. Sand miners operating for the building industry want to mine the sand from sources where it is easy and cheap to extract. One of those sources is the Thu Bon River Basin nearby Hoi An. This way the sand miners could sell the extracted sand for a low price and the sand and concrete industry stays financially attractive for domestic use and for export to other countries. This will be a good income for these industries and the country.

Although this is already prohibited without license, it still occurs. However, when it can be proven that this sand mining is affecting the erosion, this might lead to extra control in the future. This is the dilemma that sand miners have to deal with to maintain a profitable business in the years to come:

*How to maintain a profitable sand mining business, when sand mining in the river is prohibited in the future?*

A profitable sand mining business, means that the costs for mining are low and the sales of the material is high. The prohibition is more difficult to break down into sub-goals. It is translated into the goal of small legal drawbacks for sand mining. This means that there are little restrictions, low change of conviction, but also a low level of penalty when caught. Although it seems strange to put this as goals in a goal tree, it fits the fact that people are still willing to mine sand in the river, despite being a prohibited business. This would imply that the business continuation is the main goal for sand miners.

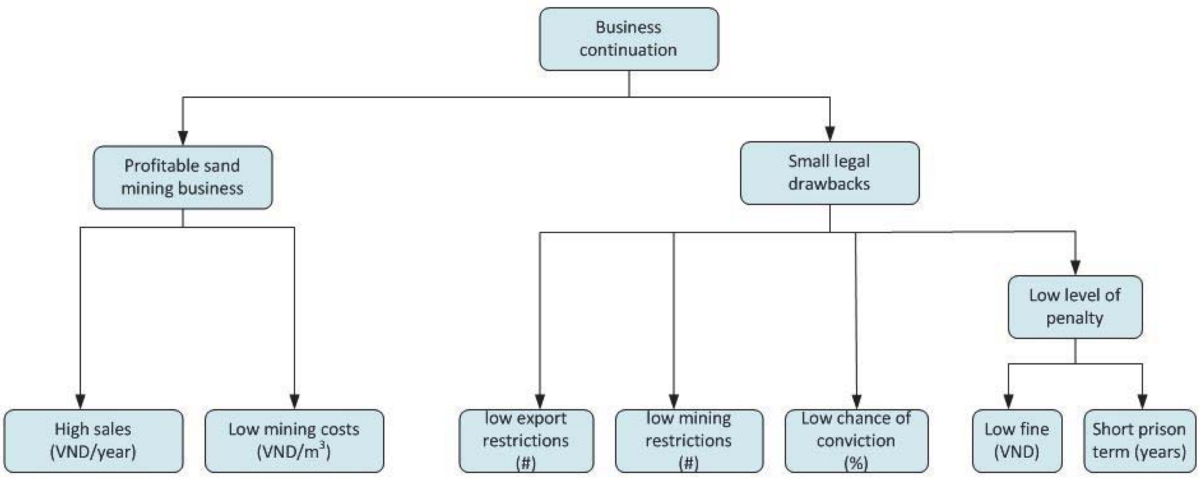



**Figure B.7 - Goal tree sand miners**

**Tourists**

The problem of the tourists is of a different kind than of the other stakeholders. They have the wish for a nice beach, but not only for themselves, also for the environment and local community. Tourists are flexible and can therefore always shift to a place that matches their interests more. However, if the wider beach can be achieved, they would like to see more cheap and public space instead of resort owned beaches. This is the dilemma here, because a public beach would imply that the government has to invest in it. Currently, it is unclear whether this funding will ever come and when. This can be summarized in the following problem statement:

*How to get a nice beach, without paying too much for the beach use?*

The sub-goals of having a nice beach are taken almost the same as how the resort managers see a nice beach: large width, small distance to the beach and presence of coconut trees. Low costs for a chair and umbrella, parking and cheap restaurants at the beach all contribute to a cheap beach visit.The nice beach together with the price that is spend for visiting it leads to the main goal of an enjoyable beach visit.

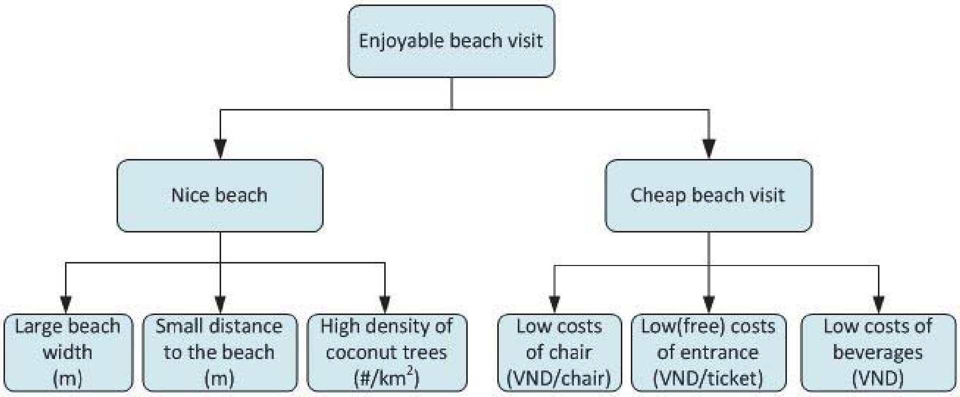



Figure B.8 - Goal tree tourists

## B.4 Estimation of hotel values

**Table B.1 - Tax income Hoi An from hotels Cua Dai Beach**

| | Rooms | Price per room [₫/day] | Occupancy | Income [₫/year] | Income [€/jaar] |
|---|---|---|---|---|---|
| Cua Dai Beach Hotel* | 60 | VND 450,000 | 20% | VND 1,972 $*10^6$ | € 79,000 |
| Sunrise Hoi An Resort | 222 | VND 3,500,000 | 60% | VND 170,275 $*10^6$ | € 6,888,000 |
| Golden Sands Resort and Spa | 212 | VND 5,681,818 | 60% | VND 263,970 $*10^6$ | € 10,679,000 |
| MuongThanh* | 159 | VND1,483,084 | 60% | VND 51,676 $*10^6$ | € 2,090,000 |
| Victoria Resort and Spa | 109 | VND 4,000,000 | 60% | VND 95,547 $*10^6$ | € 3,865,000 |
| Hoi An beach resort | 121 | VND 2,150,000 | 60% | VND 57,010 $*10^6$ | € 2,306,000 |
| Palm Garden Resort | 214 | VND3,000,000 | 60% | VND 140,691 $*10^6$ | € 5,691,000 |
| Agribank Resort | 166 | VND 1,750,000 | 60% | VND 63,661 $*10^6$ | € 2,575,000 |
| Boutique Hoi An Resort | 82 | VND3,000,000 | 60% | VND53,909, $*10^6$ | € 2,180,000 |
| *not located directly at the sea | | | **Total** | VND 898,716 $*10^6$ | € 36,359,000 |
| | | | VAT (10%) | VND 89,871, $*10^6$ | €3,636,000 |

The value generated by the presence of the hotels at the beach was estimated by the amount of rooms and price of each of the hotels. With an average 60% occupancy around the year the income of each hotel is calculated. The exception is Cua Dai Beach Hotel which looked abandoned during the time of our visit but still offers rooms online.

The current value added tax (VAT) is 10% meaning this percentage of the income generated is an income for the state. If the occupancy of the hotels drops or hotels and resorts are abandoned due to the continued erosion, the state loses a significant portion of its income. Even though the benefits of an attractive beach exceed the economic value this analysis highlights the importance of maintaining the coastline.

# C. Coastal system

This appendix supplements Chapter 4 about the coastal system around Hoi An. A principle that is used several times throughout the report is that of Bruun, which is first described here. After that the CERC formula, bathymetry, wave data, tide data, the sand balance calculation and the estimation for the erosion rate are given.

## C.1 Bruun Rule

The cross-shore profile of a beach is dynamic during the year. Depending on the wave conditions the profile shifts. However, averaged over one or several years a constant equilibrium profile can be expected as extreme conditions and mild conditions average out over a long period. Bruun found a way to describe such a beach profile with a simple expression:

Eq. C-1 $$y(x) = Ax^{\rho}$$ (Bruun, Coast erosion and the development of beach profiles, 1954)

With:

$y = water\ depth\ [m]$
$x = offshore\ disctance\ [m]$
$A = fitting\ parameter\ [m^{1-\rho}]$
$\rho = \frac{2}{3} = fitting\ parameter\ [-]$

The assumption of an equilibrium profile can be applied for the case of sea level rise (see Figure C.1). As the sea level rises the original profile [1] no longer ‘fits’ the new equilibrium profile [2]. Since the volume of sand in the cross-section remains constant the profile needs to shift such that the erosion at the upper part of the profile is equal to the accretion at the lower part. This results in the final profile [3] that both satisfies the shape of the equilibrium profile and continuity. This method can be expressed with the following formula known as the Bruun rule:

Eq. C-2 $$a = \frac{(L \times SLR)}{h + d}$$ (Bruun, 1962)

In which:

$a = coastal\ retreat\ [m]$
$L = width\ of\ the\ active\ profile\ [m]$
$SLR = sea\ level\ rise\ [m]$
$d = closure\ depth\ [m]$
$h = elevation\ of\ the\ beach\ or\ dune\ [m]$

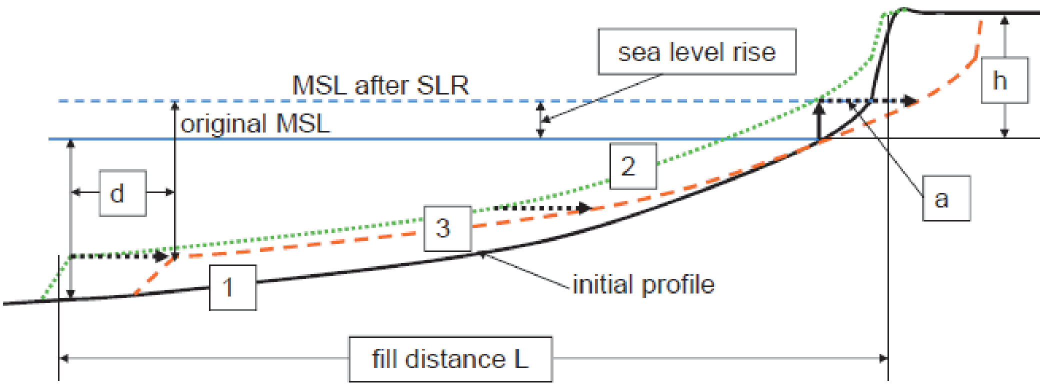


Figure C.1 - The Bruun rule explained visually (Bosboom & Stive, 2015)

## C.2 CERC formula

In this section erosion and accretion will be assessed by looking at the wave driven sediment transport. The capacity for wave driven sediment transport can be approximated by the CERC formula (rewritten for waves at the breaker zone):

Eq. C-3 $$S = \frac{K}{16(s-1)(1-p)}\sqrt{\frac{g}{\gamma}}\sin(2\varphi_b)\,H_b^{2.5}$$ (Bosboom & Stive, 2015)

With:
$S = along\ shore\ sediment\ transportcapacity\ [m^3/s]$
$K = coefficient\ [-]$
$s = relative\ densityof\ sediment\ \rho_s/\rho_w\ [-]$
$p = porosity\ [-]$
$g = gravitational\ acceleration\ [m/s^2]$
$\gamma = breaker\ index \approx 0.78\ [-]$
$\varphi_b = angle\ of\ incidence\ at\ thebreaker\ zone\ [-]$
$H_b = wave\ height\ at\ thebreaker\ zone\ [m]$

As expressed in the formula, the alongshore sediment transport is dependent on both wave height and angle of incidence. Transport of sediment itself does not cause erosion or accretion, but gradients in transport do. If more sediment is transported into a section of the coast than is transported out of it, accretion has taken place and the coast grows in offshore direction. If more sediment is transported out of a section of the coast than is transported into it erosion has occurred and the coast retreats. This single line approach can be expressed as:

Eq. C-4 $$\frac{\partial Y}{\partial t} + \frac{1}{d}\frac{\partial S_x}{\partial x} = 0$$ (Bosboom & Stive, 2015)

In which:
$Y = position\ of\ the\ coastline\ in\ offshore\ direction\ [m]$
$d = closure\ depth\ [m]$
$S_x = alongshore\ sedimenttransport\ [m^3/s]$
$x = along\ shore\ position[m]$
$t = time\ [s]$

Eq. C-4 expresses that changes in the coastline occur when the alongshore sediment transport ($S_x$) is not constant while Eq. C-3 expresses that this transport changes when waves break at different angles along the shore or the wave heights are different (assuming there is no difference in sediment characteristics alongshore). If wave heights decrease in alongshore direction accretion is expected while if wave heights increase in alongshore direction erosion can be expected. Another consequence of these relations is that an alongshore uniform wave climate with a low angle of incidence (which is true for all waves close to the shore due to refraction) will strive to create a straight coast smoothing out any humps created by, for example, rivers.

## C.3 Bathymetry


**Figure C.2 - Map bathymetry East Sea / South China Sea near Hoi An (U.S. Army Map Service, 1984)**

## C.4 Wave climate

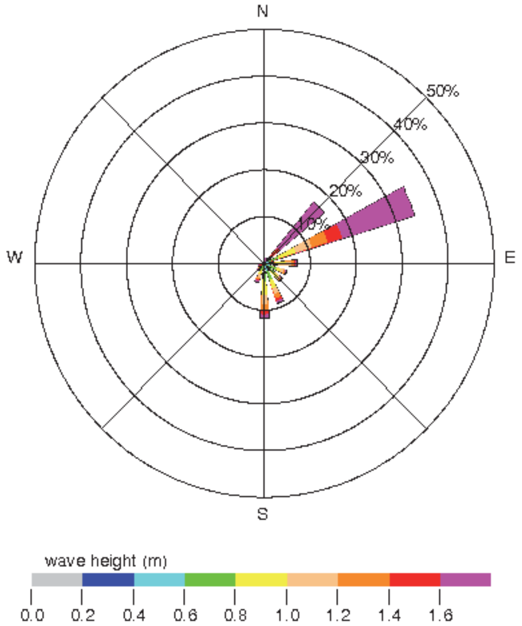



Figure C.3 - Wave compass of the offshore wave climate of Hoi An (ARGOSS, 2015)

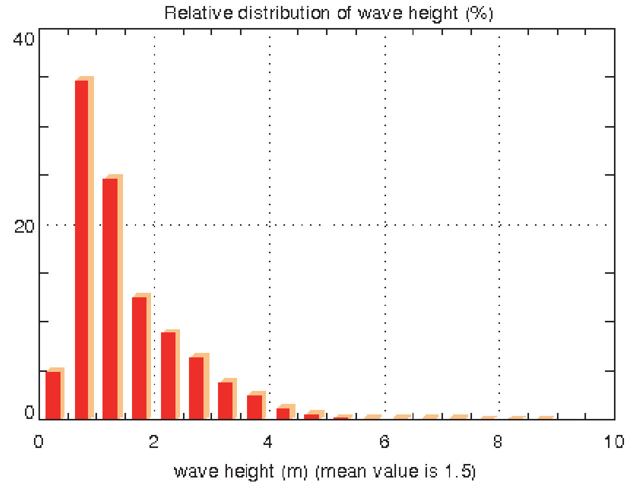



Figure C.4 - Histogram of the offshore wave climate of Hoi An (ARGOSS, 2015)

Wave height and angle of incidence are important for sediment transport and consequently for structural erosion of the coast, as was explained in paragraph C.2 with the CERC formula. It is known that due to the monsoon strong winds from the north can be expected while in the summer calmer winds from the south are expected. As a result the highest waves are from the north while milder waves are from the south, see Figure C.3. Important to note is that the dominant wave direction (ENE) cannot directly reach Hoi An due the Cham Island.

Figure 3.7 - Estimated sediment transport directions by Professor Stive illustrates that when waves are incoming from the north east a large part is blocked by Cham Island. Due to refraction around the island and diffraction behind it, the wave climate at Hoi An can be altered significantly. However, a lot of research has still to be done concerning the influence of this island, since it is not exactly known how or if it is related to the coastal erosion along the Cua Dai Beach in Hoi An. For the purpose of this study it is assumed the island creates a window in which only waves from the north and from the south to south east can reach Hoi An.

The average wave climate as a whole is assumed to be composed of high winter waves from the north east with wave heights around 2 to 3 meter and mild summer waves from the south of about 1 to 2 meter. For a better understanding of the wave climate just offshore of Hoi An, yearly wave statistics would be required which are not available yet.

## C.5 Tide

Along the coastal stretch of Quang Nam province a mixed semi-diurnal tide occurs (Vu Thi Thu Thuy, 2003). Mixed semidiurnal tide contains two low tides and two high tides of different heights. This can also be seen in Figure C.5, where within most of the tidal cycles low water and high water take place twice.

The major tidal constituents having influence on this tidal system are $O_1$ (Diurnal lunar delination tide), $K_1$ (Diurnal lunar-solar declination), $M_2$ (Semi-diurnal principle lunar) and $S_2$ (Principle solar semi-diurnal) (Vu Thi Thu Thuy, 2003).

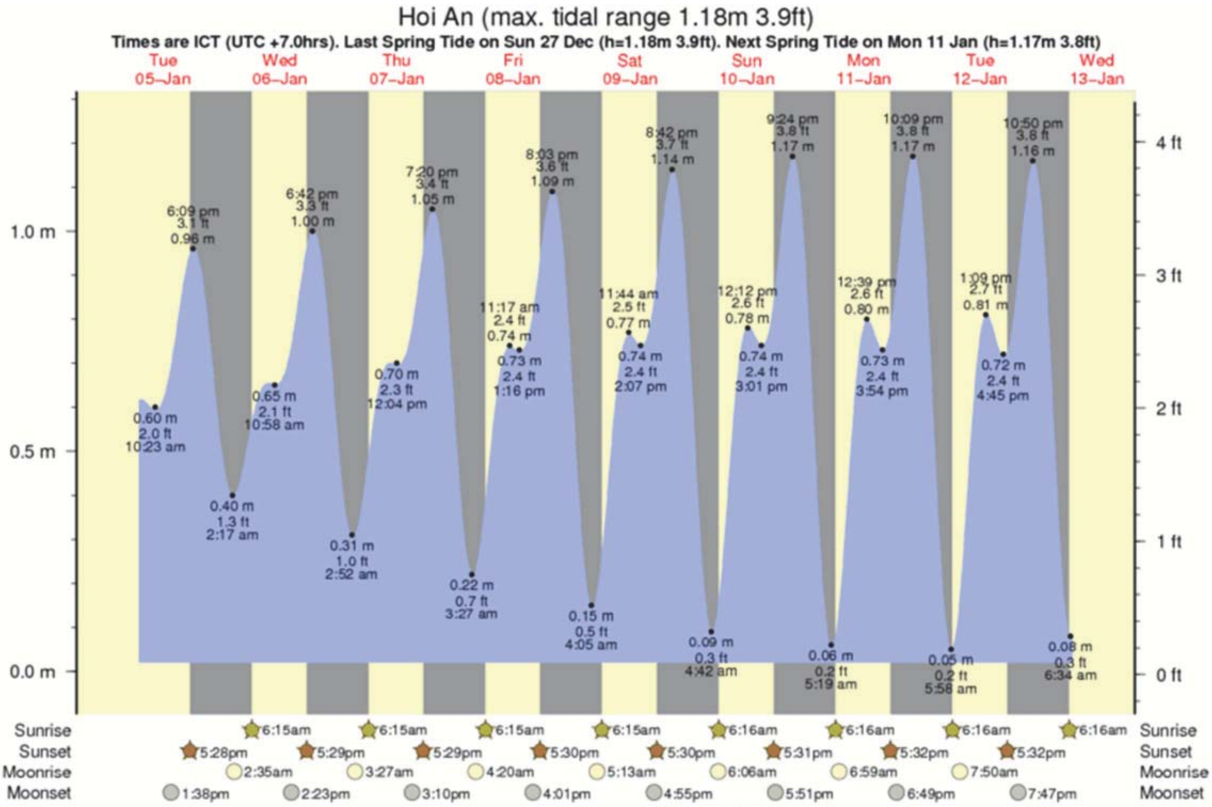



Figure C.5 - Tide chart Hoi An (Tide-forecast, 2016)

## C.6 Sand Balance

From three years, 1965, 2001 and 2014, the bathymetry is shown in Figure C.6. In the figure there are depth contour lines for 5, 10 and 15 meters. Based on this picture the volume of sand above the 15 m depth line can be calculated for each year. First the area between the contour lines is measured and converted to the real area with the drawing scale. Secondly the area between contour lines is assumed to be constant in depth and equal to the average of the depth contours it lies between. This gives a water depth of 2.5, 7.5 and 12.5 for each area. Since only the area above -15m is considered these water depths can be expressed as the height of sand above -15m and is referred to as 'sand depth'. From light blue to dark blue this gives sand depths of 12.5m, 7.5m and 2.5m. Multiplying the sand depth with the measured area of each section and adding up these sections one arrives at an estimate for the sand volume above -15m. This volume has increased over the years, with which it looks like that either more sand had moved towards the coast or the foreshore has extended.

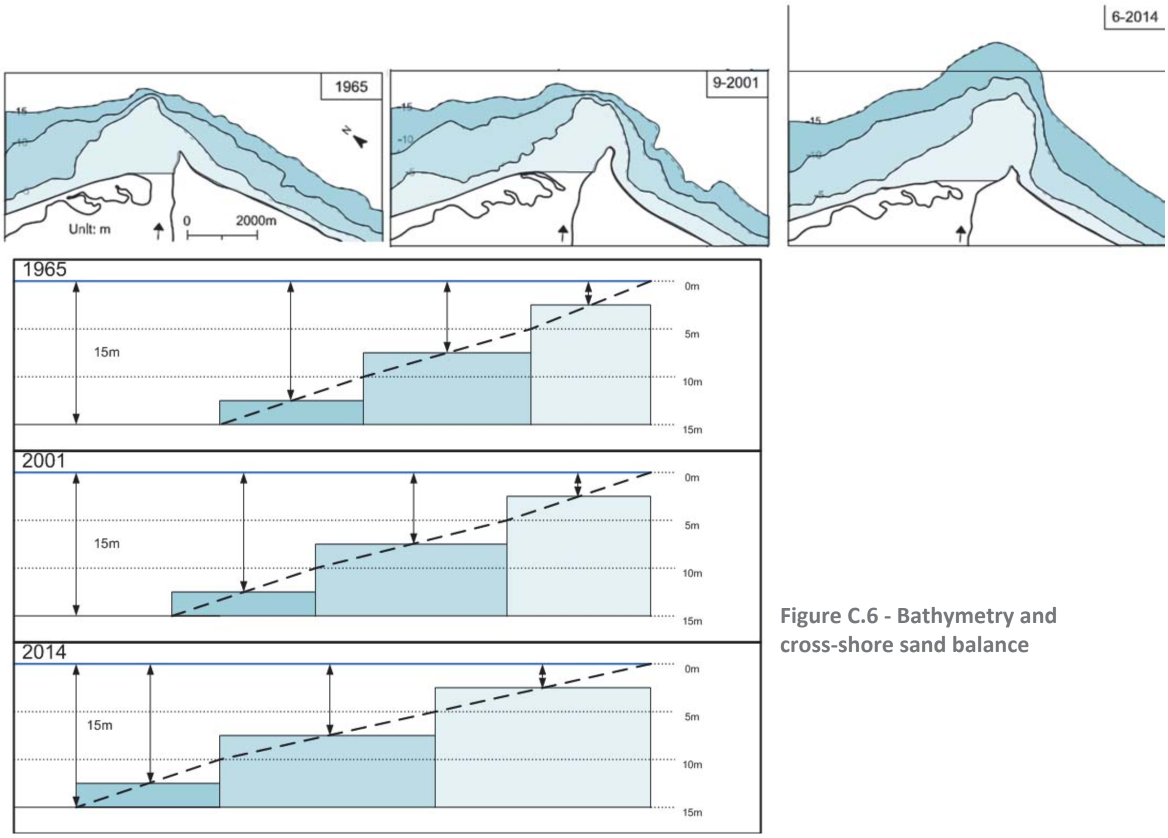



Figure C.6 - Bathymetry and cross-shore sand balance

| 1965 | water depth | Sand depth | Area(mm^2 in visio) | Area(km^2) | X10^6 m^3 sand | | |
|---|---|---|---|---|---|---|---|
| | 12.5 | 2.5 | 1509 | 5.7 | 14.3 | | |
| | 7.5 | 7.5 | 2091 | 7.9 | 59.4 | | |
| | 2.5 | 12.5 | 2047 | 7.8 | 96.9 | | |
| total | | | | 21.4 | 170.6 | | |
| **2001/9** | water depth | Sand depth | Area(mm^2 in visio) | Area(km^2) | X10^6 m^3 sand | | |
| | 12.5 | 2.5 | 1689 | 6.4 | 16.0 | | |
| | 7.5 | 7.5 | 2430 | 9.2 | 69.0 | | |
| | 2.5 | 12.5 | 2119 | 8.0 | 100.3 | | X10^6 m^3 sand |
| total | | | | 23.6 | 185.3 | **Difference with 1965** | **+14.7** |
| **2014/6** | depth | Sand depth | Area(mm^2 in visio) | Area(km^2) | X10^6 m^3 sand | | |
| | 12.5 | 2.5 | 2784 | 10.5 | 26.4 | | |
| | 7.5 | 7.5 | 2825 | 10.7 | 80.2 | | |
| | 2.5 | 12.5 | 2197 | 8.3 | 104.0 | | X10^6 m^3 sand |
| total | | | | 29.6 | 210.6 | **Difference with 2001** | **+25.3** |

Table C.1 - Sand balance calculation

| Area(mm^2 in visio) | Area(km^2) |
|---|---|
| 264.0625 | 1 |

| Sand depth relative to 15m |
|---|

## C.7 Erosion rate estimates

Based on measurements with Google Earth views from 2004-2015, which are supported by Landsat images, the yearly erosion is 12 meters a year for a stretch of 3.5 kilometres after which it gradually reduces. To account for this gradually reduced erosion outside the 3.5 kilometres stretch an 500 m stretch of 12 meter erosion is added. Therefore a beach length of 4km is considered.

The active depth was estimated with 2 similar formulas:

Eq. C-5 $$d_c = 2.28H_s - 68.5 * \left(\frac{H_s^2}{gT^2}\right)$$ (Hallermeier, 1981)

Eq. C-6 $$d_c = 1.75H_s - 57.9 * \left(\frac{H_s^2}{gT^2}\right)$$ (Birkemeier, 1985)

In which: $H_s = wave\ height\ exceeded\ 12\ hours\ per\ year\ [m]$

$T = wave\ period\ [s]$

Using the extrapolated yearly wave height and period data from appendix E3.1 ($H_s$=2.62m and $T_p$=11.1s) the closure depth is estimated to be between 5.58m and 4.25m. Taking the average of these values the closure depth is estimated to be 5m.

The amount of square meters of erosion follow from the logical assumption that the bed profile stays stable and erosion means a landwards movement of the active zone. See Figure C.7.

Eq. C -7 $$V_e = d_c * R * L_{beach}$$

with

$V_e = eroded\ beach\ volume\ per\ year\ \left[\frac{m^3}{year}\right]$

$d_c = active\ depth\ [m]$

$R = shoreline\ retreat\ per\ year\ \left[\frac{m}{year}\right]$

$L_{beach} = length\ of\ the\ beach\ [m]$

When multiplied with the beach length an average yearly erosion of 240,000 $m^3$ is estimated, as shown in
Table C.2.

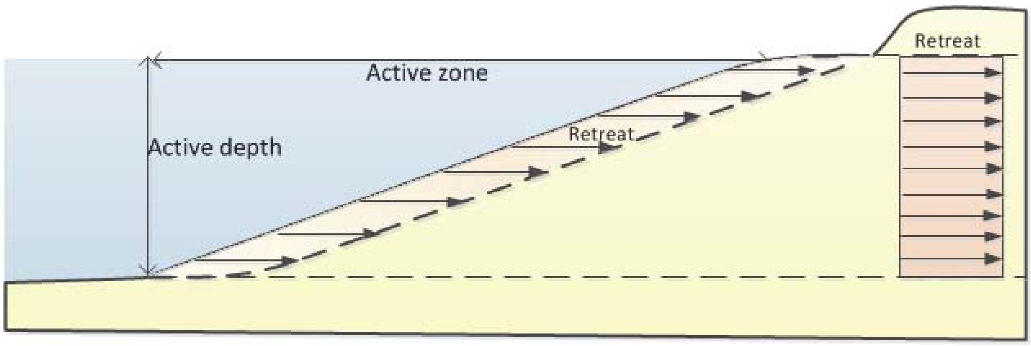



Figure C.7 - Erosion schematisation

Table C.2 - Table summary of used data for erosion

| Active depth (m) | Beach length (m) | Yearly retreat (m/year) | Area eroded from profile ($m^2$/year) | Eroded volume per year ($m^3$/year) |
|---|---|---|---|---|
| 5 | 4,000 | 12 | 60 | 240,000 |

# D. Estimates of river sediment supply

This appendix shows the different calculation methods for the estimation of the Thu Bon river sediment supply. On some places, data from own Thu Bon river observations are used, which are described in Appendix I.2.

### D.1 Estimation based on comparable river catchment area

This method used by Viet and Tanaka (2015) is based on the comparison between the Thu Bon river and several other river systems in the world. First, the specific sediment yield of several river systems around the world in [m3/km2/y] and the catchment area in [$km^2$] of these river systems are determined. These relationships between the specific sediment yield and catchment area can be shown in a diagram, see Figure D.1. After that, trends between the same type of rivers can be observed and this is used for determining the specific sediment yield of the Thu Bon river. Therefore the catchment area of the Thu Bon River system has to be known and a river system with a similar catchment area (in this case the Tenryu River in Japan) can be used to determine the sediment discharge of the Thu Bon River system (Viet & Tanaka, 2015).

This method gives a yearly amount of sediment supply of this river of **$Q_s$=600,000 $m^3$/year**.

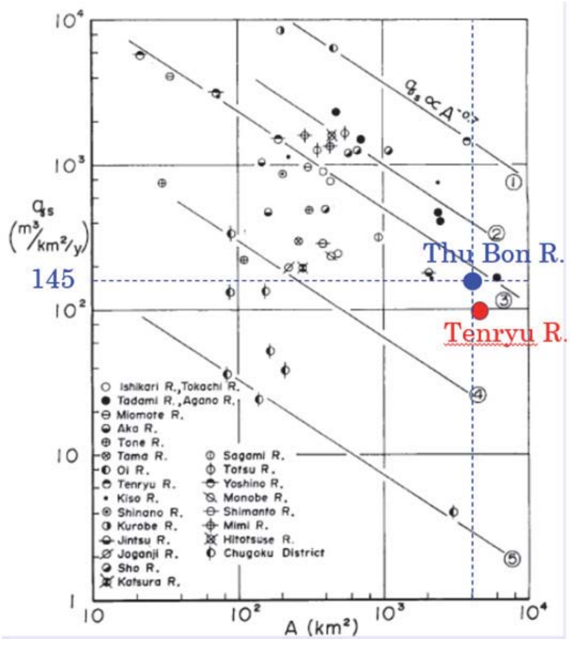



Figure D.1 - Estimation of sediment supply by comparable catchment area (Viet & Tanaka, 2015)

## D.2 Estimation with a calculation with the river bed slope and dominant discharge

For this estimation of the river sediment supply the Engelund and Hansen formula is applied. To define the annual sediment transport the dominant discharge is needed, which is calculated with the formula for dominant discharge shown below. Values for the base-, peak1- and peak2 discharge are obtained from a report of the (Department of Natural Resources and Environment, 2011) of the Quang Nam Province. The month November has the highest peak discharge and the months September, October and December have less high peak discharge. The remaining months have a base discharge as can be seen in Table D.2.

Eq. D-1 (de Vriend, H.J. et all., 2011)

$$Q_{dom} = \left[\int_0^\infty Q^{\frac{n}{3}}\, p(Q)\, dQ\right]^{3/n}$$

$$Q_{dom} \approx \left[\alpha_1 Q_{peak1}^{n/3} + \alpha_2 Q_{peak2}^{n/3} + (1-\alpha_1-\alpha_2) Q_{base}^{n/3}\right]^{3/n}$$

With:

$n = empirically\ derived\ factor = 5$
$\alpha_1 = probability\ of\ occurence\ of\ Q_{peak1} = 1/12$
$\alpha_2 = probability\ of\ occurence\ of\ Q_{peak2} = 3/12$
$Q_{peak1} = lowest\ peak\ discharge = 177\ m^3/s$
$Q_{peak2} = highest\ peak\ discharge = 471\ m^3/s$
$Q_{base} = lowest\ or\ base\ discharge = 1099\ m^3/s$

Finally this formula gives a dominant discharge of $Q_{dom} = 386 m^3/s$. The Engelund and Hansen method can be used to calculate the total sediment transport in the cross section of the river. Several parameters like the width, friction factor, gravitational constant, river bed slope and the coefficient 'm' have to be determined before calculating the sediment discharge in the Thu Bon River. The width is defined with Google Earth and the friction factor by checking the river bed during fieldwork. Furthermore, the bed slope is also determined with Google Earth by measuring the height at the begin and endpoint of the section taken and dividing by the total length of the river. The coefficient 'm' is defined in literature.

Eq. D-2 (de Vriend, H.J. et all., 2011)

$$i_{bed} = \frac{c_f B^{1-3/n}}{g Q_{dom}} \left(\frac{E(S)}{m}\right)^{3/n}$$

With:

$c_f = friction\ coefficient = 0.01\ [-]$
$n = empirically\ derived\ factor = 5$
$g = gravitational\ constant = 9.81\ m/s^2$
$Q_{dom} = dominant\ discharge = 386 m^3/s$
$m = empirically\ derived\ factor = 1 * 10^{-4}$
$B = conveying\ width\ of\ river\ [m]$
$i_{bed} = bed\ slope\ of\ river\ bed\ [-]$
$E(S) = estimated\ sediment\ discharge\ [m^3/s]$

Eq. D-3 $$E(S) = m\left(\frac{\frac{i_{bed}}{c_f B^{1-3/n}}}{gQ_{dom}}\right)^{5/3}$$ (de Vriend, H.J. et all., 2011)

With:
$m = empirically\ derived\ factor = 1 * 10^{-4}$
$Q_{dom} = dominant\ discharge = 386\ m^3/s$
$c_f = friction\ coefficient = 0.01$
$n = empirically\ derived\ factor = 5$
$B\ =\ conveying\ width\ of river\ [m]$
$i_{bed} = bed\ slope\ of\ river\ bed\ [-]$
$E(S) = estimated\ sediment\ discharge\ [m^3/s]$

For the calculation five different sections are defined based on different widths and side channels pouring into the river. The sections are between Tan An and Hoi An and shown in Figure D.2. The sediment transport calculation with the formulas given above and the bed slope and width are given in Table D.1.

**Table D.1 - Sediment discharge river sections**

| **Location** | Tan An | Thon 5 | Hiep Hoa | Dai Hoa | Dien Puong | Mouth |
|---|---|---|---|---|---|---|
| Wet width [m] | 59 | 80 | 131 | 201 | 612 | 1000 |
| Dry width [m] | 172 | 198 | 131 | 596 | 612 | 1000 |
| Height [m] | 22 | 18 | 14 | 5 | 2 | 0 |
| Distance from mouth[m] | 90,000 | 82,000 | 70,000 | 37,000 | 15,000 | 0 |
| Bed slope | 5.00E-04 | 3.33E-04 | 2.73E-04 | 1.36E-04 | 1.33E-04 | - |
| B [m] | 59 | 80 | 131 | 201 | 612 | - |
| $c_f$*B^0.4/(9.81*386) | 1.34923E-05 | 1.52E-05 | 1.86E-05 | 2.2E-05 | 3.4391E-05 | - |
| E(S) [$m^3$/s] | 0.041092566 | 0.017072 | 0.008797 | 0.002084 | 0.000955943 | - |
| E(S) [$m^3$/year] | 1,295,895 | 538,367 | 277,431 | 65,726 | 30,146 | - |

According to the calculations shown above, the yearly sediment discharge flowing through the Cua Dai Inlet is only **$Q_s$ = 30,150 m3/year** sediment. This is a very low amount compared to the other calculation methods. The reason for that could be that with this method several sections are considered from upstream to the downstream end and with the other methods only one section for the whole river is taken. When the average bed slope and the average width for the whole river is used for the calculation the resulting average sediment transport is higher compared to the calculation within each river section. The last section close to the mouth has the lowest bed slope and largest width causing a much lower sediment transport through that section. This leads to a large amount of sediment that will be deposited in the downstream sections. Note that this deposited sediment finally also might be transported to the sea, however that is not due to normal flow conditions. This deposited sediment might be eroded again and transported to the sea by a flush flow through the river in the months with peak discharge. This peak discharge is actually taken into account with the calculation of the dominant discharge. Nevertheless the highest peak discharge might have more impact on the sediment flush of the river and that is why an approximation of the sediment discharge is done by averaging it over the five sections: **Qs = 441513 m3/year**.


**Figure D.2 - River section used for the calculations**

## D.3 Estimation by calculation with sediment concentration

This method (Gray & Simoes, 2008) follows from the possibility to make sediment concentration measurements at locations in the river and then multiply those with the discharge. Accuracy depends on the amount of measurements of sediment concentration, and correct choosing of the locations in the river. Furthermore, the knowledge about the discharge of the river and the change of sediment concentration with high or low discharge would influence the accuracy. The formula for this method is shown below.

Eq. D-4 $$Q_s = Q_w C_s k$$ (Gray & Simoes, 2008)

With:
$Q_s = suspended\ sediment\ discharge\ [m^3/year]$
$C_s = sediment\ concentration\ [mg/L]$
$Q_w = water\ discharge [m^3/year]$
$K = coefficient = 0.978[L/mg]^*$

**A coefficient based on the unit of time measured and the unit of weight used and including the density of the material (60*60*24*30*1/10^6*1000*1/2650) = 0.9781132*

When the Thu Bon river was observed one of the purposes of this field trip was to obtain sediment concentration data. However, measurements could not be done at the moment of the field trip. So sediment concentration data from other measurements done before are used for this calculation, following from (Le Dinh Mau M.Sc., 2006). The discharge being around the yearly average discharge of 327m$^3$/s (Huyen, 2009). The results of the calculation with the formula of Gray and Simoes are shown in Table D.2.

Table D.2 - Sediment discharge calculation with formula of Gray and Simoes

| | Discharge distribution (%) | Discharge [$m^3/s$] | Sediment concentration [mg/L] | Sediment transport [$m^3$/year] |
|---|---|---|---|---|
| Jan | 4.5 | 177 | 13 | 2,245 |
| Feb | 4.5 | 177 | 13 | 2,245 |
| Mar | 4.5 | 177 | 13 | 2,245 |
| Apr | 4.5 | 177 | 13 | 2,245 |
| May | 4.5 | 177 | 13 | 2,245 |
| Jun | 4.5 | 177 | 13 | 2,245 |
| Jul | 4.5 | 177 | 13 | 2,245 |
| Aug | 4.5 | 177 | 13 | 2,245 |
| Sep | 12 | 471 | 150 | 69,086 |
| Oct | 12 | 471 | 150 | 69,086 |
| Nov | 28 | 1099 | 150 | 161,200 |
| Dec | 12 | 471 | 150 | 69,086 |
| **Total** | **100** | **Average= 327** | | **386,421** |

As can be seen in Table D.2 the total amount of annual sediment transport obtained with this method is **$Q_s$=390,000 $m^3$/year**. Hold in mind that actually this is only the suspended sediment transport. A distinction has to be made between the suspended and bed load sediment transport. The total sediment transport is the total of the suspended and bed load transport. This is why this value might be lower than the value obtained with the first two methods.

# E. Research into reasons for shoreline retreat

In this appendix a wide range of possible reasons for shoreline erosion will be discussed and their impact quantified within the boundaries of uncertainty. First the human impact will be discussed: a change in the watershed of the river, land subsidence due to water extraction, less sediment supply due to sand mining, water and sediment discharge changes following dam construction and changes in the river mouth flow patterns. Secondly the nature impact will be addressed: tectonic subsidence, climate change(sea level rise and increased storm surges), and a change in foreshore morphology. As a third part the natural yearly and multi-yearly variation of the shoreline is researched.

## E.1 Human impacts

### E.1.1 Change in watershed

Order of magnitude: None

The amount of sediment transport in the Thu Bon River might change if there are changes in the watershed of the river and this can contribute to the coastal erosion. A new river connection with another main river and deforestation are the main factors that have a high influence on the amount of sediment transported by the river. In addition the removing of vegetation on the beaches and dunes has a negative impact on the prevention against coastal erosion.

The Vu Gia River and Thu Bon River have two connections between each other relatively far downstream to manage the floods. The exchange of flow between the two rivers in the wet season from the Vu Gia to the Thu Bon River flows through the Quang Hue cross-connection. Further downstream the exchange of water from the Thu Bon River to the Vu Gia flows through the Vinh Dien River as shown in Figure E.1.

Due to the construction of upstream reservoirs the difference in water level between the Vu Gia River and Thu Bon River has increased. This is an increase of about 30 cm. Due to this increase about 20% to 40% more water is flowing from the Vu Gia River to the Thu Bon River nowadays (Ngo Le Long, Tran Thanh Tung, & Duong Quoc Huy, 2014). Further downstream of the Thu Bon River a little part of the discharge flows back through the Vinh Dien River to the Vu Gia River during the wet season (Ministry of Agriculture and Rural Development, 2012), no exact amounts are known however it can be said that this amount will not be higher than the amount of discharge flowing into the Thu Bon River from the Vu Gia through the Quang Hue.

After the construction of the Quang Hue River there has been a lot of sand eroding from the river banks in this part and also downstream of this connection between the Vu Gia River and the Thu Bon River (Tran Tan Van, 2002) indicating that the sediment concentration in the flowing water is increasing. Due to the fact that both the water discharge and so on also the sediment discharge are increasing in the Thu Bon River in the wet season it is unlikely that there will be less sediment transported to the shoreline nearby Cua Dai inlet.

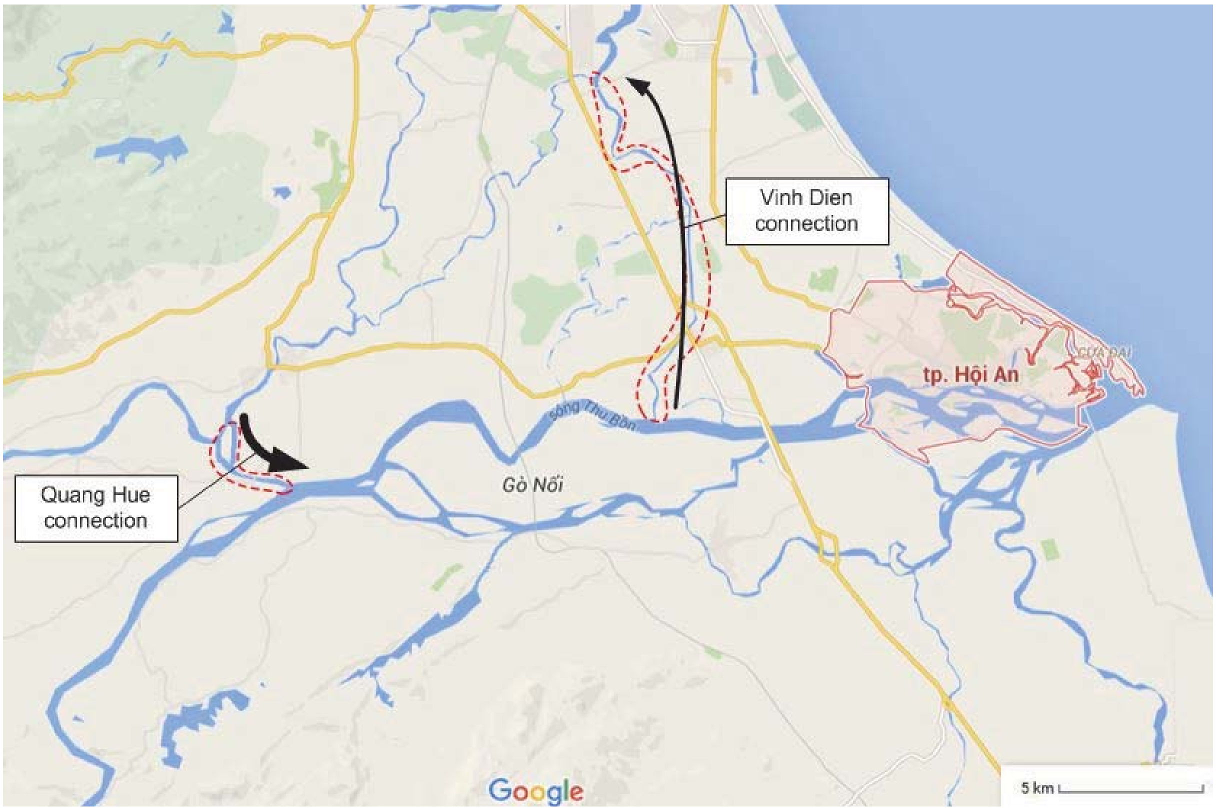



**Figure E.1 - River connections between the Vu Gia River and Thu Bon River distributing discharge**

Other factors like deforestation within the watershed of the Thu Bon River Basin are unlikely to contribute to the coastal erosion because deforestation would probably lead to a more loose soil on the river banks and mountain areas and so on lead to higher amount of soil flushed away to the river. That is why it is likely that deforestation will lead to a higher sediment discharge in the river and thus cause accretion instead of erosion.

Coastal forests and trees function as coastal protection against erosion and the removal of trees, coastal forests and other vegetation increased the vulnerability of the coastline to erosion. Human interventions like deforestation of the coastline at Central Vietnam are mostly to build resorts, residents and restaurants for the tourists.

As described above, the river connection between the Vu Gia and Thu Bon River has no impact on the shoreline retreat of Cua Dai Beach. What might have had some impact on the shoreline retreat after a lot of erosion already occurred is the coastal deforestation. Due to the fact that normally (in the history of Cua Dai Beach, several years ago) coastal trees and vegetation are located several tens of meter from the shoreline, the deforestation has only an influence on the shoreline retreat when the beach is already gone. So in conclusion the order of magnitude of shoreline retreat is none.

## E.1.2 Land subsidence

Order of magnitude: None

A relative sea level rise can contribute to the coastal erosion problem. Land subsidence occurs when large amounts of groundwater are withdrawn from the soil. Ground water is pumped from pore spaces between the soil grains, causing the soil particles to get closer together. Land subsidence may cause many problems, such as changes in river bed slopes, damage to bridges, roads and buildings. In some coastal areas, subsidence has resulted in tides moving into low-lying areas that were previously above high-tide levels.

Groundwater exploitation is mainly executed in Hanoi and in the lower regions of the Mekong Delta. Due to socio-economic growth in Hanoi, the groundwater extraction system has been broadened, which has led to land subsidence. In some places, the ground surface has declined up to 1.0 m in some parts of Hanoi (Phi & Strokova, 2015).The lower regions of the Mekong Delta, most of which lies <2 m above sea level, is also subjected to land subsidence. If pumping continues at present rates, approximately 0.88 m (0.35–1.4 m) of land subsidence is expected by 2050 (Erban, Gorelick, & Zebker, 2014).

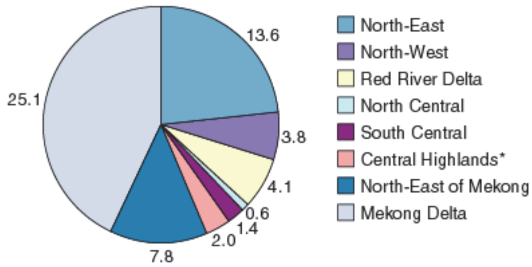



**Figure E.2 - Exploitable groundwater in Billion $m^3$/year( National Water Sector profile, 2002)**

According to the Water Environment Partnership in Asia (WEPA), groundwater extraction in central Vietnam is very low. The distribution of the exploitable groundwater over the whole country is shown in Figure E.2 (WEPA, 2015). Based on this information, it is concluded that the city of Hoi An, located in the central part of Vietnam is not subjected to significant land subsidence caused by groundwater exploitation. Very minor(<1mm a year) average subsidence can still be present but this is considered as (near) zero influence and thus excluded as reason for shoreline retreat.

### E.1.3 Sand mining

Order of magnitude: 5 m/year (100,000$m^3$/year)

In the Quang Nam province it is only allowed to mine sand from the river or from the river banks with a license. One of the sediment sources for the coastal area in the system area is the Thu Bon River, this river takes sediment from inland areas to transport it to the ebb tidal delta in front of the Cua Dai inlet and after that it will be distributed along the coast. The amount of the sediment transported by the river to the coastal area is approximated in 3.2 River influence. This amount is influenced by different factors next to sand mining like river regulation works.

If the sediment balance of a general river section is considered as shown in Figure E.3sediment extraction from the river bed or river bank can be considered as a sediment sink. Sand mining in the Thu Bon River causes less supply of sediment to the shoreline and might contribute to the coastal erosion of Cua Dai Beach.

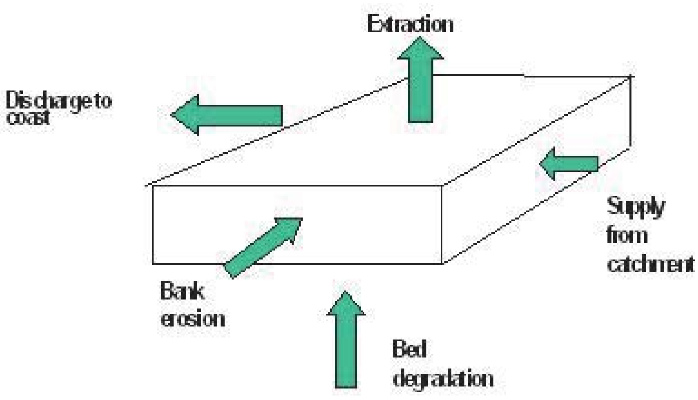



**Figure E.3 - Sediment balance of a river segment (Mangor, 2008)**

In this sediment balance extraction of sediment and sediment discharge to the coast are sinks and the bank erosion, bed degradation and supply from the catchment area of the river are sources of the sediment in the river segment. Of course, the sources and the sinks have to balance each other as formulated in Eq. E-1 (Mangor, 2008).

Eq. E-1 $$Q_{catchment} + Q_{bed} + Q_{bank} = Q_{extraction} + Q_{coast}$$ (Mangor, 2008)

The impact of sand mining in the upper part of the river differs from the impact of sand mining in the lower part of the river. The upper part of the river is the steep and less width river segment up in the mountains and the lower part is the gently sloping river segment near the coast.

When sand is mined in the upper part of the river it does not directly change the total sediment transport in the river to the shoreline because the loss in sediment due to the extraction is initially compensated by the degradation of the river bed.

When close to the mouth a trench in the river bed at the location of the extraction exists this trench will gradually travel towards the coast, as shown in Figure E.4. This is similar to sand mining upstream but the movement has to cover less distance so it effects the shoreline faster.

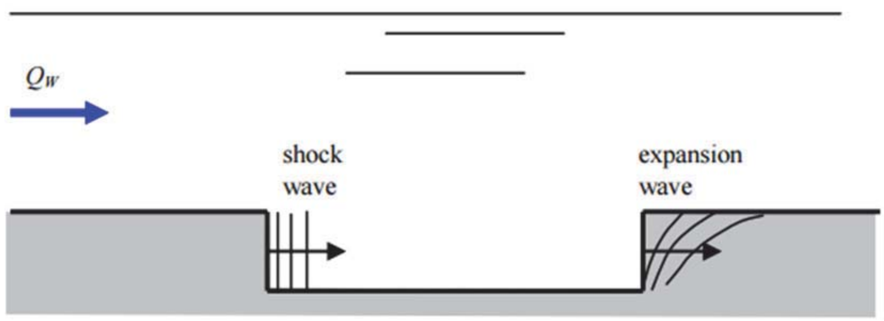



Figure E.4 - Initial deformation and propagation of a trench towards the downstream end of the river

The amount of sand extraction in the Thu Bon River is not known. There have been observations done in the lower part of the river at daytime and there are several forms of sand extraction in this lower part of the river like extraction from river banks, also inner banks of river bends and from the river bed. About 25 sand miners were active in the lower stretch of the Thu Bon River during daytime the day the observations were done and each sand miner operates approximately 300 days a year and can produce a daily amount of approximately 10 $m^3$. Including the sand extraction at night, approximately 10 sand miners, this might lead to a total amount of sand mining of approximately 100 000 $m^3$ sand per year. This is an very rough approximation based on limited observations , the exact amount of sand miners differs per day and the sand miners active at night could not be counted. Taking this amount of sand extraction in mind, this might lead to approximately a sediment reduction of 100 000 $m^3$/year because this is the extraction in the lower part of the river.

Assume that according to the observations at the Thu Bon River the sediment transport is reduced with 25%. Namely the total amount of sediment transport in the river (without sand mining and dams) is approximately in the order of 400,000 to 600,000 $m^3$ (calculation is shown in Appendix D). With a reduction of the sediment supply to the coast of approximately 25% there will be a shoreline retreat of the order of magnitude of 5m per year. This is calculated by taken an active water depth of 5m and a shoreline length of 4000 m, when the active depth is multiplied by the shoreline retreat and the shoreline length this gives 100,000 $m^3$/year.

Figure E.5 - Sand mining on Thu Bon river

### E.1.4 Dam construction upstream in Thu Bon River

Order of magnitude: 0.5m/year (20,000$m^3$/year)

Possible coastal erosion by sediment blockage by hydropower dams requires the blocking of a sediment rich part of the rivers catchments area and will influence the area downstream of the dam first. For now it is unlikely that the sediment blockage by the dams is influencing the erosion at the mouth of Hoi An because of the following three reasons:

- The sediment blockage of the river is something of the recent years. The first dam in the Thu Bon was finished in 2011, the second dam is finished in this year. While the third dam that would block a significant part is cancelled.
- The upstream reach of the river has a relatively small impact at the amount of sediment compared with the middle reach of a river. The realised hydropower dams are located in the upstream reach.
- When sediment gets blocked by a dam first the location downstream of the dam this will result in erosion of the river bed. Since the transport capacity of the river has not changed the amount of sediment blocked will be balanced by bed degradation and there is no direct impact of the supply of sand to the coast.

However, a different flow regime will change the yearly transport capacity of the river and this will influence the amount of sediment arriving at the mouth of the river. In the future also the change of bed level due to the (slightly) reduced amount of sediment will decrease the transport capacity of the river. With an over assumption of reservoir capacity the reduced flow near Hoi An leads to a reduction in the order of magnitude of 3% of the yearly sediment discharge of the river. Based on a reduction of the dominant flow from 386 $m^3/s$ to 378 $m^3/s$.

Table E.1 - Sediment reduction due to dam

| | discharge distribution(%) | discharge [m^3] | estimation of Δdischarge due to reservoir management | discharge with reservoir [m^3] |
|---|---|---|---|---|
| jan | 4.50% | 177 | 20 | 197 |
| feb | 4.50% | 177 | 5 | 182 |
| mar | 4.50% | 177 | 0 | 177 |
| apr | 4.50% | 177 | 0 | 177 |
| may | 4.50% | 177 | 0 | 177 |
| jun | 4.50% | 177 | 0 | 177 |
| jul | 4.50% | 177 | 0 | 177 |
| aug | 4.50% | 177 | 10 | 187 |
| sep | 12.00% | 471 | 15 | 486 |
| oct | 12.00% | 471 | 25 | 496 |
| nov | 28.00% | 1,099 | -100 | 999 |
| dec | 12.00% | 471 | 25 | 496 |
| **Year average** | | 327 | 0 | 327 |
| | | Qdom [m^3] 386 | | Qdom [m^3] 379 |

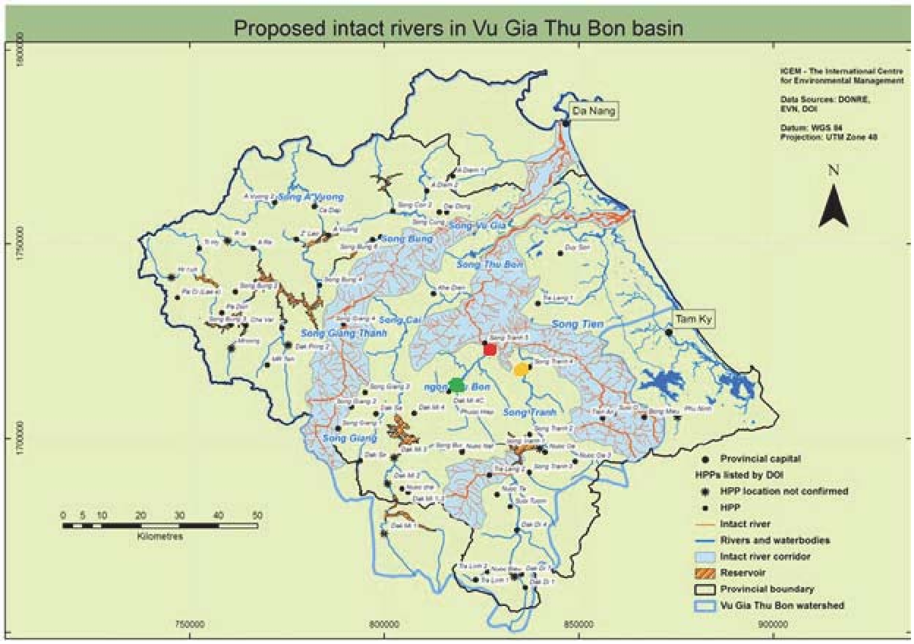



Figure E.6 - Hydropower dams in theThu Bon river (ADB, MONRE, EVN, MOIT, Quang Nam DONRE, 2008)

Dak mi 4C is in use from 2011(green dot in Figure E.6 (Operation News, 2012)

The proposed Song Tranh 5(red dot inFigure E.6) was halted along with other projects (News, 2012)

The building of Song Tranh 4(yellow dot in Figure E.6) has started in 2011 (QNDN, 2011)

## E.1.5 Land reclamation influencing flow pattern

Order of magnitude: None

A possible cause for local erosion is the change of conditions just before the mouth. Any changes in dynamics in such location would have an quick impact on the coastal zone.

In 2009 (Cua Dai bridge ground –breaking ceremony , 2010) the building of the Cua Dai Bridge started with the temporary reclamation of land to build bridge parts. In December 2015 this land is still reclaimed after finishing the bridge two years ago. The width of the river is reduced by this reclamation by one-third from the north side as seen inFigure E.7.

Such change would definitely change the river dynamics and flow conditions and thus can be seen as a reason to cause erosion at Cua Dai Beach. However there are also valid reasons why the erosion is not significantly caused by this land reclamation. Here follows a list of reason why not:

- The erosion started several years before the start of the construction of the bridge.
- A narrowing of the river will cause accretion around the reclaimed land but also erosion in the narrowed bed.
- The flow of the river is at the location of the bridge still 700 meters wide compared to a width of only 400 meters in the mouth.
- The north side of the river that is blocked seems to be the side that carries a very small amount of (sediment) discharge compared to the south side which is still unblocked.

To support/confirm this hypothesis that this temporary reclamation is not a significant factor for the erosion at Cua Dai Beach there would be a need for data. Several aerial photographs or maps from the last ten years for the river area could be used. Also a model can be set up to simulate the situation with and without. This would require time and resources and the result would be as reliable as the data. With the listed reasons it is not advised to research further into this direction. To regain as much as the original conditions to prevent a possible negative influence, it is however highly advised to remove the land reclamation in the near future.

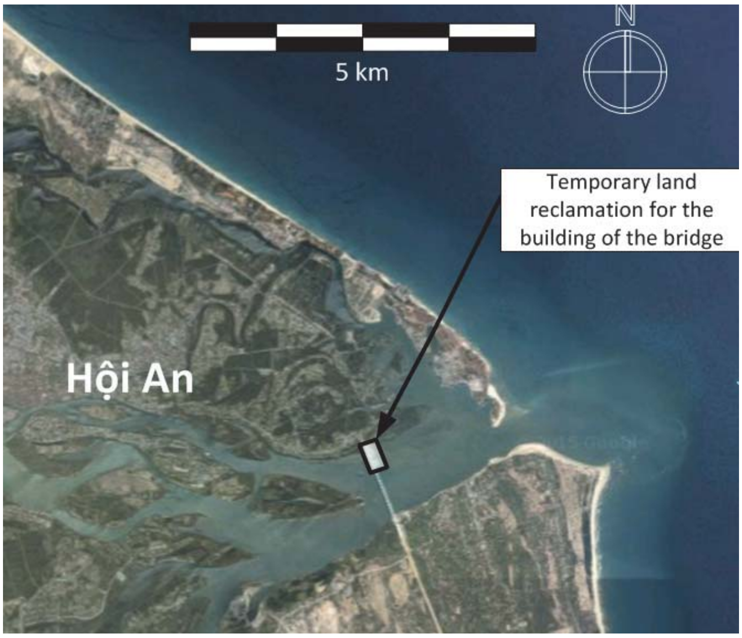



Figure E.7 - Narrowing by reclamation for the building of the Cua Dai Bridge

## E.2 Natural causes

### E.2.1 Tectonic subsidence

<u>Order of magnitude: None</u>

Since erosion is occurring along almost the entire coast of Vietnam, you might suspect a common cause. One of the reasons for the erosion could be tectonic movements, which can lead to relative sea level rise compared to Vietnam's shore and therefore erode the coast. The earth's crust is broken up in several earth plates, which can converge to and diverge from each other. In the following map, the major earth plates are depicted.

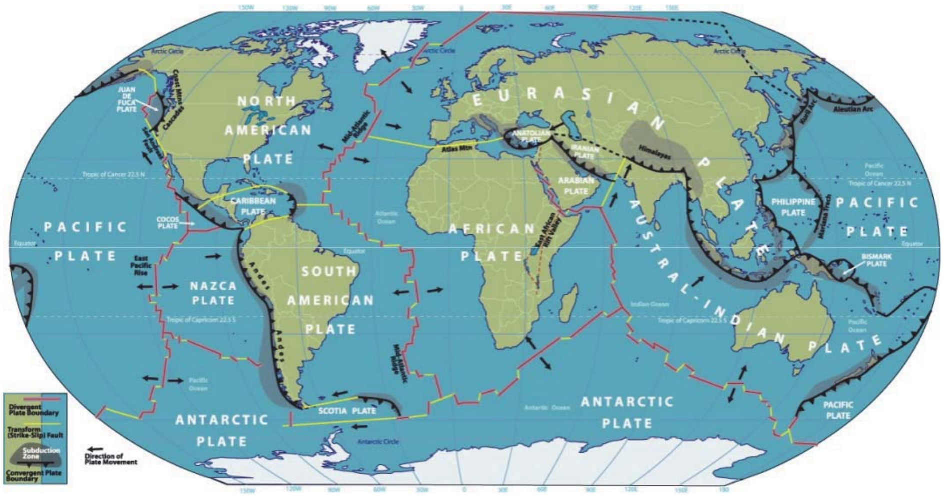



Figure E.8 - Earth plates (JohoMaps, 2015)

The edges of earth plates are most active in shaping the landscape. Converging earth plates (depicted by the black lines in Figure E.8) can shift over each other, diverging earth plates (depicted by the red lines) can create rifts. Besides the occurrence of earthquakes in those regions, the converging movement of plates can also push land up or pull land down beneath another plate, called tectonic subsidence.

Vietnam, part on the Eurasian plate, is not located on the edge of a plate. However, the Austral-Indian Plate is subsiding under the end of the Eurasian Plate.  This end is a minor earth plate, called the Sunda Shelf of Sunda Plate, on which the southern half of Vietnam is located. This colliding zones, as depicted in the map, are the most active in the world and caused amongst other the disastrous December 2004 tsunami (Earth Scope, 2014).

The complex play of earth plates can cause edges to sink and would generate a relative sea level rise that erodes the coast. Measurements of vertical movements, by for example GPS, are not available for Hoi An or any other part of Vietnam. Other tectonic subsidence mechanisms than the earth plates collision are not known and could also not be verified with movement data. A definitive exclusion of tectonic influences is therefore difficult. However, Hoi An is not located along a colliding edge and due to the elasticity of the plates, the influence of collision between the Austral-Indian Plate and Sunda Plate would be minor. Furthermore, the vertical movements are relatively slow compared to other contributors of coastal erosion (Thao, 2014). The assumed influence is therefore near zero.

### E.2.2 Climate change

There are two options why climate change is a possible contributing factor in the erosion at Hoi An. The first being sea level rise and the second being changing weather conditions. The changing weather conditions mostly focus on an increasing frequency and intensity of storms or typhoons due to global warming (Feng Caia, 2009).

**Sea level rise**

Order of magnitude: 0.5m/year

Sea level rise is a well-known driver for coastal retreat. The sea level rise at Hoi An is around 4mm/year for the last 50 years (ISPonre Vietnam, 2009) and expected to rise 6mm/year (Ministry of Natural Resources and Environment, 2009).

Following the Bruun Rule, as explained in Appendix C.1 the shoreline retreats due to the an adaption of the bed. Sand from the shore is transported to the near shore to form the same bed slope as before the sea level rise. Although sea level rise valid for Hoi An, the extreme amount of erosion cannot be solely explained by a minor change in sea level (Son, 2016).

Eq. E-2 $$a = \frac{(L \times SLR)}{h + d}$$ (Bruun, 1962)

In which: $SLR = sea\ level\ rise = 0.006\ [m/year]$
$L = width\ of\ the\ active\ profile \approx 2000\ [m]$
$d = closure\ depth\ \approx 5\ [m]$
$h = elevation\ of\ the\ beach\ or\ dune \approx 15\ [m]$
$a = coastal\ retreat \approx 0.6\ [m/year]$

The Bruun Rule has some critics and therefore also the Leatherman analysis is used. Following the Leatherman analysis this would cause an retreat of 0.480 m/year when not taking into account the accretion due to the river supply (Bosboom & Stive, 2015).

Erosion or more precise, shoreline retreat, due to sea level rise is expected to be taking place at a rate of half a meter per year.

**Increasing storms**

Order of magnitude: 2.5m/year

Another effect of a changing climate that can impact the coastal balance and cause erosion is the increasing amount of storms. As explained in chapter four, during storm conditions sediment is transported seawards. Normally this in balance with the return of sediment during calmer conditions. However when there is an increasing frequency and/or intensity of the storm the loss of sediment can be partly permanent.

Due to the warmer air at the equator and therefore larger temperature differences between equator and poles, heavier storms will form with more extreme wave conditions (ISPonre Vietnam, 2009) ( Prime Minister Nguyen Tan Dung, 2011) (NASA, n.d.). This can already be seen when looking at the rate of typhoons hitting the central coast in Vietnam over the last century (Cat & al., n.d.):

1901-1930: 117 typhoons
1931-1960: 134 typhoons
1961-1990: 171 typhoons

It can be noticed that the amount of typhoons is increasing. Again, higher waves that arise during typhoons can cause more erosion, and with more storms this erosion will occur more often.

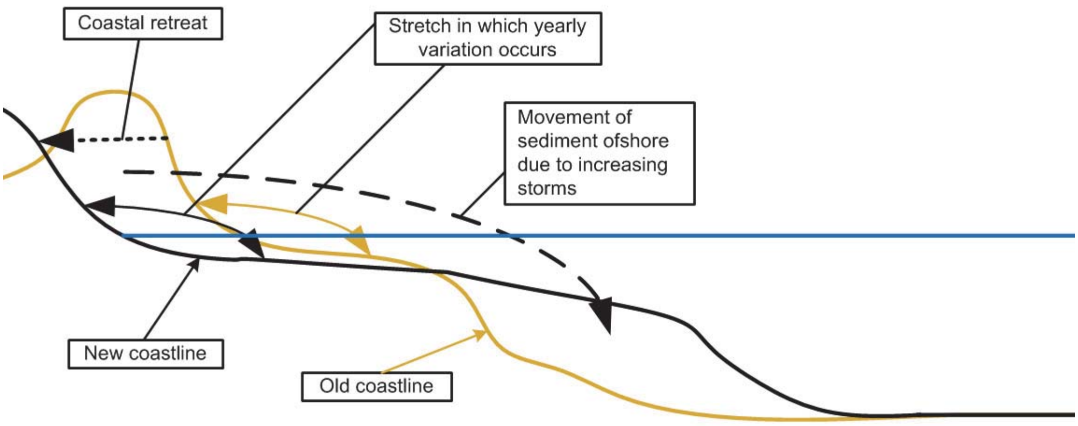



Figure E.9 - Shoreline change due to increased rough conditions

A relative rougher wave climate (due to increasing storms) could change the offshore bathymetry as shown inFigure E.9. The mild condition -rough condition variation of sediment is present. However next to this there is also a movement of sediment offshore to make a longer relatively flat stretch of sea bed. The sand for this increased stretch is likely to come from the coast.

The following is a very rough estimation of the sediment loss due to increased storm conditions. A new bed is expected to form in a period of a decade after which a stable situation should appear in respect to increased storm conditions. In this decade it is assumed that the sediment that is lost temporary to the foreshore during the extra storms will not return. The amount of storms is expected to rise analogue and are expected to rise similar to the typhoons. A large storm displaces 40.000 cubic meters of sand over a four kilometre stretch of beach, see the section E.3.1 'Storm variation'. The amount of storms increased with 171-134=37 per year ~1.2 storms. This results in a slight overestimation with 1.2 times 40,000 ~ 50,000 $m^3$/year or 2.5m/year. The overestimation comes from taking a one in five year storm.

### E.2.3 Near shore conditions

<u>Order of magnitude: None</u>

Near shore underwater conditions like morphology and water depth influence the local wave climate. Due to changing underwater conditions, like shifting sand bars or accretion wave climate is likely to change. If larger waves can meet the shore, more erosion compared to the past will happen. The change in near shore bathymetry as depicted in Chapter 4.3.5 might change the stream directions.

The change in stream directions might change the local sediment balance and such result in accretion and erosion at locations as explained in the paragraph about river streaming. If this change in bathymetry also changes the waves conditions negatively is unsure.

Reasons why it is likely that the erosion is caused by a change in wave climate due to the bathymetry change:

- There is a large change in the near shore bathymetry, this will definitely in some way influence the nearby beach.
- Waves coming from the south are partly blocked by the reduced depth. This might reduce the accretion in the mild season since erosion takes place on the location of breaking.
- Storm surge levels can slightly increase due to an increased funnel effect.

Reasons against erosion caused by a change in flow due to the bathymetry change:

- Normally a reduction in water depth will result in a reduction of the significant wave height and therefore results in reduced erosion, not increased erosion.
- It is not likely to cause a sediment loss over a longer stretch of coast. The effect would expected to be more local.

Following this reasoning the expected effect, if any, would be in favour of accretion instead of erosion. In both causes the effect is limited in time and therefore the order of magnitude will be expected to be zero.

## E.3 Natural variation

The shape of most coastlines is dynamic. In Hoi An the coastline has a seasonal character due to typhoons and storms in the storm season and milder conditions the rest of the year. Furthermore an onshore moving sand bar has been observed between 1989 and 1995. It cannot be determined yet whether such a sand bar is a cyclical occurrence or that it was a single instance, since long term records are not available.

Whereas storm appear yearly the amount and intensity varies. Even without climate change this influences the yearly and multi-yearly variation of the shoreline. The coast can move landwards in one decade and move seawards in the next. With the storm variation this is a proven concept for this location, however if the sand bar movement onshore or the river stream direction are cyclic events it is less sure. In this section it is therefore chosen to give the order of magnitude of different erosion drivers in meters instead of meters per year.

### E.3.1 Storm variation

Order of magnitude: $^{1}/_{5}$ year storm : 35 m
$^{1}/_{50}$ year typhoon: 120 m

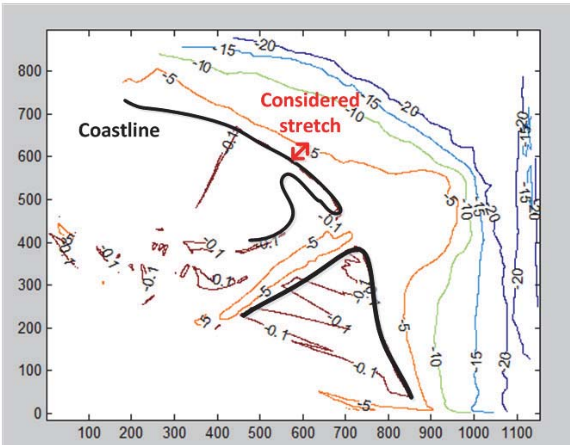



**Figure E.10 - Considered cross-shore profile. (Chang, 2015)**

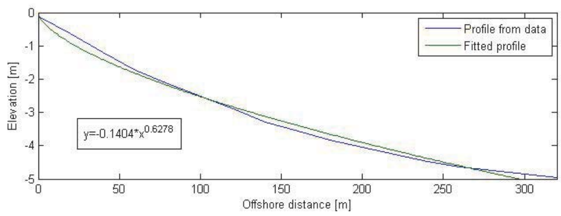



**Figure E.11 - Data fitted to the Bruun profile from Figure E.10**

The Bruun profile was used to fit the profile of the erosional beach in Hai Hau in northern Vietnam. For the parameters A and ρ the values 0.136 $m^{1-\rho}$ and 0.553 were found respectively (Nguyen, Zheng, & Zhang, 2012). Although this erosional beach is at a different location in Vietnam it can be used as a reference for the Cua Dai beach profile as this beach is also in a state of erosion.

Fitting bathymetric data of the cross-shore profile of Cua Dai beach from the year 2010 resulted in a similar value for A of 0.1404 $m^{1-\rho}$.There was however a larger value for ρ of 0.629 that is closer to the value suggested by Bruun. Bruun suggests a value for ρ of 2/3. This gives confidence in the assumption that the profile from the data is trustworthy. Since it is in line with observations of other coasts and therefore reliable to be used for further analysis. This check is done since the source of the data and the method of measurements are not known.

The cross-shore profile shifts due to a heavier wave attack during storms. This is the cause of the variation in the profile and makes for a temporary loss of sand of the beach. The extent of this temporary erosion is important as structures close the beach can be threatened.

To quantify the retreat of the coastline due the storms the DUROS+ method will be used. The input is formed by the profile found in the data, the sediment, the characteristics of the storm waves and the surge level. The edge at the dune will erode with an angle of 1:1 while the angle underwater at the toe will stabilise at 1:12.5 (Den Heijer, 2013). In between a profile is fitted such that the total volume deposited at the toe is equal to the volume of sand eroded at the coast. The profile has the formula:

Eq. E-3

$$\frac{7.6}{H_{0s}} * y = 0.4714 * \left[\left(\frac{7.6}{H_{0s}}\right)^{1.28} * \left(\frac{12}{T_p}\right)^{0.45} * \left(\frac{w}{0.0268}\right)^{0.56} * x + 18\right]^{0.5} - 2.0$$

(Den Heijer, 2013)

With:
$H_{0s} = significant\ wave\ height\ [m]$
$T_p = peak\ period\ [s]$
$w = sediment\ fall\ velocity\ [m/s]$

The formula can be used for both storms and typhoons. Between 1945 and 2003 roughly 1.2 typhoons reached Hoi An each year. For Hoi An the largest typhoon was named Fritz. It had an offshore significant wave height of 10.5m and peak period of 13.4s but due to the shallow depth in front of Hoi An wave breaking reduced the wave height to 6m (Mau, 2006). Since this storm was the largest in about 50 years to strike Hoi An it is assumed these are the 1 in 50 year conditions. The local storm surge conditions with a 1/50 return period is a surge of 2.86 m (Thuy, 2003). Based on this input the effect of a such a typhoon can be calculated. Based on this calculation 79.5 $m^3$/m of beach would be temporarily eroded and it extends 120m land inward. This is however an extreme situation. Over wash and subsequent flooding are ignored in this empirical calculation.

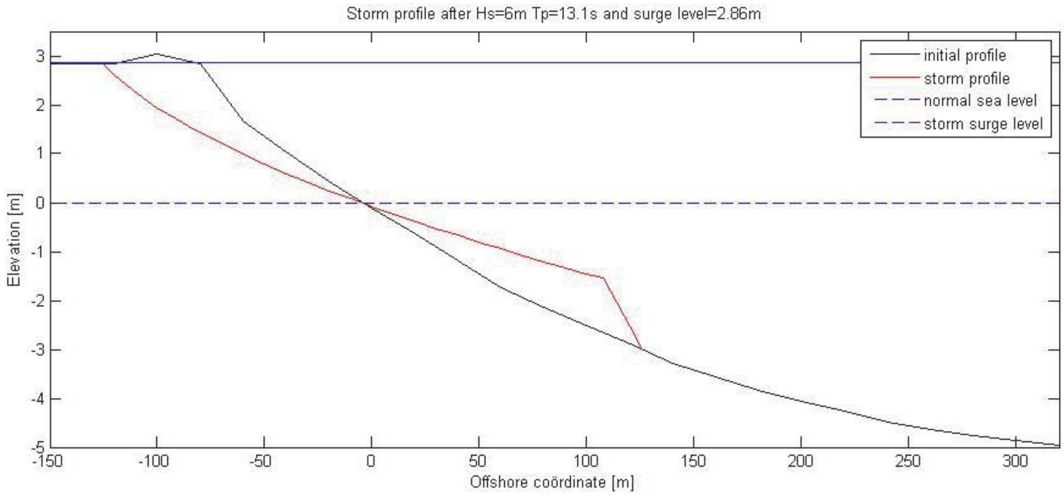



Figure E.12 - DUROS+ result for 1/50 year typhoon conditions

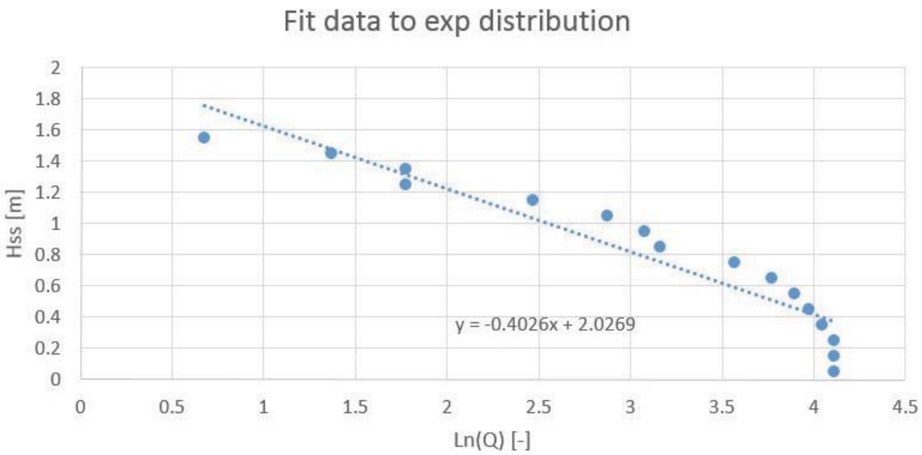
The more common storms can also move sand from the beach offshore. Data about more average storms was limited. Only between 2-10-2010 and 17-10-2010 wave data was collected. Dividing this data from (Thủy, 2010) into 12 hour blocks and averaging the wave heights and periods within these blocks gives representative 'storm' wave conditions when assuming each storm lasts 12 hours. As the data is from October, which is a month in the storm season that last from September to December, it is assumed the measured climate is about the same as for the other months in the storm season. If larger storms are expected later in the storm season this analysis will underestimate wave conditions on larger return periods. However since no better data is available this assumption has to be taken. The yearly storm conditions are derived by calculating the once in four months wave conditions based on the measured data. Since the other months outside the storm season are assumed to contain no storms this also translates into a once per year storm. Also important to note is that no typhoons were measured in the data so these are not included.

**Table E.2 - Wave height calculation**

| *Hss_bin [m]* | | *Observations* | *Cumulative observations* | *P* | *Q* | *Higher Hss expected per month* | *LN(Q)* |
|---|---|---|---|---|---|---|---|
| 0 | 0.1 | 0 | 0 | 0 | 1 | 61 | 4.1108739 |
| 0.1 | 0.2 | 0 | 0 | 0 | 1 | 61 | 4.1108739 |
| 0.2 | 0.3 | 0 | 0 | 0 | 1 | 61 | 4.1108739 |
| 0.3 | 0.4 | 2 | 2 | 0.06451613 | 0.935484 | 57.06451613 | 4.0441825 |
| 0.4 | 0.5 | 2 | 4 | 0.12903226 | 0.870968 | 53.12903226 | 3.9727235 |
| 0.5 | 0.6 | 2 | 6 | 0.19354839 | 0.806452 | 49.19354839 | 3.8957625 |
| 0.6 | 0.7 | 3 | 9 | 0.29032258 | 0.709677 | 43.29032258 | 3.7679291 |
| 0.7 | 0.8 | 4 | 13 | 0.41935484 | 0.580645 | 35.41935484 | 3.5672584 |
| 0.8 | 0.9 | 6 | 19 | 0.61290323 | 0.387097 | 23.61290323 | 3.1617933 |
| 0.9 | 1 | 1 | 20 | 0.64516129 | 0.354839 | 21.64516129 | 3.0747819 |
| 1 | 1.1 | 2 | 22 | 0.70967742 | 0.290323 | 17.70967742 | 2.8741112 |
| 1.1 | 1.2 | 3 | 25 | 0.80645161 | 0.193548 | 11.80645161 | 2.4686461 |
| 1.2 | 1.3 | 3 | 28 | 0.90322581 | 0.096774 | 5.903225806 | 1.7754989 |
| 1.3 | 1.4 | 0 | 28 | 0.90322581 | 0.096774 | 5.903225806 | 1.7754989 |
| 1.4 | 1.5 | 1 | 29 | 0.93548387 | 0.064516 | 3.935483871 | 1.3700338 |
| 1.5 | 1.6 | 1 | 30 | 0.96774194 | 0.032258 | 1.967741935 | 0.6768867 |
| 1.6 | 1.7 | 1 | 31 | 1 | 0 | 0 | |
| *Total of 12h measurements* | | 31 | | | | | |

**Table E.3 - Wave period calculation**

| *Tp_bin [m]* | | *Observations* | *Cumulative observations* | *P* | *Q* | *Higher Tp expected per month* | *LN(Q)* |
|---|---|---|---|---|---|---|---|
| 0 | 0.5 | 0 | 0 | 0 | 1 | 61 | 4.1108739 |
| 0.5 | 1 | 0 | 0 | 0 | 1 | 61 | 4.1108739 |
| 1 | 1.5 | 0 | 0 | 0 | 1 | 61 | 4.1108739 |
| 1.5 | 2 | 0 | 0 | 0 | 1 | 61 | 4.1108739 |
| 2 | 2.5 | 0 | 0 | 0 | 1 | 61 | 4.1108739 |
| 2.5 | 3 | 0 | 0 | 0 | 1 | 61 | 4.1108739 |
| 3 | 3.5 | 0 | 0 | 0 | 1 | 61 | 4.1108739 |
| 3.5 | 4 | 0 | 0 | 0 | 1 | 61 | 4.1108739 |
| 4 | 4.5 | 0 | 0 | 0 | 1 | 61 | 4.1108739 |
| 4.5 | 5 | 0 | 0 | 0 | 1 | 61 | 4.1108739 |
| 5 | 5.5 | 0 | 0 | 0 | 1 | 61 | 4.1108739 |
| 5.5 | 6 | 0 | 0 | 0 | 1 | 61 | 4.1108739 |
| 6 | 6.5 | 1 | 1 | 0.03225806 | 0.967742 | 59.03225806 | 4.078084 |
| 6.5 | 7 | 3 | 4 | 0.12903226 | 0.870968 | 53.12903226 | 3.9727235 |
| 7 | 7.5 | 2 | 6 | 0.19354839 | 0.806452 | 49.19354839 | 3.8957625 |
| 7.5 | 8 | 7 | 13 | 0.41935484 | 0.580645 | 35.41935484 | 3.5672584 |
| 8 | 8.5 | 4 | 17 | 0.5483871 | 0.451613 | 27.5483871 | 3.315944 |
| 8.5 | 9 | 9 | 26 | 0.83870968 | 0.16129 | 9.838709677 | 2.2863246 |
| 9 | 9.5 | 5 | 31 | 1 | 0 | 0 | |
| 9.5 | 10 | 0 | 31 | 1 | 0 | 0 | |
| *Total of 12h measurements* | | 31 | | | | | |



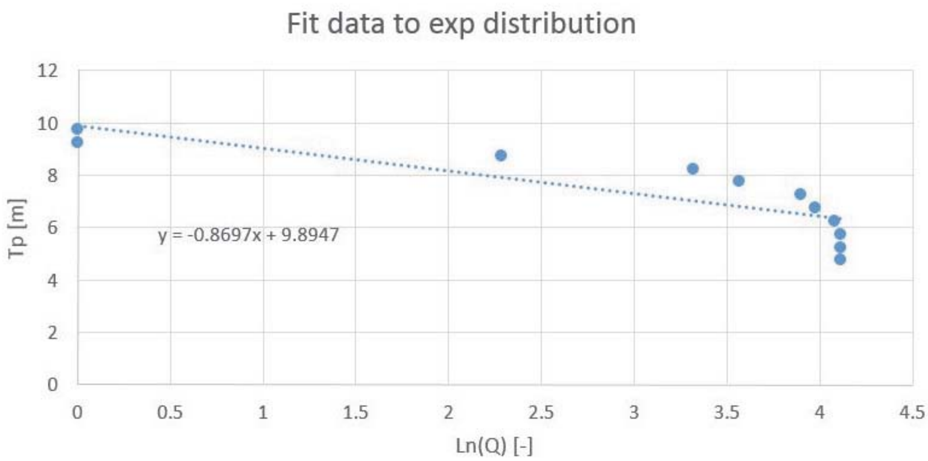




Figure E.13 - Hss and Tp fittings

The fit to the data gives storm conditions that are not related to typhoons. By using these values the storm profiles for lesser storms can be computed. Monthly and yearly storms turn out to be not strong enough to be suitable for a calculation with DUROS+. However the storm with a return period once per 5 years does. The corresponding surge level is 0.86 m (Thuy, 2003). Damage to the beach extends 35 m inland as10.6m$^3$/m is moved from the beach to the foreshore.

Table E.4 - Extrapolation of Hss and Tp for longer return periods based on measured data from (hải, 2010)

| | Q (prob. of exceedance) | Hss | Tp |
|---|---|---|---|
| per month | 1 | 2.027 | 9.8947 |
| per year* | 0.25 | 2.616912 | 11.10036021 |
| per 5 years | 0.05 | 3.30178 | 12.50008836 |
| per 25 years | 0.01 | 3.986647 | 13.89981651 |
| per 50 years | 0.005 | 4.281603 | 14.50264661 |
| per 100 years | 0.0025 | 4.576559 | 15.10547672 |

**assuming 4 months of storm season with no storms the rest of the year*

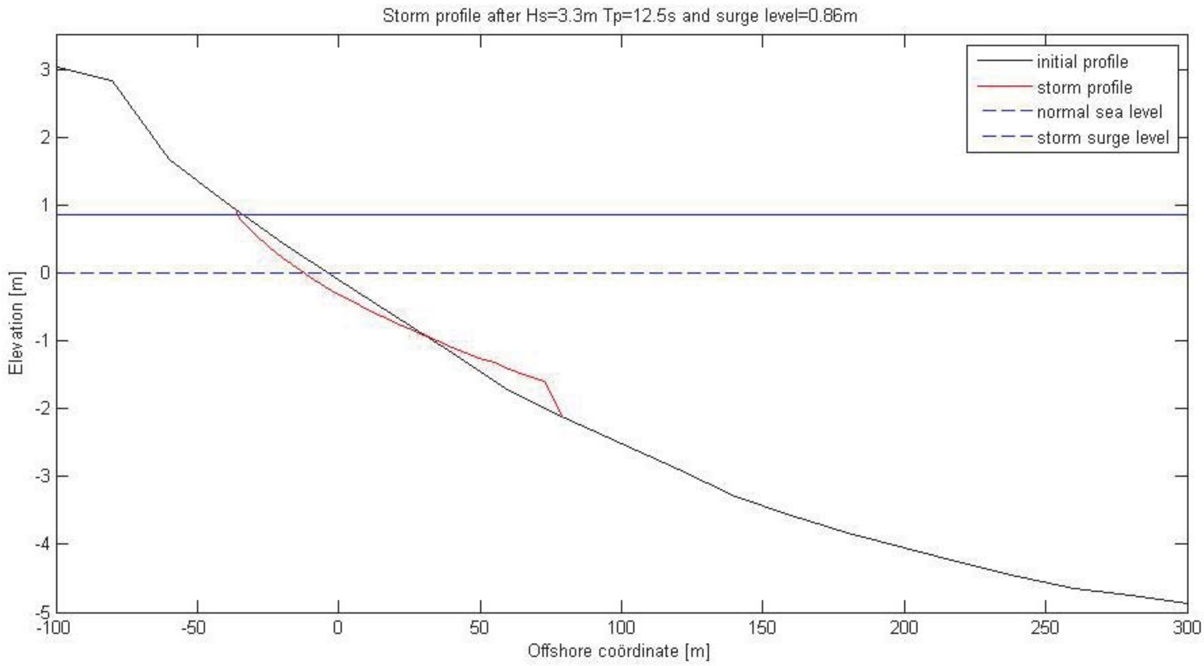



Figure E.14 - DUROS+ result for 1/5 year conditions

In conclusion the effect of typhoons on the beach can be temporary devastating over a large width of the beach moving a lot of sand to the foreshore. The empirical calculation suggests 120 m of beach impacted by it and 79.5 $m^3$/m of sand displaced. Lesser storms with a return period of 4 to 5 years or longer can cause sand to move to the foreshore. The calculation suggests 35 m of beach is affected and 10.6 $m^3$/m sand displaced. For these storms the problem is rather limited if there sufficient beach to compensate the temporary loss. Under normal conditions sand that is moved to the foreshore can return provided there is sufficient time between consecutive storms.

### E.3.2 Sand bar moving onshore

Order of magnitude: averaged 60 m (1,230,000 $m^3$)

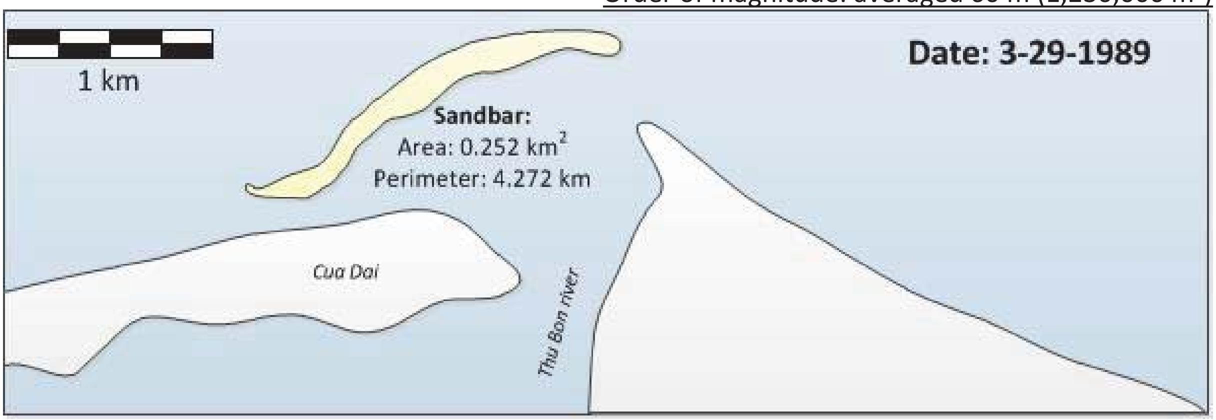



Figure E.15 - Observed sandbar in in 1989. Adapted on data from (Hoang, Tanaka, Viet, & Duy, 2015)

In 1989 a sandbar was observed approaching the coast of Hoi An. As stated earlier in section3.1 Evolution of the coast, this sand bar eventually merged with the coast between 1991 and 2000 and widened the beaches. The volume of sand carried by the sand bar to the coast can be approximated from the Landsat images. Assuming an average water depth around the bar of 3m, a slope of 1:20 (≈3 degrees) and that an additional 20% of the volume of the bar is present under water the volume can be calculated as follows:

Eq. E-4

$$V_{Sandbar} = \left( A_{Sandbar} * d + P_{sandbar} * \frac{d^2}{2\tan(\alpha)} \right) * C$$

With:

$V_{Sandbar} = Volume\ of\ sand\ in\ the\ sandbar$
$A_{Sandbar} = area\ of the\ sandbar\ [m^2]$
$P_{Sandbar} = perimeter\ of\ the\ sandbar\ [m]$
$d = water\ depth\ [m]$
$\alpha = slope\ [degrees]$
$C = correction\ factor\ for\ sandbar\ features\ under\ water$ [-]

With this calculation the volume of sand amounts to 1,370,000 $m^3$ or 1.37 million cubic meters. The assumption is that 90% of this volume, 1,230,000 $m^3$, was added to Cua Dai beach. Cua Dai beach has a length of about 3 km and with an assumed active depth of 5 m it is calculated that the beach widened by such a nourishment with about 80 m. Indeed a large advancement of the coast has been observed in subsequent years with the most advancement close to the river mouth and less at the end of Cua Dai. Although these are very rough calculations, it illustrates the scale of such a natural sand bar and its effect on the coast. Last years the natural equilibrium is recovering and that is why there is a lot of erosion these years.

### E.3.3 Sediment streaming due to river flow direction variation

<u>Order of magnitude: 5 m/year</u>

Another natural cause for the erosion might be the movements of the Thu Bon river mouth and in which direction most of the sediment is flowing when it reaches the sea. This would explain the sand bar that is visible in 1989 in a different way.

Namely, as part of the ebb tidal delta above sea level, formed by sediment from the river. The hypothesis is that the major outflow direction of the Thu Bon river has shifted from northwards to southwards in about 30 years, while the amount of accretion at the spit was influenced by the sandbank in front of it. How this might have happened is described in the text below.

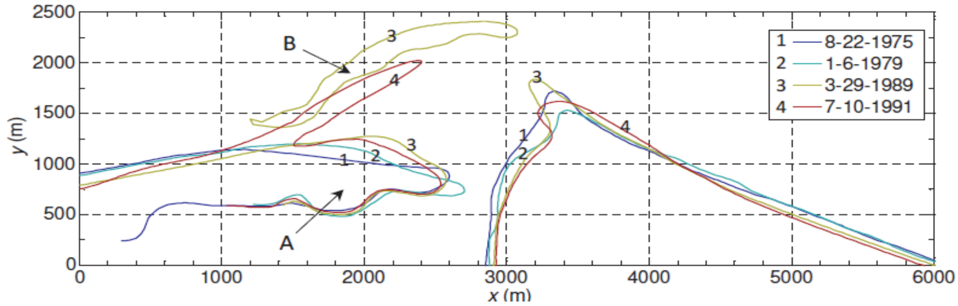



Figure E.16 - Coastline variation between 1975 and 1991 (Hoang, Tanaka, Viet, & Duy, 2015)

It is presumed that 40 years ago the main outflow direction was directed to the north. This preference for a certain outflow is the result of how the river bank is shaped before the river flows into the sea. The sandbank might be explained by several years of excess sediment supply from the river. With a growing height of the bank, more sediment was trapped and accreted on the bank until it was pushed up above the sea level by waves and wind from the sea and river flow from the other direction.

Looking at Figure E.16, the width of the spit has increased between 1975 and 1989 and was declining again when the sandbank was getting smaller. The sandbank might be the cause for this.

Sediment can be trapped between the coast and the bank, leading to accretion at the end of the spit and a reducing amount of sediment that is distributed over the total stretch of coast north of the river mouth. The erosion that would arise at this northern stretch is also visible on the Landsat image: between 1975 and 1989 the beach is retreating.

At some point in time, probably around 1990, the shape of the spit has changed so much that the easiest outflow direction began turning southwards. The erosion by waves on the sand bank starts overruling the accretion by sediment supply and the sand bank is getting smaller. The sand bank is also shifting to the coast due to the reduced water outflow against the sand bank, while waves push the sand towards the coast. When the bank reached the coast, it lead to an initial increase in beach width of about 80m, as calculated in the previous section. That the dominant outflow direction has turned southwards is also visible from Landsat image in Figure E.17. From 1975 to 2015, the land south of the river mouth is following the expected outflow direction.

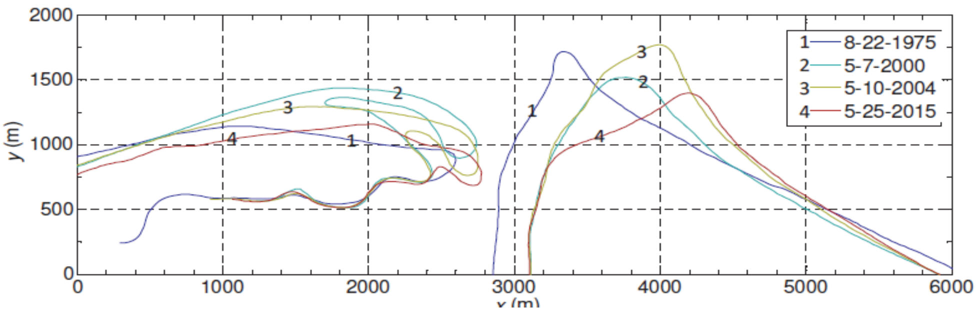



**Figure E.17 - Coastline variation between 1975 and 2015 (Hoang, Tanaka, Viet, & Duy, 2015)**

With the sediment supply moving southwards, the spit started changing fast. Figure E.17 shows a major retreat between 2000 and 2015, which is explained purely by natural processes in this hypothesis. The shape of the spit is adapting to the reduced sediment supply from the river, which was directed towards the spit by the sand bank. Using the satellite images of Google Earth, the width of the tip of the spit has decreased 60m from 2004 to 2012 and another 100m until 2015. Without any fixation from trees or buildings, this end of the spit is changing from year to year. Meanwhile, the ebb tidal delta is shifting southwards as well, since this delta is formed by river sediment supply. This is showed in Figure E.18. It is also clearly visible here how the shape of the land just south of the river mouth has changed over the years.

Much slower rates of erosion compared to those at the end of the dynamic spit are occurring now at Cua Dai Beach. This can also be explained by the reduced sediment supply due to the southward shifting outflow of the river. To quantify the influence of the change in river outflow direction is difficult. The alongshore transport of sediment that distributes the sediment along the coast is for a large part based on waves and winds. The contribution of the direction of the outflow direction is therefore hard to measure. From the shape of the tidal delta, the major outflow direction of the river can be seen. In Figure E.18, the black line shows is placed perpendicular to the coast.

If outflow of the river, depicted with the red line, coincides with the black line, equal amounts of sediment are delivered to both sides of the river mouth (not taking into account the action of waves and wind). It is assumed that the delta shape in 1965 is comparable to that in 1975, because it is similar to the 1975 shape in the Landsat images. The outflow direction is slightly directed to the north, and based on eye comparison it is sending about 55% of the sediment north and 45% southwards. In 2014 the direction is more southwards. The distribution is around 35% to the north and 65% to the south. The sediment supply to the north has therefore decreased by 20%. Using an annual river sediment supply of 500,000 $m^3$, the sediment decline is 100,000 $m^3$. This is comparable to the sediment reduction caused by sand mining and therefore the order of magnitude of erosion due to changes in the river outflow direction is also 5 m/year.

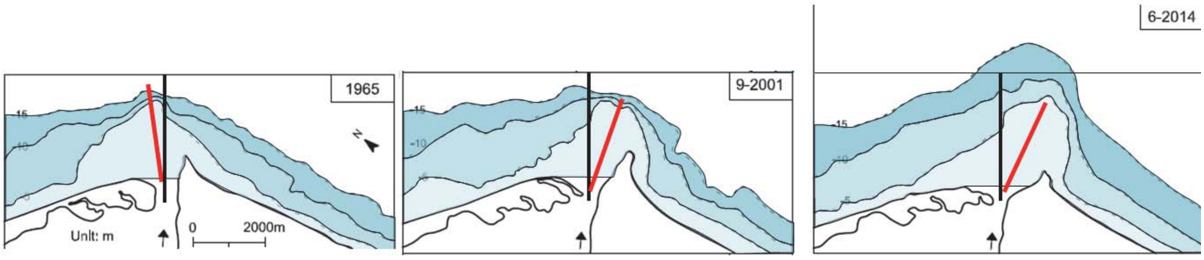



**Figure E.18 - Direction of sediment outflow from the river**

Following this hypothesis, it might well be possible that the outflow direction will turn northwards again in the future. However, when the spit is getting more and more fixed by the construction of buildings, this natural process might be disturbed to such extent that much variation is not possible anymore.

# F. Currently applied solutions

In Hoi An, several coastal protection measures have been installed along the Cua Dai Beach, which can be found at location 1 to 7, as shown in Figure F.1. In this section, an analysis of these measures is given. It starts with an overview of the current measures, the second part describes how current seawalls and revetments can fail.

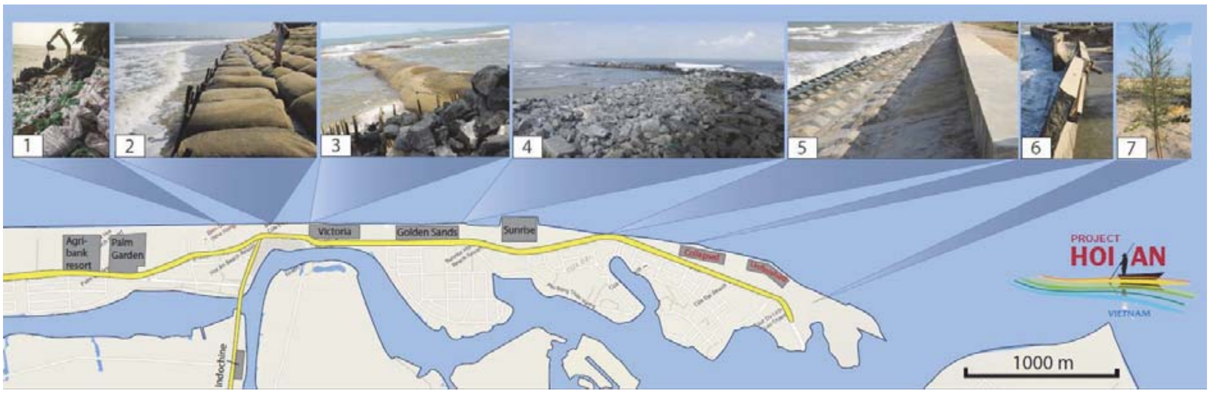



Figure F.1 - Locations of coastal protection measures along Cua Dai Beach

## F.1 Applied solutions

### F.1.1 Small sand bags

Starting on the left at location 1, a simple shore protection has been built which consists of small sand bags in order to protect the beach from wave impact. These bags should fulfil the same function as the geotextile bags, but due to their smaller dimensions and weight, they are more susceptible to displacement, as can be seen in Figure F.2.To increase the resistance against sliding, dozens of small bags are put into one large bag of approximately 2 x 2 x 3 m. On a stormy day, it can be seen that these improvised sand bag structures do not work properly, because the bags are moving due to the wave impact.

Figure F.2 - Man looking down at failure of the improvised sandbags

### F.1.2 Geotextile sand bags

At location 2, a five hundred meter long revetment of geotextile sand bags is installed to limit the coastal erosion. According to (Viet N. T., 2015)the bags cost approximately €140 each and are imported from the Netherlands. This is a governmental investment, which only protects a certain stretch of the beach.

#### Function

The geotextile sand bags need to protect the beach from strong wave impact. The sandy beach behind the bags is kept in place. As a result, the sand cannot wash out and the beach width is maintained.

**Method of placement**
The bags placed on Cua Dai Beach are measured and have dimensions of 230 x 130 x 45 cm, containing about 3 tons of sand. The filling and placing is done on site with sand from the beach. First, a geotextile sheet is placed on the sandy beach slope.

A relatively steep slope can be built with a maximum of 1:1.5, as shown in Figure F.4 (Scottish National Heritage, 2015). A double row of bags could prevent waves from penetrating into the gaps between the bags and thus prevent a washout of sediment. In Hoi An however, only a single row of bags is installed. The sand bags are stacked against the prepared slope with their long axes parallel to the shoreline and fixed at the toe with wooden piles.

**(Dis)advantages**
The bags can be placed without costly equipment or skilled labour and can follow any shoreline form, but they have a short life expectancy due to a low resistance to physical damage (debris and vandalism) or UV sunlight. Generally, the bags have an unattractive appearance, which could be solved by burying the bags with an additional sand layer to put the complete revetment under the dune face. This is however not done in Hoi An.

Figure F.3 - Geotextile sand bags along a section of Cua Dai Beach

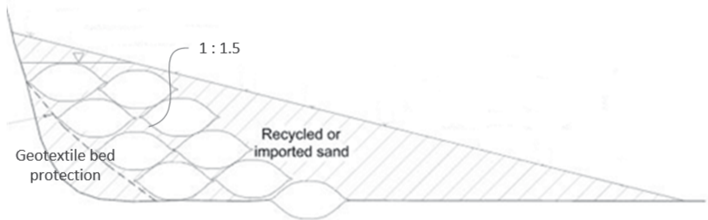



Figure F.4 - Schematic cross-section of sand bag revetment

## F.1.3 Breakwater with long geotextile bags
The long geotextile bag is made out of a woven polypropylene geotextile. It ranges in size from 1.5 to 5m in theoretical diameter (TenCate, 2015).

**Function**
The long geotextile bags can be seen as an emerged or submerged breakwater, which reduces the wave impact on the sandy beach. Consequently, soil is retained and therefore erosion is prevented. As such it can be used in revetments and breakwaters. At location 3 (see Figure F.1) an entire breakwater has been constructed using these sand bag units. It fulfils the same function as a normal breakwater.

**Method of placement**
First the area is prepared and cleared of debris. Then a layer of geotextile sheet is applied on which the unfilled bags will be placed. Finally a mix of sand and water is pumped into the bag to fill it (TenCate, 2015). The installation usually takes place around low water to make installation of all the bags easier. This entire process can be completed quite quickly.

**(Dis)advantages**
Advantages of the long geotextile bags are the relative low cost and simple installation. Because of this they can easily be applied. However, there are several disadvantages. Geotextiles are prone to creep over time when subjected to repeated strain. Polypropylene in particular is vulnerable as it has a high elasticity modulus. As a result the tensile strength is reduced by 75% for designs with this application of a polypropylene geotextile (Schiereck & Verhagen, 2012). Additionally, the creep causes the bags to sag and shift over time causing parts of the structure to become unstable.

This makes the application of geotextile sand bags less suitable as a long-term solution. An outer rock layer and a rock under layer as suggested by the manufacturer can mitigate this problem as the bags will no longer be exposed to the repeated wave forcing. This could have turned the structure into a more conventional rubble mound breakwater, but they are not applied in Hoi An this way.

Figure F.5 - Breakwater in front of Victoria resort

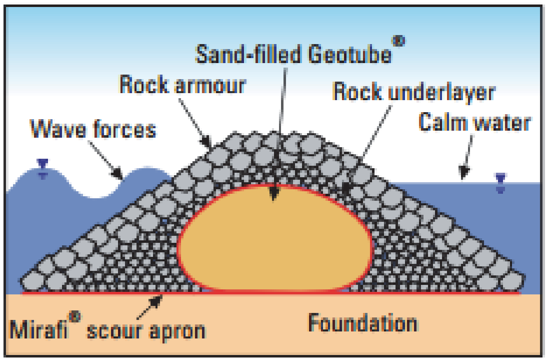



Figure F.6 - Long geotextile bags as core of a permanent breakwater (Ten Cate, 2015)

### F.1.4 Rubble mound breakwater

**Function**

The breakwater blocks incoming waves and provides a calmer wave climate behind it. In turn this prevents erosion by waves behind the breakwater. At location 4 (see Figure F-1) an L-shaped breakwater has been built to protect the resort at that location. Within the L-shape some sand has accumulated and forms a small beach.

**Method of placement**

Usually a breakwater consists of a core, one or several filter layers, an under layer and an outer armour layer. In this case only one layer of rocks has been applied as breakwater. The stones range in size between a diameter of 500 mm to 1250mm. Assuming a density of 2000 kg/m$^3$ the weight of the stones ranges between 250 kg and 3750 kg. No filter layer seems to have been applied beneath these stones. The stones have simply been dumped in the appropriate shape as protection.

**(Dis)advantages**

The advantage of a well-designed breakwater is that it can block longshore transport over some distance and stop the structural erosion over a particular area. Furthermore it can easily be maintained due to its simple construction elements. However the construction can be expensive as it requires the use of large rocks that often need to be transported for some distance to the intended site. Breakwaters also do not solve the erosion on a larger scale. The breakwater enhances the erosion downdrift of the breakwater which usually results in the building of more breakwaters until an area is reached that is allowed to erode.

Finally, in this particular case no bed protection seems to be applied under the rocks. This allows sand to be transported out of the gaps between the rocks of the breakwater and scour develops. This can lead to damage and even failure of the structure over time.

Figure F.7 - L-shaped breakwater at Golden Sands resort

## F.1.5 Impermeable concrete revetment

The 750m long impermeable concrete revetment can be found at location 5, where the road is very close to the sea. The structure is paid by governmental investment.

**Function**

The main function of the hard revetment structure is to prevent seasonal erosion by creating a impervious surface. Roughness elements are placed on top of the slope to reduce the wave run-up. From visual observations, it has to be noted that the stairs in the revetment were more effective at reducing the run-op than the roughness elements themselves.

The slope and height of the revetment were calculated by measuring the dimensions of the stairs, which is built in the revetment and therefore has an identical slope. At low water, 21 stairs of 0.55 m long and 0.16 m high were counted. Since it is not possible to look below the waterline, it is assumed that the revetment has four additional stairs until it reaches the concrete cylinder foundation; the so called 'Vietnamese toes' (Hoop, 2006).

Figure F.8 - Concrete revetment

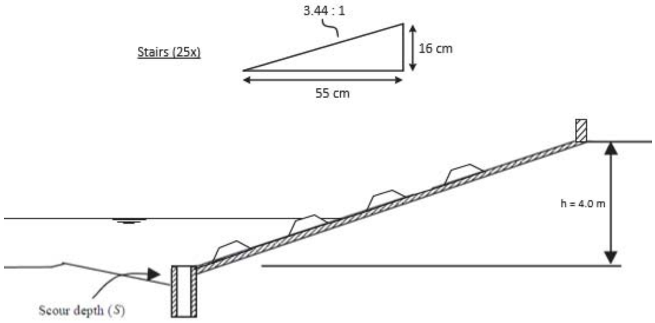



Figure F.9 - Schematic cross section of concrete revetment.

**Method of placement**

The height of the dike consists of the design water level, the wave run-up and the extra height needed for the relative sea level rise during the plan period. The slope of the revetment should extend well below the normal beach level to allow some foreshore erosion.

In Vietnam, vertically placed concrete cylinders with a length of about two meters and a diameter of about one meter, are placed at the toe of the revetment structure. Rock armour placed in front of the toe structure will provide additional support and reduce the intensity of the foreshore erosion. The crest level for the concrete revetment will be higher than a rock revetment since the structure will suffer greater wave run-up over the smooth and impermeable surface.

**(Dis)advantages**

The advantages are that they are strong and provide good protection by absorbing the wave energy. The continuous and impermeable concrete revetment presents neat appearance and allows easy access to the water. They have high initial investment costs, but a low maintenance costs (Scottish National Heritage (2015). Another advantage is that buildings can be placed close to the sea. The disadvantage is that the concrete appearance is not attracting tourists compared to the sandy beaches they expected. Also, the smooth surface of the revetment discourages habitation by wildlife or marine organisms.

## F.1.6 Seawall

Location 6 indicates the position of the vertical seawall at Cua Dai Beach. This hard structure in the form of a vertical concrete wall is often applied in areas where good protection is needed and where space is scarce. The exposed beach fronts of the resorts are a good example. At location 8, the vertical seawall has collapsed, which has caused tremendous damage to the Hoi An Hideaway resort.

**Function**
The primary function of a seawall is to prevent damage to structures close to the shoreline. They are built parallel to the shore and aim to hold or prevent sliding of the soil, while providing protection from wave action. Hard engineered structures such as the seawall have a secondary function as coastal flood defences.

**Method of placement**
Due to the reflecting waves, the scour can become too large, which may lead to total failure of the structure. The seawall at the collapsed Hoi An Hideaway resort seemed to be built on a pile foundation. This was visible at the bottom side of the collapsed wall section. Approximately three meters in front of the seawall (at the sea side), a row of cylindrical concrete tubes was visible during low water. Possibly they were implemented to induce wave breaking away from the wall and thus reducing the wave impact or for geotechnical stability of the wall. Horizontal anchor rods are placed in the soil for horizontal equilibrium. As can be seen in Figure F.10, these anchor rods are broken due to the failure of the wall.

**(Dis)advantages**
An advantage of seawalls is that they can be constructed at locations where there is less space available. That is just in front of the hotels along the beach strip. Seawalls are strong defences that are durable even in increased energy environments.

On the other hand, the construction of seawalls is expensive and makes the beach non-functional for recreation. The structure is not a pleasing sight and may ruin the landscape of the sea, which is an important factor for the tourism in Hoi An.


Figure F.10 - Collapsed Hoi An Hideaway resort

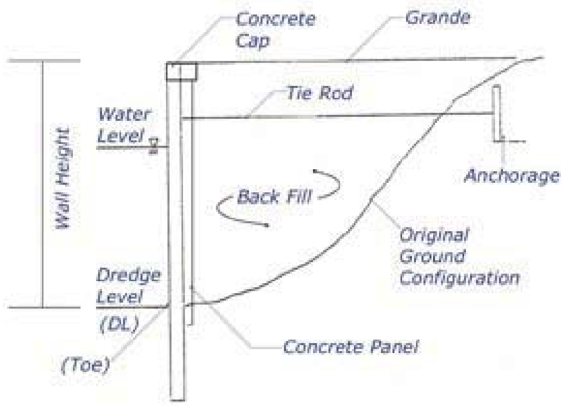


Figure F.11 - Schematic cross section of seawall.

## F.1.7. Vegetation
At the tip of the spit (location 7), young vegetation has been planted in the dune area. It takes a couple of years for it to become a fully developed vegetation zone. Nevertheless, effort is done to install a protection measure in a natural way. In other words: building with nature.

**Function**
Planting vegetation helps in stabilizing dunes by reducing the impact of wind and water. The very young vegetation at Cua Dai Beach (plant name: Casuarina equisetifolia. In Dutch: Australische pijnboom) can be found in the dune area at the full width of the spit.

**Method**
To provide maximum wind erosion control, vegetation is planted on the dunes of the spit, which hold to loose soil in place.

**(Dis)advantages**
For a minimum investment, vegetation plantings will help bind the soil against erosion and extend the lifetime of the protected sand body. The plants need to bear high salinity conditions, direct sun, extreme heat, lack of fertile soil and a fluctuating water supply. Especially very young vegetation is not able to protect against tough storm conditions. Vegetation will also need occasional fertilization.

Figure F.12 - Casuarina equisetifolia located on spit

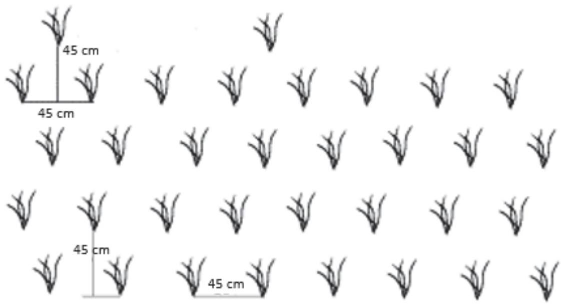



Figure F.13 - Staggered pattern in planting vegetation

## F.2 Failure of seawalls and revetments

The Hoi An Hideaway resort is an abandoned establishment along Cua Dai Beach. Due to the severe coastal erosion, the beach has disappeared and the buildings are very close to the water. For protection against further degradation, a vertical seawall has been built at the waterline. As can be seen from the pictures below, the vertical wall has failed and the property has been destructed heavily. Consequently, the resort has been closed. The failure mechanism behind this collapse is analysed here. Furthermore other similar structures like revetments face the same risk and as such make this analysis more valuable.

Figure F.14 - Current failed sea wall in Hoi An

### F.2.1 Calculation for scour in front of a vertical wall

Based on visual observations, two scour failure mechanisms can be identified (compare F.14 with F.15): seaward overturning and settlement of a gravity wall (left) and toe scour undercut and rotation of a vertical wall (right). Both failures are caused by scour in front of the structure, which leads to geotechnical instability. A quantitative estimation for the scour profile in front of the wall can be calculated with the formulas:

Eq. F-1 $$y = 0.4 \frac{H_s}{\left[\sinh \frac{2\pi h}{L}\right]^{1.35}}$$ (Xie, 1981)

With:
$L = local\ shallow\ water\ wave\ length\ [m]$
$H_s = significant\ wave\ height [m]$
$y = depth\ scour\ profile [m]$
$h = water\ depth\ in\ front\ of\ structure [m]$
$x = offshore\ distance\ from\ seawall\ to\ maximum\ scour\ [m]$
For fine sediment: $x = L/4$
For coarse sediment: $x = L/8$

The scour at any moment can be calculated with:

Eq. F-2 $$\frac{y_t}{y_{max}} = \left(\frac{t}{t_{max}}\right)^{0.3}$$ (Xie, 1981)

With:
$H_s = undisturbed\ incoming\ wave\ height = 3.1m$
$T_p = peak\ period\ of\ the\ incoming\ wave = 9.0s$
$h = water\ depth\ in\ front\ of\ structure = 2m$
$\gamma = breaker\ index = 0.5$
$t_{max} = max. duration\ of\ scour\ process = 7000{\sim}10000 waves$

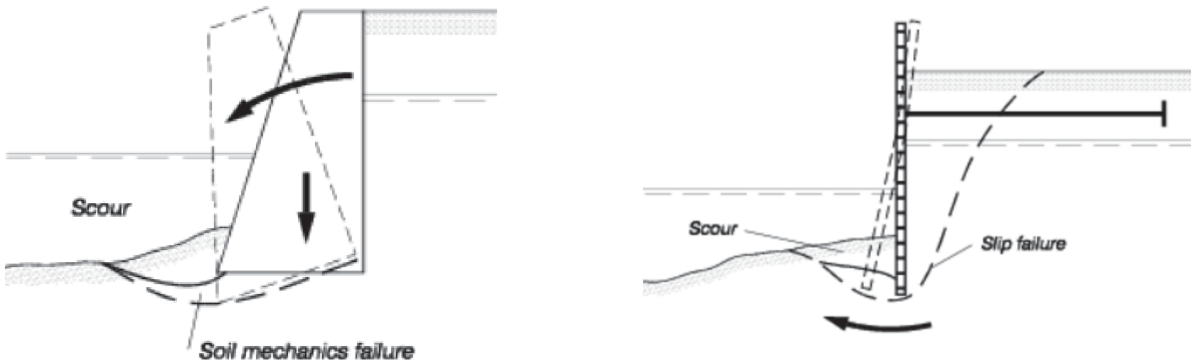



**Figure F.15 - Failure mechanisms. Seaward overturning (left) toe scour and rotation(right)**

The wave height and wave period is taken as the highest measured wave in October 2010 (Thủy, 2010) and the water depth in front of the structure is assumed to be 2 meter. The breaker index is the ratio between the breaking wave height and the water depth at breaking ($H_b = \gamma h_b$). In nature, waves are irregular and random. The time-averaged value of the breaker index is then in the order of 0.35-0.5. Here, the upper limit of γ=0.5 is taken.
Another model study found that the scouring patterns of a sand bed in front of a vertical wall under the action of standing waves was different with the sand grain sizes . Fine material ($D_{50}$ = 130 μm) is transported largely in suspension, which scours at the nodes and deposits near the antinodes of the standing wave.

The coarse material ($D_{50}$ = 220 µm) moves mainly as bed load and is scoured halfway between the nodes and the antinodes and deposited at the nodes (Best, Bijker, & Wichers, 1971). Figure F.16 shows the typical bottom profiles for fine and coarse materials mentioned above.

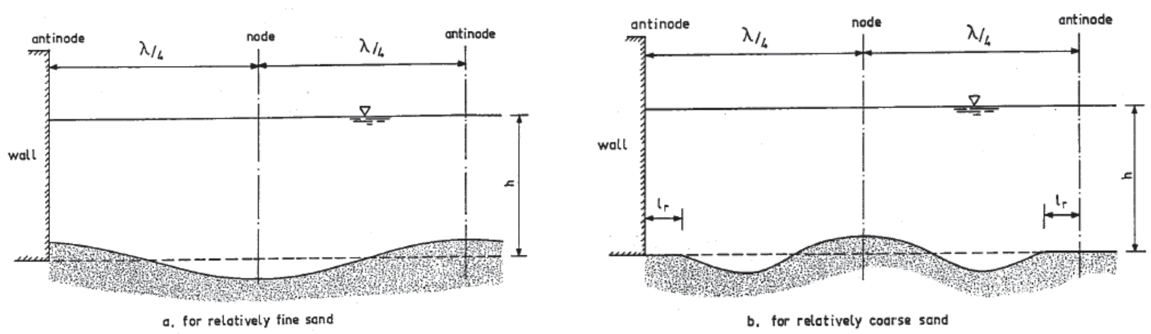



Figure F.16 - Typical bottom scour profiles for fine (left) and coarse material (right)

Using formula F-1, the maximum local scour depth is calculated at a certain distance from the structure. The calculation indicates that a scour hole of $y_{max}$= 1.13 m occurs at at 3.50m from the vertical wall at L/8 since the sand on the beach is coarse ($D_{50}$> 220 µm), see Appendix I.3. Although 1.13m is a significant scour hole, given the 3.5 m distance it is unlikely to have been the sole cause of the failure. Structural erosion must have played a part as well, increasing the depth in front of the structure leading to its eventual failure.

### F.2.2 Scour in front of a revetment

A study conducted on Vietnamese dikes found that a typical concrete revetment can expect 1.5m of scour (Hoop, 2006). Since the toes generally are only 2m deep instead of the required 4m this has caused several dike failures (Hoop, 2006). Similar scour can be expected at the revetments currently implemented in Hoi An.Over the last few years, displacement of these cylinders is observed at several locations in Vietnam. Several mechanisms can lead to this failure:

- *Scour*. Failure occurs when the scour hole gets deep enough to undermine the toe.
- *Geotechnical instability*. Failure occurs if the load on the toe exceeds the strength of the soil that supports it.
- *Outwash of the foundation due to flow through the cylinder.* Failure occurs in the situation where there is a high water level inside the dike and a lower water level in front. As a result, ground water flows through the dike to the toe. Water flowing through the cylinder might wash away the sediment underneath. The problem can easily be avoided by applying a filter layer or closing off the top of the cylinder (see Figure F.17).

However the revetment in Hoi An shows no signs of damage, although the toes under water could not be observed for damage. Since the revetment was built in 2012 it is possible some minor damage has occurred (especially at the toes) that is not visible yet.

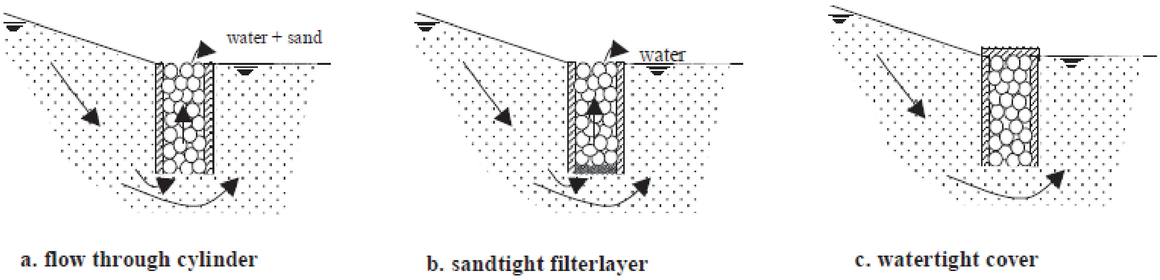



Figure F.17 - Ground water flow through toe cylinder (Hoop, 2006)

### F.2.3 Structural erosion

A final aspect to cover is the fact that along Cua Dai Beach structural erosion is present. Under normal conditions it is assumed that as the wave conditions and sand characteristics remain similar, the profile should remain similar as well. The erosion will therefore only lead to a landward migration of the coastline. However, in the case of the revetment sand is taken out of the system by the revetments. This means that the profile can no longer migrate landward. Although there is limited research into how the profile continues to develop in the presence of a revetment or seawall, observations in California show no significant differences between the beach profiles fronting the wall and those from the adjacent beach (Griggs, et al., 1997).

If assumed that the profile moves downward to compensate for the erosion an estimate can be given as to how fast it would be. This situation would resemble an infinitely long revetment where no erosion is possible from the beach. At Cua Dai Beach 60 $m^3$/m/year is lost (see section C.7). At 300m from the coast the active depth of 5m is reached. Dividing the 60 $m^3$/m/year by 300 m of active length the conclusion is that the seabed would erode by 0.2m/year. This is however a rough estimation based on the assumption that the revetment is infinitely long. It is also possible to assume that the profile continues to migrate landward and is cut off by the revetment. The revetment prevents erosion on the upper part of the profile and leads to a greater shortage of sediment downdrift. This assumption also fits with observations from (Griggs, et al., 1997). The 0.2m/year will be used as an approximation with the knowledge that the actual depth change might be different.

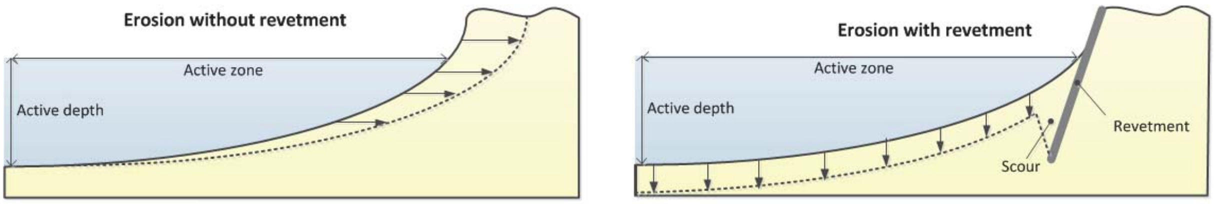



Figure F.18 - Downward profile changes with an infinitely long revetment

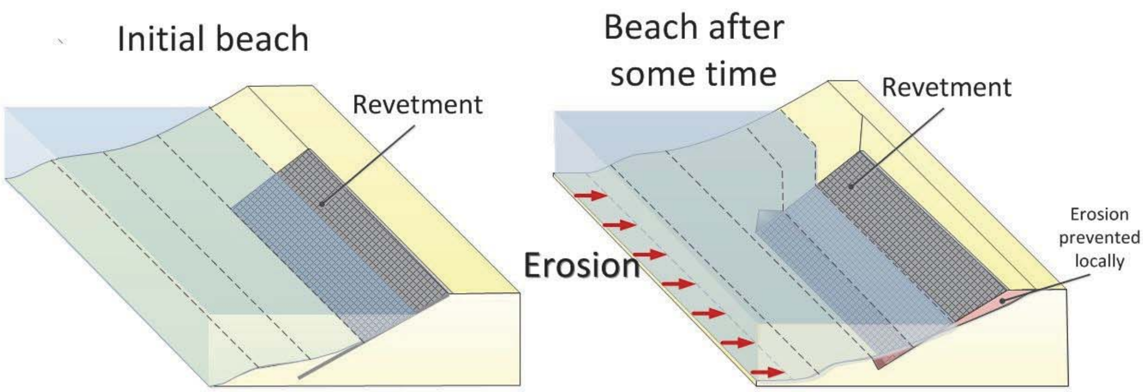



Figure F.19 - Landward migrating profile when a finite revetment is considered

### F.2.4 Consequences for the current structures

A typical Vietnamese dike is not expected to survive a storm with surge levels of 3m (Hoop, 2006). Luckily these storm surges only have a return period of 50 years (Thuy, 2003). If after two years of erosion the bed level has dropped 0.4m the return period has reduced to only 33 years (Thuy, 2003). If erosion continues at the same rate after 8 years once in 10 year storms will cause the revetment to fail. Consequently the life expectancy of these revetments is reduced significantly by the continued erosion.

# G. Erosion prevention possibilities

This appendix supplements Chapter 6 about solutions to the current problems. It starts by showing the systematic approach that is used to translate the stakeholder's wishes into criteria. After that, an overview of the total problem field is given. This diagram will be used to determine the concrete requirements for designing alternatives. It also facilitates in finding measures for the current issues. The possible measures are started with a comparison between hard and soft measures. After this, several possible measures are given and ranked with the help of a multi-criteria analysis.

## G.1 Systematic criteria and option finding

Before designing alternatives, it is necessary to know how the alternatives should perform. It is important to know beforehand what the criteria and requirements are for a good solution. The requirements can be taken from the stakeholder analysis and an overview of the total system.

### G.1.1 Criteria

The stakeholder goal trees, as given in Chapter 4.1, can be used to select criteria. When designing alternatives for dealing with the problems along the beach of Hoi An, the criteria will be used to check whether the alternatives meet the criteria. Potential criteria are all items in the lowest level of the goal trees. These items could all be used to analyse the coastal erosion problem. Many of the stakeholders have overlapping goals. Items that appear to be important to multiple actors become the most important criteria. These criteria describe the wishes for the whole system on which alternatives can be tested.

**Potential criteria**

Taking all the lowest levels from the goal trees, the following potential criteria arise for the different stakeholders:

**National government**
Low amount of erosion
Low amount of flooding
High personal income
Similar allocation of funds
Few legislation exemptions

**Local government of the Quang Nam Province**
Low structural damage to hotels
Low structural damage to homes
Low economic damage to hotel owners
Low economic damage to city inhabitants
Low economic damage to Cham Island
Low economic damage to rest of the province
High industrial income
High industrial growth

**Local government of Hoi An**
Low structural damage to hotels
Low structural damage to homes
Low economic damage to hotel owners
Low economic damage to city inhabitants
Part of budget to erosion problems
Part of budget to other matters

**Building industry**
High amount of sand available
High amount of alternative materials available
Low costs of sand
Low costs of alternative materials

**Resort managers**
Large beach width
Small distance to the sea from room
High density of coconut trees
High governmental funding
High amount of shared wished with government
High amount of shared wished with other resorts
Frequent meetings with other resorts

**Tourists**
Large beach width
Small distance to the beach
High density of coconut trees
Low costs of chair
Low costs of entrance
Low costs of beverages

**Citizens living from the beach in Hoi An**
High number of restaurants
High number of bars
High number of other job possibilities
High flexibility to move
High financial power
High governmental funding
High amount of shared wished with government

**Sand miners**
High sales of sand
Low mining costs of sand
Low export restrictions
Low mining restrictions
Low chance of conviction
Low fine
Short prison term

**Selected criteria**

In order to describe the wishes for all the stakeholders in the system, it is wise to select criteria from different stakeholders and especially those criteria that are found most important for several stakeholders. This prevents disagreements about the solution in the future and makes everybody feel engaged. The following list of eight criteria cover the most important wishes. They are generated from the list above by taking some goals together or rewriting them in order to make them fit several stakeholders. All stakeholders have some of their wishes incorporated in these criteria.

1. *Low structural damage along the coast*
   The erosion rate at some places is so severe that it leads to structural damage. Until now, two resorts have been damaged and abandoned . In the future, more resorts and also local residences might be structurally damaged. A suitable alternative should prevent more damage.
2. *Low economic damage to local beach users*
   The structural damage leads to economic damage, but this is not the only kind of economic damage. For example, a decline in tourists will damage those who live from the beach too. Other factors that lead to economic damage to local beach users (restaurant/bar owners, life guards, salesmen, et cetera) are defined later on. The beach users are economically dependent of activities on the beach and therefore a prevention of more economic damage is an important criterion for a suitable alternative.
3. *Low economic damage to resorts*
   The distinction between economic damage between local beach users and resorts is made on purpose. Both stakeholders have different ideas about what should happen to the beach. The most important one is that the local users would like to see more public beach. Since resorts are an important stakeholder in the problem and perhaps also financial contributors to a solution, a low rate of economic damage to resorts is an important criterion for an alternative.
4. *Low economic damage to others in the area*
   Something less common in Vietnam, but a criterion that would fit the governmental bodies, is that the problem may not be shifted to adjacent areas. Current measures are not stopping the erosion, but moving the process northwards. An efficient and long lasting solution reduces the problems on a large spatial scale and should not bring disadvantages to other regions. The goal of low economic damage to other people in the area than resorts and citizens in Hoi An is therefore an important criterion for a future alternative.
5. *Large beach width*
   This more physical goal is supported by both resorts and local beach users as tourists. A more attractive, large beach would lead to more tourism, which is advantageous for the local residents and resorts. Since a large part of the stakeholders find this goal important, it is a criterion that should be taken into account when designing an alternative. The definition of beach is here the area of sand between the waterline and the first trees, dune or other obstacles.

6. *Small distance to the beach*
   The distance to the beach is an important factor for resorts and tourists. Tourists would not like to travel too far for a public beach and resort visitors like to walk out of their room straight onto the beach. The tourism affects the resorts and local citizens and therefore another criterion that is important for a large part of the stakeholders in the system.
7. *High industrial income*
   Until now, most criteria fitted the tourists, resorts and local beach users. However, future alternatives may not hamper the industrial sector in the area. Besides tourism, this is another important source of income for Vietnam. The industries, for example sand mining or hydropower generation in the river, and beach erosion might turn out to be interrelated. An alternative for the problem may disadvantage on of the sectors too much.
8. *Low costs of beach visit*
   If there were to be enough financial resources available for the implementation of an alternative, the situation would not be so difficult to solve. This money might come from resorts or entrance fees to the beach. However, the beach becomes less attractive to tourists when the costs of a beach visit become too high and when there is less public space. Less tourists would again affect the local beach users and resorts. Therefore, this criterion is important to keep in mind when designing alternatives and it indirectly keeps the costs of a solution low.

### G.1.2 System overview

The eight criteria described above are supported by the all of the stakeholders. All the factors that influence these criteria are factors that can be changed with alternatives to push the criteria in the required direction. Combine this with the possible causes for erosion as derived in Chapter 5 and a total system overview can be made, as given in Figure G.1. The diagram that arose here is called a causal diagram. It shows all the causal relations between the different factors.

The causal relation can positive or negative, given with a plus or minus sign respectively. A positive relation means that when a factor is increasing, the factor it is influencing will also increase. For example, an increase in global temperature will lead to an increase in sea level rise, indicated with a plus sign near the arrow. An example of a negative relation is the one between rough waves and the safety of swimming water. If the amount of rough waves is increasing, the safety for swimming is decreasing.

The causal diagram is split into two main parts: the causes for erosion and its effects. The causes are given above the dashed grey line. These causes are climate change (light blue factors), natural variation (green factors) and sediment reduction from the river to Cua Dai Beach (brown factors). They all lead eventually to the factor of beach erosion, made bold to show the centre of the diagram.

Below the grey line are the effects of beach erosion. These effects are divided into beach tourism (yellow factors), income and damage (red factors) and how the implementation of measures influences the tourism and income and damage (dark blue).

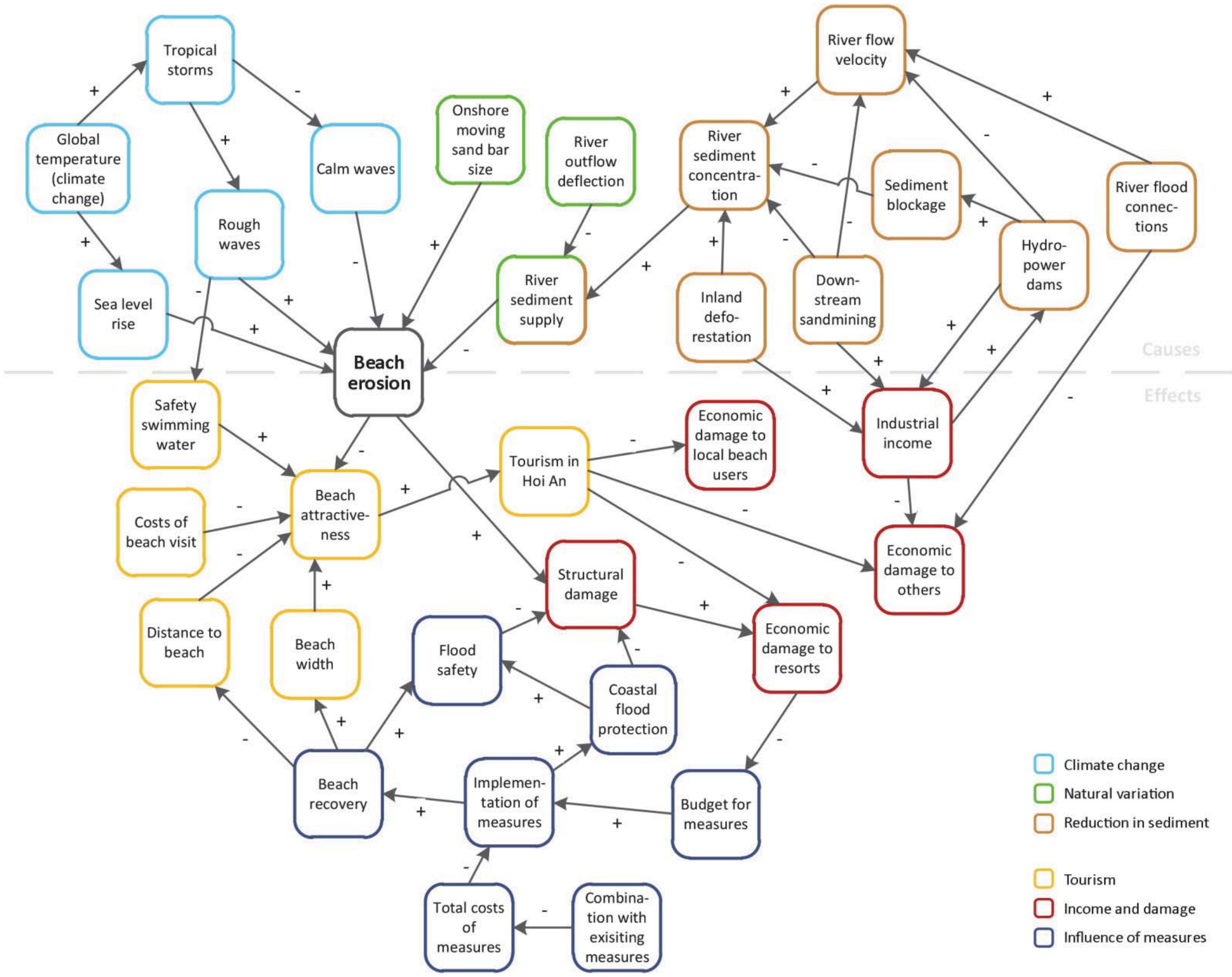



**Figure G.1 - Causal diagram**

Going through the diagram, most links will speak for itself. It is a summary of the system as derived in Chapter 3 to Chapter 5and therefore follows from technical analysis and the interviews with the stakeholders. It shows the total system and what factors can be influenced by alternatives to change something in the problem.

Two important loops arise in this diagram that will probably not be seen immediately. The first loop shows the vicious circle between the declining tourism due to the reducing beach attractiveness, this leads to economic damage to the resorts, which results in a lower budget for measures and a lower rate of the implementation of measures. The implementation of measures is positively related to beach recovery, so if no measures will be implemented the beach will further deteriorate, reducing the beach width and attractiveness of the beach even further, leading to a further decline in tourism. To mitigate effects of economic damage this circle needs to be broken by a suitable alternative.

The second loop is smaller and starts with structural damage due to the erosion, leading again to economic damage to resorts, a reducing budget for measures and a decline in the implementation of measures, reducing the coastal flood protection even further, leading to more structural and economic damage. This is another vicious circle that will go on until the resorts run out of resources to repair itself, if it is not broken by an alternative. The requirements that ultimately flowed out of this diagram are given in Chapter 6.2.

## G.2 Hard versus soft measures

There are two possibilities for coastal protection when erosion occurs: hard or soft solutions. Hard solutions are manmade structures that protect the shore from further erosion and/or create wave climates where sand can accrete. Soft solutions are used to restore the beach with sand from elsewhere or by steering the natural process of sediment supply. Below, both coastal engineering techniques are further explained and assessed.

### G.2.1 Soft methods

Soft engineering is an appropriate measure when the cause of the erosion cannot be taken away. This can be the case for sea level rise, for example, or a situation in which solving the problem creates more disadvantages than maintaining the current situation and nourishing the beach to counteract the erosion. This also implies that, when the cause of erosion is not taken away, the beach will continue to erode with the use of soft methods. However, when the erosion becomes problematic again, a new nourishment can be carried out.

Soft methods are given extra benefits when the motto ‘building with nature’ instead of ‘building against nature’ is used (de Vriend & van Koningsveld, 2012). Examples of building with nature are the so called sand engine along the Dutch coast and the use of mangrove forests in tropical areas. Also the Dutch coast is eroding, due to climate change, reduced river sediment supply and the still ongoing adaptation of the Waddensea to the closure of the IJselmeer (Elias, van der Spek, Wang, & de Ronde, 2012) (Wang, et al., 2012). The sand engine is a large stock of sand placed near the coast, that will be distributed along the coast by littoral and aeolian transport. Mangrove forests along the shore restore and/or preserve the ecosystem. The forest dissipates the wave energy and traps sediment that would otherwise flow back into the sea. The benefits of these solutions are that they also create extra value by stimulating the opportunities for recreation and nature preservation.

Nourishing of sand has many advantages, however also disadvantages. These will be discussed in the following part. First some advantages of a beach nourishment in general.

- One of the main advantages of a beach nourishment compared with solutions of only just a hard structure is that it provides additional sand to compensate for the beach erosion. When only a hard structure is applied as coastal erosion protection it takes away the erosion at the location of placement but there will be more severe erosion at adjacent updrift locations. The beach erosion will continue with this alternative. However the widened beach has a protective function for the coastal structures, infrastructure and other assets for the effects of erosion and storm damage.
- Due to the fact the erosion continues it provides sediment to the longshore sediment flow which transport the sediment to adjacent areas and redistributes it along the coastline. So beach nourishment might have a positive effect on those adjacent areas which did not have a nourishment. The amount of sediment can be assumed constant within one coastal cell, a coastal cell is a stretch of coastline where no sediment is transported in or out of (e.g due to rocky outcrops).
- Natural appearance of the beach nourishment is also beneficial for the landscape and natural values of the coastline. By a sand nourishment the natural landscape of the beach is retained or even increased.
- The tourism of a city like Hoi An depends mainly on the wide beaches and the sea. It attracts tourists and is positive for the recreation at the beach. The attraction of more tourists leads to a better development of the city.

Every beach nourishment has also its disadvantages. These disadvantages for a general nourishment are described below.

- A disadvantage of this alternative is that it does not give the same feeling of safety as with a hard structure. A hard structure like a revetment gives the intention it protects the hinterland better against storm surge levels and so gives a safer feeling for the people living beyond the beach and dunes and the people who have properties over there. Anyway this intention is right, because a wide beach cannot give protection against high storm surge levels and typhoons and will remain exposed to natural disasters with long return periods.
- Also the beach nourishment is no permanent solution. It does not give any protection against further erosion and the erosion will continue. Due to that periodic re-nourishments are needed to keep the wide beach as a protection for the structures and properties beyond the beach. However these top-ups or re-nourishments can be seen as maintenance costs.
- Placing new sand in front of the beach or on top of the current beach might have negative effects on the beach and ocean habitats of birds and other species living on the beach when their living and nesting pattern is unknown. That is why the properties of the nourished sand have to be (nearly) equal the properties of the current sand on the beach otherwise it might have negative effects (IOC, 2009).
- Dredging sediment and nourishing it on the beach can have negative environmental effects. When deposited on the beach it can bury animals, vegetation and organisms on the beach. It might cause more water turbidity and the different sediment compositions can affect the fauna which inhabit the area (Dean, 2002).

### G.2.2 Hard methods

Hard engineering can fulfil a fixed protection for a long period, if constructed well. Options for hard methods are the construction of sea walls, groins and breakwaters. Sea walls are used to protect the hinterland from further erosion, but do not maintain the beach. Groins are placed perpendicular to the beach and trap the longshore flow of transport by interrupting the flow.

However, sand is trapped on one side of the groin at the expense of erosion on the other side. Breakwaters can have various shapes and are used to provide calm water, by blocking the waves. In this calmer water, erosion will be less severe and the sand may even accrete. Advantages of hard structures are the following:

- Low cost compared to lifetime
- The lifetime of the solution is long

The main disadvantage is that with the construction of hard structures the problem of erosion shifts to another place, when the cause of erosion is not taken away. The sand in front of seawalls may continue to erode, influencing its stability, or the beach next to the sea wall will erode. Groins can trap sediment at the expense of other places next to it and breakwaters can act in the same way. As long as the equilibrium in the sand budget is not restored, hard structures may solve the problem on location, but worsen it somewhere else. Other disadvantages are:

- Large initial investment
- Difficult forecasting of effects on location and on surrounding beaches

## G.3 Possible measures

In Appendix F, the current measures are given and evaluated on their effectiveness. If useful, those measures or elements from it can be applied as a solution for the total stretch of coast. All the applied measures are hard measures, but looking at the previous paragraph of this appendix soft measures might also be an option. There are other possibilities than the ones currently used, both as hard and soft measure. When looking at the causal diagram, there are several factors that can be dealt with to take the cause of coastal erosion away or mitigate its effects.

Some conventional measures are given in the first six alternatives. The last three are less common, more creative and probably unfeasible solutions. Whether or not they will exceed the other possibilities becomes clear in the comparing analysis in paragraph G.4, where a multi criteria analysis is conducted.

### G.3.1 Restore sediment supply from the river

**Function**
To take away the possible cause of erosion, the river sediment supply can be restored. This focusses on the brown part of the causal diagram. The supply has reduced due to sand mining and hydropower dams. Hydropower dams not only trap sediment, they also reduce the flow velocity of the river. This reduces the sediment carry capacity of the water and sediment will settle on the river bed before it has reached the sea. By restoring the original sediment supply from the river, it is expected that the erosion will stop or accreting might even occur.

**Method of placement**
Although nothing has to be placed, certain things have to be done to restore the sediment supply. Setting stricter rules on sand mining is one part of this alternative. It is already prohibited without license, but it still occurs. When certain types of sand mining are possible without eroding the beach, these should be regulated and stimulated above other types with more control on the river. The other part of the alternative is better hydropower dam management. With regular flushing of the reservoir, the sediment can be released. Also the river flow can be more regulated, to keep the flow velocity high during more periods over the year.

**(Dis)advantages**
The advantage of restoring the original sediment supply to the situation before sand mining and hydropower generation started to take place is clear: it takes away a possible cause for the erosion. Increasing the sediment supply again would stop the erosion. If the coast of Hoi An was accreting before distortions in the river started, the coast might even advance again.
The disadvantage is that it will take years to be an effective solution. Furthermore, sand mining and hydropower generation are taking place for economic reasons. If they are limited, it will result in financial losses.

### G.3.2 Divert river stream direction

**Function**
One of the natural causes for sediment reduction is the diversion of the river outflow towards the south instead of Cua Dai Beach, lying north of the river mouth. This is given by one of the green factors in the causal diagram. With the help of hard structures the river mouth can be modified such that the river will flow out in the right direction again. This would stop the erosion and might even lead to accretion.

**Method of placement**
The river has to be controlled to flow out in the northern direction. For example, groynes can be placed along the southern river bank, restoring a higher flow velocity along the northern bank. This constructed from the land, so no pontoons are needed for this. The size of the groynes and the stones with which they can be built depend on the flow conditions. More calculations are needed to design groynes there.

**(Dis)advantages**
The advantage of this solution is that it would take away another possible cause for the erosion. The only changes take place in the river, so along Cua Dai Beach no further structures have to be built. There are however two main disadvantages.

First, by diverting the river outflow towards the north, erosion at the beach south of the river outlet can occur. Second, how the river will behave after the placement of groynes is difficult to predict and detailed models are needed for this.

### G.3.3 Submerged breakwater offshore

**Function**

Another possible cause for the erosion was the increased storm conditions, given as light blue factors in the causal diagram. It is impossible to reverse the climate change, at least on short notice, so this cause cannot be taken away. It is however a possibility to adapt to the higher waves. Emerged breakwaters are already in use at some places at Cua Dai Beach. Submerged breakwaters are another type of detached breakwaters. This type also lies offshore in front of the beach, but is submerges under water. They have the same function, namely reducing the wave energy. It reduces the wave impact on the shore and can also trap sediment.

**Method of placement**

Submerged breakwaters usually consist of a core, which can be sand, and an armour layer on top. Filter layers between the core and armour are used to prevent the core from washing away. However, other methods exist for placing an submerged breakwater. For example old trains or ships can be sunk down to create a structure that breaks the waves. Although this seems environmentally dangerous, when the polluting parts are stripped it does not have to be. Furthermore, new ecosystems can arise in the open spaces of the improvised structures.

**(Dis)advantages**

The same (dis)advantages exist for submerged breakwaters as their emerged relatives. They can stop the structural erosion over a certain stretch and can stimulate accretion in the calmer water. Submerged breakwaters can be a little less effective in reducing the wave energy than emerged breakwaters and their effect is difficult to predict, but it does not spoil the sight on the horizon. A large disadvantage is that is does not solve the erosion, but shift the problem to downdrift stretches of coast.

### G.3.4 Mangrove forests

**Function**

The wave energy of rough waves, again the light blue factor in the diagram, can also be reduced by the use of mangrove forests in front of the coast. Mangrove forests did not occur naturally at Hoi An in the recent period, but they are present in the south of Vietnam. Unfortunately the mangrove forests are removed there, which is one of the reasons for an eroding coast there now. Planting trees in front of the beach of Hoi An would work the other way around and can counteract the erosion.

The network of trees and branches break the waves before they can reach the coast. Furthermore, they are effective in trapping the sediment. The high stability of the mangrove forests helps to prevent shoreline erosion, shielding inland areas from severe damage during typhoons and tidal waves.

**Method of placement**

Mangroves could be placed on the beach itself or in the sea in front of the beach. It is very important the roots of the mangroves are penetrated deep enough into the sand so their functionality is optimized. Also when planting these mangrove trees it is of great value that the trees are well developed and full grown when exposed to (storm) waves.

**(Dis)advantages**

The effectiveness of the sand trapping of the mangroves is very high. However, when placed on the beach it has a negative effect on the recreation on the beach.

It blocks the way to the ocean and the people who want to swim in the water in front of the beach cannot reach that water. One of the advantages is that it has a high environmental value.

### G.3.5 Groynes along the beach

**Function**
If the cause of erosion cannot be taken away, there is always the possibility to mitigate the effects. If an attractive beach can be restored, given in yellow in the causal diagram, the loop between declining tourism and economic damage can be broken. One possibility for this is the use of hard shoreline protection structures like groynes. Groynes partly block the longshore transport. It reduces the gradient in longshore transport and therefore the erosion reduces. A well designed groyne blocks exactly enough sediment to bring the increased transport to a halt and keep it constant. The result is a saw tooth shape coast, since sand is trapped between the groynes and adapts to the wave conditions. No extra sand is added to the system here.

**Method of placement**
Groynes normally are placed perpendicular or slight obliquely to the shoreline depending on the dominant wave direction and the shape of the coastline. Different types of groynes can be applied, some function better by blocking longshore sediment transport and some are semi-permeable and do not entirely block sediment transport in longshore direction. Different groyne types are the wooden groynes, steel groynes, groynes of concrete elements, rubble-mound groynes or sand-filled bag groynes. Because of the disadvantages of a groyne-type structure (which are shown below) the best system is to combine the groynes with soft shore protection measures like artificial beach nourishment or shore nourishment.

**(Dis)advantages**
Most times the construction of groynes is chosen because sand is trapped in between the groynes and it prevents erosion. Erosion will occur at the lee side of the groyne as the longshore transport increases again since it is no longer blocked by groynes. This causes a washing out of the beach at that side.

### G.3.6 Sand nourishment

**Function**
Another possibility to regain an attractive beach without taking away the cause is sand nourishment. Sand from elsewhere is placed on the current beach. When this has eroded too much, the next nourishment will take place. The function of a sand nourishment is to recreate a wide beach which can be used for mainly recreational values. If the nourishments are done on the right moments it prevents the erosion will reach the dunes and probably endangers the buildings, land and structures behind the dunes.

**Method of placement**
There exist several possibilities for sand nourishments. The sand can be directly placed on the beach, by pipelines or spraying. After that, bulldozers can distribute the new beach evenly over the total stretch. Sand can be also be placed offshore, while waiting for the calm waves to bring it to the beach. Another possibility is the placement of a large stock of sand somewhere along the coast. Longshore transport and wind will distribute this sand along the coast over several years. All of the possible measures above do not restore the beach immediately. The combination with sand nourishment is a possibility to restore the beach before the action has taken effect.

**(Dis)advantages**
One of the advantages of a sand nourishment is that it has a high natural, environmental and recreational value. There are no concrete structures used and there is a wide beach which can be used for recreation. One of the disadvantages is that the erosion still continues and that is still as severe as before due to this relatively a lot of maintenance is needed. Furthermore, depending on the nourish method used, it might take some time before the nourishment is finished like with the foreshore nourishment.

*The last three alternatives follow from a brainstorm session and are with the current resources not feasible or effective solutions. The brainstorm session was used to come up with more creative options that might have led to more out of the box ideas.*

### G.3.7 Enclosed sea

**Function**
The idea of this very unconventional measure is that the touristic beach and first few hundred meters of sea will be enclosed by a structure with a cross section comparable to a regular emerged breakwater. This measure would not take any cause of erosion away, but facilitates in constructing an attractive beach, to draw tourists back to Hoi An. Similar to a detached breakwater, it reduces the wave energy that reaches the shore. Furthermore, once a beach is recreated sediment cannot leave this enclosed sea, so a wide beach will always be present.

**Method of placement**
The enclosing structure can be constructed similar to a breakwater, with sandy core, armour cover and filter layers. Afterwards the beach has to be reconstructed to the original width, as it was before the erosion started.

**(Dis)advantages**
The main advantage is that an attractive beach will be recreated that is hardly affected by influences from outside. There are more downsides to this measure. It is very costly, the structure spoils the horizon, the water may become dirty due to the reduced connection with the sea and a large amount of labour and materials is needed for the construction. With the current resources this is not a feasible idea.

### G.3.8 Barrier islands

**Function**
Cham Island works as a wave blocker against waves from the open sea. Due to the relatively large distance between this barrier island and the coast of mainland Vietnam compared to its width, this is not protecting the beach at Hoi An. However, more barrier islands more close to the coast is a theoretical option to assure that large storm waves cannot reach the coast. Therefore this measure is based on the light blue part of the causal diagram. The barrier islands can block or break the wave energy from open sea and therefore reduce the erosion caused by large waves.

**Method of placement**
These artificial barrier islands can be constructed from rocks and sand. With large boulders the base of the islands can be constructed, after which a large amount of sand can turn it into a natural island on which flora can grow and fauna can thrive.

**(Dis)advantages**
This other unconventional measure has more disadvantages than advantages. The main advantages are that it blocks wave from open sea and can therefore reduce the wave energy that reaches the coast. This should reduce the erosion caused by waves.

Another benefit can be the sight of barrier islands offshore, which can also be visited for recreation. Of course, this measure is too expensive to carry out. It is an ineffective measure in terms of resources and effects.

### G.3.9 Temporary (inflatable) winter protection

**Function**

A possible solution to reduce the wave height or even block the waves approaching the beach is an inflatable protection that operates during the storm season (the winter season) between September and December. This way there will be no waves hitting the beach or the when the protection is not as high as the wave height the waves hitting the beach have less energy. Due to that the erosion of the beach will be less severe than it is nowadays. During the summer the air and water in the protection is released and it is laying on the bottom of the sea. A reference project of this protection is the Ramspol barrier in the Netherlands.

**Method of placement**

Because of the large length of Cua Dai Beach this inflatable winter protection has to be as long as this beach. The construction is placed at the bottom of the sea and should be located about several tens of meters in front of the coastline. About every 80 meters of barrier it should have a small pumping station which is able to pump air and water into the barrier so it can rise above the water level of the sea. In the summer months this construction is laying on the seabed and there is no air or water inside and in the winter months it is fully inflated and rises above the water level of the sea.

**(Dis)advantages**

During the storm season it effectively blocks the waves and reduces the wave energy and during the summer it is invisible so no one can see the construction. Some disadvantages are that it has difficulties with the deflation of the barrier and it is very costly.

## G.4 Multi criteria analysis

A multi criteria analysis is conducted in this section to rank the different measures. The currently used and possible measures are rated respectively in Table G.1 and Table G.2. The following paragraphs will provide an explanation about the criteria itself, how they were rated in the analysis and on their weighing factors in the overall result.

The criteria follow from the goal trees of the different stakeholders and are then translated into comparable criteria.  The criteria are explained  in more detail earlier in this appendix. The rating of the different measures is based on a relative ranking on a 1 to 5 scale. The highest score in the table is a five and is depicted by green, an average score is depicted by yellow and a red colour means it scores not that well on that criteria. It is an broad comparison and a more detailed comparison will be used later in the process.

The weight of the different criteria in the overall result is not equal since it followed from the interviews that were conducted that certain criteria were considered more important by the stakeholders. The different weighing factors are shown in Table G.1. Most weighing is self-explanatory, but the extra weighing of the attractiveness and speed of effectiveness will be explained. The attractiveness strongly influences the amount of tourism which is the main source of income and is thus of very large influence on the benefit side.

Table G.1 - Weight of different criteria

| Criteria | x |
|---|---|
| Protects buildings | 3 |
| Attractiveness | 6 |
| Costs | 3 |
| Lifetime | 1 |
| Speed of effectiveness | 3 |
| Problem shifting to adjacent areas | 1 |
| Safety and reliability | 2 |
| Combines well with current measures | 2 |
| Bad influence on other industries | 1 |

The speed of effectiveness is also of more than expected importance because of two reasons: when a measure is implemented it is preferred to show quick result for the investment done and it decreases the need for temporary measures.

### G.4.1 Ranking

In the following two tables the currently used measures and the other possible measures are ranked, using the above explained criteria and weight factors.

Table G.2 - Currently used measures

| | | Currently used measures | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Geotextile sand bags | Small sandbags | Emerged breakwater | | Concrete revetment | Seawall | Vegetation |
| | x | | | Stones | Geotube | | | |
| Protects buildings | 3 | | | | | | | |
| Attractivenes | 6 | | | | | | | |
| Costs | 3 | | | | | | | |
| Lifetime | 1 | | | | | | | |
| Speed of effectiveness | 3 | | | | | | | |
| Shifts problem to adjacent areas | 1 | | | | | | | |
| Safety and reliability | 2 | | | | | | | |
| No bad influence on other industries | 1 | | | | | | | |
| Range 20-100 | | 50 | 39 | 63 | 61 | 66 | 51 | 52 |

Table G.3 - Other possible measures

| | | Possible measures | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | (Semi) Soft measures | | | Hard measures | | | Out of the box measures | | |
| | x | Sand suppletion | Restore sediment supply | Divert river stream direction | Groynes | Submerged breakwater | Mangroves | Temporary winter protection | Closed sea | Barrier island (Cham 2) |
| Protects buildings | 3 | | | | | | | | | |
| Attractivenes | 6 | | | | | | | | | |
| Costs | 3 | | | | | | | | | |
| Lifetime | 1 | | | | | | | | | |
| Speed of effectiveness | 3 | | | | | | | | | |
| Shifts problem to adjacent areas | 1 | | | | | | | | | |
| Safety and reliability | 2 | | | | | | | | | |
| Combines well with current measures | 2 | | | | | | | | | |
| No bad influence on other industries | 1 | | | | | | | | | |
| Range 20-100 | | 91 | 63 | 59 | 57 | 66 | 45 | 56 | 55 | 42 |

Some interesting parts of the analysis:

- The costs of the sandbags are higher per year than of most other solutions, since they need to be replaced more often.
- Safety and reliability is for most measures not perfect except for a concrete revetment.
- A natural solution is not an preferred option.
- Groynes score less than expected, this follows from a relatively low score on attractiveness.

The three highest scoring measures are:

1. Sand nourishment
2. Submerged breakwater
3. Concrete revetment

Quite close to those solutions are: Restore sediment supply and an emerged breakwater. The restore of sediment supply has some major positive points, however it is still not that interesting as a sole measure, since the other soft measures like sand nourishment has the same positive points without the large drawbacks. The emerged breakwater is quite similar to the submerged and the positive points of the emerged one will be used in the design of the submerged breakwater.

To get a better results some of the measures can be combined with other measures. Especially a low amount of sand nourishment can be very well combined with other measures to improve or the effectives of the nourishment, or to mitigate negative effects of other options. However often such a combination leads to an unwanted increase of the costs. How this concludes is shown in Chapter6.3 Results of analysis of possible measures.

# H. Main alternatives + nourishment strategy

This appendix provides additional information about the three main alternatives that are given in Chapter 6.4. It elaborates on the amount of sand that needs to be nourished, the costs and sketch designs of the used structures. The same order is used as in the main chapter: first large sand nourishment, after that the medium nourishment with groynes as sediment retaining structure and finally a small nourishment combined with a revetment. The appendix concludes with an advice for beach policy and a nourishment strategy to use for the three alternatives.

## H.1 Large sand nourishment

The first alternative is a sand nourishment along the entire beach without any further protection of a hard structure.

### H.1.1 Design

The nourished beach has to withstand the 1 in 5 year storms and the 1 in 50 year typhoons which give 35m and 120m erosion respectively, as calculated in E.3.1 ‘Storm variation’. In addition the erosion rate of 12m per year has to be taken into account and also the prevention against this erosion is important. Furthermore, there has to be a buffer in front of the restaurants and resorts when the most extreme erosion occurs. The most extreme situation is defined as the erosion at the end of the five years just after a typhoon, assuming that a typhoon and a storm do not occur both within five years.

Due to these factors the beach has to have a width of 180 meter when constructed. With every five year a maintenance nourishing of 60m plus erosion damage due to storms or typhoons is needed. This width of the beach gives a reliable protection for restaurants, resorts and other structures and properties beyond the beach. It should protect against a possible storm and typhoon occurring in these five years and the erosion rate within these years.

Table H.1 - Total needed beach width

| | |
|---|---|
| Structural erosion | 60 m |
| Typhoon erosion | 120 m |
| **Total beach width** | **180 m** |

The amount of sand needed for the nourishment can be determined with the formula below.

Eq. H-1 $$S_n = \left((W_b + W_v) + (W_e * I)\right) * D_a * L$$

With:

$S_n = Nourishment_{initial}\ [m^3]$
$W_v = Natural\ variation\ [m]$
$D_a = D_{active\ zone}\ [m]$
$W_b = required\ overdue\ maintenance\ [m]$
$W_e = Yearly\ erosion\ [m/y]$
$I = Maintenance\ interval\ [y]$
$L = Beach\ length\ [m]$

$$S_n = \left((20 + 120) + (12 * 5)\right) * 5 * 4000 = 4{,}000{,}000\ m^3$$

Nevertheless, most resorts have already a hard structure protecting their property. Due to this the beach in front of the resorts may be less wide than the beaches without any hard structure as protection. The resorts are located approximately 40m more seaward than the current shoreline at the south part of Cua Dai Beach. This leads to an initial beach width of 140m in front of the resorts.

At the north part of Cua Dai Beach there is still beach left, so less nourishment is needed. The resorts at the northern part have no hard structure as protection against storms and typhoons, so in front of these resorts there should also be 180m of beach. There is already a revetment placed at the south part of Cua Dai Beach, which can be taken into account for the protection. Because of this revetment a less wide beach is possible to meet the requirements for protection against storms, typhoons and erosion. Nevertheless, the beach adjacent to this part in front of the revetment has to be 180m wide, because at that part no revetment is placed. Therefore the beach in front of the revetment still has to be 180m in width. Nearby the river mouth the shoreline has to be gradually bended so that it has no places where the erosion is more extreme than other locations. This results in a very wide beach at this location, but when coastal management is applied at this part it can turn into a useful beach. In short, the beach width of Cua Dai Beach just after nourishing will look the following:

**Table H.2 - Total nourishment widths of different parts of Cua Dai Beach**

| Resorts North Part | Beach North Part | Resorts South Part | Beach South Part | Already placed Revetment | Spit |
|---|---|---|---|---|---|
| 180m | 180m | 140m | 180m | 180m | 180m |

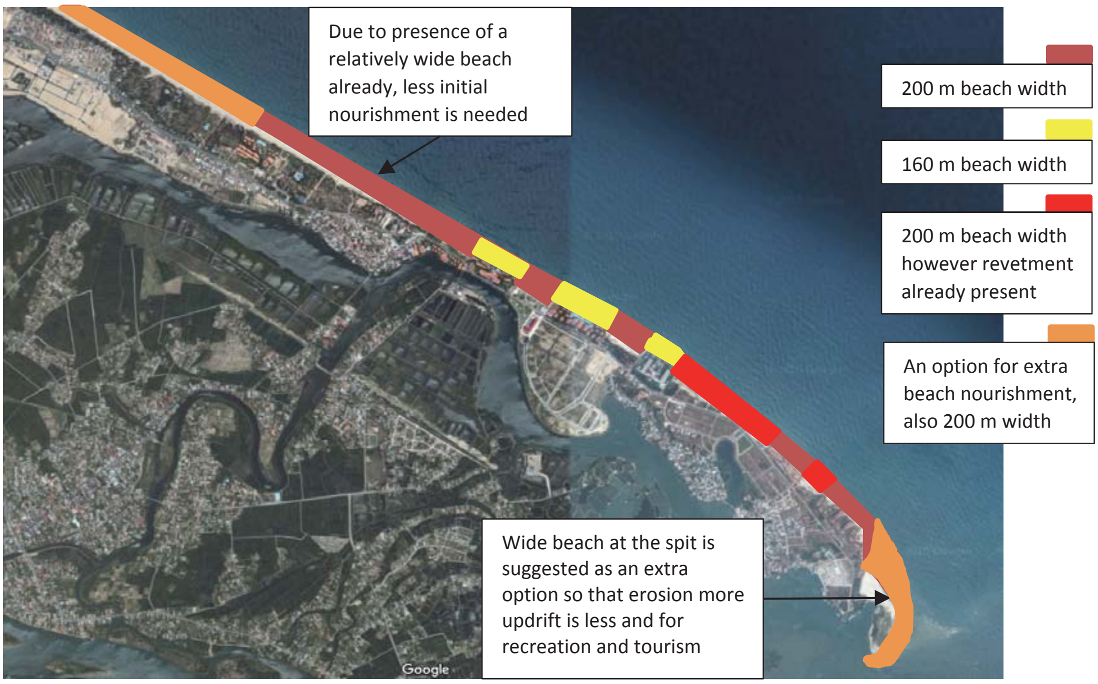



**Figure H.1 - Nourishment width of different coastal sections**

### H.1.2 Costs estimation

The costs for the beach nourishment are mainly initial costs for the construction of the wide beach. Compared to the other two alternatives the initial sand costs are more expensive. The costs are based on reference projects, as is described in Appendix H.4.3.

| | | |
|---|---|---|
| Total initial costs | VND 640 billion | € 25.5 million |
| NPV including maintenance for 20 year | VND 950 billion | € 37.8 million |

## H.2 Medium nourishment + groynes

In this alternative a set of 145m long groynes will be placed to protect the Cua Dai Beach and several resorts from further erosion. Once protected the beaches between the groynes can be restored to a width of 60m by a sand nourishment. On average the beach will be 50m over the four kilometre stretch. However, the groynes will worsen the erosion on the unprotected areas, hence a yearly nourishment scheme will be used to mitigate these effects. A large benefit of this approach is that the valuable beaches of Cua Dai are stabilised and will only occasionally require maintenance after large storm events.

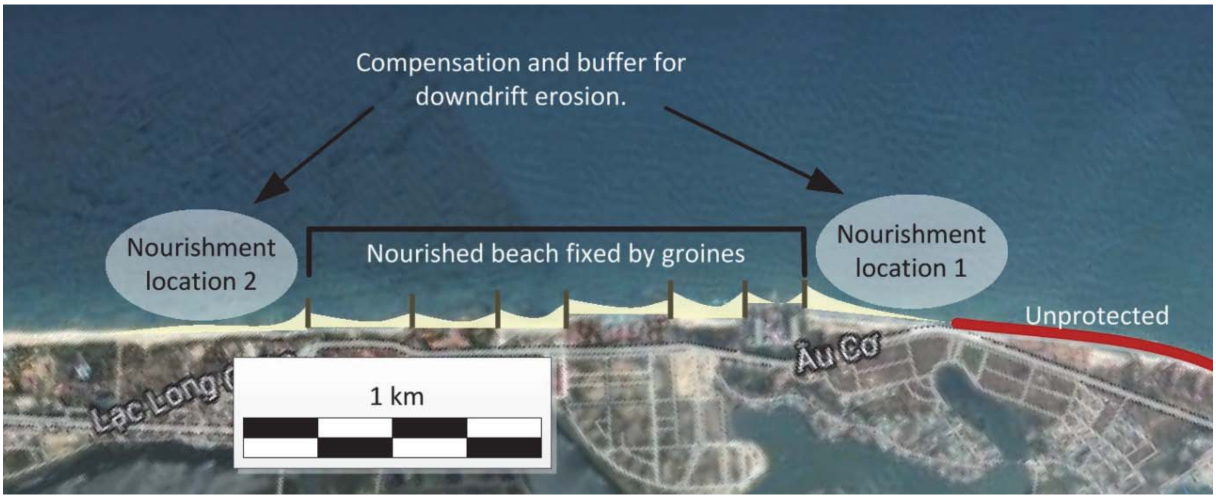


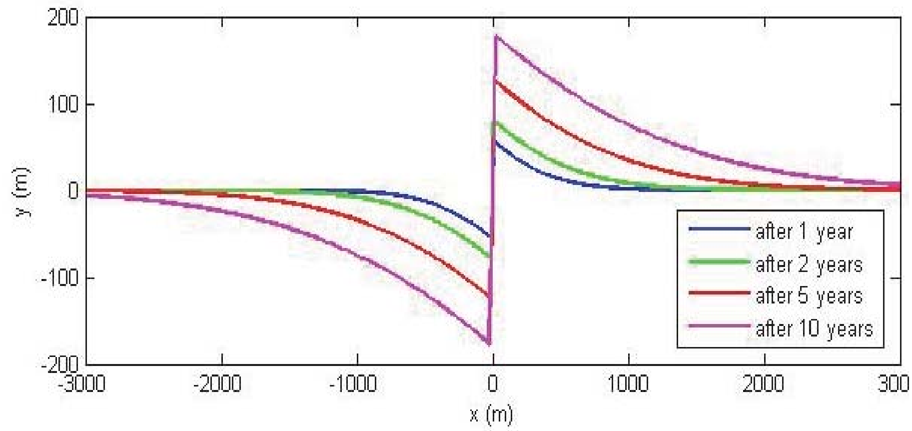

Figure H.2 - Basic design of alternative

At nourishment location 1 the area will be nourished for 1km and increase the width until the tip of the first groyne is reached. This allows bypassing of the longshore sediment and prevents erosion at the downdrift. The regular nourishments are focused only on nourishment location 2 which makes the nourishment operation much easier. Here the structural erosion is amplified by the presence of the groynes such that 240,000m$^3$ of sand must be nourished to mitigate it each year (see Appendix C.7). The downsides are the relatively high construction costs of the groynes, the uncertainty in the design aspects of the groynes and intensified erosion of the area adjacent to the groynes.

### H.2.1 Effects

As explained before, groynes work by interrupting the longshore transport and thus reducing or even inhibiting its capacity to erode the beach. The beaches between the groynes are thus protected from the structural erosion induced by longshore transport gradients. These beaches can be restored with a single large nourishment that would require little maintenance, as only storms are strong enough to move sand out of the system and induce erosion of these beaches.

However updrift of the groyne system sand will accumulate whereas downdrift additional erosion will be induced. The extent of which is determined by their effect on the longshore transport (see section 3.3 Shoreline movements). Using the analytical solution of the Pelnard-Considere equation for a groyne (derived from Eq C-3 and C-4) (Roelvink & Reniers, 2012) and making a few assumptions regarding wave direction a rough approximation of the expected retreat at the end of the groyne field can be given. The retreat in the first year would be around 55 m, the second year 80m and after five years 125m. After 10 years the erosion would be 180 m. At the other side the same amount of accretion is expected. This erosion will continue until the sand on the southern end has reached the tip of the groyne after which the sand will bypass the groynes. Mitigation of this erosion can be done by placing additional nourishments at this location. This will be discussed in more detail in the following section about the design of the nourishment.




*Calculated by super-imposing the solutions for S=20,000 $m^3$/year with wave angle of 20 degrees and S=340,000 $m^3$/year with wave angle of -10 degrees assuming the active depth=5m.*

**Figure H.3 - Expected erosion and accretion next to a groyne.**

### H.2.2 Design

**Spacing of the groynes**
Based on the 100 $m^2$/year gradient along Cua Dai beach (Ponsioen, 2015) the groyne system would need to block 200,000 $m^3$/year of northward sediment transport to stabilise the 2 km long stretch of beach protected in this alternative. The northward sediment transport is around 340,000 $m^3$/year (Ponsioen, 2015) meaning 58% of transport needs to be blocked. Estimating from satellite images that the surf zone is about 150m wide and the longshore transport is equally distributed in this region the length of the groyne would be about 145mlong (60m nourished beach +85m to block transport).

The spacing of groynes is another design aspect. Although there is no easy way to compute the optimal spacing without modelling there is good experience for which amount of spacing works. (Kraus, Hanson, & Blomgren, 1994)suggested that groynes on sandy beaches perform best if their spacing is two to four times the groyne length. The (SPM, 1984) recommended a spacing ratio of two to three, while the CEM (USACE, 2006) suggested a groyne spacing to length ratio of two to four. (Silvester, 1992)presented a graphical procedure for estimating the ratio of groyne spacing to length. The ratio is a function of the incident wave angle and varies from two to fourteen. However, no field or laboratory data was cited to support this method. Based on all these findings the spacing should be between two to four times the groyne length which results in a spacing between 170 m and 340m.

Note that there are many assumptions, simplifications and uncertainties in determining these design aspects and they should be verified by a large model study to obtain the optimal groyne dimensions. These models would require more input data on the bathymetry, wave climate, currents and sediment to make viable predictions. Since only limited data is available these should be measured in advance. Such research is important, but also translates in a much longer design phase of the project for collecting data.

**Location of the groynes**
Groynes are costly so the amount of groynes should be limited as much as possible. This means that only a limited length of beach can be protected. South of the Sunrise Hoi An Beach resort there is only limited value left. It consists of a revetment and a stretch of abandoned resorts. Therefore these will not be protected as the costs for additional groynes would not outweigh the value it protects. Between the Sunrise Hoi An Beach resort and the Victoria Beach resort north there is one other active resort and two beaches. Further north of Victoria there is a beach currently protected by sandbags with a few restaurants even further north.

Since this section does have economic activity it is considered valuable enough to protect with groynes. Next to these restaurants there is section of about 500m that is currently unprotected and undeveloped. The groyne field will end at the last restaurant and this undeveloped section can be used to focus the nourishment and mitigate the most of the erosion induced by the groynes. North of this area is the Palm Garden resort which has not suffered large erosion. By monitoring the erosion and doing regular nourishments at the nourishment location the propagation of the erosion to the north can be stopped.

With the stretch that needs to be protected defined, the location of the groynes can be determined. The easiest and probably most convenient way is to place them at the edges of the current resorts and hotels as their widths do not exceed the 340m spacing limit. The beach currently protected by sand bags between the restaurants and Victoria will be divided in two sections of about 300 m. The spacing is also presented in figure H.2.

**Determination stone size for groynes**

There are many empirical methods to estimate the size of the armour stone for a groyne or breakwater, which is required for stability or rocks under wave attack. Each stability formula, derived by Iribarren (1938), Hudson (1953, 1959), Hedar (1960, 1986) and Van der Meer (1988) has its own range of validity and a specific field of application. (CIRIA, The Rock Manual, 2007).

The Hudson formula is well known for its simplicity, but it has been found by many users to have a lot of shortcomings. For example, it uses regular waves only, it does not include the influence of wave period and storm duration, there is no description of the damage level and it can only be used at non-overtopped and permeable structures.

A more advanced equation for multiple layers of rubble under wave attack can be calculated with the Van der Meer formula. On the basis of his experiments, Van der Meer found that a distinction should be made between plunging and surging breakers, which resulted in the following set of equations.

Eq. H-2 $$\frac{H_s}{\Delta D_{n50}} = c_{pl} P^{0.18} \left(\frac{S}{\sqrt{N}}\right)^{0.2} \zeta_m{}^{-0.5}$$ For plunging waves (Van der Meer, 1988)

Eq. H-3 $$\frac{H_s}{\Delta D_{n50}} = c_s P^{-0.13} \left(\frac{S}{\sqrt{N}}\right)^{0.2} \sqrt{\cot\alpha}\, \zeta_m{}^{P}$$ For surging waves

With:

$H_s = Significant\ wave\ height\ [m]$

$\Delta = relative\ density\ [-]$

$D_{n50} = nominal\ material\ diamter\ [m]$

$P = permeability\ factor\ [-]$

*P = 0.1 in an impermeable foundation (sand -clay body)*

*P = 0.5 in a permeable foundation (e.g. with multiple layers of rubble)*

*P = 0.6 in a very permeable foundation*

$S = damage\ number\ [-]$

The number of lost stones per transverse cross-section

$N = number\ of\ incident\ waves\ at\ the\ toe, which\ depens\ on\ the\ duration\ of\ the\ wave\ conditions. Maximum\ 7500\ [-]$

$c_{pl} = coefficient\ for\ plunging\ wave\ load = 6.2\ [-]$

$c_{pl} = coefficient\ for\ surging\ wave\ load = 1.0\ [-]$

$\alpha = slope\ angle\ of\ structure\ [°]$

$\zeta_m = breaker\ parameter\ [-]$

The breaker parameter (also known as the Iribarren number) is computed to determine which formula to use; for plunging or for surging waves. For computation, an assumption for several parameters has to be given. Assuming the volumetric weight of the stones to be 2650 kg/m$^3$ leads to a relative density of 1.59. The permeability factor is assumed to be 0.5, the bed slope is 1:50 and the maximum water depth at the toe of the structure is taken as 5 meters. The value of the damage level is taken to be 2, which means that only a minor amount of damage is allowed for the design. Table H.3 indicates the required stone sizes ($D_{n50}$) for different return periods.

Eq. H-4 $$\zeta_m = \frac{\tan\alpha}{\sqrt{H_s/L}}$$ Iribarren number (Iribarren, 1988)

Eq. H-5 $$\zeta_c = \frac{c_{pl}}{c_s} P^{0.31}\sqrt{\tan\alpha}$$ Critical value Iribarren number

With $\alpha = bed\ slope\ angle\ [°]$
$L = wave\ length\ [m]$
$c_{pl} = 6.2\ and\ c_s = 1.0$

**Table H.3 - Required stone sizes ($D_{n50}$) for the groynes indicated for different return periods**

| | Prob. of exceedance | Hs [m] | T [s] | Required stone size, $D_{n50}$ [m] |
|---|---|---|---|---|
| Per month | 1 | 2.03 | 9.89 | 0.17 m |
| Per year | 0.25 | 2.62 | 11.10 | 0.21 m |
| Per 5 years | 0.05 | 3.30 | 12.50 | 0.26 m |
| Per 25 years | 0.01 | 3.99 | 13.90 | 0.31 m |
| Per 50 years | 0.005 | 4.28 | 14.50 | 0.33 m |
| Per 100 years | 0.0025 | 4.58 | 15.11 | 0.35 m |

Compared to the stone sizes that were used for the protection of the Victoria Hoi An resort and the Golden Sand resort, the calculated $D_{n50}$ is much lower than the actual stones present, even for high return periods. The required stone sizes are comparable to the smallest stone size measured at Victoria resort. The relatively low value $D_{n50}$ might mean that the rubble mound revetments at these resorts are over-engineered or the wave conditions have been underestimated.

**Table H.4 - Measured stone sizes at Victoria and Golden Sand resort, categorized**

| Stone size [in cm] | | Victoria Hoi An resort | Golden Sand resort |
|---|---|---|---|
| Small | L x B x H | 55 x 35 x 30 | 60 x 50 x 45 |
| Medium | L x B x H | 75 x 95 x 40 | 75 x 70 x 50 |
| Large | L x B x H | 130 x 85 x 120 | 250 x 100 x 75 |

**Figure H.4 - Current rock revetments**

**Nourishment**
The nourishment must accomplish three things: restoration of the beach to an acceptable width, mitigate the erosion induced by the groynes and compensate for the structural erosion in the future. Each requires a different approach in this alternative.

The restoration of the beach should return the entire beach from the Sunrise resort to the Palm Garden resort to a sufficient width. Out of cost considerations it cannot be made too large, as nourishment costs increases as well as the total length of the groyne. Based on the economic value of the beach from appendix B.4 an economically viable beach width is 60m . This will be the state the beach will be restored to. Additionally as Appendix E.3.1 'Storm variation' demonstrated such a beach width is large enough to deal with temporary storm erosion from minor storms.

Figure H.3 shows the effect of a groyne (field) on the beach with downdrift erosion and updrift accretion. Since the groynes need to extend an estimated 85m beyond the shore and 60m of beach will be nourished the total length amounts 145m. Based on the calculation it would take an estimated six years before enough sand has accreted for by-passing. Instead this amount of sand will be nourished directly after construction of the groynes so no downdrift erosion will occur. This means that an initial nourishment is required that moves the coastline on average 40m seaward in the 1.5 km updrift of the first groyne. The shape however will need to look like the pink line in Figure H.3.

The final nourishment is of structural nature to counteract the structural erosion. The retreat measured in the last several years is 12m per year over the 3.5km of Cua Dai. As calculated in Appendix C.7 the amount of sand lost is 240,000 $m^3$/year. Since this sand can no longer be eroded from the beaches protected by the groynes, additional structural erosion is expected. A rough approximation for this effect is calculated with a numerical model combining the CERC-formula with the one-line coastline model (model explained in Appendix C.2 CERC formula'). Adding a 12m per year erosion and fixing the coastline for 2 kilometres to simulate the groyne field gives insight into the consequences. Most notably the downdrift erosion has significantly increased to almost 80m/year such that regular nourishments become inevitable. On average the erosion is 32 m in the first 1.5 km downdrift. The yearly nourishment north of the groynes should mirror the shape of the blue coastline of Figure H.5.

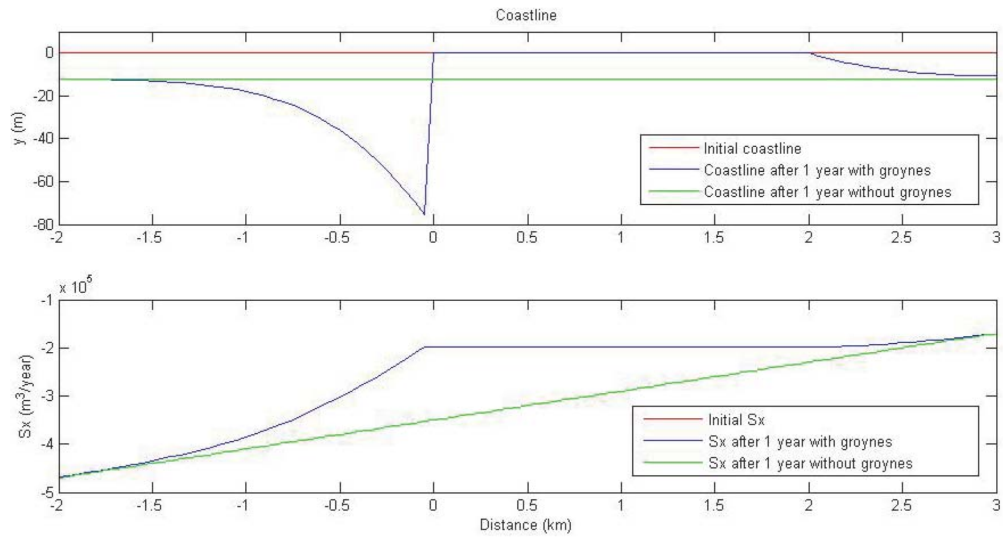



Figure H.5 - Effect of the groyne field without nourishments

In total the nourishment amounts to an average of 40m for 1.5 km updrift of the groynes, 60m for the 2km of beach within the groynes and every year 32 m the first 500m downdrift of the groynes.

With an active depth of 5m this amounts to 400,000m$^3$ updrift of the groynes, 600,000m$^3$ within the groynes and every year and 240,000 m$^3$ downdrift of the groynes.

**Trial groyne**

Before the stone groynes are adopted, it is recommended that a trial structure is built to assess the effectiveness of a groyne field. A trial-and-error approach is followed whereby the effects of the groynes are closely monitored. The trial groyne could be progressively built out from the shoreline until 145m. The shoreline changes are measured at each trial configuration. Data retrieved from actual processes along the beach can enhance the modelling predictions significantly. These models can then be used to assess the long term solutions. The obtained data is necessary to understand the uncertainties concerning the erosion problem at Cua Dai beach, such as:

- *Local wave climate*. A lack of local directional wave data limits the understanding of sediment transport processes and the influence of important features such as Cham Island.
- *Information on sediment budget*. The volume of sediment moving into and out of the coastal cell.

Temporary groynes can be constructed from geotextile fabric containers like Geotube®, which is a relatively cheap short term protection measure. According to the bathymetry map in Appendix C.3, the water depth at the tip of the 145m long groyne is five meters. A total of 13 long geotextile bags, with dimension shown in Figure H.6, should be stacked according to the indicated geometry. Multiplied with a unit cost price per volume of €18 per m$^3$ (U.S. Army Corps of Engineers, 2008) leads to a costs of €32,000,- per bag. The total construction costs for seventeen long geotextile bags is estimated to be €544,000,-.

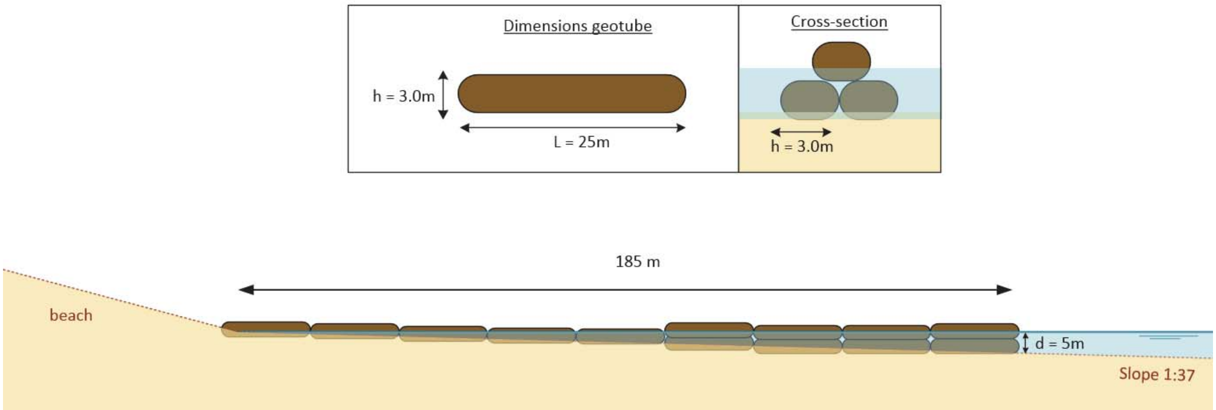



Figure H.6 - Dimensions and stacking of the long geotextile bags for the trial groynes

## H.2.4 Costs estimation

**Costs groynes**

Costs of groynes differ considerably due to different wave conditions, bathymetry and investment budgets. Therefore different designs are applied which makes each project unique. To estimate the costs of rubble mound groynes along Cua Dai beach, a construction cost estimation per meter groyne length is made based on several reference projects. Averaging the costs of these reference projects gives a cost of €1,550,000 (or 38 VND) per groyne. This design alternative consists of seven groynes, leading to a total cost for groynes of €10 million.

Table H.5 - Reference projects

| Details | Length [m] | Costs for 1 groyne | |
|---|---|---|---|
| | | EUR | VND$^{x1,000,000}$ |
| Groyne extension Lake View Park, Ohio | - | €252,296 | 6,183 |
| Lake Cathie groyne | 180 | €2,060,426 | 50,492 |
| Rock groynes | - | €2,117,508 | 51,891 |
| Swanage frontage | 175 | €982,723 | 24,082 |
| Rock groynes series | 70 | €491,512 | 12,045 |
| Coastal protection measures | - | €270,332 | 6,625 |
| Kings cliff beach | 150 | €1,111,059 | 27,227 |
| Kingscliffbeach | 150 | €1,880,255 | 46,077 |
| Kirra Point groyne | 180 | €4,615,170 | 113,098 |
| Bang Khunthiancoast | 200 | €1,714,286 | 42,010 |
| | Average cost for a stone groyne: | €1,550,000 | 38,000 |

Groynes are cost-effective coastal defence measures, which require little maintenance. Once installed, it is relatively simple and inexpensive to replace damaged or dislodged stones. Costs associated with maintenance works for groynes are not widely recorded and therefore not readily available. Inspection of the groynes are an important element in the coastal maintenance strategy and can be done in various ways such as visual inspections at low tide, aerial surveys, beach profile surveys and diver surveys.

**Total costs**

The costs for the nourishment with groynes are partly initial costs for the construction of the groynes(€10 million) and partly initial nourishment(€11.1 million). During the maintenance the costs are a little higher than with the other alternatives, because of the fact a yearly nourishment strategy has to be applied.

| | | |
|---|---|---|
| Total initial costs | VND 530 billion | € 21.2 million |
| NPV including maintenance for 20 year | VND 1025 billion | € 41.0 million |

## H.3 Small nourishment + revetment

This alternative is a combination of a revetment and sand nourishment. The revetments deal with the task of storm protection of present building by preventing incidental erosion. The nourishment creates a beach and prevents the structural erosion and undermining of the toe of the revetments.

Figure H.7 - Location of revetments

Currently, two revetments are already in place along Cua Dai Beach, consisting of a small stretch and longer stretch. Looking from the south (from the right side of the map in H.7), the first two solid lines are showing these revetments. They are built as concrete revetments, as described in Appendix F.1.5.

For this option, another revetment has to be placed along the part that is now temporary protected by sandbags and other provisional methods. Starting at the Victoria Beach Resort this revetment will stretch 900m northwards.

The dashed lines in the map are optional. It shows locations in front of resorts that currently have their own protection. If this is a sufficient measure, there is no need for replacement. It is the responsibility of the resorts to protect their own property. Two dashed lines most south show the two abandoned resorts. Dependent on if these projects will be continued if there is sufficient protection again, revetments or other forms of protection can also be applied here. If they remain abandoned, there is no need for a revetment; the sand nourishment will prevent further land loss and stabilise the situation. There is also no need for revetments along the beaches between the Victoria, Golden Sand and Sunrise beach resorts. The protecting structures of the resorts act as groynes and shelter the beaches for further erosion. Especially with sand nourishment the width of this beach is also sufficient to deal with incidental erosion due to storms.

The second part of this option is sand nourishment. The nourishment creates a beach, which is an important attraction for tourists. It also maintains the foundation and protection of the revetments. Without taking away the cause of erosion, it will still continue. The sand is there to prevent undermining of the revetments that ultimately leads to failure. The beach is nourished regularly, to keep the amount of sand sufficient over a longer period of time.

The revetment does not have to look like a solid block of concrete, but can be turned into a modern looking protection. Furthermore, the revetment cannot only be used for protection or walking down to the beach, it also provides extra space for recreation. However, the friendly and easy appearance will reduce with the placement of a revetment. The natural look disappears, compared to the option of a full beach nourishment.

On the land side of the revetment, several options are possible. It can be kept as it is now, but the revetment also creates possibilities for a boulevard. This might stimulate the whole Cua Dai Beach area, making it a popular attraction again. Both possible options are further described in paragraph Landward options'.

### H.3.2 Design

The combination of the concrete revetment with a beach in front sustained by nourishment will be designed in two parts. First the beach creation (nourishment) will be looked upon and secondly the revetment.

**Nourishment**

To retain the beach a maintenance nourishment to prevent the structural erosion is needed. This means a 240,000 $m^3$/year, see Appendix C.7. A minimum width of 1 meter at high tide is wanted when the beach is at its smallest width in the year. In combination with the most effective maintenance interval of two years, the needed initial nourishment can be calculated. In Figure H.8 the beach width is shown at its largest width during a year and at it smallest.

Eq. H-6 $$S_n = \left((W_b) + (W_e * I)\right) * D_a * L$$

With:
$S_n = nourishment_{initial}\ [m^3]$
$D_a = D_{active\ zone}\ [m]$
$W_b = required\ overdue\ maintenance\ [m]$
$W_e = yearly\ erosion\ [m/y]$
$I = maintenance\ interval\ [y]$
$L = beach\ length\ [m]$

$$S_n = \left((20) + (12 * 2)\right) * 5 * 4000 = 880{,}000\ m^3$$

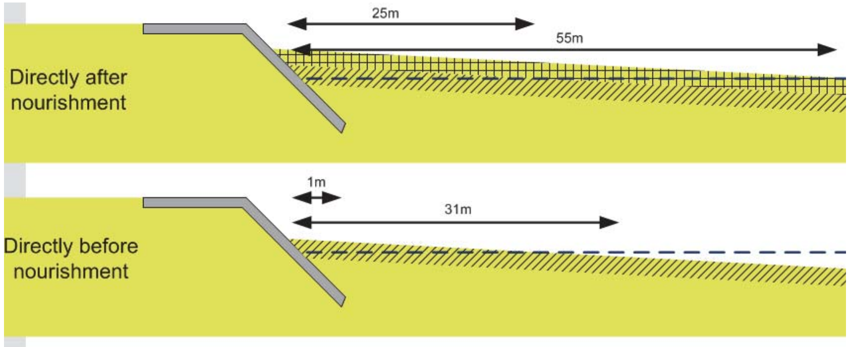



Figure H.8 - Beach width

For the initial nourishment it is here advised to add ten meter beach for unforeseen consequences and show an increase visibility of the solution. Ten meters of beach will mean a 220.000 $m^3$ extra, 22% extra. It can also be chosen to not do this and schedule a nourishment in the start of year two instead (size in accordance with inspection of the initial nourishments effect), and start with the two year interval after this. As stated before, since the beach/nourishment is only for structural erosion, incidental erosion margins are not included in the calculation above. The revetment is preventing damage to the buildings and palm trees along the coast.

**Revetment**

The other part of the coastal defence is a solid revetment. A solid revetment in this alternative is needed since the location also has recreational uses. A rock revetment is less suited for recreational use. The revetment has two major functions. There is a height difference between the height of the road and the restaurants along it and the height of the recreated beach. This height difference can be overcome without using a lot of sand and width by a revetment, since it allows for a steeper slope. The second function is a fixing of the shoreline against incidental erosion during, for example, a typhoon. It does not prevent structural erosion; however, the shifting of erosion can prevent damage to buildings. The erosion takes place in front of the revetment where it does not cause damage to buildings. The striped yellow in Figure H.9 is where the erosion would occur without a revetment, the light striped yellow is where it occurs with a revetment.

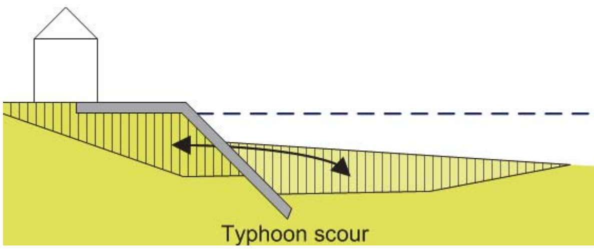



Figure H.9 - Shifting of erosion

The depth of the revetment follows from the maximum expected incidental erosion with an added extra length for safety. The incidental erosion comes from storms as typhoons. The area on where this scour takes place is quite concentrated near such revetment.

Eq. H-7
$$D_{rev} = (E_{typhoon} / (\frac{1}{2} * W_{scour})) + D_{safety}$$

With: $D_{rev} = depth\ of\ revetment\ (below\ waterline)[m]$
$W_{scour} = scour\ width\ [m]$
$D_{safety} = safety\ depth\ [m]$
$E_{typhoon} = temporary\ erosion_{typhoon}\ [m]$

$$D_{rev} = \frac{80}{\frac{1}{2}*120} + 1 = 2.33m$$

The estimate with E1. H-7 of scour of 1.33 meter is also in line with the reference resource of scour at sea dikes in Vietnam, with a calculation scour of 1.5 meter (Hoop, 2006). The value of 1.5 is used from here on.

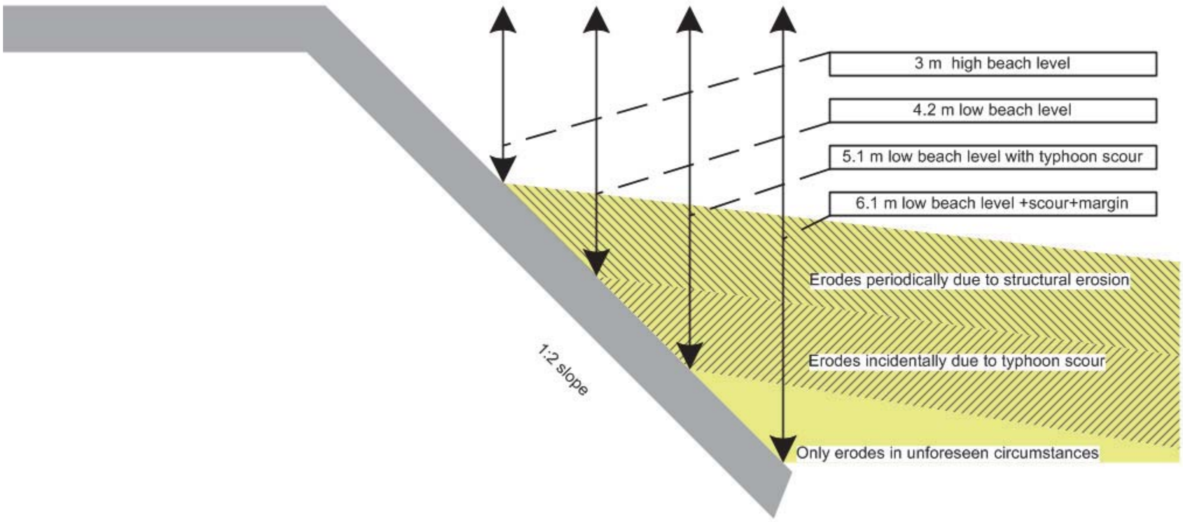



Figure H.10 - Visual overview of different beach/bed levels

The solid revetment should be less reflective at the location below the waterline level of the normal situation. Since this part is not visible and normally covered by sand, it is less important that it is useful for recreation. More scour reducing measures can be applied which will result in a less reflective surface.

At the location where normally no wave action is present a stairs is constructed to facilitate easy reaching of the bech, see Figure H.12, with no wave reducing measures. At the location closer the bottom, depicted by the striped grey in Figure H.11, there will be wave reducing measures to reduce the wave action when incidental erosion starts to create a scour hole.

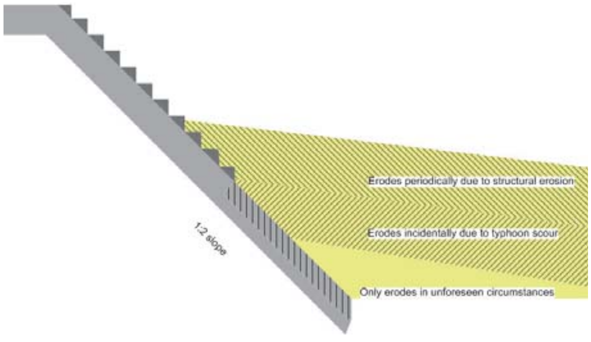



Figure H.11 - Revetment surface

Figure H.12 - Stairs example

## Landward options

For the land side of the new revetment there are two options: keep it mostly as it is now, or change it into a boulevard. Both options are elaborated in this paragraph.

*Maintain current land use*

Currently, the land use near Cua Dai Beach is composed of sand, palm trees and some undeveloped plots of land. It gives a natural and relaxing appearance, which can still be maintained with the construction of the revetment. An example of how it can look like is shown in the picture below. It shows the stretch of coast that is currently protected with the geotextile sandbags.

**Figure H.13 - Top view with new beach with revetment**

The revetment can be constructed on the current coastline. By keeping the room between the road and the revetment sandy, it maintains the beach feeling, complete with palm trees and beach chairs. The only disturbance between the sand on the landside of the line of protection and the sea would be the revetment.

*Boulevard*

Another option is expanding the alternative by adding a boulevard on the landside of the revetment. This long street along the sea can be used for cycling, walking or relaxing. It changes the sandy look to a more modern look. After construction of the infrastructure, the adjacent plots of land can be further developed into more shops, combining with the current resorts and restaurants. Again a map of the modified beach is showed in Figure H.14, accompanied by an impression of how it might look like.

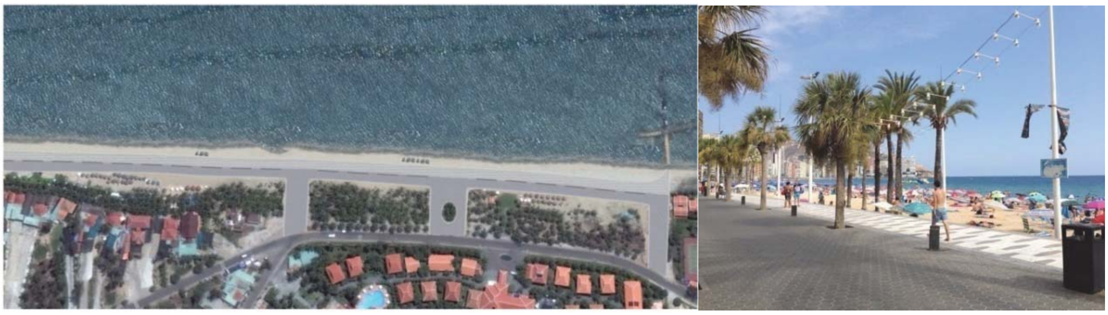


**Figure H.14 - Top view and impression of boulevard (Verkeersbureausinfo.nl, 2014)**

This example of area development shows a pavement area along the revetment and open squares towards the main road. The keep the tropical feeling, enough green area can be maintained. The map depicted in paragraph H.2.1 that showed the location of revetments and nourishment is expanded in Figure H.15with the current location of resorts and hotels, current green areas and current road. The area highlighted in red is currently undeveloped and able to change into boulevard area and surrounding squares.


Figure H.15 - Land classification

### H.3.4 Costs estimation

The costs for the nourishment with revetment are partly initial costs for the construction of the revetment(€1 million) and partly initial nourishment(€6.3 million). This variant is cheaper, but has a very small beach. Permanently adding 10 meter beach increases the cost with one million.

| | | |
|---|---|---|
| Total initial costs | VND 210 billion | € 7.3 million |
| NPV including maintenance for 20 year | VND 630 billion | € 23.9 million |

## H.4 Nourishment strategy

The elaboration on which nourishment strategy is most (cost)effective addresses the following parts:

- Source/location the sand comes from
- Cross-shore location of the nourishment
- Interval time of the nourishment.
- Longshore location of the nourishment

The yearly amount of sand that needs to be applied is 240,000 cubic meters, as followed from Appendix C.7.

### H.4.1 Source

The distance to the nearest sediment reservoir is one of the largest factors determining the price per cubic meter of sand (M. Marchand, 2012). The costs and availability of different sources are showed in Figure H.16 and Table H.6. *The river deposit in front of the mouth is preferred as source*, s*ince the distance makes it the cheapest adequate supply.* This source is however not yet confirmed with sufficient bathymetry charts to be available. The dunes could be used as a quick fix or as emergency reserve. The quantity is too small for anything more.

The second best source is further offshore dredging. It is not yet certain where to find suitable mining locations. However, it is known that the depth at those locations is around 80 meters and the distance is larger. Subsequently the costs rise.

The landwards option of getting sand is not preferred, because of its negative side effects. Such a large demand will lead to rising prices. Also the sand mining in the river, which creates part of the erosion, will likely rise when such a demand is introduced to the market.

The coast south of Hoi An is less developed and mining at such a location will shift the problem to a location with less value present. It is an option that will likely be too costly for just moving the shoreline retreat instead of halting it.

Table H.6 - Sand sources overview

| Location of the source | €/m$^3$order of magnitude | Availability m$^3$ | Depicted in Figure H.17, by… |
|---|---|---|---|
| Landwards | 10 | Adequate | Light blue |
| Adjacent dune | < 1 | 4*200*200=160,000 | Arrow and purple |
| River deposit before mouth | 3 -6 | Possibly 10,000,000-25,000,000 | Green, amount uncertain |
| Further offshore | > 6 | Adequate | Orange, location uncertain |
| Coast south of Hoi An | 5 | Shifts problem | Not depicted |


Figure H.16 - Sand sources

## H.4.2 Cross shore location of nourishment

The main options for nourishment at Cua Dai beach are shoreface or beach nourishment. With a shoreface nourishment larger nourishment volumes are required as only 30% to 50% of nourishment volume will reach the beach. With beach nourishments the sand is directly placed on the dry beach and no sand volume is lost, whereas with a shoreface nourishment part of the sand is lost in the transport process from shoreface towards the dunes. However, shore nourishments are 50% to 70% cheaper per m$^3$ because of the fact that the sediment can be placed offshore at a place where the ships have sufficient navigational depth (Bosboom & Stive, 2015).

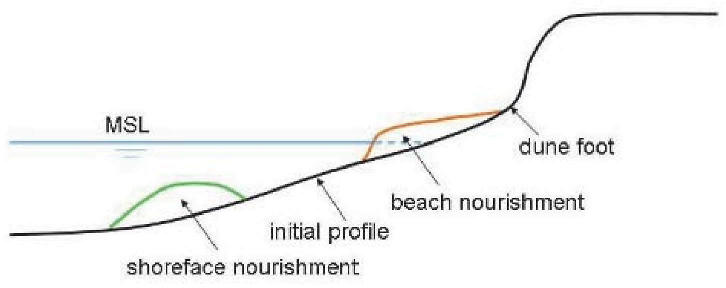



Figure H.17 - Cross shore location of nourishment

The shoreface nourishment provides a more stable coastal profile compared to the beach nourishment, because it is part of the bar zone within the shore zone and therefore the nourishment quickly becomes an integrated part of the bar system instead of being eroded away (US army corps of engineers, 2007). Furthermore, when the optimal situation is considered (which is however not very likely) where 50% of the shoreface nourishment volume will reach the beach and the costs are 70% cheaper per $m^3$ compared to the beach nourishment, shoreface nourishment will be more cost effective. However, it also increases the longshore transport according to a research project of a combined nourishment at Egmond Aan Zee (Nipius, 2002). When a limited amount of cubic meters of nearby nourishment material is present, beach nourishment might be cheaper than a shoreface nourishment.

For the current erosion problem of Cua Dai Beach it is best to use the combination of both nourishment options because there is as quick solution needed. The beach option acts quick and is highly visible while the shoreface nourishment is slightly cheaper and gives a more stable coast.

### H.4.3 Interval time of nourishment

The best interval time of nourishment is in this paragraph calculated on a few basis rules:

- It is more cost efficient to deposit larger amounts of sand at the same time
- Future costs are translated to today's costs with a discount rate

The cost efficiency of depositing large amounts at the same time is calculated with a fixed costs and a unit cost which decreases with an increasing nourishment amount. The used numbers in Eq H-9 are fitted with a multitude of reference projects (20) from multiple countries (11) and rough estimate numbers from dredging companies (2). The referenced projects are using different kind of cross shore nourishments.

Eq. H-9 *For* $V_{nourished} \geq \sim 500.000\ \mathrm{m}^3$ till ~8.000.000 $m^3$

$$Cost_{total} = 21 \times (V_{nourished})^{0.9216}$$

Eq.H-10 *For* $V_{nourished} < \sim 500.000\ m^3$

$$Cost_{total} = 21 \times (V_{nourished})^{0.9216} + Cost_{Base}$$

With: $V_{nourished} = nourished\ volume\ [m^3]$

$Cost_{total} = total\ costs\ [VND\ or\ €]$

$Cost_{base} = base\ costs\ [VND\ or\ €]$

The discount rate used in the calculation is 8%, following from an average of the government discount rate in New Zealand (The Treasury, 2015) and the central bank rate in Vietnam (CIA world factbook, 2015).

Following from Figure H.18 the most cost efficient maintenance strategy is nourishing every two years. However, the costs of nourishing every five years is around the same and this option has advantages with less disturbance for the beach users. Since coastal nourishment can have unforeseen side effects it is not advised to start with a large initial nourishment of five years as first nourishment in an area. A mega nourishment in the Netherlands, the so-called 'sand engine', was only placed after a multitude of decades of experience with coastal nourishments and research. *For the first nourishment an interval of two years is advised and when additional research is done a five year interval is advised.*

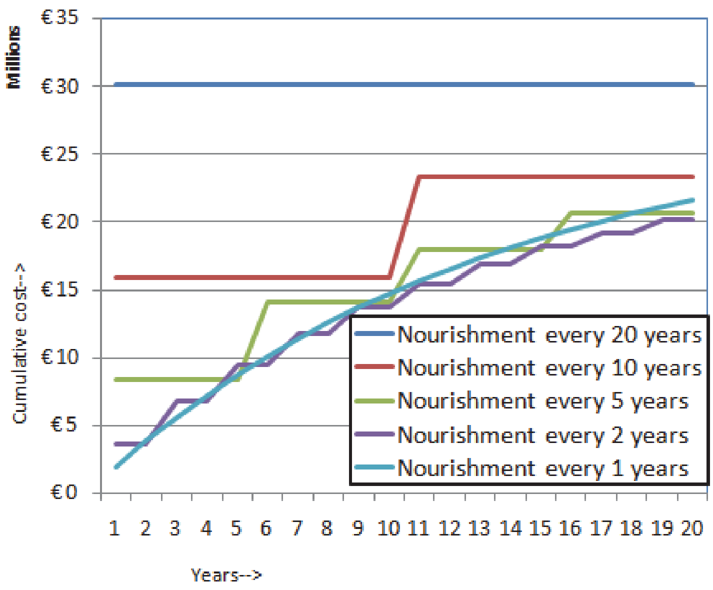



Figure H.18 - Nourishment interval strategy

## H.4.4 Longshore location of nourishment

There are some options concerning the longshore location of the nourishment. The basic three options are depicted in figure H.19. The options are an evenly spread out nourishment, (multiple) spot nourishments from where the sand spreads by waves or by focusing the nourishment on the location where the erosion focuses.

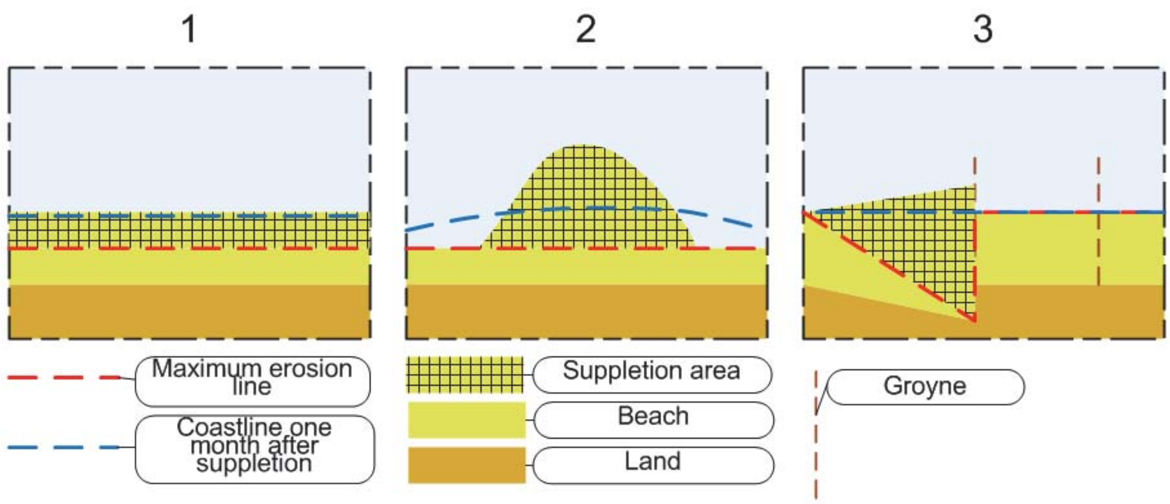



Figure H.19 - Longshore nourishment locations

Option 2 is the cheapest, however option 1 is preferred for the view, option 3 is only possible in combination with groynes or similar structures which focuses the erosion. A combination of option 2 and 1 is advised. Focus point of nourishment at locations ~200 meters apart (further research needed) which would result in the situation as depicted in Figure H.20. The distance in between is chosen in such a way that in a few months after the nourishment the coast is almost a fluent line without a need to move it with onshore land moving equipment. *To summarize: Nourishment at focus points at ~200meter with a natural spreading due to waves is advised.*

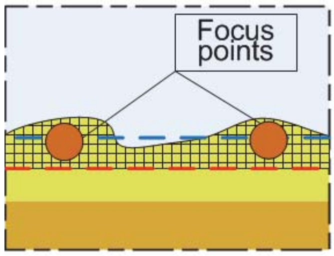



**Figure H.20 - Focus points of nourishments**

## H.5 Beach policy

Effective management of the coastal zone will mitigate or prevent similar problems in the future. After an introduction to coastal zone management (CZM), in this paragraph a general strategy will be given on how to retain coastal resources and prevent conflicts. In the first part a strategy is given for Cua Dai Beach, in the second part it is given for the stretch of coast south of the Thu Bon River. If that beach will be further developed in the near future, a strategy is needed to prevent the current problems of Cua Dai from happening there.

### H.5.1 Introduction to CZM

Coastal zones are the most exploited areas throughout the world and are also the areas that are likely to undergo the most change in the future (Post & Lundin, 1996). This combination will lead to future dilemmas between different usages of the area as a so called 'resource'. Present nature should not be forgotten in this equation, partly for tourist attractiveness and partly for intrinsic value. If these resources need to be maintained, utilised and protected for socio-economic development, an integrated management approach is needed.

Coastal zone management is a broad subject that can be applied on a large scale, but here it will be used on a few kilometres to set up a strategy for the preservation of the Cua Dai area and the stretch of beach south of the Thu Bon River. The focus will be on the use, and development, of the beach and nearby sea instead of the whole coastal zone which can reach several kilometres inland. Already on this small area of the coast, policy is needed to exploit the limited resources without large drawbacks and to anticipate on changes in the environment. One of the current problems is that buildings are constructed too close to the sea, which leaves no room for adaptation to the erosion. Better management in the future can prevent similar problems from happening again after the beach is recreated.

Citing from (Thia-Eng, 2015), chairman of the East Asian Seas Partnership Council, coastal zone management can be used to reach the following four goals:

- Maintaining the functional integrity of the coastal resource systems
- Reducing resource-use conflicts
- Maintaining the health of the environment
- Facilitating the progress of multi-sectoral development

Guided by these four goals strategies are designed for the two beaches around Hoi An. The goals are translated into three steps to create the strategy. The following sections each go through the steps of elaborating on the present coastal resources and possible conflicts first, after which this is translated into a strategy for preservation and development of the area.

## H.5.2 Cua Dai

**Coastal resources**
The three major resources in the study area are: the beach, the dunes with its vegetation and the sea. All are elaborated below.

The beach is an important resource and in terms of area it is limited. Tourists come to Hoi An partly for the beach and use it to relax or do sports. Resorts and family restaurants/bars know that a beach is an important attraction, these two kind of exploiters have to share the beach. Resorts often have their own private part of the beach, the smaller restaurants and bars have to use the public areas to do business. Besides the tourism sector, fishermen also use the beach. The little boats do not lie in a harbour, but are parked on the beach overnight until it is time to sail out again. More landward, the beach changes into dunes.

In the past, dunes have been flattened to construct resort buildings on it. The still existing dunes are not directly used by tourists, but some homes and restaurants are built on it. The vegetation that grows on the dunes and the dunes itself are another resources in this area. The scenery of palm trees is important for tourists and therefore again also for the tourism sector. Furthermore, the vegetation on the dunes is important to keep the cattle alive.

Next to the beach and dunes lies the sea, which is again important for the tourism sector. A sea that is easily accessible and safe to swim in is important for tourists and therefore needed for those who live from this business. Again, these are not the only users. The sea is used by the fishermen to catch their fish and subsequently sell it to make a living. Important for them are the conditions of the sea and the limited amount of fish that is present. Disturbances in the sea can change the ecosystem and therefore also the fishing strategies.

**Possible conflicts**
Above the three major limited resources are mentioned. They have to be shared by several users and everyone prefers to get the opportunity to exploit their part. Conflicts can arise when resources are not equally distributed and businesses are hampered by others. The following conflict of interests can arise:

- *Resorts versus local restaurants/bars.* The major issue here is that some resorts claim a part of the public beach and make it private property. If too much beach becomes private, there is no place for the local family restaurants to do their business anymore.
- *Resorts versus fishermen.* The possible cause for this conflict of interest in division of beach area is again the privatisation by resorts. Fishermen need space to store their material, which can only take place on public parts. Furthermore, the modification of the coast as it is currently done by resorts can affect the fishery.
- *Resorts versus homes and farmers.* The final conflict involving resorts is with homes and farmers on the dunes. As said, dunes are changed or occupied by resorts to construct their property. This can take away land for farming and living.
- *Tourists versus fishermen.* Although not on purpose, conflicts involving tourists can arise if the beach and sea use becomes too extensive. If the public beaches become too crowded, it becomes harder for the fishermen too sail out and to fish a little distance offshore. Also tourist activities as water sports can disturb the fishery.
- *Nature versus people.* Conflict of interests do not arise solely between people, also between people and nature conflict of interests are possible. If all human activities become too extensive, it is harder to maintain or even further develop the natural systems. This is further explained in the next paragraph.

**CZM Strategy**

*Environment preservation*
The ecosystems in the sea and on the beaches and dunes have to be maintained for an attractive environment for tourists. This is also important for the fishery, the (eco) tourism and the flora and fauna in and around the region. However with the current measures this is not the case.

Several years ago there was much more vegetation at the dunes and at the beach than at this moment. In addition the ecosystems in the sea, mainly at the foreshore, and at the beach were not damaged by concrete revetments, and geotextile and plactic bags. When continuing the way of handling the environment at this moment the health of it will drop. The plastic sand bags, geotextile sand bags and other erosion prevention measures used in combination with the erosion itself will damage the ecosystems and the vegetation on the beach and the dunes. In addition there are a lot of unmanaged dune and beach zones with garbage and unused structures or buildings on it.

When applying the alternative of only sand nourishment the use of plastic and geotextile sand bags becomes unnecessary and therefore is preferred for the environment. At the nourished beach a zone can be created for beach vegetation and palm trees conforming the current ecosystems at the location. Furthermore, by using sand for the nourishment that has the same properties, organisms living on the beach can maintain their habitat. And by using the same type of vegetation the ecosystems are disturbed as little as possible.

*Development*
It is important to have a strategy to facilitate the progress of multi-sectoral development. When there was no tourism, resorts and restaurants on Cua Dai Beach yet, it was a wide beach with palm trees. At the time the location for the first hotel or resort along Cua Dai Beach was defined, the designers were not aware of the future coastline variations at the defined location. This holds for most of the hotels, resorts and restaurants at the south part of Cua Dai Beach. For years most resorts, hotels and restaurants were built too close to the coastline, if you keep the natural coastline variation in mind. One of the most important suggestions to facilitate the progress of multi-sectoral development is to construct any future building or structure far enough from the coastline. This way there will be no erosion issues threatening the resorts, hotels or restaurant along the beach.

How this translated into a zoning map is given in Chapter 6.7.1.

## H.5.3 Southern stretch

**Coastal resources**
The coastal resources in the stretch of beach south of the Thu Bon river mouth are mostly similar to those on the other side. One of the differences is the size of the beach and dune area. When looking at the map below and comparing the land use, the larger beach width on the south is clearly visible. Even if the beach at Cua Dai will be recreated, the dune width at the south is still a lot larger. The distance from the bulge on the southern stretch to the closest road is around 700 meter. The area in-between is covered by trees and small sand dunes and sparsely inhabited. Some agriculture takes place in the area.

**Figure H.21 - Difference in resources (Google Earth, 2015)**

**Possible conflicts**
Currently, the southern beach is not intensively used. Fishermen are the most important beach users and no large amount of tourists have found the area yet. The only conflicts that can arise at this time are those between nature and fisherman. Fishermen do not have much reasons to disturb the inland resources. The tourism is for now limited in this area however the beach on the southern part is still largely present, and because of this it is possible that tourism will increase at this location in the near future. Especially due to the bridge that is recently constructed over the river. Together with tourists the construction of resorts and restaurants might be expected, resulting in the same possible conflict of interests as described for Cua Dai Beach.

**CZM Strategy**
It should not be thought that with the currently low tourism it is less important to have a good coastal planning than at Cua Dai Beach. To avoid future problems a good coastal zone management strategy is important. Adaption to shoreline variation or erosion is preferred over taking positive action since it requires no investment. Adaption is best done when adequate foresight is displayed with the development of the area. Adaptation means no use of certain zones, or usages that can be moved without any costs.

*Environment preservation*
The current environment at the beach of South Hoi An has not much changed the past several years. This beach is widely used by fishermen and there are no structures or measures for erosion prevention like at Cua Dai Beach. This is why the ecosystems at and around this beach are sufficiently maintained.

It is advised to manage the fishery around the coast so that the existing ecosystems can be conserved and there will be no overfishing. Next to that the suggestion for Cua Dai Beach should also be followed for this beach of South Hoi An; it is important to replant vegetation when cut or removed so that ecosystem is conserved.

*Development*
This part is given in Chapter 6.7.2.

# I. Measurements

## I.1 Measurement stick

Located on the lower shoreface of the beach section between Golden Sands and Sunrise resort, there is a plastic measurement stick fixed into the ground, with which the vertical shoreline change could be monitored. According to the life guards who manage this private beach section, the resort owners installed the stick to obtain some data by themselves. The length of the stick is measured on a weekly basis for a total of five weeks in order to get information about the vertical shoreline change of this beach.

Table I.1shows the weekly measurements of the length of the stick, which corresponds to the graph in Figure I.2. When measurement #1 is taken as a reference point (height of beach = 0), the graph of Figure I.3 can be drawn. Some interesting, yet adverse results were observed. Between measurement number 1 and 2, calm weather was present. However, the beach eroded significantly and a very gently beach slope was observed. Stormy weather had prevailed in the days between measurement number 2 and 3 and yet, the beach accreted to above the reference level again. Only a small part of the stick was visible and a much steeper beach slope was observed, as can be seen in picture #2 inFigure I.1. The weather in the remaining two weeks was quite 'normal', but the steep beach slope remained.


Figure I.1 - Photo series of measurement stick

Table I.1 - Weekly measurements of the stick length at Cua Dai beach, Hoi An.

| Measurement | Date | Length stick [cm] | Vertical beach change* [cm] |
|---|---|---|---|
| #1 | 4-dec-15 | 100.8 | 0 |
| #2 | 11-dec-15 | 9.6 | -91.2 |
| #3 | 18-dec-15 | 25.0 | 15.4 |
| #4 | 25-dec-15 | 51.4 | 26.4 |
| #5 | 1-jan-16 | 29.0 | -22.4 |

*Take measurement #1 as a reference level. The start point is taken as zero.

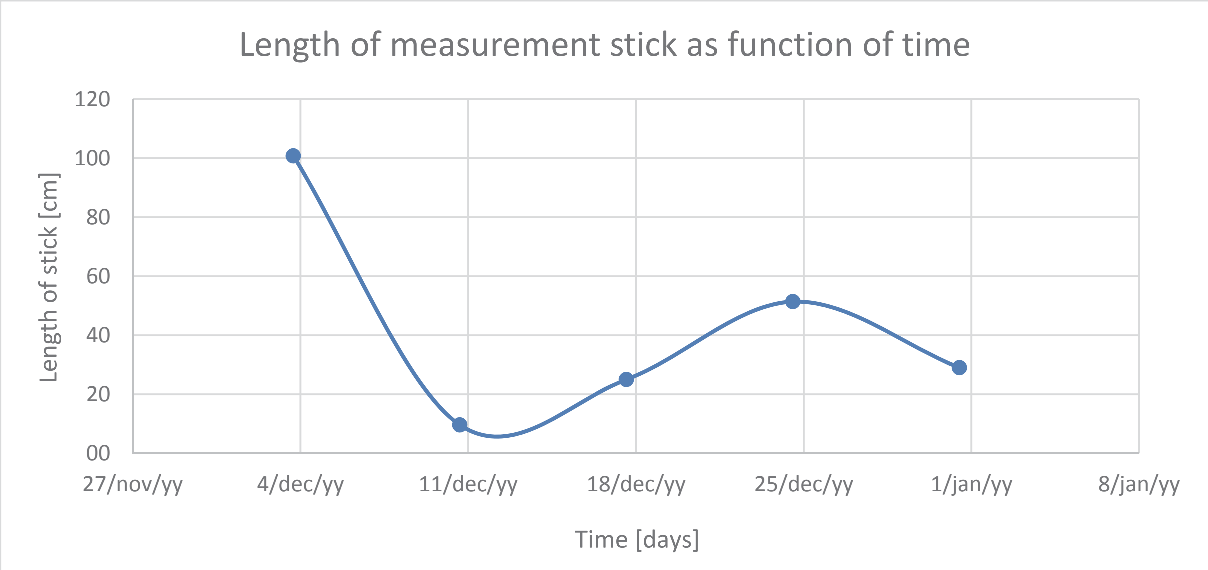



**Figure I.2 - Graph indicating the length of the stick as function of time**

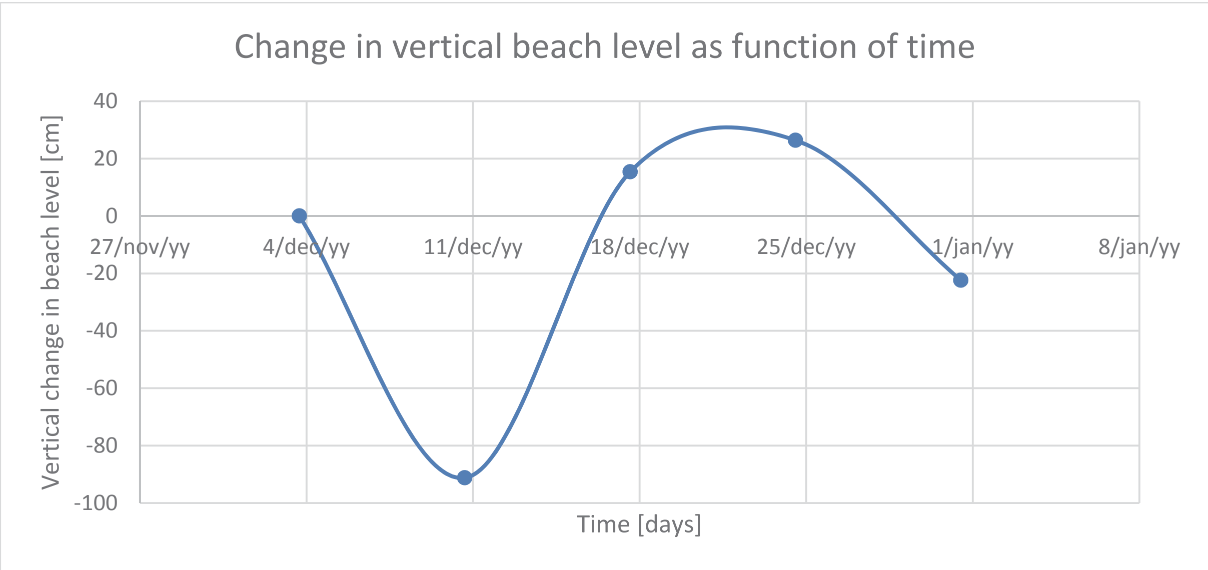



**Figure I.3 - Graph indicating the relative vertical beach change as function of time**

## I.2 Thu Bon river observations

Observations were made for the river part from Tan An to the upstream end of Hoi An, an around 82km stretch of the river. This has taken place in the beginning of december after the peak floods but still above average discharges. Seen from the plastic hanging in the trees the water level with peak discharge present will rise two meters in the upper reach and less than one meter close to Hoi An

**Upper reach**

In the upper reach part normal erosion and accretion is seen in the respective outer and inner bend of the river. Not that much activity on the river and flow velocities are in the order of 2 m/s

**Middle reach**

In the middle reach there was more activity on the river, a few occasions of small amount sand extractions from the plentiful present sandy banks . The flow velocity was present but smaller. Just between the middle and the bottom reach a high water channel is present between the Thu Bon and the Vu Gia. The direction of the inlet suggests the flow goes mostly from the Gia to Thu Bon.

**Bottom reach**

In this part there were around 10-20 sand mining ships, but only in three occasions they were active. The ships were small in size and mostly active at the river banks. The river in this part was very wide and flow velocities were very low. Some signs of sand mining were present, like deep pits in unexpected parts of the river. Also some banks seemed to be excavated (Actually one sand excavation activity on the bank was spotted).

Close to Hoi An there were no signs of erosion and the river area appeared to be reduced compared to maps. The flow velocity was very small <1m/s.

**Interpretations**

Erosion due to sediment blockage of the dam does not seem apparent. A very sandy bed still so depletion of sediment supply in the area is also not likely to reduce the sediment concentration. Sand mining is present (quantities unsure) but seems not to be causing erosion downstream in the river so it is not likely to be a very large influence. Sedimentation in the rivers bottom reach might be an reason for reduced sediment outflow at the mouth since the not peak flow velocity is very small  in the bottom reach.

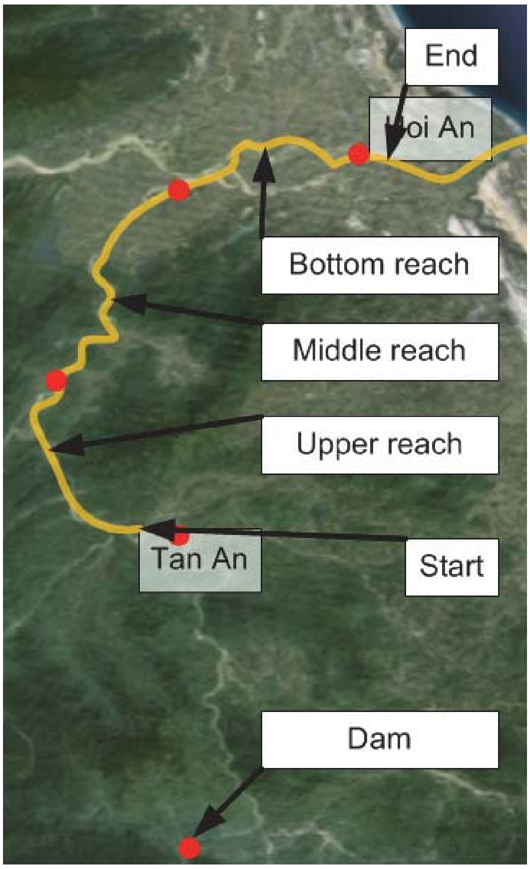



Figure I.4 - Observations map

Figure I.5 - Fieldwork river observation

Figure I.6 - Sand mining example

## I.3 Sediment samples analysis

On the 24th of December sediment samples from the sea bottom several kilometres offshore at the East Sea/South China Sea were taken for an analysis to find a suitable sand extraction location. For the proposed beach nourishment a sand source is needed and from an economic point of view, it is preferred to get it from a nearby location. The location of each sediment sample taken is indicated in Figure I.7. For every sediment sample the grain size distribution and the type of sediment is determined, which is given in the data sheets at the end of this paragraph. The same is done for the native beach sand at several locations along Cua Dai Beach and the shoreline more northwards. With this information it is possible to determine if the sediment at that specific location in the sea is suitable for nourishing Cua Dai Beach.

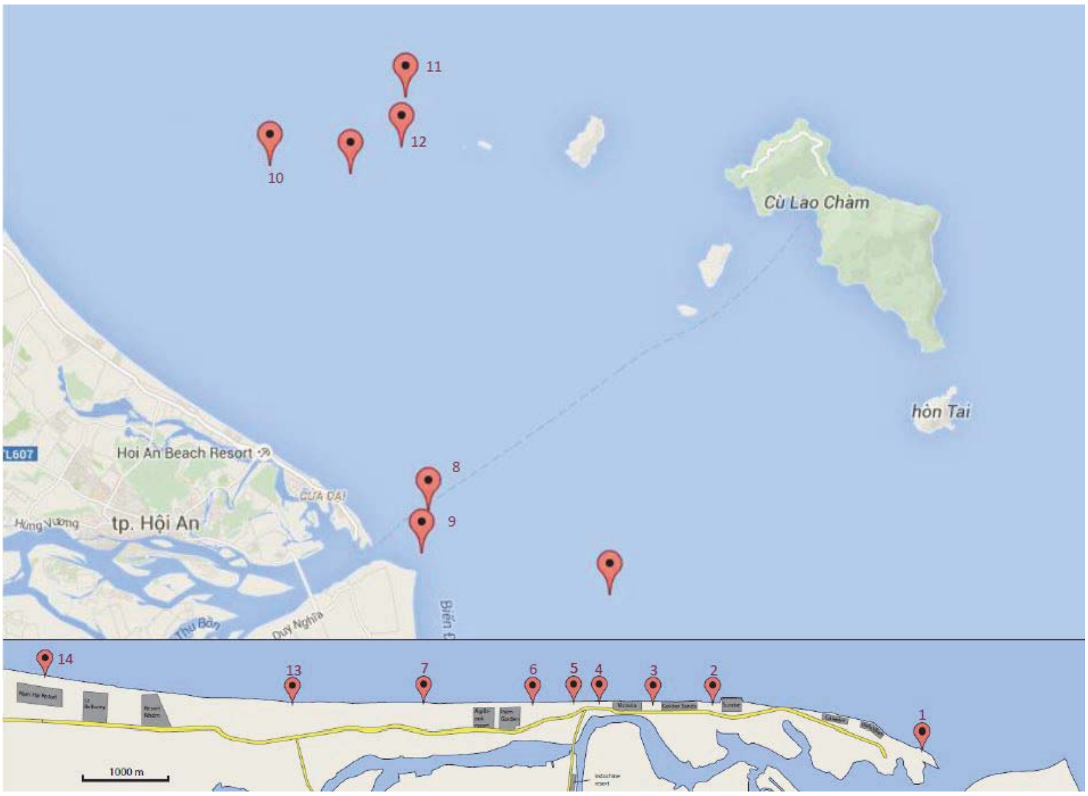



Figure I.7 - Locations of the sediment samples

In total fourteen samples are taken, nine from the beach and five from the sea bed. All the beach samples (1 until 7, 13 and 14) and the ebb tidal delta samples (8 and 9) are sand samples. The locations of the samples from the beach start at the spit near the river mouth and ends at Ha My. Two of the sea samples were taken in front of the river mouth at the ebb tidal delta and the three other samples north of Cham Island. Next to these fourteen samples mud was observed south and north of Cham Island (indicated with the red dots in Figure I.7 without a number).

Figure I.8 - Sieves

### I.3.1 Method

First the sand samples were analysed by the dry and wet sieving method. For the grain size distribution a sieve analysis is used with sieves of the ASTM Standard, see Figure I.8. It shows the sieves used at dry (2.00mm - 1.00mm - 0.500mm - 0.250mm) and wet sieving method (0.100mm - 0.075mm - 0.063mm).

Note that the 0.100mm sieve is not an ASTM standard, but due to a lack of ASTM sieves, 0.100mm sieve was included for a better fit of the grain size distribution. From the results of this grain size distribution the percentages of fines, sand and gravel are determined and also the gradation of the soil. After that the mud samples were analysed by using a hydrometer test. With the fall velocity of the fines in water the particle diameter is calculated and this way the grain size distribution is determined.

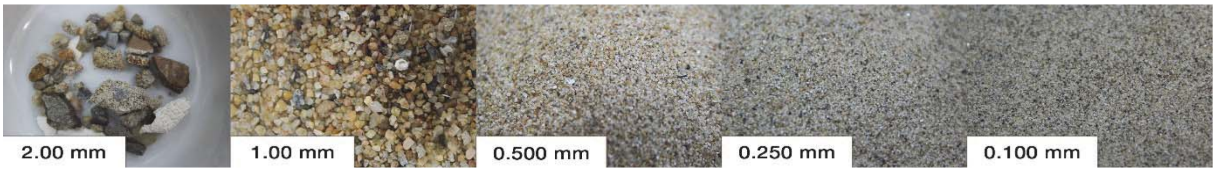



Figure I.9 - Gradation of soil by dry sieving method

A way of representing grain sizes in a soil is by analysing the corresponding grain size distribution curve. It is a mathematical function that defines the relative mass percentages of particles in a soil mixture, according to size. Three soil parameters can be determined from the curve:

- *Effective size ($D_{10}$).* A measure of particle size range ($D_{10}$= the grain diameter, for which 10% of the sample will be finer).
- *Uniformity coefficient ($C_u$).* A measure in variation in particle sizes, given by the ratio:
$$C_u = \frac{D_{60}}{D_{10}}$$
- *Coefficient of curvature ($C_c$).* A measure of the shape of the particle size curve, given by:
$$C_c = \frac{{D_{30}}^2}{D_{10} \cdot D_{60}}$$

Certain coefficients lead to different kind of grain distribution curves. This is shown in Figure I.10. How the coefficients determine the type of soil can furthermore be seen in the Table I.2 below.

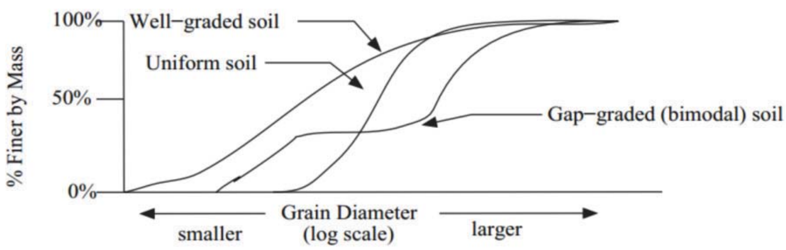
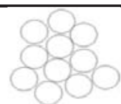
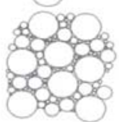



Figure I.10 - Grain size distribution curve (Verruijt, 2012)

Table I.2 - Classification of soils (Verruijt, 2012)

| Soil gradation | | | |
|---|---|---|---|
| Shape of grading curve | $C_u$ | $C_c$ | Schematisation |
| Very uniform, poorly graded | <5 | <1 |  |
| Medium uniform, gap graded | 5 | <1 |  |
| Non-uniform, well graded | >5 | $1<C_c<3$ |  |

### I.3.2 Results overview

The results from the grain size distributions of all the samples are given in Table I.2.

**Table I.3 - Grain Size Distribution Curve Results**

| | D10 [mm] | D30 [mm] | D50 [mm] | D60 [mm] | D90 [mm] | Gravel [%] | Sand [%] | Fines [%] | $C_u$ | $C_c$ |
|---|---|---|---|---|---|---|---|---|---|---|
| **Sample 1** | 0.13 | 0.23 | 0.34 | 0.41 | 0.77 | 0.03 | 99.31 | 0.66 | 3.15 | 0.99 |
| **Sample 2** | 0.14 | 0.25 | 0.38 | 0.44 | 0.79 | 0.03 | 98.99 | 0.99 | 3.14 | 1.01 |
| **Sample 3** | 0.22 | 0.33 | 0.42 | 0.48 | 0.78 | 0 | 99.26 | 0.74 | 2.18 | 1.03 |
| **Sample 4** | 0.12 | 0.17 | 0.23 | 0.28 | 0.63 | 0.74 | 96.15 | 3.11 | 2.33 | 0.86 |
| **Sample 5** | 0.15 | 0.27 | 0.45 | 0.55 | 0.87 | 0.12 | 98.98 | 0.89 | 3.67 | 0.88 |
| **Sample 6** | 0.14 | 0.21 | 0.29 | 0.34 | 0.54 | 0 | 99.33 | 0.67 | 2.43 | 0.93 |
| **Sample 7** | 0.13 | 0.19 | 0.27 | 0.32 | 0.48 | 0 | 98.66 | 1.34 | 2.46 | 0.87 |
| **Sample 8** | 0.14 | 0.20 | 0.30 | 0.35 | 0.62 | 0.06 | 98.31 | 1.62 | 2.5 | 0.82 |
| **Sample 9** | 0.26 | 0.37 | 0.48 | 0.55 | 0.84 | 0.17 | 98.88 | 0.95 | 2.12 | 0.96 |
| **Sample 10** | 0.00 | 0.063 | 0.083 | 0.086 | 0.12 | 0 | 71.20 | 28.80 | - | - |
| **Sample 11** | 0.00 | 0.045 | 0.061 | 0.067 | 0.085 | 0 | 41.20 | 58.80 | - | - |
| **Sample 12** | 0.00 | 0.060 | 0.084 | 0.086 | 0.13 | 0 | 64.20 | 35.80 | - | - |
| **Sample 13** | 0.15 | 0.23 | 0.32 | 0.36 | 0.55 | 0 | 99.24 | 0.72 | 2.4 | 0.98 |
| **Sample 14** | 0.13 | 0.19 | 0.27 | 0.31 | 0.46 | 0 | 99.09 | 0.91 | 2.38 | 0.9 |

From the results shown in Table I.3 it can be concluded that all samples are poorly graded and have a very uniform grading curve. Using the grain size distribution diagrams and table, the following observations can be made:

- Sample 4 contains more fines. This is because this sample is taken from the dunes behind the small geotextile sandbags. Dunes normally contain more fines or finer sand.
- Sample 5 is the least uniform graded soil as it has the highest uniformity coefficient $C_u$.
- Sample 3 has higher content of coarse grains compared to the other samples.
- Sample 9 is the most uniform graded soil as it has the lowest uniformity coefficient $C_u$.
- All the beach samples (Sample 1 until 7, 13 and 14), except for sample 4, have all quite similar properties. All have a very high content of sand particles and a very low content of fines and gravel. Next to that these samples have quite similar uniformity coefficients and curvature coefficients. This can be explained by the fact that the samples are taken from the beach within a small range of ten kilometres, so properties are expected to be the same.
- Sample 8 and Sample 9 show a little difference in properties. Both samples are taken close to each other in the ebb tidal delta. Sample 9 contains coarser sand particles than sample 8, however the percentages of sand, gravel and fines content are similar. Also the uniformity and curvature coefficients are quite similar. The difference in size of the sand particles can be explained by the fact that sample 8 is taken several tens of meters further away from the river mouth and smaller particles can travel further before depositing on the seabed.

Figure I.11 shows the grain size distributions of all soil samples in one single graph. Sample 1- 9, 13 and 14 are all in the range of medium sand and show more or less the same curve. Samples 10, 11 and 12 are taken from the seabed and indicate very fine sand and fines. These samples have a steep curve which indicates a very poor soil gradation. In Figure I.12 the range of beach samples is depicted together with the sea samples. It can be seen that samples 8 and 9, which are taken from the river delta, match with all the beach samples. Samples 10, 11 and 12 are taken several kilometres offshore. They contain a lot of fines, which does not match the native beach sand.

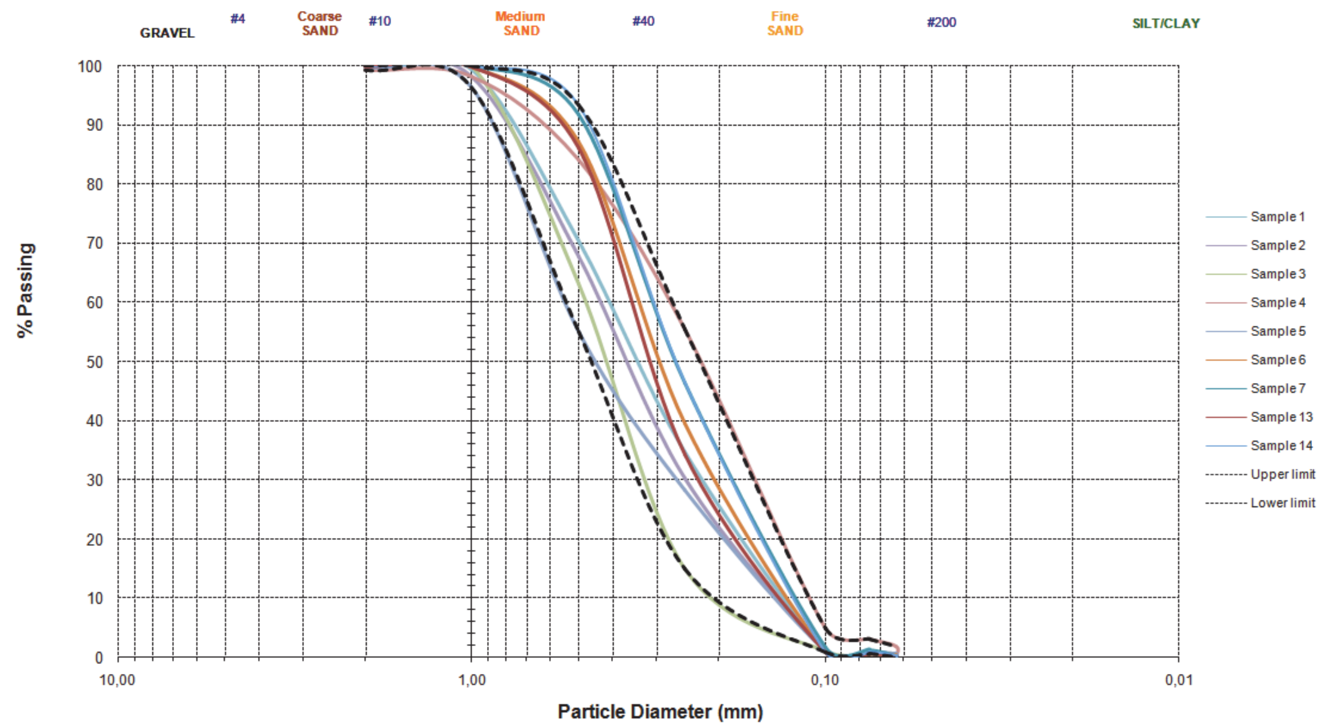



Figure I.11 - Grain size distributions of beach samples

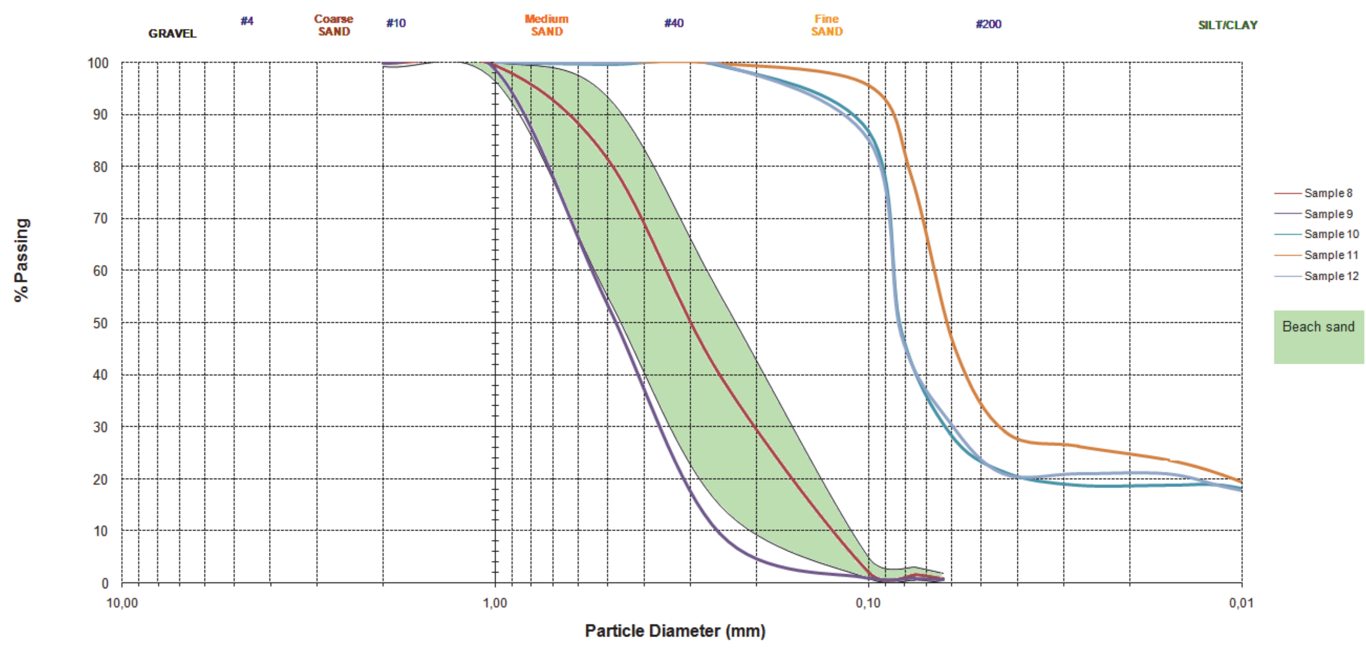



Figure I.12 - Grain size distributions of sea samples compared to beach sand

### I.3.3 Conclusion

In conclusion it can be said, following the observations done during the obtaining of the sediment samples and the results of the sediment sample analysis, that the sand in the ebb tidal delta has similar properties as the sand from the beach. Grain sizes of the sand further away from the river mouth (location 8) is more similar to the grain sizes of the sand from the beach than the grain size of the sand closer to the river mouth (location 9).

At the locations north (locations 10, 11 and 12) and south of Cham Island (at a distance of at least 6 km from the beach) there is only mud and that is why those locations are not suitable as source for the nourishment. Due to this information the entire area around Cham Island and beyond Cham Island are not suitable for sand extraction.

Further investigation is possible closer than 6 km to the beach and further northwards to the city of Danang and further south from Cham Island. However, further away from the nourishment location the costs will rise. That is why further investigation to a suitable sand extraction location is only advised if sand extraction closer than 6 km to the beach is desirable, this is shown in Figure I.13.

Nevertheless, at the location of sample 8 (in front of the river mouth) there might be a suitable sand extraction location if there is enough sand available at that location in the ebb tidal delta. According to the calculation of the sand balance there should be a large amount of sand at the foreshore.

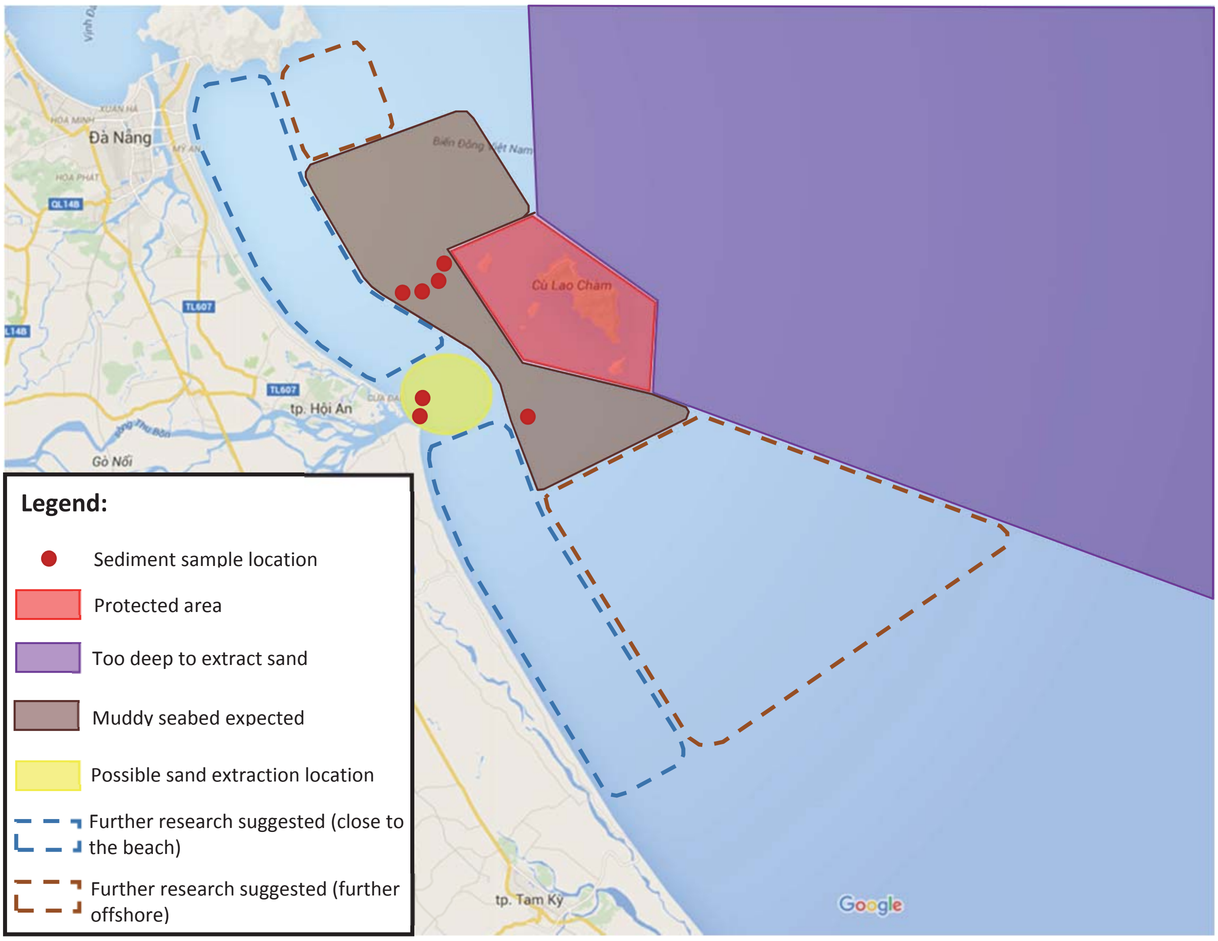



Figure I.13 - Research locations seabed East Sea / South China Sea

# Sieve Analysis Data Sheet

ASTM E 11-70

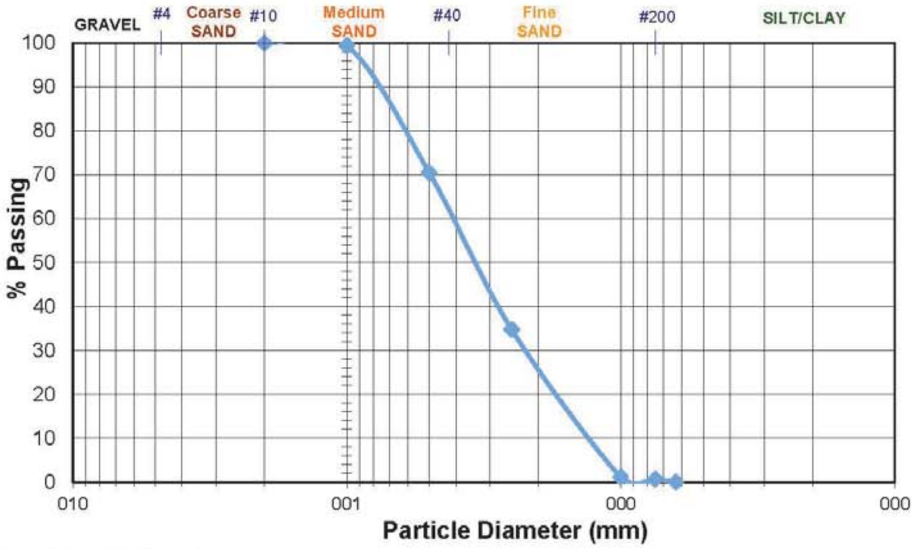
| | | | |
|---|---|---|---|
| **Project Name:** | Project Hoi An | **TestedBy:** | Joep Fila |
| **Lab location:** | WRU, Hanoi | | Roel van Noort |
| **Sample No:** | 1 | **CheckedBy:** | Richard Marijnissen |
| **Sample location:** | Spit | **Test Number:** | 1 |
| **Date taken:** | 28-12-2015 | **Date:** | 6-1-2016 |

**Weight of Dry Sample (g):** 396,82

**USCS SoilClassification:** SP - Poorlygradedsand

**AASHTO SoilClassification:** A-3

| SieveNumber | Diameter (mm) | Cumulativeweight (g) | SoilRetained (g) | SoilRetained (%) | Soil Passing (%) |
|---|---|---|---|---|---|
| #10 | 2,00 | 0,12 | 0,12 | 0,03 | 99,97 |
| #18 | 1,00 | 2,30 | 2,18 | 0,55 | 99,42 |
| #35 | 0,500 | 117,30 | 115,00 | 28,98 | 70,44 |
| #60 | 0,250 | 259,05 | 141,75 | 35,72 | 34,72 |
| / | 0,100 | 392,26 | 133,21 | 33,57 | 1,15 |
| #200 | 0,075 | 394,22 | 1,96 | 0,49 | 0,66 |
| | 0,063 | 396,82 | 2,60 | 0,66 | 0,00 |
| **Pan** | | | | | |
| | | | **TOTAL:** | **396,82** | **100,0** |




**Grain Size Distribution Curve Results:**

| | | | | | |
|---|---|---|---|---|---|
| **% Gravel:** | 0,03 | $D_{10}$: | 0.13 mm | $C_u$: | 3,15 |
| **% Sand:** | 99,31 | $D_{30}$: | 0.23 mm | $C_c$: | 0,99 |
| **% Fines:** | 0,66 | $D_{50}$: | 0.34 mm | | |
| | | $D_{60}$: | 0.41 mm | | |
| | | $D_{90}$: | 0.77 mm | | |

# Sieve Analysis Data Sheet

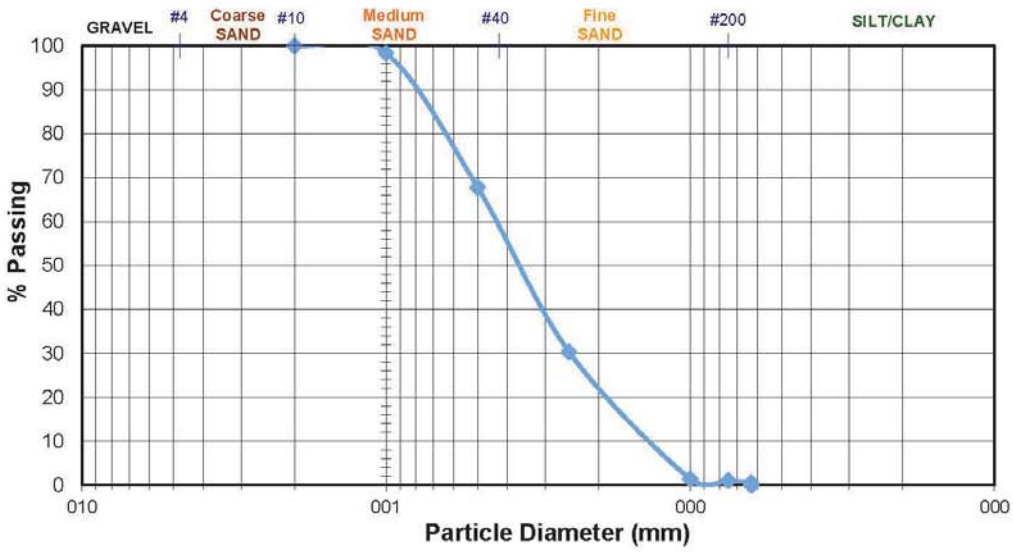
ASTM E 11-70

| | | | |
|---|---|---|---|
| **Project Name:** | Project Hoi An | **TestedBy:** | Joep Fila |
| **Lab location:** | WRU, Hanoi | | Roel van Noort |
| **Sample No:** | 2 | **CheckedBy:** | Richard Marijnissen |
| **Sample location:** | Sunrise - Golden Sands | **Test Number:** | 1 |
| **Date taken:** | 24-12-2015 | **Date:** | 6-1-2016 |

**Weight of Dry Sample (g):** 400,00 **USCS SoilClassification:** SP - Poorlygradedsand

**AASHTO SoilClassification:** A-3

| SieveNumber | Diameter (mm) | Cumulativeweight (g) | SoilRetained (g) | SoilRetained (%) | Soil Passing (%) |
|---|---|---|---|---|---|
| #10 | 2,00 | 0,11 | 0,11 | 0,03 | 99,97 |
| #18 | 1,00 | 6,76 | 6,65 | 1,66 | 98,31 |
| #35 | 0,500 | 128,95 | 122,19 | 30,55 | 67,76 |
| #60 | 0,250 | 278,95 | 150,00 | 37,50 | 30,26 |
| / | 0,100 | 394,56 | 115,61 | 28,90 | 1,36 |
| #200 | 0,075 | 396,05 | 1,49 | 0,37 | 0,99 |
| #230 | 0,063 | 397,93 | 1,88 | 0,47 | 0,52 |
| | 0,063 | 400,00 | 2,07 | 0,52 | 0,00 |
| **Pan** | | | | | |
| | | | **TOTAL:** | **400,00** | **100,0** |




**Grain Size Distribution Curve Results:**

| | | | | | |
|---|---|---|---|---|---|
| **% Gravel:** | 0,03 | **$D_{10}$:** | 0.14 mm | **$C_u$:** | 3,14 |
| **% Sand:** | 98,99 | **$D_{30}$:** | 0.25 mm | **$C_c$:** | 1,01 |
| **% Fines:** | 0,99 | **$D_{50}$:** | 0.38 mm | | |
| | | **$D_{60}$:** | 0.44 mm | | |
| | | **$D_{90}$:** | 0.79 mm | | |

# Sieve Analysis Data Sheet

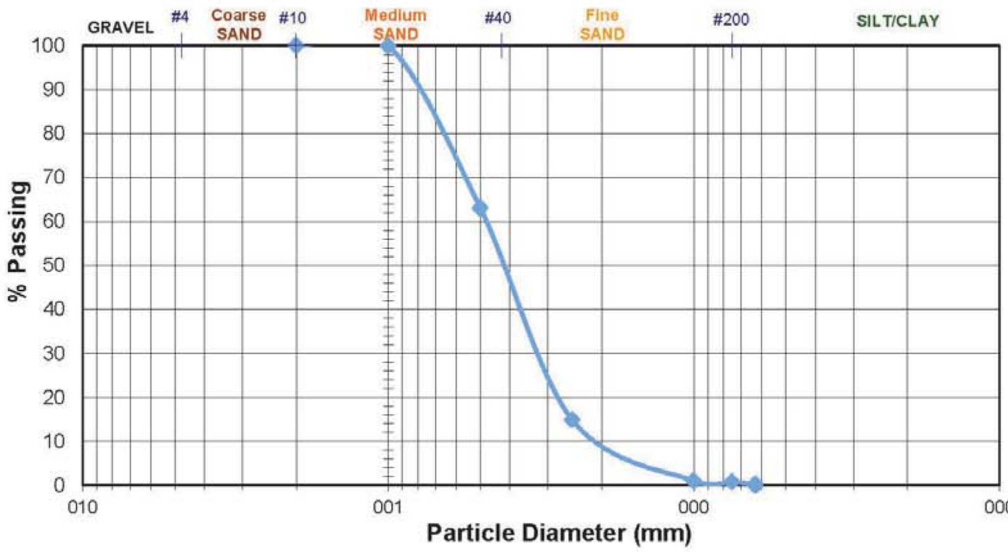
ASTM E 11-70

| | | | |
|---|---|---|---|
| **Project Name:** | Project Hoi An | **TestedBy:** | Joep Fila |
| **Lab location:** | WRU, Hanoi | | Roel van Noort |
| **Sample No:** | 3 | **CheckedBy:** | Richard Marijnissen |
| **Sample location:** | Golden Sands - Victoria | **Test Number:** | 1 |
| **Date taken:** | 28-12-2015 | **Date:** | 6-1-2016 |

**Weight of Dry Sample (g):** 414,04  **USCS SoilClassification:** SP - Poorlygradedsand

**AASHTO SoilClassification:** A-3

| SieveNumber | Diameter (mm) | Cumulativeweight (g) | SoilRetained (g) | SoilRetained (%) | Soil Passing (%) |
|---|---|---|---|---|---|
| #10 | 2,00 | 0,00 | 0,00 | 0,00 | 100,00 |
| #18 | 1,00 | 0,03 | 0,03 | 0,01 | 99,99 |
| #35 | 0,500 | 152,69 | 152,66 | 36,87 | 63,12 |
| #60 | 0,250 | 352,40 | 199,71 | 48,23 | 14,89 |
| / | 0,100 | 409,95 | 57,55 | 13,90 | 0,99 |
| #200 | 0,075 | 410,97 | 1,02 | 0,25 | 0,74 |
| #230 | 0,063 | 413,02 | 2,05 | 0,50 | 0,25 |
| | 0,063 | 414,04 | 1,02 | 0,25 | 0,00 |
| **Pan** | | | | | |
| | | | **TOTAL:** | **414,04** | **100,0** |




**Grain Size Distribution Curve Results:**

| | | | | | |
|---|---|---|---|---|---|
| **% Gravel:** | 0,00 | $D_{10}$: | 0.22 mm | $C_u$: | 2,18 |
| **% Sand:** | 99,26 | $D_{30}$: | 0.33 mm | $C_c$: | 1,03 |
| **% Fines:** | 0,74 | $D_{50}$: | 0.42 mm | | |
| | | $D_{60}$: | 0.48 mm | | |
| | | $D_{90}$: | 0.78 mm | | |

## Sieve Analysis Data Sheet

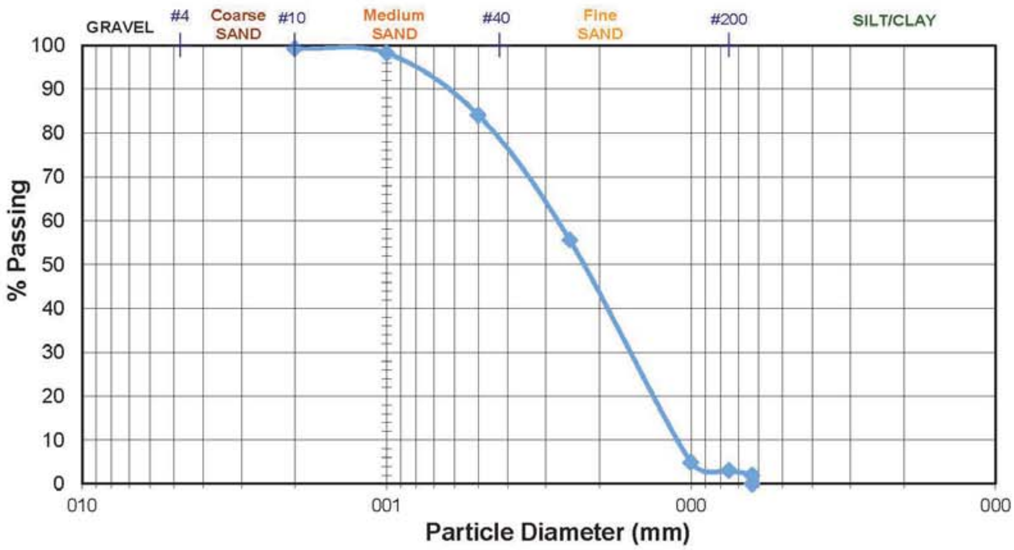
ASTM E 11-70

| | | | |
|---|---|---|---|
| **Project Name:** | Project Hoi An | **TestedBy:** | Joep Fila |
| **Lab location:** | WRU, Hanoi | | Roel van Noort |
| **Sample No:** | 4 | **CheckedBy:** | Richard Marijnissen |
| **Sample location:** | Geotextilesandbags | **Test Number:** | 1 |
| **Date taken:** | 28-12-2015 | **Date:** | 6-1-2016 |

**Weight of Dry Sample (g):** 400,00 **USCS SoilClassification:** SP - Poorlygradedsand

**AASHTO SoilClassification:** A-3

| SieveNumber | Diameter (mm) | Cumulativeweight (g) | SoilRetained (g) | SoilRetained (%) | Soil Passing (%) |
|---|---|---|---|---|---|
| #10 | 2,00 | 2,95 | 2,95 | 0,74 | 99,26 |
| #18 | 1,00 | 7,12 | 4,17 | 1,04 | 98,22 |
| #35 | 0,500 | 63,68 | 56,56 | 14,14 | 84,08 |
| #60 | 0,250 | 177,77 | 114,09 | 28,52 | 55,56 |
| / | 0,100 | 380,46 | 202,69 | 50,67 | 4,89 |
| #200 | 0,075 | 387,55 | 7,09 | 1,77 | 3,11 |
| #230 | 0,063 | 392,14 | 4,59 | 1,15 | 1,97 |
| | 0,063 | 400,00 | 7,86 | 1,96 | 0,00 |
| Pan | | | | | |
| | | | **TOTAL:** | **400** | **100,0** |




**Grain Size Distribution Curve Results:**

| | | | | | |
|---|---|---|---|---|---|
| **% Gravel:** | 0,74 | $D_{10}$: | 0.12 mm | $C_u$: | 2,33 |
| **% Sand:** | 96,15 | $D_{30}$: | 0.17 mm | $C_c$: | 0,86 |
| **% Fines:** | 3,11 | $D_{50}$: | 0.23 mm | | |
| | | $D_{60}$: | 0.28 mm | | |
| | | $D_{90}$: | 0.63 mm | | |

# Sieve Analysis Data Sheet

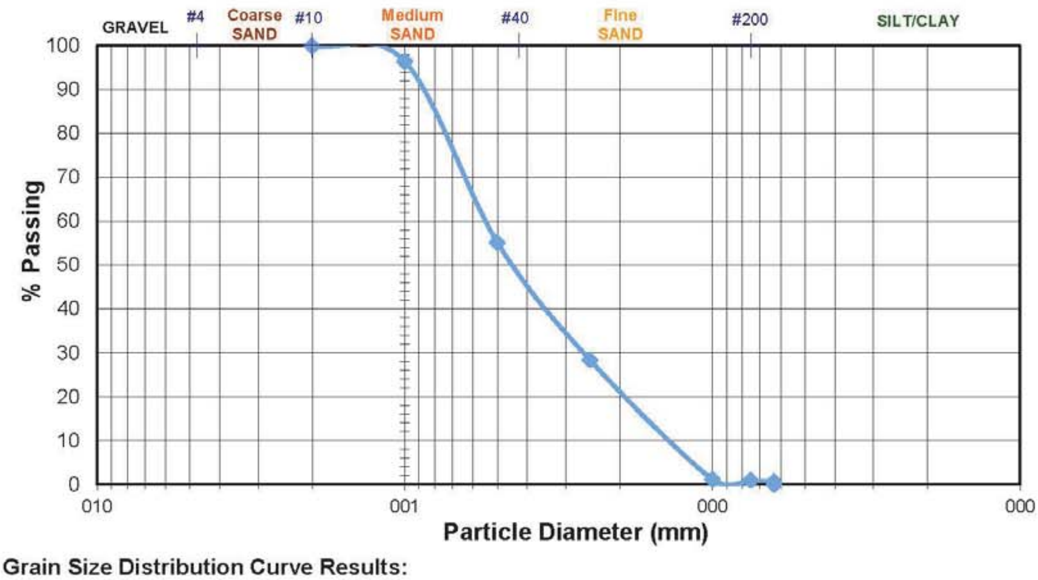
ASTM E 11-70

| | | | |
|---|---|---|---|
| **Project Name:** | Project Hoi An | **TestedBy:** | Joep Fila |
| **Lab location:** | WRU, Hanoi | | Roel van Noort |
| **Sample No:** | 5 | **CheckedBy:** | Richard Marijnissen |
| **Sample location:** | Geotubebesidessandbags | **Test Number:** | 1 |
| **Date taken:** | 28-12-2015 | **Date:** | 6-1-2016 |

**Weight of Dry Sample (g):** 400,05 **USCS SoilClassification:** SP - Poorlygradedsand

**AASHTO SoilClassification:** A-3

| SieveNumber | Diameter (mm) | Cumulativeweight (g) | SoilRetained (g) | SoilRetained (%) | Soil Passing (%) |
|---|---|---|---|---|---|
| #10 | 2,00 | 0,50 | 0,50 | 0,12 | 99,88 |
| #18 | 1,00 | 14,55 | 14,05 | 3,51 | 96,36 |
| #35 | 0,500 | 179,58 | 165,03 | 41,25 | 55,11 |
| #60 | 0,250 | 286,64 | 107,06 | 26,76 | 28,35 |
| / | 0,100 | 395,54 | 108,90 | 27,22 | 1,13 |
| #200 | 0,075 | 396,48 | 0,94 | 0,23 | 0,89 |
| #230 | 0,063 | 397,59 | 1,11 | 0,28 | 0,61 |
| | 0,063 | 400,05 | 2,46 | 0,61 | 0,00 |
| **Pan** | | | | | |
| | | | **TOTAL:** | **400,05** | **100,0** |




**Grain Size Distribution Curve Results:**

| | | | | | |
|---|---|---|---|---|---|
| **% Gravel:** | 0,12 | **$D_{10}$:** | 0.15 mm | **$C_u$:** | 3,67 |
| **% Sand:** | 98,98 | **$D_{30}$:** | 0.27 mm | **$C_c$:** | 0,88 |
| **% Fines:** | 0,89 | **$D_{50}$:** | 0.45 mm | | |
| | | **$D_{60}$:** | 0.55 mm | | |
| | | **$D_{90}$:** | 0.87 mm | | |

# Sieve Analysis Data Sheet

ASTM E 11-70

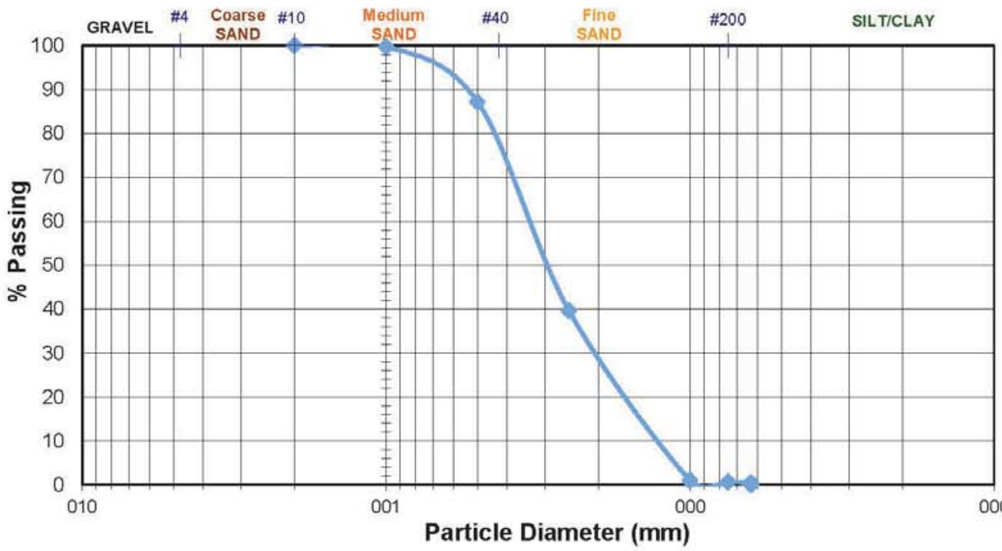
| | | | |
|---|---|---|---|
| **Project Name:** | Project Hoi An | **TestedBy:** | Joep Fila |
| **Lab location:** | WRU, Hanoi | | Roel van Noort |
| **Sample No:** | 6 | **CheckedBy:** | Richard Marijnissen |
| **Sample location:** | Camera location | **Test Number:** | 1 |
| **Date taken:** | 28-12-2015 | **Date:** | 6-1-2016 |

**Weight of Dry Sample (g):** 370,06

**USCS SoilClassification:** SP - Poorlygradedsand

**AASHTO SoilClassification:** A-3

| SieveNumber | Diameter (mm) | Cumulativeweight (g) | SoilRetained (g) | SoilRetained (%) | Soil Passing (%) |
|---|---|---|---|---|---|
| #10 | 2,00 | 0,00 | 0,00 | 0,00 | 100,00 |
| #18 | 1,00 | 0,66 | 0,66 | 0,18 | 99,82 |
| #35 | 0,500 | 47,53 | 46,87 | 12,67 | 87,16 |
| #60 | 0,250 | 223,51 | 175,98 | 47,55 | 39,60 |
| / | 0,100 | 366,44 | 142,93 | 38,62 | 0,98 |
| #200 | 0,075 | 367,57 | 1,13 | 0,31 | 0,67 |
| #230 | 0,063 | 368,53 | 0,96 | 0,26 | 0,41 |
| | 0,063 | 370,06 | 1,53 | 0,41 | 0,00 |
| **Pan** | | | | | |
| | | | **TOTAL:** | **370,06** | **100,0** |




**Grain Size Distribution Curve Results:**

| | | | | | |
|---|---|---|---|---|---|
| **% Gravel:** | 0,00 | $D_{10}$: | 0.14 mm | $C_u$: | 2,43 |
| **% Sand:** | 99,33 | $D_{30}$: | 0.21 mm | $C_c$: | 0,93 |
| **% Fines:** | 0,67 | $D_{50}$: | 0.29 mm | | |
| | | $D_{60}$: | 0.34 mm | | |
| | | $D_{90}$: | 0.54 mm | | |

# Sieve Analysis Data Sheet

ASTM E 11-70

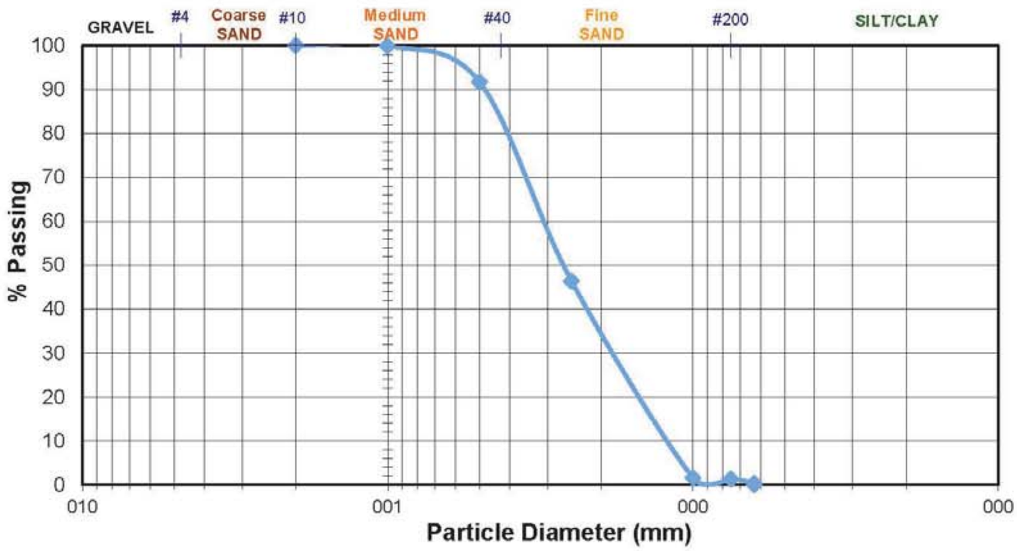
| | | | |
|---|---|---|---|
| **Project Name:** | Project Hoi An | **TestedBy:** | Joep Fila |
| **Lab location:** | WRU, Hanoi | | Roel van Noort |
| **Sample No:** | 7 | **CheckedBy:** | Richard Marijnissen |
| **Sample location:** | Agribank resort | **Test Number:** | 1 |
| **Date taken:** | 28-12-2015 | **Date:** | 6-1-2016 |

**Weight of Dry Sample (g):** 420,02

**USCS SoilClassification:** SP - Poorlygradedsand

**AASHTO SoilClassification:** A-3

| SieveNumber | Diameter (mm) | Cumulativeweight (g) | SoilRetained (g) | SoilRetained (%) | Soil Passing (%) |
|---|---|---|---|---|---|
| #10 | 2,00 | 0,00 | 0,00 | 0,00 | 100,00 |
| #18 | 1,00 | 0,26 | 0,26 | 0,06 | 99,94 |
| #35 | 0,500 | 34,89 | 34,63 | 8,27 | 91,67 |
| #60 | 0,250 | 224,64 | 189,75 | 45,31 | 46,36 |
| / | 0,100 | 412,10 | 187,46 | 44,76 | 1,60 |
| #200 | 0,075 | 413,17 | 1,07 | 0,26 | 1,34 |
| #230 | 0,063 | 417,48 | 4,31 | 1,03 | 0,32 |
| | 0,063 | 418,80 | 1,32 | 0,32 | 0,00 |
| **Pan** | | | | | |
| | | | **TOTAL:** | **418,8** | **100,0** |




**Grain Size Distribution Curve Results:**

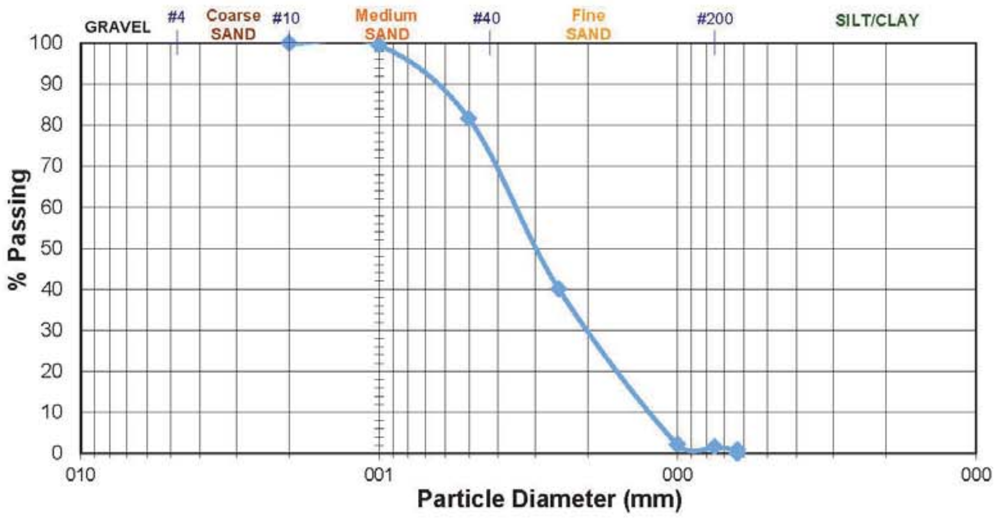
| | | | | | |
|---|---|---|---|---|---|
| **% Gravel:** | 0,00 | **$D_{10}$:** | 0.13 mm | **$C_u$:** | 2,46 |
| **% Sand:** | 98,66 | **$D_{30}$:** | 0.19 mm | **$C_c$:** | 0,87 |
| **% Fines:** | 1,34 | **$D_{50}$:** | 0.27 mm | | |
| | | **$D_{60}$:** | 0.32 mm | | |
| | | **$D_{90}$:** | 0.48 mm | | |

# Sieve Analysis Data Sheet

ASTM E 11-70

| | | | |
|---|---|---|---|
| **Project Name:** | Project Hoi An | **TestedBy:** | Joep Fila<br>Roel van Noort |
| **Lab location:** | WRU, Hanoi | | |
| **Sample No:** | 8 | **CheckedBy:** | Richard Marijnissen |
| **Coordinates:** | N 15 52 580 | **Test Number:** | 1 |
| | E 108 23 893 | **Date:** | 6-1-2016 |
| **Date taken:** | 24-12-2015 | | |
| **Weight of Dry Sample (g):** | 360,04 | **USCS SoilClassification:** | SP - Poorlygradedsand |
| | | **AASHTO SoilClassification:** | A-3 |

| SieveNumber | Diameter (mm) | Cumulativeweight (g) | SoilRetained (g) | SoilRetained (%) | Soil Passing (%) |
|---|---|---|---|---|---|
| #10 | 2,00 | 0,22 | 0,22 | 0,06 | 99,94 |
| #18 | 1,00 | 2,00 | 1,78 | 0,49 | 99,44 |
| #35 | 0,500 | 66,47 | 64,47 | 17,91 | 81,54 |
| #60 | 0,250 | 215,86 | 149,39 | 41,49 | 40,04 |
| / | 0,100 | 352,40 | 136,54 | 37,93 | 2,12 |
| #200 | 0,075 | 354,17 | 1,77 | 0,49 | 1,62 |
| #230 | 0,063 | 357,00 | 2,83 | 0,79 | 0,84 |
| | 0,063 | 360,02 | 3,02 | 0,84 | 0,00 |
| **Pan** | | | | | |
| | | | **TOTAL:** | **360,02** | **100,0** |




**Grain Size Distribution Curve Results:**

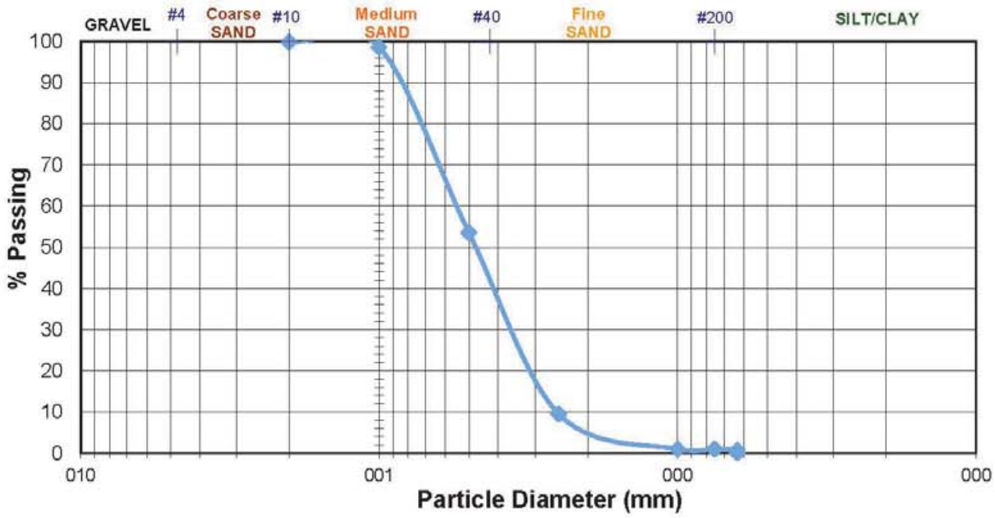
| | | | | | |
|---|---|---|---|---|---|
| **% Gravel:** | 0,06 | $D_{10}$: | 0.14 mm | $C_u$: | 2,50 |
| **% Sand:** | 98,31 | $D_{30}$: | 0.20 mm | $C_c$: | 0,82 |
| **% Fines:** | 1,62 | $D_{50}$: | 0.30 mm | | |
| | | $D_{60}$: | 0.35 mm | | |
| | | $D_{90}$: | 0.62 mm | | |

# Sieve Analysis Data Sheet

ASTM E 11-70

| | | | |
|---|---|---|---|
| **Project Name:** | Project Hoi An | **TestedBy:** | Joep Fila |
| **Lab location:** | WRU, Hanoi | | Roel van Noort |
| **Sample No:** | 9 | **CheckedBy:** | Richard Marijnissen |
| **Coordinates:** | N 15 52 21 | **Test Number:** | 1 |
| | E 108 24 23 | **Date:** | 6-1-2016 |
| **Date taken:** | 24-12-2015 | | |
| **Weight of Dry Sample (g):** | 350,06 | **USCS SoilClassification:** | SP - Poorlygradedsand |
| | | **AASHTO SoilClassification:** | A-3 |

| SieveNumber | Diameter (mm) | Cumulativeweight (g) | SoilRetained (g) | SoilRetained (%) | Soil Passing (%) |
|---|---|---|---|---|---|
| #10 | 2,00 | 0,60 | 0,60 | 0,17 | 99,83 |
| #18 | 1,00 | 5,01 | 4,41 | 1,26 | 98,57 |
| #35 | 0,500 | 162,53 | 157,52 | 45,05 | 53,52 |
| #60 | 0,250 | 316,51 | 153,98 | 44,03 | 9,49 |
| / | 0,100 | 346,22 | 29,71 | 8,50 | 0,99 |
| #200 | 0,075 | 346,36 | 0,14 | 0,04 | 0,95 |
| #230 | 0,063 | 347,14 | 0,78 | 0,22 | 0,73 |
| | 0,063 | 349,69 | 2,55 | 0,73 | 0,00 |
| **Pan** | | | | | |
| | | | **TOTAL:** | **349,69** | **100,0** |




**Grain Size Distribution Curve Results:**

| | | | | | |
|---|---|---|---|---|---|
| **% Gravel:** | 0,17 | **$D_{10}$:** | 0.26 mm | **$C_u$:** | 2,12 |
| **% Sand:** | 98,88 | **$D_{30}$:** | 0.37 mm | **$C_c$:** | 0,96 |
| **% Fines:** | 0,95 | **$D_{50}$:** | 0.48 mm | | |
| | | **$D_{60}$:** | 0.55 mm | | |
| | | **$D_{90}$:** | 0.84 mm | | |

# Hydrometer test Data Sheet

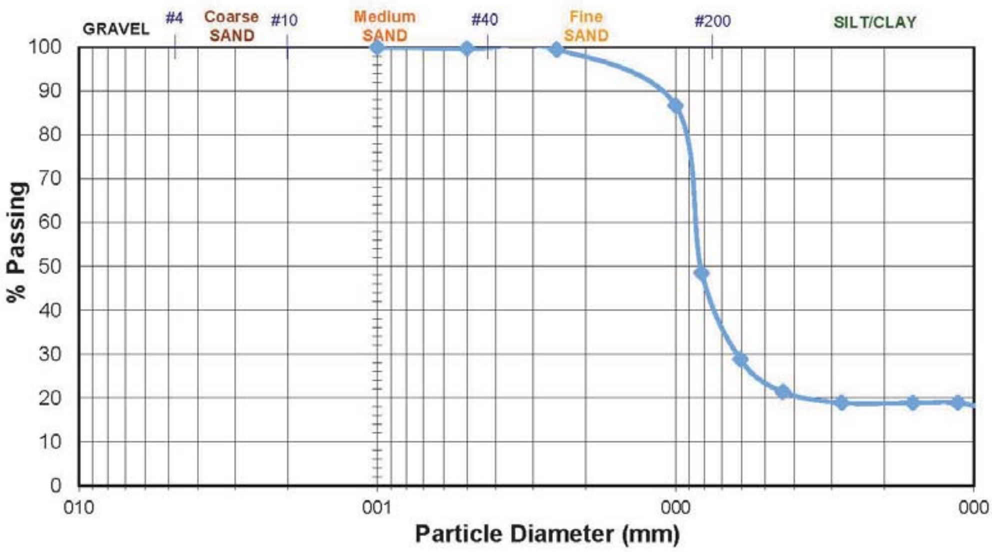
ASTM 152H

| | | | |
|---|---|---|---|
| **Project Name:** | Project Hoi An | **TestedBy:** | Joep Fila |
| **Lab location:** | WRU, Hanoi | | Roel van Noort |
| **Sample No:** | 10 | **CheckedBy:** | Richard Marijnissen |
| **Coordinates:** | N 15 57 652 | **Test Number:** | 1 |
| | E 108 24 072 | **Date:** | 13-1-2016 |
| **Date taken:** | 24-12-2015 | | |

**Weight of Dry Sample (g):** 35,00

**Specificweight (g/cm3)** 2,67

| SieveNumber | Diameter (mm) | Cumulativeweight (g) | SoilRetained (g) | SoilRetained (%) | Soil Passing (%) |
|---|---|---|---|---|---|
| Sieves | 1,00 | 0,00 | 0,00 | 0,00 | 100,00 |
| | 0,500 | 0,11 | 0,11 | 0,31 | 99,69 |
| | 0,250 | 0,18 | 0,07 | 0,20 | 99,49 |
| | 0,100 | 4,66 | 4,48 | 12,80 | 86,69 |
| | | | | | |
| Hydrometer (152H) | **Diameter (mm)** | **Elapsed time (min)** | **Temp. (°C)** | **Hydrometer reading R** | **Soil Passing (%)** |
| | 0,0817 | 0,50 | 21,9 | 17,00 | 48,50 |
| | 0,0606 | 1,00 | 21,9 | 9,00 | 28,80 |
| | 0,0436 | 2,00 | 21,9 | 6,00 | 21,40 |
| | 0,0277 | 5,00 | 21,9 | 5,00 | 18,90 |
| | 0,0160 | 15,00 | 21,9 | 5,00 | 18,90 |
| | 0,0113 | 30,00 | 21,9 | 5,00 | 18,90 |
| | 0,0080 | 60,00 | 21,9 | 4,00 | 16,40 |
| | 0,0066 | 90,00 | 21,9 | 3,00 | 14,00 |
| | 0,0057 | 120,00 | 21,9 | 2,50 | 12,70 |
| | 0,0047 | 180,00 | 21,9 | 2,50 | 12,70 |
| | 0,0041 | 240,00 | 21,9 | 2,50 | 12,70 |
| | 0,0017 | 1440,00 | 21,9 | 2,00 | 11,50 |
| | 0,0000 | | | | 0,00 |
| | | | | | |




**Grain Size Distribution Curve Results:**

| | | | | | |
|---|---|---|---|---|---|
| **% Gravel:** | 0,00 | **$D_{10}$:** | 0 mm | **$C_u$:** | / |
| **% (fine) Sand:** | 71,20 | **$D_{30}$:** | 0,063 mm | **$C_c$:** | / |
| **% Fines:** | 28,80 | **$D_{50}$:** | 0,083 mm | | |
| | | **$D_{60}$:** | 0,086 mm | | |
| | | **$D_{90}$:** | 0,12 mm | | |

# Hydrometer test Data Sheet

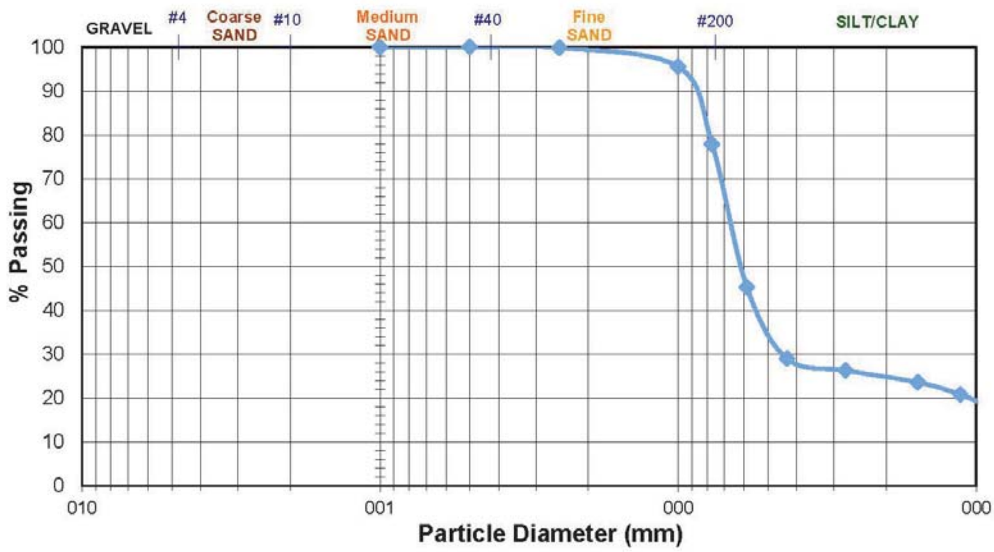
ASTM 152H

| | | | |
|---|---|---|---|
| **Project Name:** | Project Hoi An | **TestedBy:** | Joep Fila |
| **Lab location:** | WRU, Hanoi | | Roel van Noort |
| **Sample No:** | 11 | **CheckedBy:** | Richard Marijnissen |
| **Coordinates:** | N 15 59 05 | **Test Number:** | 1 |
| | E 108 24 07 | **Date:** | 13-1-2016 |
| **Date taken:** | 24-12-2015 | | |

**Weight of Dry Sample (g):** 35,00

**Specificweight (g/cm3)** 2,67

| SieveNumber | Diameter (mm) | Cumulativeweight (g) | SoilRetained (g) | SoilRetained (%) | Soil Passing (%) |
|---|---|---|---|---|---|
| Sieves | 1,00 | 0,00 | 0,00 | 0,00 | 100,00 |
| | 0,500 | 0,00 | 0,00 | 0,00 | 100,00 |
| | 0,250 | 0,05 | 0,05 | 0,14 | 99,86 |
| | 0,100 | 1,56 | 1,51 | 4,31 | 95,54 |
| | | | | | |
| Hydrometer (152H) | **Diameter (mm)** | **Elapsed time (min)** | **Temp. (°C)** | **Hydrometer reading R** | **Soil Passing (%)** |
| | 0,0769 | 0,50 | 21,9 | 26,00 | 77,90 |
| | 0,0588 | 1,00 | 21,9 | 14,00 | 45,30 |
| | 0,0431 | 2,00 | 21,9 | 8,00 | 29,00 |
| | 0,0274 | 5,00 | 21,9 | 7,00 | 26,30 |
| | 0,0157 | 15,00 | 21,9 | 6,00 | 23,60 |
| | 0,0113 | 30,00 | 21,9 | 5,00 | 20,80 |
| | 0,0081 | 60,00 | 21,9 | 3,50 | 16,80 |
| | 0,0066 | 90,00 | 21,9 | 3,00 | 15,40 |
| | 0,0057 | 120,00 | 21,9 | 2,50 | 14,00 |
| | 0,0047 | 180,00 | 21,9 | 2,50 | 14,00 |
| | 0,0041 | 240,00 | 21,9 | 2,00 | 12,70 |
| | 0,0017 | 1440,00 | 21,9 | 1,00 | 10,00 |
| | 0,0000 | | | | 0,00 |
| | | | | | |
| | | | | | |




**Grain Size Distribution Curve Results:**

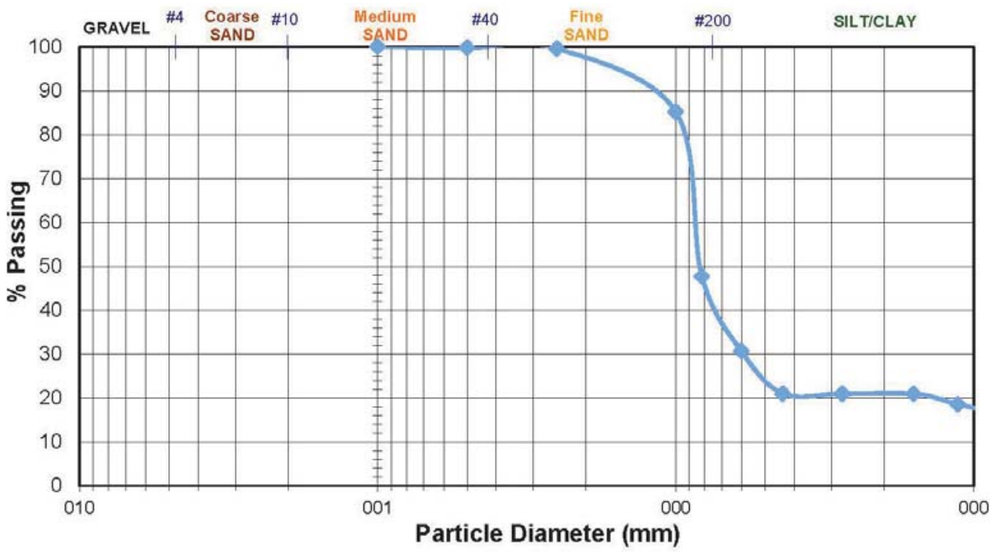
| | | | | | |
|---|---|---|---|---|---|
| **% Gravel:** | 0,00 | $D_{10}$: | 0 mm | **$C_u$:** | / |
| **% (fine) sand:** | 41,2 | **$D_{30}$:** | 0,045 mm | **$C_c$:** | / |
| **% Fines:** | 58,8 | **$D_{50}$:** | 0,061 mm | | |
| | | **$D_{60}$:** | 0,067 mm | | |
| | | **$D_{90}$:** | 0,085 mm | | |

# Hydrometer test Data Sheet
ASTM 152H

| | | | |
|---|---|---|---|
| **Project Name:** | Project Hoi An | **TestedBy:** | Joep Fila |
| **Lab location:** | WRU, Hanoi | | Roel van Noort |
| **Sample No:** | 12 | **CheckedBy:** | Richard Marijnissen |
| **Coordinates:** | N 15 58 21 | **Test Number:** | 1 |
| | E 108 40 11 | **Date:** | 12-1-2016 |
| **Date taken:** | 24-12-2015 | | |

| | |
|---|---|
| **Weight of Dry Sample (g):** | 35,00 |
| **Specificweight (g/cm3)** | 2,67 |

| SieveNumber | Diameter (mm) | Cumulativeweight (g) | SoilRetained (g) | SoilRetained (%) | Soil Passing (%) |
|---|---|---|---|---|---|
| Sieves | 1,00 | 0,00 | 0,00 | 0,00 | 100,00 |
| | 0,500 | 0,06 | 0,06 | 0,17 | 99,83 |
| | 0,250 | 0,14 | 0,08 | 0,23 | 99,60 |
| | 0,100 | 5,18 | 5,04 | 14,40 | 85,20 |
| | | | | | |
| | **Diameter (mm)** | **Elapsed time (min)** | **Temp. (°C)** | **Hydrometer reading R** | **Soil Passing (%)** |
| Hydrometer (152H) | 0,0817 | 0,50 | 21,9 | 17,00 | 47,70 |
| | 0,0602 | 1,00 | 21,9 | 10,00 | 30,70 |
| | 0,0436 | 2,00 | 21,9 | 6,00 | 21,00 |
| | 0,0276 | 5,00 | 21,9 | 6,00 | 21,00 |
| | 0,0159 | 15,00 | 21,9 | 6,00 | 21,00 |
| | 0,0113 | 30,00 | 21,9 | 5,00 | 18,60 |
| | 0,0080 | 60,00 | 21,9 | 4,00 | 16,20 |
| | 0,0066 | 90,00 | 21,9 | 3,00 | 13,70 |
| | 0,0057 | 120,00 | 21,9 | 2,50 | 12,50 |
| | 0,0047 | 180,00 | 21,9 | 2,00 | 11,30 |
| | 0,0041 | 240,00 | 21,9 | 2,00 | 11,30 |
| | 0,0017 | 1440,00 | 21,9 | 1,00 | 8,90 |
| | 0,0000 | | | | 0,00 |
| | | | | | |
| | | | | | |




## Grain Size Distribution Curve Results:

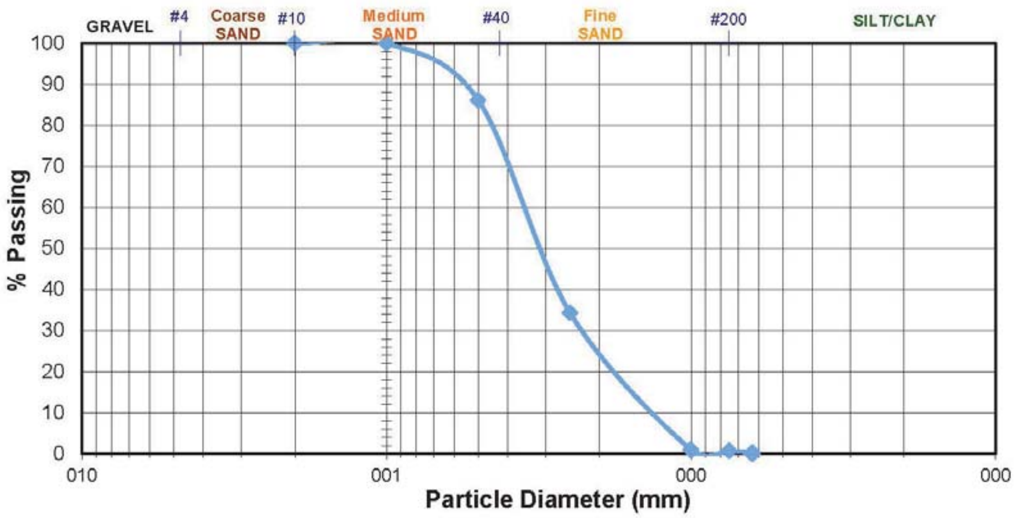
| | | | | | |
|---|---|---|---|---|---|
| **% Gravel:** | 0,00 | $D_{10}$: | 0 mm | $C_u$: | / |
| **% (fine) sand:** | 64,2 | $D_{30}$: | 0,060 mm | $C_c$: | / |
| **% Fines:** | 35,8 | $D_{50}$: | 0,084 mm | | |
| | | $D_{60}$: | 0,086 mm | | |
| | | $D_{90}$: | 0,13 mm | | |

# Sieve Analysis Data Sheet

ASTM E 11-70

| | | | |
|---|---|---|---|
| **Project Name:** | Project Hoi An | **TestedBy:** | Joep Fila |
| **Lab location:** | WRU, Hanoi | | Roel van Noort |
| **Sample No:** | 13 | **CheckedBy:** | Richard Marijnissen |
| **Sample location:** | An Bang Beach | **Test Number:** | 1 |
| **Date taken:** | 28-12-2015 | **Date:** | 6-1-2016 |
| **Weight of Dry Sample (g):** | 412,14 | **USCS SoilClassification:** | SP - Poorlygradedsand |
| | | **AASHTO SoilClassification:** | A-3 |

| SieveNumber | Diameter (mm) | Cumulativeweight (g) | SoilRetained (g) | SoilRetained (%) | Soil Passing (%) |
|---|---|---|---|---|---|
| #10 | 2,00 | 0,15 | 0,15 | 0,04 | 99,96 |
| #18 | 1,00 | 0,42 | 0,27 | 0,07 | 99,90 |
| #35 | 0,500 | 57,30 | 56,88 | 13,83 | 86,07 |
| #60 | 0,250 | 270,09 | 212,79 | 51,72 | 34,35 |
| / | 0,100 | 407,51 | 137,42 | 33,40 | 0,95 |
| #200 | 0,075 | 408,42 | 0,91 | 0,22 | 0,72 |
| #230 | 0,063 | 410,18 | 1,76 | 0,43 | 0,30 |
| | 0,063 | 411,40 | 1,22 | 0,30 | 0,00 |
| **Pan** | | | | | |
| | | | **TOTAL:** | **411,4** | **100,0** |




**Grain Size Distribution Curve Results:**

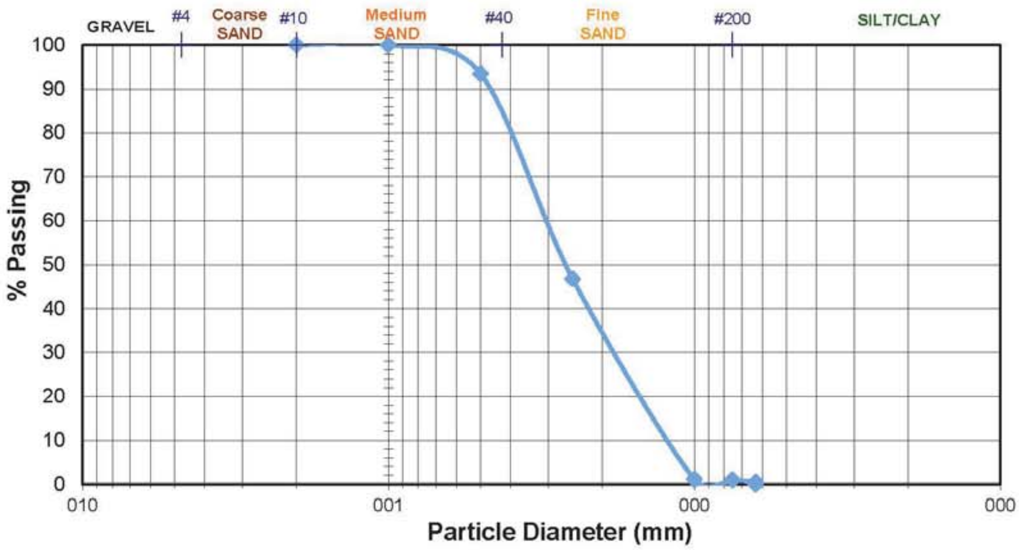
| | | | | | |
|---|---|---|---|---|---|
| **% Gravel:** | 0,04 | **$D_{10}$:** | 0.15 mm | **$C_u$:** | 2,40 |
| **% Sand:** | 99,24 | **$D_{30}$:** | 0.23 mm | **$C_c$:** | 0,98 |
| **% Fines:** | 0,72 | **$D_{50}$:** | 0.32 mm | | |
| | | **$D_{60}$:** | 0.36 mm | | |
| | | **$D_{90}$:** | 0.55 mm | | |

# Sieve Analysis Data Sheet

ASTM E 11-70

| | | | |
|---|---|---|---|
| **Project Name:** | Project Hoi An | **TestedBy:** | Joep Fila |
| **Lab location:** | WRU, Hanoi | | Roel van Noort |
| **Sample No:** | 14 | **CheckedBy:** | Richard Marijnissen |
| **Sample location:** | Ha My (Nam Hai resort) | **Test Number:** | 1 |
| **Date taken:** | 28-12-2015 | **Date:** | 6-1-2016 |
| **Weight of Dry Sample (g):** | 396,28 | **USCS SoilClassification:** | SP - Poorlygradedsand |
| | | **AASHTO SoilClassification:** | A-3 |

| SieveNumber | Diameter (mm) | Cumulativeweight (g) | SoilRetained (g) | SoilRetained (%) | Soil Passing (%) |
|---|---|---|---|---|---|
| #10 | 2,00 | 0,00 | 0,00 | 0,00 | 100,00 |
| #18 | 1,00 | 0,08 | 0,08 | 0,02 | 99,98 |
| #35 | 0,500 | 26,08 | 26,00 | 6,57 | 93,41 |
| #60 | 0,250 | 210,81 | 184,73 | 46,66 | 46,75 |
| / | 0,100 | 391,82 | 181,01 | 45,72 | 1,04 |
| #200 | 0,075 | 392,31 | 0,49 | 0,12 | 0,91 |
| #230 | 0,063 | 394,25 | 1,94 | 0,49 | 0,42 |
| | 0,063 | 395,92 | 1,67 | 0,42 | 0,00 |
| Pan | | | | | |
| | | | **TOTAL:** | **395,92** | **100,0** |




**Grain Size Distribution Curve Results:**

| | | | | | |
|---|---|---|---|---|---|
| **% Gravel:** | 0,00 | $D_{10}$: | 0.13 mm | $C_u$: | 2,38 |
| **% Sand:** | 99,09 | $D_{30}$: | 0.19 mm | $C_c$: | 0,90 |
| **% Fines:** | 0,91 | $D_{50}$: | 0.27 mm | | |
| | | $D_{60}$: | 0.31 mm | | |
| | | $D_{90}$: | 0.46 mm | | |