Coastal protection of the Bạc Liêu province by rehabilitation of the mangrove forest

Delft University of Technology

TU Delft

Mangrove Project Vietnam

Mangrove Project Vietnam

Coastal protection of the Bạc Liêu province by rehabilitation of the mangrove forest

By

Maurits Enschedé 4253817 **Harm van Oorschot** 4005597
Zoë van Looij 4087429 **Remco Oudshoorn** 4457994
Roos van der Meer 4089308 **Thieu Stevens** 4315464

in partial fulfilment of the requirements for the degree of

Master of Science
in Civil Engineering

at the Delft University of Technology.

March 24, 2017

Supervisors: Ir. H.J. Verhagen
Dr. Ir. S. van Nederveen
Ir. P. de Vries

This project was made possible by:

In cooperation with:

Preface

This report is part of the course CIE4061-09, which belongs to different master programs of the faculty of Civil Engineering at the Delft University of Technology. This course gives master students from different programs the opportunity to do a project abroad together. The aim of such a project is to solve an actual and recent civil engineering problem in a multidisciplinary team. This multidisciplinary team consists of Roos van der Meer, a Structural Engineering student, Remco Oudshoorn and Zoë van Looij, Construction Management and Engineering students, and Harm van Oorschot, Thieu Stevens, and Maurits Enschedé, Hydraulic Engineering students. By combining these different backgrounds, an integrated solution is sought for the chosen problem. The project started officially in November 2016 in Ho Chi Minh City, Vietnam, after months of preparations in The Netherlands.

In Vietnam, a collaboration with the Southern Institute for Water Resources Research (SIWRR), the Institute of Ecology and Works Protection (WIP), and the Gesellschaft für Internationale Zusammenarbeit (GIZ) took place. SIWRR is a company that works on salinity intrusion forecasts, flooding forecasts and protection of riverbanks and coastal areas in the Mekong Delta. WIP does research in different fields of water safety to protect the hinterland of Vietnam. GIZ is a German company, which works in Vietnam to offer support from the German Government in sustainable development. In order to protect the coastline, in five provinces of the Mekong Delta local people are replanting and managing the mangrove forests.

The objective of this report is to design a coastal protection system for a part of the Bạc Liêu province in which mangrove forests play a vital role in protecting the hinterland against flooding. A sustainable design should be executed by both the local government and local community. First, the current and ideal situation in terms of the physical and socio-economic aspects are analysed. By comparing these two situations, requirements are drafted. Thereafter, alternatives are determined that meet the system requirements. The final design is based on a multi criteria analysis of the alternatives.

The project described above would not be possible without our supervisor Ir. Henk Jan Verhagen (TU Delft) who brought us in contact with Dr. Tuan Thieu Quang from the Water Resource University (WRU). He brought us in contact with WIP and SIWRR, who provided us with the project. We would like to thank all our supervisors Ir. Henk Jan Verhagen (TU Delft), Dr. Ir. Sander van Nederveen (TU Delft) and Ir. Peter de Vries (TU Delft) who gave us helpful remarks for the preparations and the report. From SIWRR we would like to thank Assoc. Prof. Dr. San Cong Dinh, who helped us with our project and provided us with a nice working environment. From WIP we would like to thank our colleague Luan Mai Trong, who answered all questions we had about the project area. We would also like to thank Dr. Stefan Groenewold, Ir. Roman Sorgenfrei and Ir. Tinh Phan Thanh from GIZ, who helped us accomplishing the field visit and gave us insight in the local way of thinking and available data. We would also like to thank our sponsors Boskalis, van Oord, and InTech for giving us financial support and professional guidance throughout the project.

Ho Chi Minh City, 24 March 2017

Harm van Oorschot
Thieu Stevens
Maurits Enschedé
Remco Oudshoorn
Roos van der Meer
Zoë van Looij

Abstract

In the southern part of Vietnam, where the lower Mekong Delta is located, coastal erosion problems occur. In the Bạc Liêu province, one of the twelve provinces in the Mekong Delta, the width of the mangrove belt between the sea dyke and the sea is reduced by 100 m in the last four years. By rehabilitation of the mangrove forest, the hinterland can be protected against flooding. Mangrove rehabilitation is the action of improving the health of the forest to a previous condition. The primary goal of this project is to design a coastal protection system, including mangrove rehabilitation, to provide the Bạc Liêu province with a sufficient safety level against flooding till at least the year 2050. For this project a Systems Engineering (SE) approach is used.

Currently, the coastal area of the Bạc Liêu Province consists of a sea dyke and an integrated-shrimp system, which means that there are mangrove plants inside and in front of the shrimp ponds. The current characteristics of the mangrove ecosystem is described by a four spheres approach, the hydrosphere, lithosphere, biosphere and the atmosphere. Several laws have been adopted on the management of mangrove forest. The obligation to assure a 500 m width of mangrove belt in front of the sea dyke and the rule of 60% mangrove coverage in the shrimp ponds are the most important requirements for this project.

In the ideal situation, the coast is protected by a healthy mangrove ecosystem which has a variety of flora and fauna (Stieglitz, Ridd, & Müller, 2000). Older trees have more salinity resistance and can handle wave disturbances better. Therefore, a zonation is highly recommended for the ideal situation to create good living conditions for every species. Mangrove ecosystems need sediment to sustain the elevation of the trees in the tidal range and to counteract erosion. In Bạc Liêu a mangrove belt width of at least 500 m is required for flood protection.

At the moment, the ideal situation and current situation deviate. A wider mangrove forest creates better conditions for a zonation with a better distribution of different mangrove species. Sea level rise causes a backward movement of species within the mangrove forest. This backward movement is hindered by the integrated shrimp ponds and the existing sea dyke. If the mangrove forest cannot expand backwards, it is likely that mangrove trees will drown and erode at the seaside, whereby the width of the mangrove forest will decrease further. When erosion occurs, the erosion pattern will likely create a concave-up mud flat profile which leads to stronger wave attack enhancing even more erosion. The government has great power to prevent this, since they influence the land use by means of policies. After the stakeholder analysis, two dilemmas were identified. First, at locations where the width of the mangrove belt is less than 500 metre it might be more convenient to restrict the land use and make space to plant mangrove at the landside instead of taking expensive measures to improve the conditions for mangrove plants to grow at the seaside. Second, the 60% mangrove coverage rule for the shrimp farms does not guaranty 500 m of mangrove belt everywhere.

The system requirement specification, which is an overview of all the requirements for this coastal protection system, is partly based on the customer requirements, and partly on a function analysis based on the Function Analysis System Technique (FAST) method. However, the specification process is an iterative process, which is developed further during the research of different alternatives and the final design.

After the FAST method, different alternatives like groynes, soft measures and breakwaters are investigated. There are two scenarios' possible to guarantee a 500 metre mangrove belt for the flood protection system. The first scenario (scenario 1) is focussed on optimised land use behind the

mangrove belt. By rearranging the shrimp ponds, a significantly smaller area of mangrove forest has to be rehabilitated in the seaward side. In the second scenario (scenario 2), the shrimp ponds will not be adjusted and mangrove rehabilitation fully takes place in front of the ponds, which results in a large area that needs to be elevated and protected for mangrove planting. A multi criteria analysis (MCA) is executed to evaluate which alternative is considered to be most suitable for this project location. The top results from the MCA are permeable fences, Geohooks, floating breakwaters, permeable groynes and longshore sandbars (cheniers).

The final design for scenario 1 is chosen to be permeable bamboo T-fences. Calculations on the strength of the structure are made together with a mangrove-zonation, a cost estimation, a risk analysis and an implementation plan. For the second scenario, the choice is made to combine the permeable fences with a chenier, which provides a higher safety level and a faster accretion for the larger area that has to be elevated in the second scenario. Again, the structure is tested for the wave loads and risks are analysed, an implementation plan and cost estimation are made. These analyses are done for comparison with scenario 1.

Thereafter, the uncertainties, limitations of calculations and assumptions are discussed and recommendations on further research are given. The biggest limitation during this project was the limited available data, most values are based on data from other locations. Lastly, the conclusion about the best way to protect the hinterland of Bạc Liêu against flooding is given.

Nomenclature

List of abbreviations

Abbreviation	Explanation
AIPO	ASEAN Inter-Parliamentary Organization
APF	Association of Francophone Parliamentarians
CRS	Customer Requirements Specification
DARD	Department of Agriculture and Rural Development
FAST	Function Analysis System Technique
FMBs	Forest Management Boards
GIZ	The Gesellschaft für Internationale Zusammenarbeit
HAT	Highest Astronomical Tide
IPU	International Parliamentary Union
MARD	Ministry of Agriculture and Rural Development
MCA	Multi Criteria Analysis
MHW	Mean High Water
MLW	Mean Low Water
MoNRE	Ministry of Natural Resources and Environment
MSL	Mean Sea Level
NE-monsoon	Northeast monsoon
PPC	Bạc Liêu Provincial People’s Committee
SE	Systems Engineering
SE-monsoon	South Eastern monsoon
SIWRR	Southern Institute for Water Resources Research
SMART	Specific Measurable Assignable Realistic Time-related
SRS	System requirements specification
SW-monsoon	Southwest monsoon
WIP	Institute of Ecology and Works Protection

Symbols

Symbol	Explanation	Unit
D_{50}	Median grain diameter	$[mm]$
B_w	Mangrove belt width	$[m]$
TR	Tidal range	$[m]$
d	Average inner radius	$[mm]$
D	Average outer radius	$[mm]$
D_s	Distance to shoreline	[m]
A	Surface area	$[mm^2]$
I	Moment of Inertia	$[mm^4]$
E	Elasticity modulus	$[N/mm^2]$
f_t	Tension force	$[N/mm^2]$
f_c	Compression force	$[N/mm^2]$
W	Moment of resistance	$[mm^3]$
M_r	Maximum allowed moment	$[Nmm]$
T	Wave period	$[s]$
H	water depth	$[m]$
L	Wavelength	$[m]$
L_{gap}	Gap length	[m]
L_b	Length breakwater	[m]
G	gravitational constant	$[m/s^2]$
ρ	Specific weight	$[kg/m^3]$
H	wave height	$[m]$
P	Porosity	-
F_{max}	Maximum force	$[N]$
M_{max}	Maximum moment	$[Nmm]$
p	Pressure	$[N/mm^2]$
λ	characteristic length	$[m^{-1}]$
π	Pi	-
l	Length	$[m]$
V	Shear force	$[N]$
v	Deflection	$[m]$
φ	Rotation	$[Rad]$
C	Constant	-

Table of content

1. Introduction

In this introduction, a brief explanation of the background of this project, an introduction to mangroves, and the report outline are given.

1.1 Background

Like the Netherlands, Vietnam is a country living with a delta. Proper coastal management is required to deal with flood risks and coastal erosion. In the tropics and subtropics, sometimes a natural coastal defence system is present in the form of mangrove forests.

Mangrove plants can grow in harsh environmental conditions. The mangrove ecosystem occurs at the interface of land and sea and it creates good conditions such as shelter and food for many flora and fauna (Hutchings & Saenger, 1987). The importance of the role that a mangrove forest play in wave absorption and coastal protection is more and more recognised. Removing these mangrove forests results in coastal erosion and makes alternative protection essential (Schiereck & Booij, 1995).

In Vietnam, a lot of mangrove forests have been removed to make space for land use such as shrimp ponds. This reduced the width of the mangrove forest along the coast of the Mekong Delta significantly because it also induced erosion at the seaside. Since the end of 2016, the Institute of Ecology and Works Protection (WIP) is working together with the Southern Institute for Water Resources Research (SIWRR) on some new pilot projects to rehabilitate the mangrove forests. Their strategy is to improve the conditions for mangrove plants to grow at the seaside and planting young mangrove plants in front of the remaining mangrove forest.

1.2 Introduction mangrove rehabilitation

In general, a mangrove can be defined as follows: 'A mangrove is a tree, shrub, palm or ground fern, generally exceeding half a metre in height, that normally grows above mean sea level (MSL) in the intertidal zone of marine coastal environments and estuarine margins. A mangrove is also the tidal habitat comprising such trees and shrubs'.

The word 'mangrove' refers both to the plant as to the habitat. In this report 'mangrove plant' and 'mangrove forest' will be used to distinguish the plants from the tidal habitat.

There are around forty species of mangrove plants in Vietnam (Duke, 2012). As above citation states; mangrove plants are not single genetic because they are defined by their specific habitat. There are different mangrove families within the mangrove species.

Forest rehabilitation is the action of improving the health of the forest to a previous condition (Urbanska, Webb, & Edwards, 1997). Forest rehabilitation is somewhat different than forest restoration. With forest restoration, it is expected that the ecosystem is restored to its original health. In this report, the focus is to improve the degraded forest area in the Bạc Liêu province but not restore the entire mangrove forest which was originally present. This project might involve planting mangroves on sites where the mangrove plants were not originally present as well. Therefore, this report is a mangrove rehabilitation project instead of a mangrove restoration project.

1.3 Report outline

In the introduction, the background of the project is discussed. The second chapter contains the research design, this includes the problem description, the objective of the project, the design questions, the scope and the methodology. In chapter three the current and ideal situation in our research area are analysed, where after they are evaluated. In chapter four the customer requirement specification is given. In the fifth chapter, the system requirement specification is determined. In chapter six the solution alternatives are researched. In chapter seven an explanation of the scenarios is given; this chapter also includes a multi-criteria analysis of all possible solutions. In chapter eight and nine, the information of the alternative research and scenario analysis is combined in a final design. Chapter ten and eleven are the discussion, conclusion and recommendations. The appendices start with a list of figures (Appendix A), tables (Appendix B), and assumptions that are made during the research and design process (Appendix C). The other appendices are elaboration of information discussed in the report.

2. Research design

In this chapter the problem description, the objective, design questions, scope and methodology are described.

2.1 Problem description

In the last decades, the Bạc Liêu Province has been coping with many problems like mangrove forest decline and coastal erosion. These problems are caused by various events like deforestation, sea level rise, sediment shortage and inefficient land use. These events are interconnected and are causes and effects at the same time. A vicious circle has started, and this snowball effect increases the problem more. The disappearance of the mangrove forest increases the risk of flooding and more erosion.

2.2 Objective

Design objective

The goal of this project is to design a sustainable coastal protection system for part of the Bạc Liêu province, which is carried by both government and the local community, in which mangrove forests play a vital role in protecting the hinterland against flooding.

Vision

Mangrove forests give great benefits for ecology and economy. In order to make a sustainable design, rehabilitation of the mangrove forest is necessary. Preferably with the Building with Nature concept. The use of mangrove forests is a natural way to protect the hinterland against flooding. Experiences from all over the world have shown that an ecosystem-based coastal defence system is more sustainable and cost-effective than conventional coastal engineering (Temmerman, et al., 2013).

Rehabilitate the mangrove forest by only planting seeds is not possible at the seaside. Young plants are too vulnerable to the high waves, currents and storm conditions and have to be protected until they have matured (Balke, et al., 2011). Recently, trials done to protect the young mangrove forests with bamboo T-fences have been successfully carried out, by several water-related organisations, in different places in the Lower Mekong Delta area of Vietnam.

Demand

The project demand in the context of land use is exploiting the mangrove forest for economic use. On the other hand, the demand for mangrove forests is also water safety related. This research focuses on the development of a proper design to rehabilitate the mangrove forests in Bạc Liêu. An important aspect of this design is that it is well carried by the local community and government.

2.3 Design question

In this report the following question will be answered:

'What is the best design for the coastal system, including mangrove rehabilitation, which protects the hinterland of the Bạc Liêu province against flooding?'

2.3.1 Sub-Questions

1. What is the current physical and socio-economic situation?
2. What is the ideal physical and socio-economic situation?
3. How does the current situation deviate from the ideal situation?
4. What are the requirements for the system?
5. Which alternatives meet the requirements?
6. What are the best alternatives?
7. What is the final design?
    - Which measures should be taken to implement the solution?
    - Which risks are foreseen for the final design?

The sub-questions are represented in the triangle in Figure 1, where a design project approach is used. The division how the sub-questions lead to the final design is shown in this triangle. The first sub-questions are in the bottom layer. The next layer symbolises the comparison of the first two sub-questions. This is followed up by the requirements, which lead to the solution alternatives. Finally, the best solution is elaborated from these alternatives, which leads to the final design.

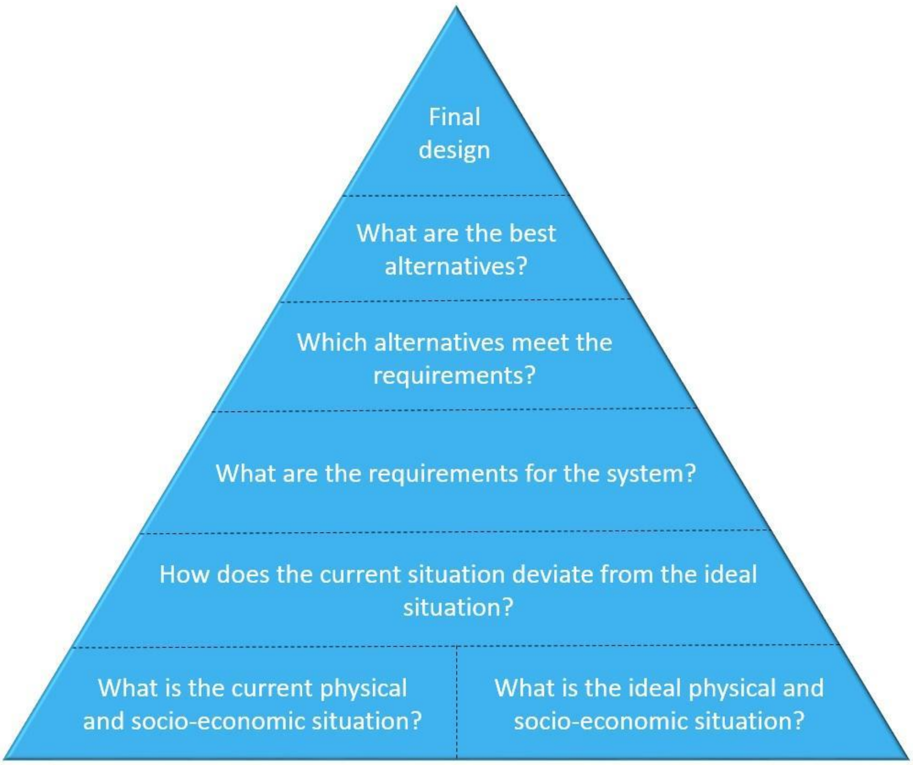


Figure 1: Sub-questions triangle

2.4 Scope

2.4.1 System scope

In this report the focus lies on a physical scope consisting of three parts (see Figure 2):

1. Creating conditions for mangrove trees to grow, including protection against waves;
2. Land use with integrated shrimp ponds;
3. An evaluation of the current coastal protection system.

The mangrove forest is a vital part of the coastal protection system, solutions without a mangrove forest are not considered.

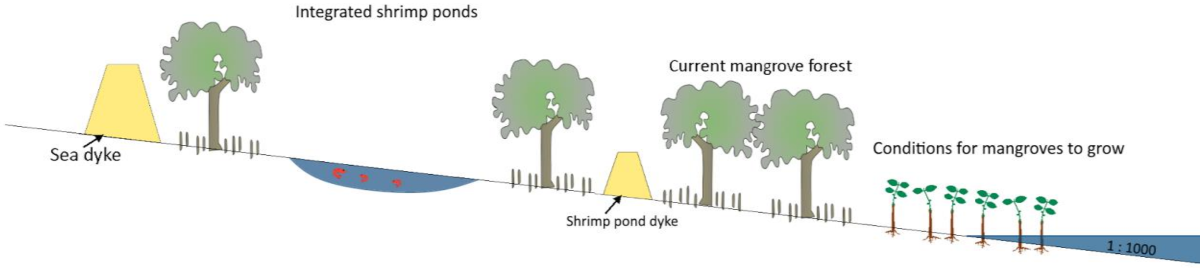


Figure 2: System scope overview

2.4.2 Geographical scope

Bạc Liêu is one of the 12 provinces in the Southern part of Vietnam, where also the Lower Mekong Delta is located (see Figure 3). WIP is working on a pilot project at the village Nhà Mát in the Bạc Liêu province. Around Nhà Mát, more than four hectares (over eight football fields) of forest disappeared during the last ten years. That is why WIP is testing different solutions at this location to create good conditions for young mangrove plants to grow. When successful, these solutions can be applied over the entire coast of Bạc Liêu province.

Figure 3: Geographical scope

The geographical scope of this research is limited over the eight kilometres South of Nhà Mát. Furthermore, in this eight-kilometre region, the most severe disappearance of mangrove forest in Bạc Liêu is visible over last ten years. The amount of disappeared mangrove forest is shown in Figure 4.

Figure 4: Amount of disappeared mangrove forest

2.4.3 Time scope

The research of this report focusses on the design of a coastal protection system. The structures which are used to recover the mangrove forest are of temporary use. In the end, the mangrove forest should be self-sustaining and able to protect the coast. The design must protect the Bạc Liêu Province with a sufficient safety level against flooding until at least 2050.

2.5 Methodology

In this paragraph, the specific methods and procedures are described to solve the different sub-questions within the scope, which are stated in paragraph 2.3. In the first section, Systems Engineering (SE) is explained. This approach is further elaborated in Appendix D.

The design project is based on an SE approach. According to the Guidelines for Systems Engineering within the civil engineering sector, version 3, the definition is as follows:

'Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing and disposal. SE considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs' (Alsem, et al., 2013).

In practice, this implies that the project is based on system thinking, which means that each system is part of a bigger system. All parties and the total life cycle of the system will be taken into account. Other important aspects for SE are developing from abstract to concrete (a top-down development), explicit working, and optimisation for the whole life cycle of the system (Alsem, et al., 2013).

The following SE processes are executed in this project. First, the stakeholders are determined by doing literature study and a project visit with representatives from the Ministry of Agriculture and Rural Development (MARD), WIP, and Gesellschaft für Internationale Zusammenarbeit (GIZ). A field visit report can be found in Appendix E. By analysing their wishes, the customer requirements can be translated into system requirements. Besides this process, an environmental analysis is executed, which means that the current and ideal situation are determined by using literature study, measurement data, satellite images, and a project site visit. Since accurate measurements of the considered area are not available, data of these neighbouring areas are projected to the Bạc Liêu shoreline. The outcome of this research gives a good insight into the current and ideal situation, and answers questions about the policies, land use, and stakeholders of the project site. In chapter 5 the requirement specification is documented, which contains all information necessary for the system. This includes a structured overview of the available solution space, the interfaces, and the requirements for the system. In this document, the requirements are divided into functional, interface and aspect requirements.

Next, the requirements are converted into several alternatives, which are verified using a Multi Criteria Analysis (MCA). The specification process is based on an iterative process between functions, requirements and the alternatives, this is shown in Figure 5. The alternatives research is further elaborated in chapter 6. At the same time, a scenario analysis is done based on the specification. These combined give multiple designs for the scenarios, of which a final design per scenario is made. The final design is validated to the project's objective, mission, vision and demand. Finally, the project's implementation plan and our recommendations are described. All these processes are documented traceable and explicitly.

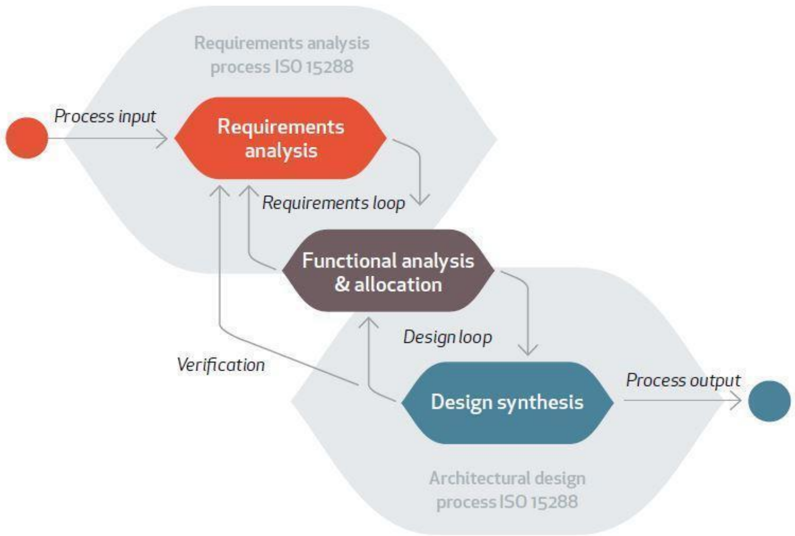


Figure 5: Iterative process specify (Alsem, et al., 2013)

3. Analyses

In this chapter, several analyses are documented. First, the current situation is investigated by observations and literature study. Various aspects are considered, such as the physical properties of the project site and the socio-economic characteristics. In the second paragraph, the ideal situation in physical and socio-economic aspects is explained by means of literature study and evaluation of pilot projects. Finally, the current and ideal situation are compared. The difference in the stakeholder's point of view between these two situations is the input for the customer requirements specification next chapter.

3.1 Current situation

To give an overview of the current system a system breakdown system (SBS) is made (see Figure 6). The goal of the SBS is to divide the system into more manageable parts.

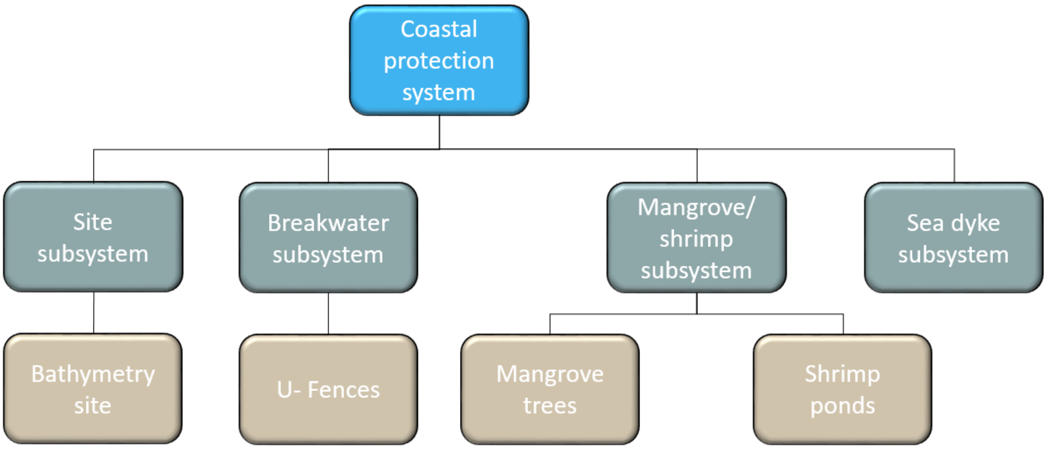


Figure 6: System Breakdown Structure (SBS) current situation

Every natural and human-made system is part of a higher order system. The coastal protection system interacts with external systems within the physical environment. Table 1 shows the systems in the physical environment. The human-made systems and natural environment can be a threat to the coastal protection system. The interfaces with these systems are analysed and taken into account in the final design.

Table 1: Overview of the physical environment domain

Element	Subdomain	Objective
Aquaculture	HUMAN-MADE SYSTEMS Element	Remain or Improve business opportunities
Mangrove forest	NATURAL ENVIRONMENT Element	Rehabilitate ecosystem.
Energy and water supply	HUMAN-MADE SYSTEMS Element	Improve the access to water and satisfy the energy demand.
Atmosphere	NATURAL ENVIRONMENT Element	Future proof design taking climate change into account.
Hydrosphere	NATURAL ENVIRONMENT Element	Protecting the hinterland from the water.
Lithosphere	NATURAL ENVIRONMENT Element	Good soil conditions for mangrove plants.
Biosphere	NATURAL ENVIRONMENT Element	A healthy population of fauna.
Ship traffic	HUMAN-MADE SYSTEMS Element	Allow ship traffic from sea to canals
Road transport	HUMAN-MADE SYSTEMS Element	Allow road traffic on the sea dyke

3.1.1 Sea dyke

The 52 km national sea dyke, which is shown in Figure 7, connects three communities of Bạc Liêu; Gành Hào, Cái Cùng and Nhà Mát. The dyke has been hardened about 40 km, with a crest elevation of +3.5 m and a crest width of 6.5 m. In total, there are 24 canal gates through the dyke, and it includes 4 large estuaries (Hien, 2016).

Figure 7: (l) Side view sea dyke; (r) Crest including road of the sea dyke at Bạc Liêu

The current sea dyke in Bạc Liêu, with the provincial road on its crest, is in good shape (Wölcke, Albers, Roth, Vorlaufer, & Korte, 2016).

3.1.2 Physical aspects

In this paragraph, the current hydrological and morphodynamic situation is described. The physical environment for a mangrove ecosystem can be described by a four spheres approach, the hydrosphere, lithosphere, biosphere, and the atmosphere. These aspects of this ecosystem interact with each other and cannot be evaluated on their own. In the hydrosphere, water-related aspects are described, the lithosphere represents the sediment conditions, the biosphere includes all living organisms and the atmosphere describes the weather and the climate.

3.1.2.1 Atmosphere

Weather conditions

The annual weather cycle of the Vietnam Mekong Delta area can be divided into two large seasons, summer and winter. During summer, from April to October, the weather is influenced by the southwest monsoon (SW-monsoon), which refers to the direction of the prevailing winds. The SW-Monsoon causes the warm and rainy season. In winter, from November to March, the south is subjected to the northeast monsoon (NE-monsoon), which is dry and a bit colder. In this season, humid air flows from the relatively warm landmass towards the colder oceans, where it loses its water load (Wölcke, Albers, Roth, Vorlaufer, & Korte, 2016). During the NE-monsoon the waves at Bạc Liêu are generally higher (Albers & von Lieberman, Current and Erosion Modelling Survey - coastal zone of Soc Trang, 2011). The NE-monsoon also causes a strong wind-driven longshore current (Albers & von Lieberman, Current and Erosion Modelling Survey - coastal zone of Soc Trang, 2011).

Typhoons / storm surges

Typhoons and storm surges can form a big threat for the delicate coastal protection of the Mekong Delta area. Fortunately, typhoons do not occur often in the southern part of Vietnam, but if a typhoon strikes the consequences can be devastating. For example, in 1997, during typhoon Linda, more than 3000 people lost their lives and major damages occurred to the coastal area (Thao, Takagi, & Esteban, 2013). This should be kept in mind during the design of the different parts that form the overall coastal protection of the Lower Mekong Delta area. Based on data from the most severe storms at the Southeast coast of the last 50 years, a maximum storm surge height of about 1 m can be assumed to be governing (Thao, Takagi, & Esteban, 2013).

3.1.2.2 Hydrosphere

Sea level rise

Global sea level rise is a problem that is likely to have considerable effects on the large, low-lying areas of the Mekong Delta (Thao, Takagi, & Esteban, 2013). A small water level elevation can cause a large area of land to flood because of the very gentle slopes. Most researchers agree that there is a global trend of sea level rise. However, they give no unanimous answer about the amount of sea level rise. Assuming sea level rise is an increasing continuous trend, it can contribute to multiple water-related problems in the Mekong delta and can be considered as a part of the problems at the Bạc Liêu shoreline.

Table 2 shows the Climate Change and Sea Level Rise Scenarios developed by the Ministry of Natural Resources and Environment (MoNRE). The high emissions scenario assumes that the sea level rise will be 33 cm in 2050 compared to that of the baseline period 1980-1999 (MoNRE, 2009).

Table 2: Difference of future sea level compared to that of the baseline period 1980-1999 (MoNRE, 2009)

Scenario	Sea level rise from 1980- 1990 till 2050	Sea level rise from 1980- 1990 till 2100
Low Emission	+28 cm	+65 cm
Medium Emission	+30 cm	+75 cm
High Emission	+33 cm	+100 cm

Tidal regime

At the Bạc Liêu shoreline, the difference between low and high water is clearly visible. The tidal range is approximately the same as in the Sóc Trăng Province, which is about 3.5 m (Wölcke, Albers, Roth, Vorlaufer, & Korte, 2016). This tidal range is based on measurements from a station in Vung Tau. The water level data in Vung Tau can be applied as the water level in the Bạc Liêu province as described in Appendix F: Data verification Vung Tau. To obtain values for the Highest Astronomical Tide (HAT), the Mean High Water level (MHW), the Mean Sea Level (MSL) and Mean Low Water level (MLW) the water level data from Vung Tau are analysed. The water level at the station in Vung Tau is recorded every hour. The data from October 2007 to March 2016 is analysed, only the reference level of the Vung Tau station is unknown. Therefore, the MHW line is estimated from the high water level line observed at the dyke behind the mangrove belt, which was approximately 10 cm above the toe of the dyke. This water level is used as a reference whereby the MSL is used as a zero level. The resulting water levels are presented in Table 3.

Table 3: Tidal regime

	Vung Tau [m]	Bạc Liêu [m]
HAT	4.1	1.4
MHW	3.6	0.9
Dyke toe	3.5	0.8
MSL	2.7	0
MLW	1.2	-1.5

Discharges of the Mekong River do not influence the tidal range (Wölcke, Albers, Roth, Vorlaufer, & Korte, 2016). The Bạc Liêu shoreline is affected by two tidal patterns, namely semi-diurnal tides from the East Sea with a tidal range of 3-4 m and diurnal tides from the Gulf of Thailand with a smaller range of only 0.5-0.8 m (Marchand, 2008). Because the Bạc Liêu shoreline has a very dynamic morphology, a large tidal range and a very gentle slope, it is impossible to determine more exact water depths.

Wave conditions

The East coast of the Mekong Delta is subjected to tidal waves and by wind-induced waves. These wind-induced waves are relatively moderate, but most significant during the NE-monsoon (Wölcke, Albers, Roth, Vorlaufer, & Korte, 2016). From measurements in Sóc Trăng, the significant wave height is estimated between 0.4 and 1.0 m (GIZ, 2012). This results in a significant wave height of about 0.65 m (Wölcke, Albers, Roth, Vorlaufer, & Korte, 2016). The corresponding wave periods are between 5 s and 6 s (Wölcke, Albers, Roth, Vorlaufer, & Korte, 2016).

Currents

The Lower Mekong Delta East coast is subjected to a strong longshore current due to the tidal wave from the East Sea. During the NE-monsoon this longshore current is strengthened, which results in a southward sediment stream along the South-East Vietnamese coast, as depicted in Figure 8.

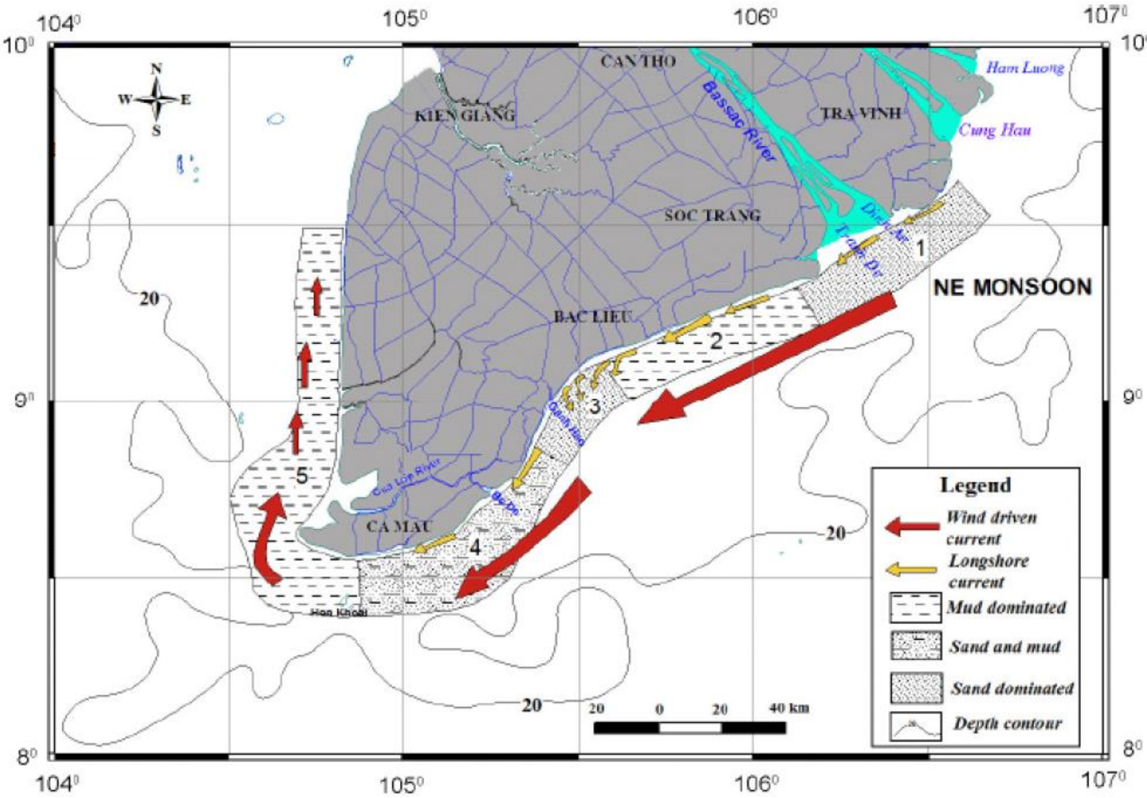


Figure 8: Longshore current in the Mekong Delta (Nguyen, 2009)

In general, the longshore current is governing for the long-term morphologic changes. The nearshore current velocities are measured to be between 0.20 and 0.50 m/s (GIZ, 2012). Cross-shore currents depend mostly on the wave conditions and are governing for short-term morphologic changes. During stormy weather conditions, heavy waves can cause a relatively large offshore directed sediment transport, which leads to erosion. In periods with less wave activity, the cross-shore current can cause accretion in the Bạc Liêu province (Ingenieursgesellschaft Von Lieberman, 2011).

3.1.2.3 Lithosphere

Bathymetry

The Southeast Mekong Delta coast is dominantly formed by tidal influences. This generally results in a very wide and flat shoreline (Bosboom & Stive, 2015). The slope along the Bạc Liêu province is estimated to be around 1:1000. However, it would be desirable to have some more accurate measurements because the coastal profile can have large variabilities over relatively short distances (Albers & von Lieberman, Current and Erosion Modelling Survey - coastal zone of Soc Trang, 2011). The downside is that it is almost impossible to map a more exact bathymetry because of the highly dynamic character of the bottom profile. The local strength of the wave attack, and therefore the amount of coastal erosion, depends partly on the local bathymetry. Also the shape of the foreshore is related to the erosion processes.

At some locations, a temporary sediment shortage resulted in a concave-up foreshore, whereby erosion problems can worsen. This relation will be further elaborated in paragraph 3.3.2.5 design remarks.

Because of the very gentle slope at Bạc Liêu, many waves break before reaching the mangrove forest. Furthermore, a small water elevation will cause a large horizontal variation in the width of the 'dry land'. For example, with a slope of 1:1000 the sea will reach 330 m more landwards in case of a sea level rise of 0.33 m. When locally a steeper slope is present, the water depth is larger which results in stronger wave attack. The bathymetry and water level elevations are therefore very important for the design of the coastal protection system. The current bathymetry is shown in Figure 9 as determined with the Navionics web application. This is simplified by an assumed bathymetry of 1:1000 as shown in Figure 10.

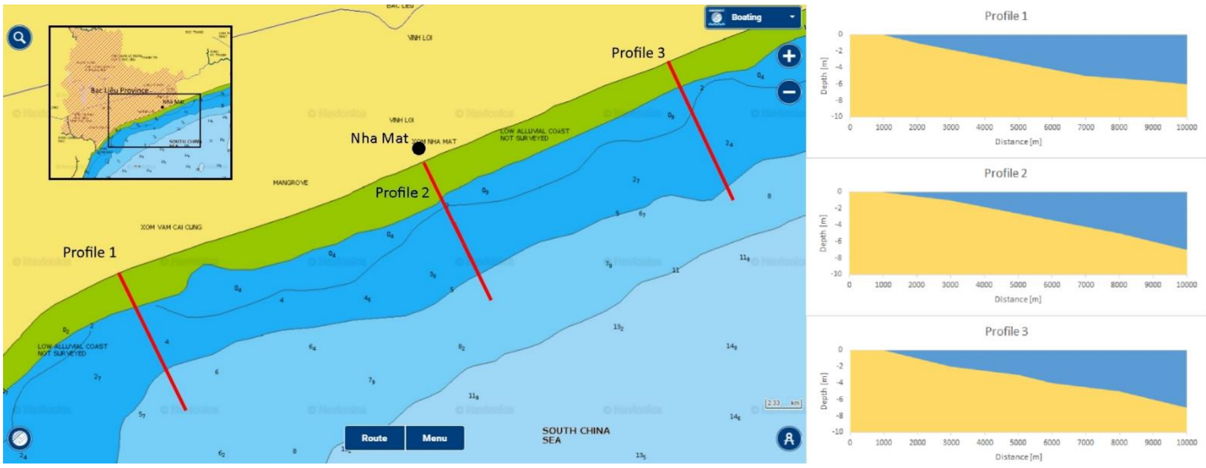


Figure 9: (l) Top view current bathymetry; (r) profile 1, 2, 3 (Navionics Web application (n.d.))

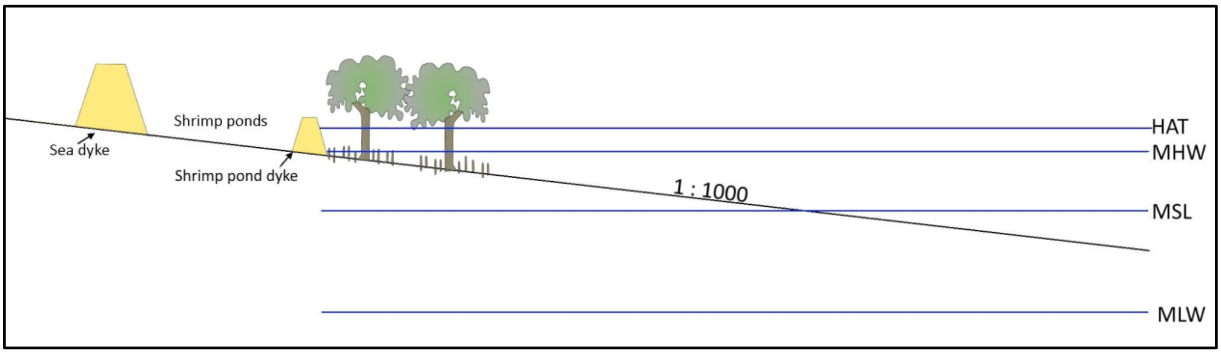


Figure 10: Assumed bathymetry (1:1000)

<u>Sediment transport</u>

The strong, southward directed longshore current along the East Mekong Delta coast carries a lot of sediment, whereby it is sometimes referred to as a 'river of sediment'. A large part of this sediment is suspended because it consists of small particles (Albers & von Lieberman, Current and Erosion Modelling Survey - coastal zone of Soc Trang, 2011). The suspended sediment concentration depends mainly on the flow velocity of the longshore current and the sediment discharge of different Mekong River branches, therefore the sediment rates are highest at the end of the SW-monsoon (Albers & von Lieberman, Current and Erosion Modelling Survey - coastal zone of Soc Trang, 2011). During the drier NE-monsoon, while the longshore current is stronger, the sediment supply is less (Albers & von Lieberman, Current and Erosion Modelling Survey - coastal zone of Soc Trang, 2011). This causes a higher erosion rate at the Mekong Delta East coast (Albers & von Lieberman, Current and Erosion Modelling Survey - coastal zone of Soc Trang, 2011).

Soil conditions

The Bạc Liêu coast mostly consists of a layer of very soft mud, a silty and clayey material (Albers & von Lieberman, Current and Erosion Modelling Survey - coastal zone of Soc Trang, 2011) (Wölcke, Albers, Roth, Vorlaufer, & Korte, 2016). Underneath this mud layer, a stronger, sandier layer is present (Ingenieursgesellschaft Von Lieberman, 2011). The thickness of these layers is very variable but can range from 0.10-1 m. From some soil samples on the coast of Vinh Tan, a median grain diameter D_{50} between 0.003 and 0.007 mm was determined (Ingenieursgesellschaft Von Lieberman, 2011). Because no soil samples are taken at the project location, the same median grain diameter is assumed for the Bạc Liêu shoreline. Figure 11 shows that the shoreline looks more like a muddy swamp than a beach.

Figure 11: A muddy swamp

3.1.2.4 Biosphere

Mangroves

In contrast to most other plants, mangrove plants thrive in hot, muddy and salty conditions, and can be found in the coastal intertidal zone. A healthy mangrove forest is a dynamic and highly productive ecosystem which consists of many different species. Besides the ecosystem, a wide mangrove forest also protects the coastal area against erosion and wave attack.

Mangrove forests are suffering under anthropogenic influences in the Mekong Delta. The mangrove belt is narrowing in the Bạc Liêu province. At the front of the mangrove belt, more than 100 metres of coastal zone eroded over the last ten years, as can be seen from Figure 4.

Width

As shown in Figure 4, many mangrove plants eroded at the seaside of the mangrove forest. The remaining width of the mangrove belt decreased significantly. In some places, less than 160 m mangrove belt in front of the shrimp ponds is remaining.

3.1.3 Socio-economic aspects

3.1.3.1 Policy

Policy is the most important factor in the management of mangrove forest. In recent years, the forest management is transferred from centralised management by the state to private management (Ha, van Dijk, & Visser, 2014). The centralised management by the state was not successful since 200 000 ha of national forest was lost every year between 1976 and 1990 (Vien, 2008). To control the private management of the forests, several laws were adopted. The management of mangrove forests is subjected to these laws. According to (ICEM, n.d.) four important national laws to protect mangrove forest are:

- Law on Land (amended 2013);
- Law on Forest Protection and Development (2004);
- Law on Environmental Protection (2005); and
- Law on Biodiversity (2008).

These laws should be implemented by the provincial government. The provinces of Tra Vinh, Sóc Trăng, Bạc Liêu and Cà Mau are implementing these laws together. The laws that are applicable regarding mangrove forests in the Bạc Liêu Province according to (Ha, van Dijk, & Visser, 2014) are included in Appendix G. Through these laws the mangrove forest in Bạc Liêu is protected and the economic activity in the area is regulated. Due to undervaluation of mangrove forests and bad farming practices, the shrimp farmers often used a non-sustainable farming approach and abandoned the farms to start a new one when the benefits decreased (Bosma, Nguyen, Siahainenia, Tran, & Tran, 2016). To prevent this, shrimp farms are currently only allowed in the mangrove forest area when the farm has a mangrove plants coverage of at least 60% of the total farm area, which is checked once a year. Only trimming of the mangrove forest is allowed.

On 27 May 2009, the Prime Minister of Vietnam approved the 667/QD-TTg plan to improve, strengthen, and upgrade the sea dyke from the Quảng Ngãi province to the Kiên Giang province (Socialist Republic of Vietnam, 2009). The goal of this plan is to create a closed system to prevent the negative impacts from the sea, create infrastructure and protect the environment on the long run. In this plan, one of the requirements for the coastal protection system is a minimal width of 500 m mangrove forest in front of the sea dyke. The program started in 2009 and will finish in 2020.

3.1.3.2 Land use

The mangrove forest is contributing to the socio-economic environment for many years and used to exploit building materials, food and many other products (Hong & San, 1993). First, this paragraph gives a brief history of the land use in mangrove forests.

During the Vietnam War (1955-1975) a large area of mangrove forest has been destroyed. Afterwards, the deforestation of mangrove areas continued to make room for human settlements, shrimp, mud crab ponds and other agricultural purposes. This led to a decline and degradation of the mangrove forest (Hong & San, 1993). The conditions for mangrove forests have also worsened due to coal exploitation and coastal water pollution (Hong & San, 1993).

In the last decades, the Bạc Liêu province has experienced a large transformation in land use. The objective was a transformation from natural exploitation of fisheries and a single traditional rice crop harvest to a modern double rice crop harvest (Hong & San, 1993).

In the early 1990s, Vietnam faced a high demand for rice. To support this, the government constructed a series of embankments and sluices, which can be closed at flood tide to protect rice lands from saltwater intrusion. The canal network was also improved to increase the supply of fresh water from the Mekong River. This resulted in a decline of shrimp farming in favour of intensified rice cultivation (Dung, Vinh, & Bousquet, 2005). However, producing rice in this soil seemed ineffective (Ingenieursgesellschaft Von Lieberman, 2011). Shrimp production in Vietnam is about five times more profitable than rice production. Therefore, the transition from shrimps to rice led to a great loss of income for the farmers and the government (Dung, Vinh, & Bousquet, 2005).

Between 1983 and 1995 the Bạc Liêu and Cà Mau province together lost 66 253 ha of mangrove forest to shrimp ponds (Cuong & Vuong , 1996). Since 2000, the original development objective is re-evaluated. As shown in Figure 12, zone 1 focuses on preventing saline-water intrusion and supplying more freshwater to develop rice-based farming. In zone 2 saline water is allowed in the dry season to harvest shrimps and fresh water is kept in the wet season to harvest rice (Dung, Vinh, & Bousquet, 2005). Zone 3 is a zone with mainly saline water and is used for aquaculture.

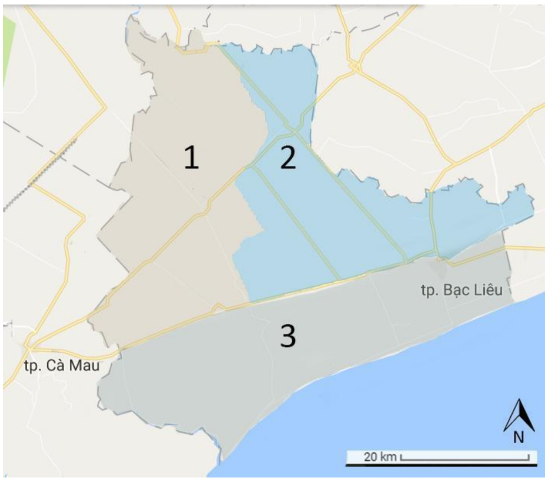


Figure 12: Zones in Bạc Liêu Province (Dung, Vinh, & Bousquet, 2005)

Over five years, the farmers were struggling with the variation in environment and their strategy of resource use. A baseline sampling survey of 350 households in the Bạc Liêu province in 2000 revealed that the rice production is the dominant cropping system, and it occupies 75.8% of the total parcels in the survey. Of the households that were interviewed, 42.9% are practising aquaculture in which 22.5% is shrimp/fish production (Dung, Vinh, & Bousquet, 2005).

In the period between 2003 and 2011, a total of 60 ha of vegetation were lost in the Bạc Liêu Province (Hien, 2016). In 2012 the mangrove forest in the Bạc Liêu province had an average width of approximately 700 m in front of the sea dyke. In the last four years, this width is reduced by 100 m. Nowadays the degradation of the mangrove forest is still ongoing, but the important role mangrove forests play in wave absorption and coastal protection is more and more recognised and several mangrove rehabilitation projects are initiated. Currently, several mangrove areas in the Bạc Liêu have a width of less than the required 500 m.

Shrimp ponds

In the coastal zone of Bạc Liêu, shrimp ponds are present at the seaside of the dyke. Mangrove-shrimp farming have higher annual returns than non-mangrove systems (Ha, van Dijk, & Visser, 2014). Besides that, mangrove forests have a positive effect on the water quality of the pond due to denitrification of the water (Matsui, Songsangjinda, & Wodehouse, 2014).

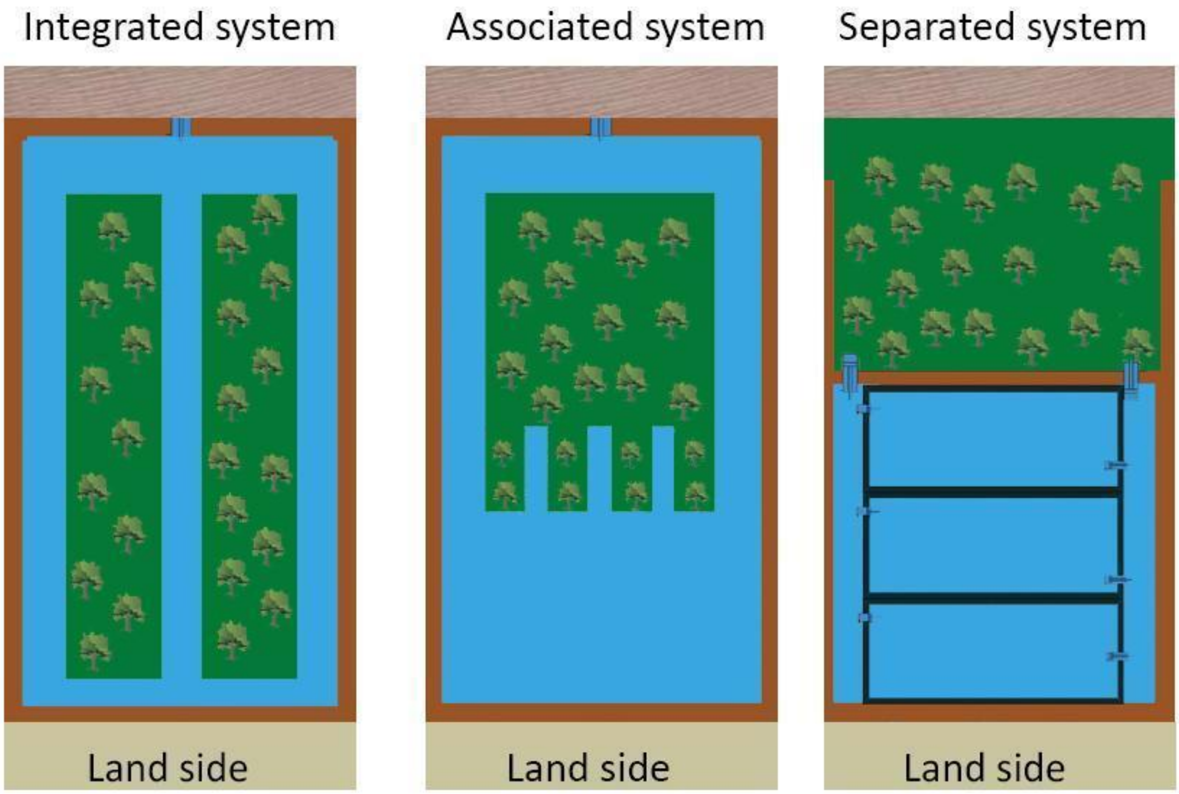


Figure 13: Several types of shrimp ponds adjusted from (Bosma, Nguyen, Siahainenia, Tran, & Tran, 2016)

Shrimp ponds can be divided in three different kinds, which is shown in Figure 13. First, the integrated ponds have canals between platforms planted with mangroves. Most of the shrimp ponds in the Bạc Liêu province are integrated systems. In integrated shrimp ponds, there is more shade compared to the other shrimp ponds. This results in lower temperature and less plankton and benthic algae, which reduces the shrimp production (Burbridge & Koesoebiono, 1984). If the canals are long and narrow, the water quality will be poorer (Hai & Yakupitiyage, 2005). The integrated shrimp ponds must be regularly dredged. Secondly, the associated ponds have large areas of land with mangrove plants and large areas of water. Mostly with one platform of mangrove plants within the shrimp pond. A dyke clearly separates the shrimp ponds. Lastly, in the separated ponds the shrimps are separated from the mangrove forest but the mangrove plants still denitrify the water inside the shrimp pond. By separating the shrimp ponds from the mangrove forest the number of leaves in the ponds is reduced.

Shrimps are harvested every two weeks, and every two months approximately 20 cm of the water is pumped out of the ponds and replaced by seawater. The amount of mangrove coverage, leaf litter in the pond, the species and age of the mangrove plants all affect the producibility of the shrimp ponds (Bosma, Nguyen, Siahainenia, Tran, & Tran, 2016). Leaf litter from all types of mangrove trees except the Nipa palm and the Avicennia have a negative effect on the water quality of the shrimp ponds (Bosma, Nguyen, Siahainenia, Tran, & Tran, 2016).

3.2 Ideal situation

In this paragraph, the ideal situation for the project location is described.

3.2.1 Physical aspects

Like the description of the current situation in paragraph 3.1.1, the ideal situation is described with the four spheres approach; the atmosphere, hydrosphere, lithosphere and biosphere.

3.2.1.1 Atmosphere

Weather

Rain is important because it lowers the salinity and thereby creates optimal conditions for the growth of the mangrove plants. Seedlings grow better in lower saline regimes, which occurs during the rainy SW-monsoon season (Deltares, n.d.).

Seedlings also need enough light penetration through the water column to grow. On the tidal flats, this is not a limiting factor. However, in a dense forest a seedling can only survive when there is enough sunlight coming through the canopies.

3.2.1.2 Hydrosphere

Salinity

Mangrove plants have the ability to grow in saline water and therefore have a competitive advantage over other plants (Deltares, n.d.), but they do not need salt water to grow. The salinity resistance depends on the mangrove species and increases with the age of the tree (Kathiresan & Bingham, 2001). The water salinity depends on the precipitation and the supply of fresh river water from rivers.

Tidal regime

Different mangrove species can resist different inundation times. This is further elaborated in the zonation in paragraph 3.2.1.4. The allowable inundation time is greater for adult trees than for seedlings.

Waves

Wave action causes sediment suspension and erosion, whereby it is closely linked to the sediment budget. Seedlings are very vulnerable to wave disturbances, especially during the first five months (Deltares, n.d.). Pioneering mangrove plants have a better resistance against these disturbances than non-pioneering species. Zonation creates a more resilient mangrove forest because the pioneering trees protect the trees behind them against wave attack.

3.2.1.3 Lithosphere

Bathymetry

Typical slopes for mangrove forests are generally very mild, in the order of 1:1000 (Burger, 2005). Therefore, this is considered as a preferable slope for a mangrove forest. The bottom height at the waterline to where the currently present mangrove forest reach, is assumed as the ideal bottom height to plant the mangrove plants.

Sediment

Mangrove ecosystems need sediment to sustain the elevation of the trees in the tidal range and to counteract sea level rise or land subsidence. Therefore, the sediment supply from nearby rivers has to be sufficient and the forest has to be in good condition to retain the sediment. However, if too much sedimentation will cover the seedlings and tree roots, it will cause the death of these plants (Ellison, 1998). Normal sediment concentrations in natural mangrove forest differ from 300 to 600 mg/l (Deltares, n.d.). The presence of a large mudflat in front of the mangrove forest is of great importance to reduce wave attack. A large mudflat also gives space for natural rejuvenation. The pioneering mangrove plants slow down the waves by their root system. The suspended sediment will settle due to the current reduction, whereby the mangrove plants consolidate the soil and build up land (Othman, 1994). Mangrove plants prefer muddy sediments as these are less oxygenated than sandy soils (Tomlinson, 1994).

3.2.1.4 Biosphere

Flora and Fauna

The local biosphere is of importance for the mangrove forest, as it depends on the plants and animals in the ecosystem. Benthic organisms such as worms and burrowing crabs aerate the soil and support flushing of salt. A healthy population of benthic fauna is therefore necessary for a healthy mangrove ecosystem (Stieglitz, Ridd, & Müller, 2000).

Local fauna is also of importance for pollination of the mangrove plants. The habitat has to meet the requirements (e.g. a large enough forest) for the pollinator species such as bats (Tomlinson, 1994). Fauna can also be a threat to the mangrove plants. When seedlings are submerged for a long time, barnacles start to grow on them and the seedlings become unstable due to the extra weight, which results in an increased mortality rate (Angsupanich & Havanond, 1996).

Width

The width of the mangrove forest needs to be at least 150 m to allow lateral change of the mangrove forest (Othman, 1994). Several types of research have been done to determine the minimal mangrove belt width for coastal protection. It should be noted that a sufficiently strong dyke behind the mangrove forest is necessary. The effectiveness of the forest in wave damping depends highly on its density. Theoretically, for a dense forest, a mangrove belt of 100 m wide is able to dissipate waves to acceptable levels, while sparser forests might need about 450 - 900 m (Janssen, 2016). Soerianegara considered in his ecological study the mangrove belt width (B_w) on the tidal range (TR) by the formula:
$B_w = 130 \cdot TR$ (Soerianegara, 1986)

Using Soerianegara's formula, with a tidal range of 3.5 m, a mangrove belt width of about 455 m is needed for coastal protection. Finally, according to Spalding et al. (2014), in a dense mangrove forest incoming waves reduce to half their height after 100 m and for a sparser forest, this can be up to 500 m (Spalding, McIvor, Tonneijck, & van Eijk, 2014).

Following these three approaches, a mangrove belt of at least 500 m is chosen to be desirable to dissipate waves in the Bạc Liêu province. Especially, when the forest is still very young and sparse, a wider belt is desired to guarantee safety. According to the reports mentioned above, a width of 500 m mangrove belt will dissipate the wave energy enough to guarantee a sufficient safety level against flooding.

Zonation

To make a design for an ideal zonation in which all different species are provided with their ideal inundation time, it is important to know the water levels and times that a specific area is inundated. Watson made a classification in 1928 for the Malay Peninsula (Watson, 1982). While only a part of the world's mangrove forests meet the same conditions, this classification is still widely used (van Loon, Dijksma, & van Mensvoort, 2007). Van Loon et al. (2007) adapted this classification for Can Gio, which is 200 km north of the Bạc Liêu province. This modified and extended classification is more suited to the irregular tidal regimes and elevation profiles as is the case in the south of Vietnam. Because there is no measurement station nearby Bạc Liêu, data from Vung Tau, a measurement station which is located 200 km North-East of Bạc Liêu, is used for the tidal data.

This data is used to make a zonation (see Table 4, second column). Each zone has a specific amount of minutes a day that it has to be inundated. There is a significant difference in water levels during the year. During the NE-monsoon (November-March) the water levels are considerably higher than during the rest of the year. Assuming March is an average and representative month, the water levels and inundation duration in minutes per day, and per zone, are shown in Table 4. In Appendix H, a brief description is giving how these specific water levels are determined. The width of each zone is also shown in this table, assuming that the bottom is uniform with a 1:1000 slope.

Table 4: The different zones depending on inundation levels (van Loon, Dijksma, & van Mensvoort, 2007)

Zone	Width zone [m]	Tidal regime	Water height [m]	Inundation frequency [times / month]	Duration of inundation [min/day]	Duration of inundation [min/inundation]	Vegetation (species)
1	-	All high tides	-0,02	56–62	>800	>400	None
2	520	Medium high tides	0,5	45–59	400–800	200–400	*Avicennia, Sonneratia*
3	390	Normal high tides	0,89	20–45	100–400	100–200	*Rhizophora, Ceriops, Bruguiera*
4	330	Spring high tides	1,22	2–20	10–100	50–100	*Lumnitzera, Bruguiera, Acrostichum aureum*
5	-	Equinoctial tides	1,3	<2	<10	<50	*Ceriops, Phoenix paludosa*

Figure 14 gives a schematic representation of the mangrove zonation. Zone 1 and 5, the foreshore with mudflat and terrestrial forest respectively, are not considered because they do not really belong to the mangrove forest. Zone 2 is the seaward zone with pioneering mangrove plants which have pencil-like root structures. Zone 3 is the mid zone, where the mangrove plants mainly have prop and stilt roots. Zone 4 is the landward zone with mangrove plants with knee-like looping pneumatophores.

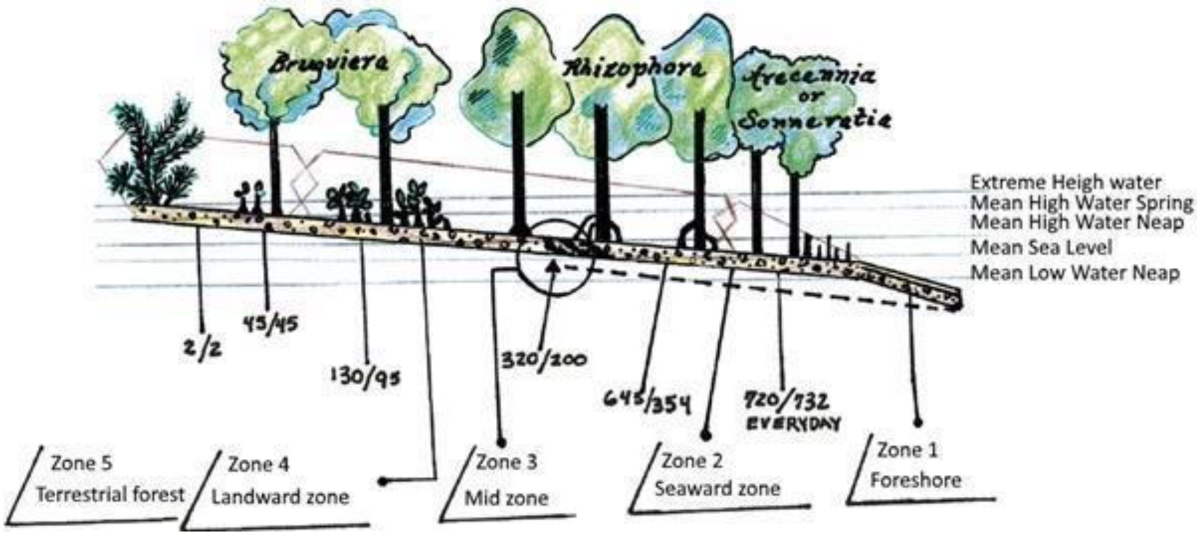


Figure 14: Schematic representation of mangrove zonation (Deltares, n.d.)

3.2.2 Socio-economic aspects

3.2.2.1 Policy

In the ideal situation, a national coastal legislation will be present to deal with integrated problems in the departments of agriculture, aquaculture, coastal protection, forests, planning and budgeting, and water management (GIZ, 2014). This policy should allow the mangrove forests to mature with a wide variety of species. A policy for the whole coast could lead to economies of scale and might improve the monitoring of the mangrove forest. Besides that, it prevents measures that reduce erosion at one place but increase the problems for the neighbouring province.

3.2.2.2 Land use

Integrated shrimp-mangrove ponds yield better results than extensive non-mangrove systems (Ha, van Dijk, & Visser, 2014). These have the highest annual return but are not very sustainable (Ha, van Dijk, & Visser, 2014). In the long run, when mangrove plants mature, the leaf litter cannot be flushed by tidal water which causes a water quality reduction (Ha, van Dijk, & Visser, 2014). Besides that, the higher amount of sediment will reduce the water quality (Ha, van Dijk, & Visser, 2014). Aquaculture-based livelihoods are needed to support optimal pond management (Bosma, Nguyen, Siahainenia, Tran, & Tran, 2016).

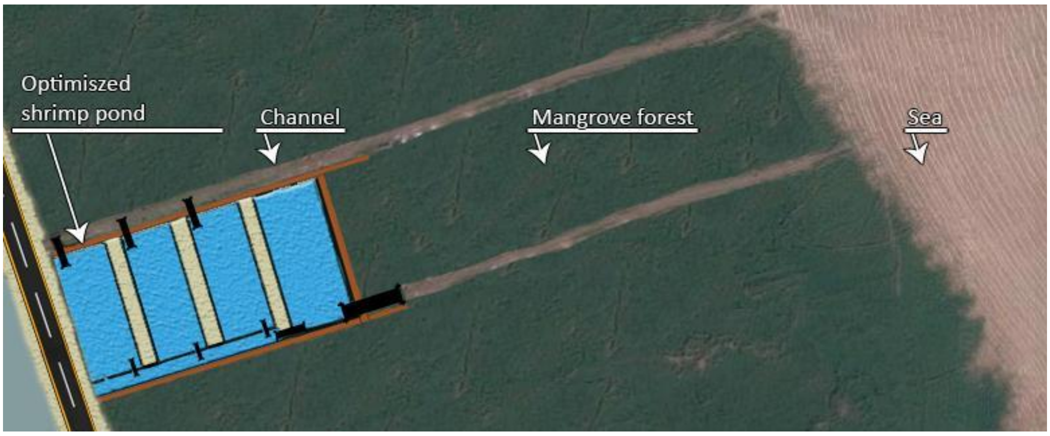


Figure 15: Design of optimised shrimp-mangrove pond (Bosma et all, 2016)

Figure 15 shows a design of an optimised shrimp-mangrove pond. This pond has a drainage canal from the mangrove forest which is used as the water inflow for the shrimp ponds. In this case, the mangrove plants and the ponds are separated to prevent leaf littering in the ponds (Ha, van Dijk, & Visser, 2014). In this way, water exchange is optimised. According to Bosma, Nguyen, Siahainenia, Tran, & Tran, 2016: 'Shrimp yield has been found to be highest in ponds with 30–50% mangrove cover.'

The location of the shrimp pond is not determined by this ideal situation for the integrated shrimp pond. It is important that the water supply of the shrimp pond is running true the mangrove forest and the output is separated from the input and running to the sea. The integrated shrimp pond can be placed behind the dyke, where it will be protected against the sea. This does require a water flow through the sea dyke. The other option is placing the shrimp pond in front of the dyke. In that case, shrimp farmers have to create a dyke that protects them and their ponds against the sea.

3.3 Evaluation

In this paragraph, the current situation is compared to the ideal situation.

3.3.1 Sea dyke

An important part of the flood protection system of Bạc Liêu is the sea dyke, which currently is in a good state. If the mangrove deforestation continues, and the foreshore is lowered, the dyke crest has to be increased and probably a revetment is needed (Hien, 2016). According to Wölcke, Albers, Roth, Vorlaufer, & Korte, 2016 the state of the sea dyke is good enough, provided that there is sufficient mangrove belt in front of the dyke. This project focuses on the rehabilitation of the mangrove forest and a coastal protection in which the mangrove forest plays a vital role. Therefore, the dyke in its current state is assumed to be sufficient and a design of the sea dyke is not further elaborated in this report.

3.3.2 Physical aspects

In this section, the physical aspects of the current situation as described in paragraph 3.1.1 is compared with the ideal situation which is elaborated in paragraph 3.2.1. This comparison is made to determine the physical problems in the system where the proposed solutions will be based on. Similar to the description of the current situation and the ideal situation, this evaluation is described with the four spheres approach.

3.3.2.1 Atmosphere

Weather

Mangrove forests are present all around the Mekong Delta area, therefore, it can be concluded that the right weather conditions are present for mangrove plants to grow. Young mangrove plants are more vulnerable to salt water than mature mangrove plants. Because of the larger supply of fresh water during the rainy SW-monsoon, the weather conditions during this season are better for planting.

3.3.2.2 Hydrosphere

Sea level rise

Sea level rise causes a backwards movement of species within the mangrove forest. This backwards movement is hindered by the existing dyke. If the mangrove forest cannot expand backwards, it is likely that mangrove plants will drown and erode on the seaside, whereby the width of the mangrove belt will decrease further. However, when the water level increases, mangrove plants can trap more sediment to recover the bathymetry inside the forest and can withstand the sea level rise to a certain extend (McIvor, Spencer, Möller, & Spalding, 2013). Depending on the location and conditions, mangrove forests can increase bed elevation by between 1-10 mm/year. Mangrove forests are able to reduce or even counteract the effects of sea level rise (McIvor, Spencer, Möller, & Spalding, 2013). Nevertheless, it is likely that sea level rise contributes to the erosion of the mangrove forest in the Bạc Liêu province. For example, if sea level rise might go too fast or there is not enough sediment available to counteract the water elevation.

Waves

Mature mangrove forests can contribute to coastal protection by absorbing lots of wave energy during storm conditions and they have proven to withstand high forces caused by waves. Young mangrove plants are much more vulnerable to these wave forces. This vulnerability to waves can be a part of the cause that the mangrove forest is not expanding in the Bạc Liêu province.

3.3.2.3 Lithosphere

Sediment

Mangrove plants are disappearing on the seaside of the forests due to erosion. Decreasing river sediment supply to the coast is deemed to be the prime cause of this erosion, and most likely due to existing dam retention of sediment and to massive channel-bed sand mining in the delta (Anthony, et al., 2015). Erosion, and therefore degradation of the bed occurs due to a (local) negative sediment transport rate. This degradation of the bed can be decreased by:

- Increasing the available amount of sediment;
- Decreasing the flow velocities and thereby increasing the amount of sediment that settles.

In chapter 6 alternatives are introduced to achieve these conditions because creating a positive sediment balance will logically be part of every possible alternative to solve the erosion problems.

Bathymetry

There is no real difference between the current bathymetry and the ideal bathymetry. In both situations, the slope is estimated to be 1:1000. As mentioned before, the bathymetry of the Bạc Liêu province is very dynamic, therefore it is impossible to use an exact profile. It is unfavourable to use an exact profile for the design because during construction the bathymetry will be different again.

3.3.2.4 Biosphere

Width

The width of the mangrove belt is far below the minimum width needed to provide sufficient protection of the dyke against wave attack. The estimated width needed to protect the dyke is 500 m, while the in the current situation the width of mangrove forest in front of the shrimp farm is less than 160 m in some places. As mentioned in paragraph 3.2.1.4, the width of the mangrove forest must be at least 150 m to allow lateral change of the mangrove forest. Currently, the mangrove forest in Bạc Liêu satisfies the minimum width at most locations. However, the width of the mangrove belt is decreasing, so countermeasures are required.

Zonation

In the ideal situation, there is a natural balance between different mangrove species. From table 4 (in the ideal situation), it can be concluded that for a fully developed mangrove forest, in which all different zones and species are present, there is a much wider mangrove belt necessary than the determined 500 m. Currently, the mangrove belt is too small for all species to grow. A wider forest creates better conditions for a zonation with a better distribution of different mangrove species. Due to the increasing slope, it is possible that some species do not match their ideal conditions anymore. Some mangrove plants are possibly inundated too long, causing them to suffocate.

Since the aim of this project is to rehabilitate the mangrove forest instead of restoring the mangrove forest it is accepted that not all mangrove species can survive in the 500 m width mangrove forest. A zonation is made to improve the diversity and health of the mangrove forest.

3.3.2.5 Design remarks

There are three main causes of the degradation of the mangrove forest in Bạc Liêu: erosion, a concave-up foreshore and high waves. These causes strengthen each other, like a snowball effect. When there is a negative sediment transport rate, erosion occurs → erosion causes a concave-up and lowering foreshore on a concave-up foreshore the wave attack is higher → higher waves cause even more erosion, see Figure 16.

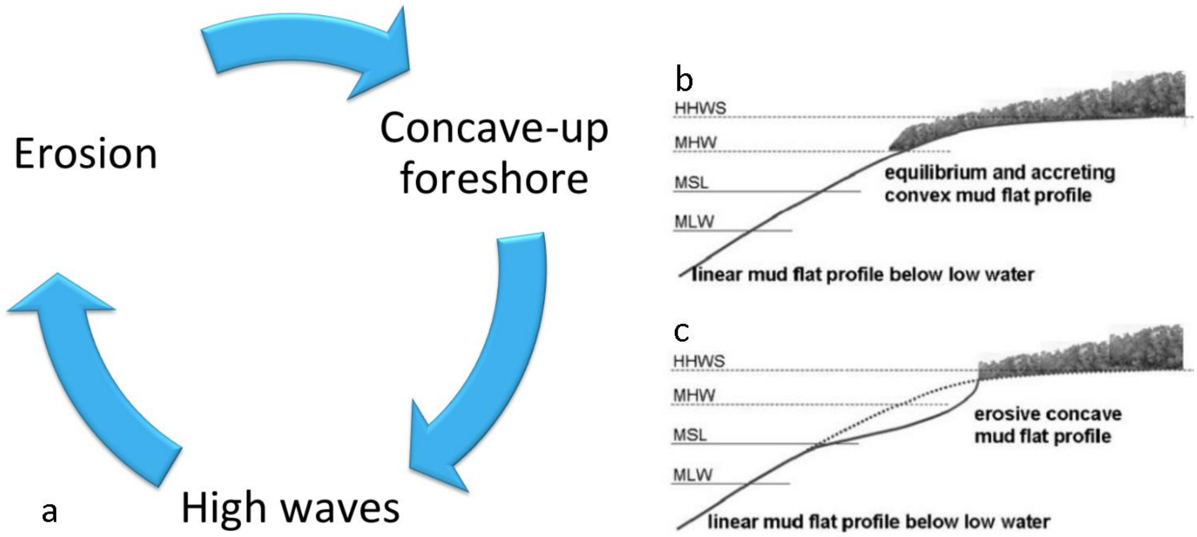


Figure 16: (a) Vicious circle of coastal erosion; (b) convex accreting; (c) concave erosion (Winterwerp, Erftemeijer, Suryadiputra, van Eijk, & Zhang, 2013)

In order to rehabilitate the mangrove forests and restore a natural coastal protection system, it is important to break this circle. It is not sufficient to solve only one of these causes. A solution for one of the causes will be counteracted immediately by the other ones. It is important to tackle all these three causes in one design.

3.3.3 Socio-economic aspects

3.3.3.1 Policy

Many problems in Bạc Liêu province have a multidisciplinary nature. In this report, the combination of agricultural land use and coastal protection is made. In Vietnam, these different issues such as water management, forestry, dykes, aquaculture and agriculture are managed by different authorities. Between these authorities, there is a low degree of coordination (Postma, Dunnewolt, Hanssen, Bouziotas, & Stoop, 2015). Using an approach from only one domain is not suitable to come to an integrated solution. Besides that, laws on managing mangrove forests differ across the different provinces. This results in preventive measures to reduce erosion that will increase the problems in the neighbouring province. The law opted by the prime minister of a mangrove forest belt of at least 500 m is adopted by all the southern provinces. In the areas where the mangrove forest is less than 500 m the provinces are trying to increase the mangrove forest seawards. This is not always successful and a smaller mangrove belt is accepted if further land reclamation at the seaside is not possible.

For the improvement of the quality of mangrove forests and the coastal defence system, this policy should be more strictly enforced and at areas where the width of the mangrove forest is less than 500 metres planting mangrove plants landwards should be considered to ensure water safety.

Partners of the project are adopting new ways to measure the width of the mangrove forest and the amount of erosion.

3.3.3.2 Land Use

During the last decades, a lot of mangrove forest was removed to make space for shrimp production. Because of the decreased width of the mangrove forest, the human settlements have an increased risk of flooding. In front of the shrimp farms only several hundred metres of mangrove forest is present and does not satisfy the 500 m required for coastal protection. The integrated fishponds are the most vulnerable since these are located in front of the sea dyke. A small dyke prevents the shrimp ponds to flood during high tide. When a storm hits the area, the people in the Bạc Liêu area are evacuated and the shrimp ponds will drown which will destroy the shrimp harvest.

One strategy to improve the coastal protection is to retreat and abandon to make room for the sea (Albers, San, & Schmitt, Shoreline management guidelines. Coastal protection in the lower Mekong Delta, 2013). The shrimp ponds are currently in front of the sea dyke because the mangrove forest has a positive influence on the shrimp yields. When the shrimp ponds are located behind the dyke these benefits will be harder to realize and additional measures are needed.

Another strategy can be expansion, creating more land by expanding the coastal defence system (Albers, San & Schmitt, 2013). This is possible by extending the mangrove belt in front of the shrimp ponds to the required 500 m. Because at some locations only a few hundred metres of mangrove belt is left, it might not be suitable to reach the required 500 m.

In the final design, both strategies should be considered. The current shrimp ponds can be optimised to create more width of mangrove belt in front of the shrimp pond. The optimised shrimp pond gives more room for the sea and is connected with the environment. This connection with the environment contributes to the water purification, storm protection, erosion sedimentation (Zavalloni, Groeneveld, & van Zwieten, 2014). Therefore, it is important to take this optimised shrimp ponds into account in the coastal protection design.

3.3.4 Stakeholder analysis

3.3.4.1 Tube model

Figure 17 shows a tube model for the coastal protection system. This model gives an overview of all systems, interfaces and stakeholders that might influence the system. Besides that, the tube model shows the scope of this project. The blue part of the tube model is the System of interests.

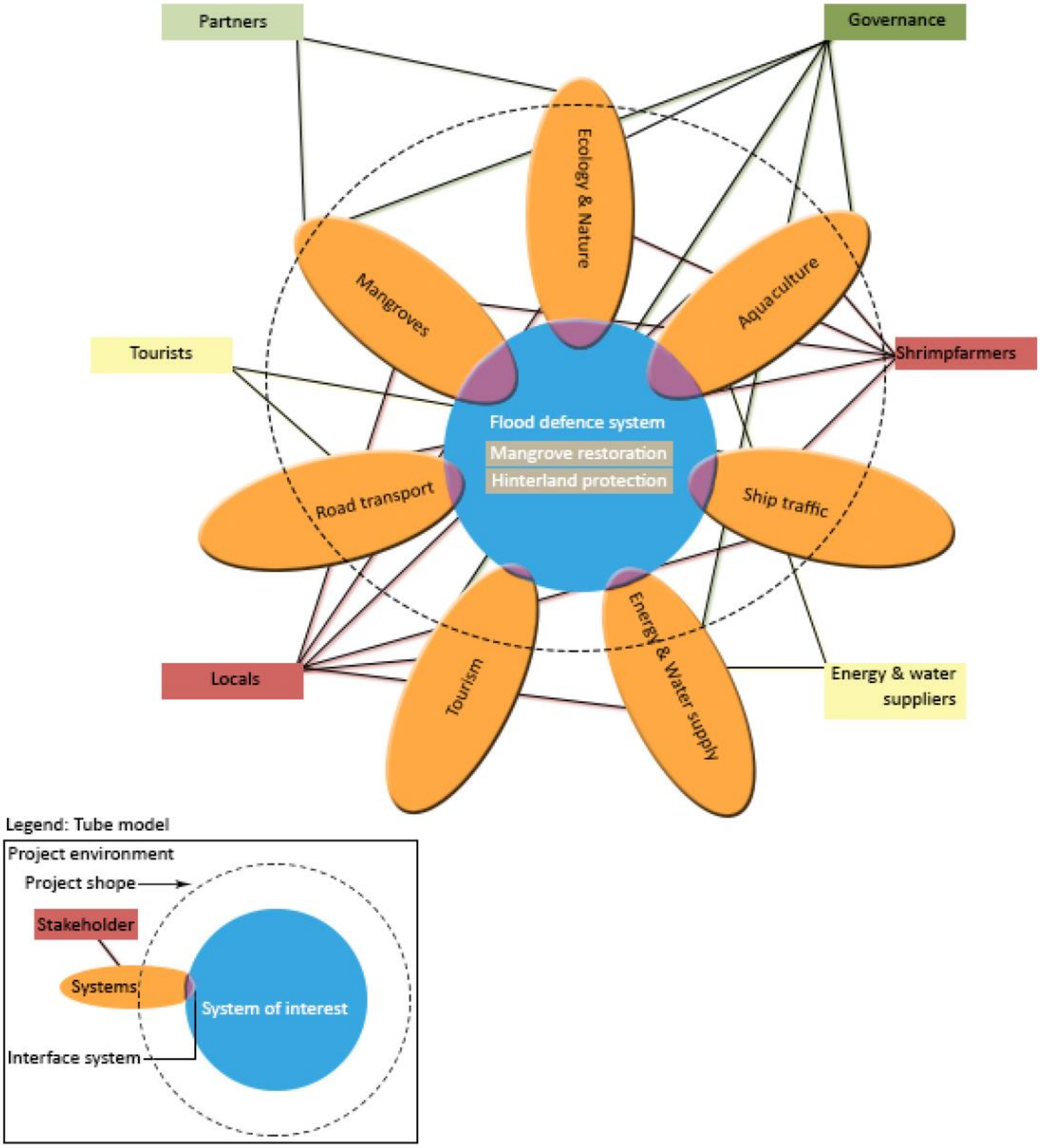


Figure 17: Tube model

In the tube model, the stakeholders for this project are divided into three main categories. The first category 'governance' is the Ministry of Natural Resources and Environment (MoNRE), the Ministry of Agriculture and Rural Development (MARD), Bạc Liêu Provincial People's Committee (PPC) and Forest Management Boards (FMBs). The next category is 'users'. In this category, the local people and the small businesses of Nhà Mát, the shrimp farmers, Energy and water suppliers and tourists can be found. The third category is 'partners'. These are organisations that do research in the development of the coastal zone in the Mekong Delta such as SIWRR, WIP and GIZ. A complete description of the stakeholders can be found in Appendix I. The interfaces are shown in the pink parts of the model. The interface requirements that are shown in the system requirement specification are based on these interfaces. Table 5 elaborates on the interfaces.

Table 5: Overview of interfaces

Object 1	Object 2	Explanation
System of interest	Tourism	One of the policies is to get more tourism in the Mekong Delta. Another element of this interface is the Nhà Mát resort and the pier.
System of interest	Road transport	Here the interface is the road that is situated on the sea dyke within our scope. It is also important that our system is accessible.
System of interest	Mangrove	The mangrove forest plays a big role in our system of interest, but there are also mangrove plants just outside of our geographical scope.
System of interest	Physical environment	In a mangrove forest atmosphere, hydrosphere, lithosphere and biosphere are very important for mangrove plants to grow.
System of interest	Aquaculture	The system of interest includes aquaculture like integrated shrimp ponds.
System of interest	Ship traffic	The system of interest is partly in the sea, so ship traffic should be taken into account as an interface.
System of interest	Energy & Water supply	This interface involves the electricity cables and water pipes in the area.

3.3.4.2 Power interest matrix

In this section, an overview of the stakeholders' interests, powers and attitudes towards this project are given in Table 6, Table 7, and Table 8. Dividing the actors into categories makes it easier to see what should be done to get the project broadly supported.

Governance

Table 6: Governance stakeholder

	Who?	Interests	Powers	Attitude
1	MoNRE	Medium-High	High	Positive
2	MARD	Medium-High	High	Positive
3	PPC	High	High	Positive
4	FMBs	High	High	Positive

Users

Table 7: Users' stakeholders

	Who?	Interests	Powers	Attitude
5	Locals and small businesses	Medium-High	Low	Neutral-Negative
6	Shrimp farmers	High	Low	Negative
7	Energy and water suppliers	Low	Low	Negative
8	Tourists	Low	Low	Positive

Partners

Table 8: Partner stakeholders

	Who?	Interests	Powers	Attitude
9	SIWRR	High	Medium - Low	Positive
10	WIP	High	Medium - High	Positive
11	Other international organisations	High	Low	Positive

For describing the influence of all the different actors, a power interest attitude diagram is provided. The stakeholders are grouped according to power, interest and attitude just like the tables above. The customer requirements of high-power and high-interest stakeholders are taken more into account for the new system design. In the power-interest matrix, several actors are distinguished. This is shown in Figure 18.

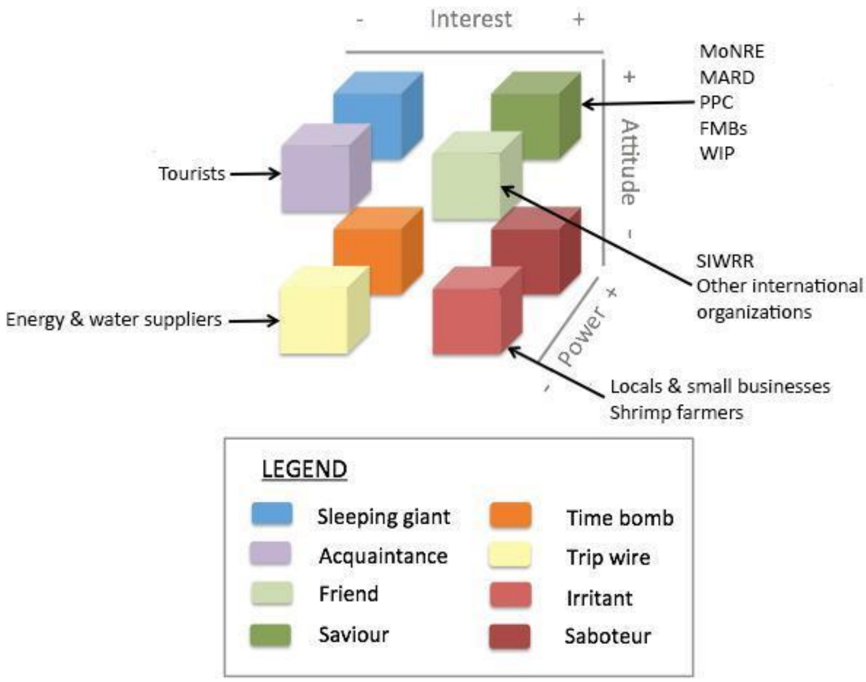


Figure 18: Power-interest matrix adjusted from (Murray-Webster & Simon, 2006)

3.3.4.3 Stakeholder engagement plan

In the design process, it is important to mobilise actors, give room to manoeuvre and create commitment, support and consensus for different actors to reach a broadly supported design. This stakeholder engagement plan gives an overview how to deal with the different actors involved in this project.

<u>Saviour</u>

Actors in the category 'Saviour' (dark green) have high power, are active and have a positive attitude towards the project (Murray-Webster & Simon, 2006). MoNRE, MARD PPC FMB's and WIP can be classified in this category. The policies of MoNRE shift towards preserving the mangrove forests and the policy of MARD shifts towards sustainable farming. This project partly focuses on the use of optimised shrimp ponds which reduce the incentive to 'clear and abandon' the mangrove forest. The PPC is the initiator of the rehabilitation of mangrove forest in the Bạc Liêu province and contracted WIP to do research about how this can be done in the Bạc Liêu province. The FMB's are concerned about sustainable management of the mangrove forest. It is important to do whatever necessary to keep the attitude of these actors towards this project positive.

<u>Friend</u>

Actors in the category 'Friend' (Light green) have low power, high interest and a positive attitude towards the project (Murray-Webster & Simon, 2006). SIWRR and other international organisations can be classified in this category. These organisations are interested in the project and have a lot of knowledge about mangrove rehabilitation. These actors should be used as a sounding board to maintain a positive attitude towards to the project. Their feedback is taken into account for the final design.

<u>Acquaintance</u>

Actors in the category 'Acquaintance' (purple) have low power, low interest and a positive attitude towards the project (Murray-Webster & Simon, 2006). Tourists can be classified in this category. The Bạc Liêu province is not very attractive for foreign tourists at the moment, rehabilitation of the mangrove forest improves the quality of nature in the area which can improve the eco-tourism. It is important to keep these actors informed about the development. The current recreational area of the Nhà Mát community is protected with a hard structure in a former mangrove forest area (see Figure 19). This project will not impact the current recreational area but this kind of hard structures in a mangrove area should not be allowed in the future.

Figure 19: Dyke revetment at Nàh Mat Community

Irritant

Actors in the category 'Irritant' (light red) have low power, high interest and a negative attitude towards the project (Murray-Webster & Simon, 2006). Local & small businesses and shrimp farmers can be classified in this category. According to Hai & Yakupitiyage (2005) Vietnamese farmers dislike mixed mangrove-shrimp systems because this is technologically challenging. The shrimp farmers prefer to intensify the system. Therefore, the attitude towards this project is negative. Since the land use in the mangrove forest is regulated, the power of shrimp farmers is low. Other locals and small businesses can also be seen as irritants. This project might reduce their business opportunities in the mangrove forest because it might influence the regulations on utilising the mangrove forest. The interfaces of the locals are considered and these actors should be engaged to identify their main concerns about the project.

Tripwire

Actors in the category 'Tripwire' (yellow) have low power, low interest and a negative attitude towards the project (Murray-Webster & Simon, 2006). This project might reduce their business opportunities in the mangrove forest because it might influence the regulations on utilising the mangrove forest. The energy and water suppliers can be classified in this category. These companies provide the water and energy infrastructure in the area. It is important to understand these actors and not hinder the energy and water suppliers to keep their interest low.

3.3.4.4 Dilemmas

Most important is the situation of the shrimp farmers in the area. During the stakeholder analysis and literature study several dilemmas were identified. These are elaborated below.

Should the mangrove forest be rehabilitated in cost of land use when the width of the mangrove belt is less than 500 m?

Nowadays, the rule of 500 m mangrove belt in front of the dyke is in use. At locations where the width of the mangrove belt is less than 500 m projects are carried out to create more mangrove plants at the seaside. These projects are not always successful because at some locations the conditions more seawards are not suitable for mangrove plants to grow. Because of this, a large part of Vietnam does not satisfy the 500metre rule. Expensive measures might improve the conditions of the mangrove plants to grow but it might be more convenient to restrict the land use in these areas and make room to plant mangroves at the landside.

Is the current 60% mangrove coverage ruling enough to preserve the 500 m width of mangrove belt?

Currently, shrimp farmers are obliged to cover 60% of their farming area with mangrove plants. In the Bạc Liêu province, most of the shrimp ponds are integrated or associated shrimp ponds. This results in large ponds with planted mangroves within the pond. The ponds have a length of approximately 350 to 700 metre measured from the sea dyke. 60 to 70% of the shrimp farm area is covered by mangrove forest. Because of the large area of shrimp farming, the width of mangrove belt in front of the shrimp farm is only 140 to 300 metre.

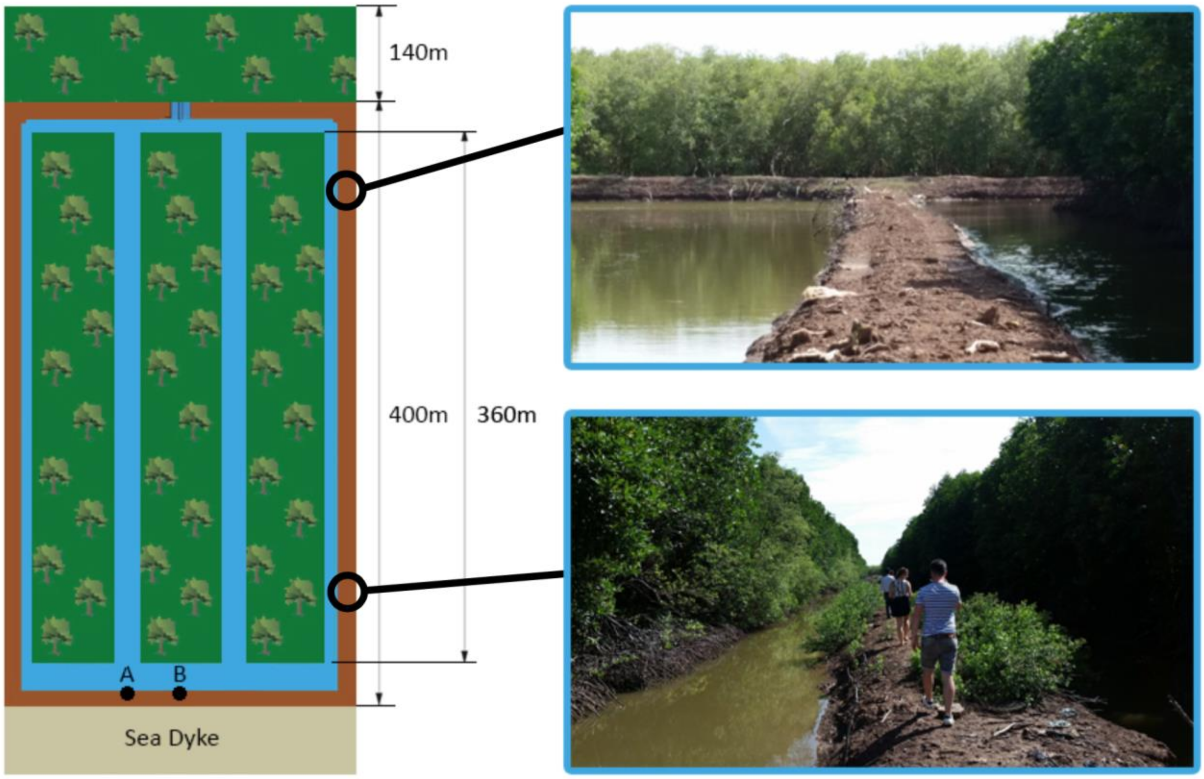


Figure 20: Example of shrimp pond in Bạc Liêu Province (Bosma, Nguyen, Siahainenia, Tran, & Tran, 2016)

Figure 20 shows an example of one of the shrimp ponds visited in the Bạc Liêu Province. The width of the mangrove forest in front of the farm was approximately 140 metre. The length of the farm is approximately 400 metres and the farm had a 60% mangrove coverage. The width of the mangrove belt within the pond is approximately 360 metre. Figure 20 shows that in front of point B 500 m of mangrove belt is present by adding the 140 metre of mangrove in front of the dyke and the 360 m of mangrove forest in the pond.

However, at point A on the sea dyke, only the 140 metre of mangrove in front of the fishpond is present. By changing the structure of the shrimp ponds to an optimised shrimp pond the width of the mangrove belt can be more than 500 m in front of the whole sea dyke in Bạc Liêu (see figure 16).

These dilemmas can be solved in different ways. One way is to enforce the 500-metre rule more strictly and withdraw permits of farmers who do not comply. However, this will probably lead to resistance since the farmers have to make large investments to restructure the shrimp pond. It is questionable whether the farmers are able to do this. MARD can reduce the resistance by making the new pond structure more beneficial by providing education to the farmers to improve the yield for the optimised ponds. Besides that, a research must be carried out how the shrimp farmers can finance this investment.

4. Customer requirements specification (CRS)

4.1 Objective and CRS process

The aim for the CRS process is two-jointed. The first part is to support and structure the interaction with stakeholders. Secondly, it is to collect input for the system developments, such as the requirements and design alternatives. This contributes to making a structured and complete inventory of all the input of the active stakeholders (Rijkswaterstaat, 2011). The CRS process has several steps to finalise the specification, which is shown in Figure 21.

Figure 21: Customer Requirement Specification (CRS) process steps

Starting with identifying the stakeholders based on a stakeholder analysis, which is done in chapter 3, the CRS is based on wishes from these stakeholders. Mostly, these wishes are unstructured, solution focused, conflicting and they can be interpreted in several ways. Therefore, it is important to find the relevant information and to translate that into system requirements. When these customer requirements are conflicting or not feasible, they need to be rejected (Kramer, 2013). The analysis from the CRS to the System requirements specification (SRS) is shown in Figure 22.

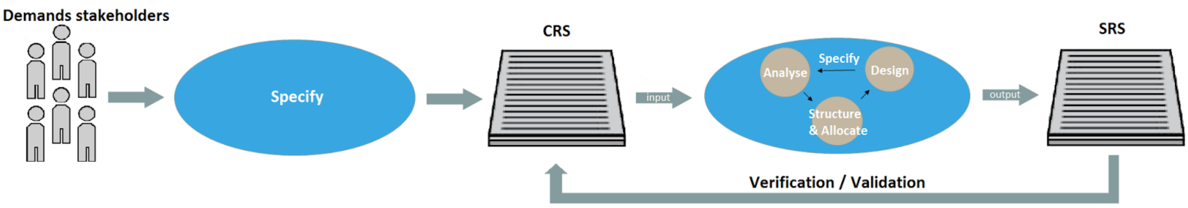


Figure 22: Analysis process from CRS to SRS (Kramer, 2013)

The CRS is not a static document, this means that during the project it constantly changes, because of the feedback loop between de CRS and SRS. Validation and verification is an important process during the whole life cycle of the project. The several verification methods that are explained in Appendix J.

The requirements are categorised by stakeholder categories, which are described in chapter 3. The requirements in the Appendix J all have the same format as shown in Table 9. This format includes a code, a title, a description, a verification method, the source document, the stakeholder that contributed the requirement, and the status of the requirement. The code for every customer requirement is a unique number that is generated automatically. There are four statuses for CR: honoured, partially honoured, rejected, and secured. When a CR is honoured, the wish of the stakeholder will be translated into a system requirement. A partially honoured CR means that with a few adjustments the requirement is honoured. If a CR is secured, the wish of the stakeholder is already secured into a national policy or the implementation plan. When the CR is rejected, the wish will not be accepted. When a customer requirement is honoured or partly honoured it is defined into one of the system requirements, which are elaborated in chapter 5 and Appendix K.

Table 9: Format customer requirements

CR_xxxx – [Title]	**Status:**	**Defined in SR**
[description]	[honoured / partially honoured / rejected / secured]	SR_xxxx
Stakeholder: [stakeholder that contributed the requirement]		**Source document:** [reference document]
Verification Method: [inspection / analysis / test / demonstration / analogy / simulation / sampling / through child requirements]		

5. System requirements specification (SRS)

This chapter provides the SRS. First, the objective of this document, the process, including analyses, and how to specify the requirements is explained. The next paragraphs contain the requirements, starting with the top requirements. Followed by the more detailed requirements concerning the system is divided into functional, aspect, and interface requirements. The complete specification can be found in Appendix K.

5.1 Objective and analyses

The aim of this document is to make a structured collection of all requirements, which should be met by the system. Mostly, the discipline of requirements analysis and management is underrated, which is odd because starting with adequate requirements can reduce or eliminate most issues during a project (Johnson Popp, 2008). These issues include project delays, a final scope that does not please the client, and budget exceedance (Johnson Popp, 2008).

The system requirement specification is based on several analyses. First, it is partly based on the customer requirement specification. Secondly, a function analysis is done, to check the completeness of the specification. The function analysis is done based on the Function Analysis System Technique (FAST) method, which means that the system is looked at by asking three different questions. The 'how'-question ensures the arrangement of the functions. The 'why'-question confirms the necessity of the functions in the diagram, and the 'if-then'-question finds supporting functions (Bartolomei & Miller, n.d.). For the functional analysis, the system is split into two main goals of the system: 'mangrove rehabilitation' and 'protection of the hinterland'. In Figure 23 and Figure 24, the FAST method for these two goals is shown. Figure 23 shows the FAST diagram for the main goal 'protection of the hinterland. In this diagram the functions that make this goal possible, are represented in the middle part. On the right side the object that can fulfil these functions are given. The same representation is used for figure 24, but for the goal 'mangrove rehabilitation'.

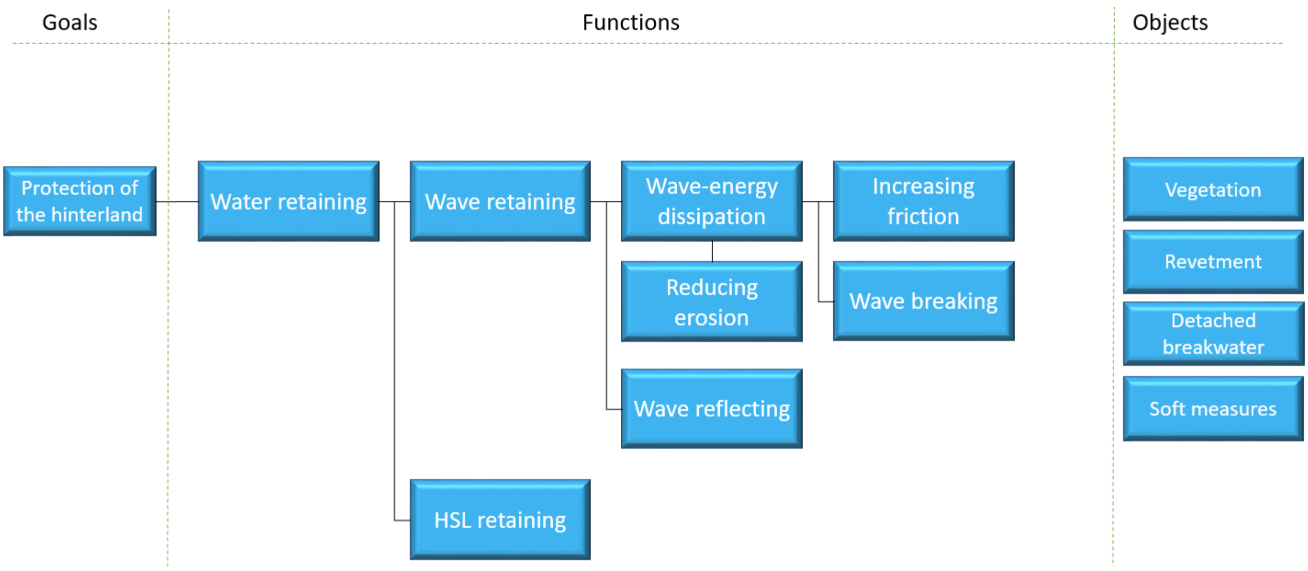


Figure 23: FAST diagram for primary goal: 'protection of the hinterland'

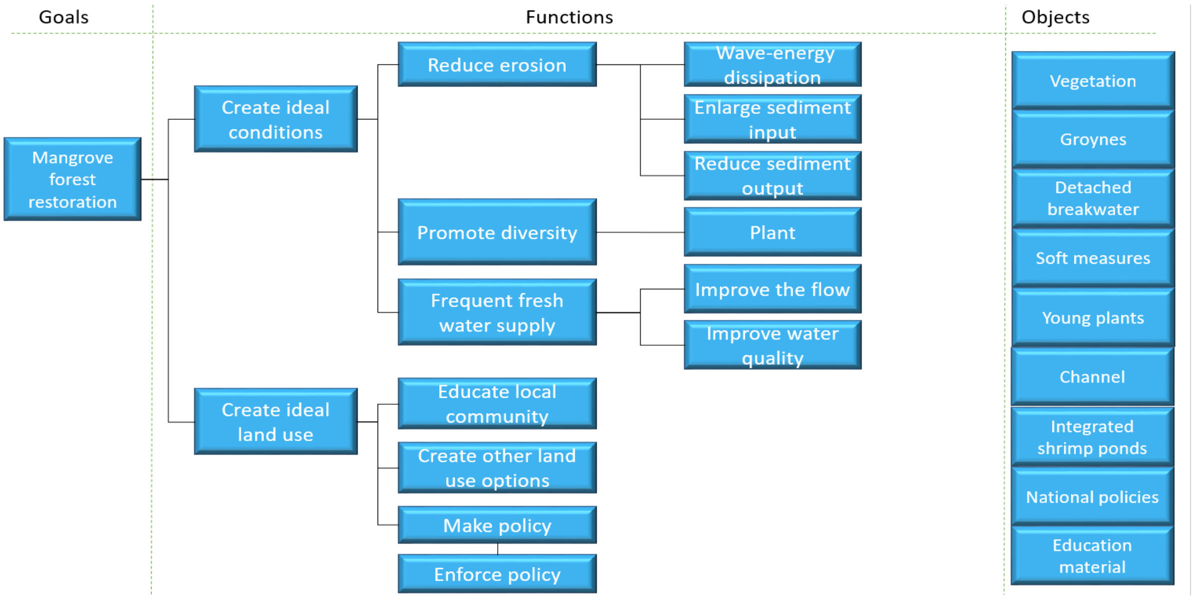


Figure 24: FAST diagram for primary goal: 'mangrove forest restoration'

5.2 Requirements specification

Requirements specification is a careful assessment of the needs that a system is to fulfil (van Lamsweerde, 2002). Normally, requirements are defined by the client in cooperation with the project team. However, defining these requirements is not that easy. Common mistakes in defining the specification are duplicated, missing or misplaced, and conflicting requirements (Wasson, 2006). Therefore, it is essential to have requirements how to specify the system requirements. The primary rule is the acronym 'SMART', which stands for Specific, Measurable, Attainable, Realisable and Time-bounded (Mannion & Keepence, 1995). An explanation of these conditions is listed in Table 10. Besides this rule, a requirement should be necessary, verifiable, unique, solution free, and traceable.

Table 10: Requirement conditions

Requirement concept	Explanation
Specific	Requirements should represent exactly what is required, this involves multiple areas: - Clear; - Consistent; - Simple, so avoid double requirements.
Measurable	It should be clear when the objective of the requirement is reached.
Attainable	The requirement should be accomplishable in terms of the social status.
Realisable	The requirement should be physically and theoretically possible, is it feasible.
Time-bounded	It should be clear when a requirement needs to be executed.
Necessary	Requirements should be crucial.
Verifiable	Requirements should have a verification method, so it is possible to check if the requirement is achieved.
Unique	Not two or more requirements that mean the same.
Solution free	Requirements cannot already describe the solution.
Traceable	Requirements includes, for example, a title and a source document

The requirements in the following paragraphs all have the same format as shown in Table 11. This format includes a title, parent and/or child requirements, a description, a verification method, and the source document.

Table 11: Format system requirements

SR_xxxx – [Title]	Parent requirements	Child requirements
[description]	SR_xxxx	SR_xxxx
Verification Method: [inspection / analysis / demonstration / test / analogy / simulation / sampling / through child requirements]		**Source document:** [reference document]

5.3 Requirements

In this paragraph the requirements are represented in a requirement overview, this is shown in Figure 25. The coastal protection system has to meet the top requirements and they are based on the objectives of the system. In the requirement overview, the three top requirements are shown. As already described in the methodology the specification process is iterative and a dynamic process with the alternative research and final design.

Functional requirements are requirements that define a function of the system or subsystem. A function is a service or activity, which the system should achieve or provide to reach the objectives of the system. This is described in the format of verb + noun + performance indicator.

Aspect requirements describe specific characteristics, which are not actively involved in the primary function of the system. These requirements can be divided in the 'RAMS' characteristics: Reliability, Availability, Maintainability, Safety. Besides RAMS, futureproof, sustainability, and design requirements are also aspect requirements.

The interface requirements are based on the interfaces determined in the tube model in paragraph 3.3.4.1. It is important to specify these requirements, considering that a lot of mistakes have been made in other coastal protection projects. The interfaces for this system are described in chapter 3.

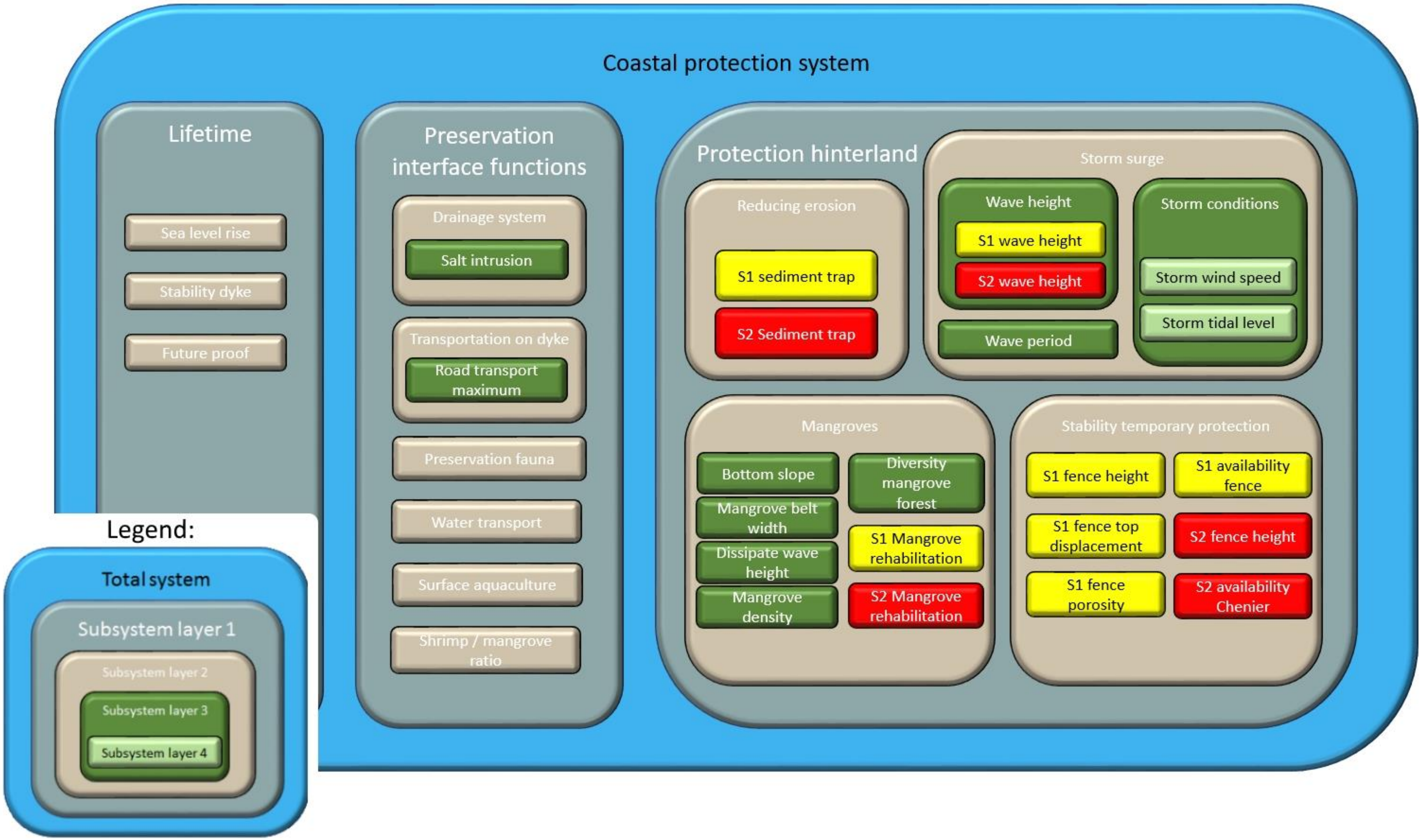


Figure 25 Requirement overview

6. Alternative research

In the next paragraphs, a description is given about different alternatives. These alternatives are derived from the FAST analysis. The alternatives are divided into three main categories: detached breakwaters, groynes and soft measures. These categories are chosen because the functions of these measures are distinctly different. Several alternatives for each category are elaborated with tables in appendices L. For each alternative, there is a short description of the purpose, advantages and disadvantages, experiences, maintenance, and costs. After the introduction of the scenarios in chapter 7, these alternatives are compared using a Multi Criteria Analysis (MCA) in paragraph 7.1.2 and 7.2.2.

6.1 Detached breakwaters

Detached breakwaters are longshore elements along the coast. The main function of these longshore elements is to protect the shoreline against wave attack and the corresponding cross-shore currents. As explained in section 3.3.1.5, due to erosion the wave attack at the Bạc Liêu shoreline is increased, which causes even more erosion. Longshore elements are necessary to dissipate this wave energy, and thereby create a more tranquil environment for sedimentation and protecting young mangrove plants to give them time to grow and gain strength. This sedimentation results in a salient or tombolo over time.

As told in section 3.1.1.2 ‘Current situation’, at the project location there is a very gentle slope of 1:1000 and a quite large tidal range of 3.5 m. Due to these characteristics, almost every breakwater design will be emerged and submerged for some time. However, from earlier experiences can be learned that most breakwaters that are submerged, are less effective or even worsen the erosion problems because the breaking waves create a longshore current behind the breakwater. Therefore, in this project, the focus lays on breakwaters that are emerged most of the time. It might be the case that, because of the large tidal range, it is not cost efficient to construct a fully emerged breakwater, but that will be further elaborated in the final design.

Different alternatives of detached breakwaters are:

- Rubble-mound breakwater
- Prefabricated emerged breakwater
- Concrete breakwater
- Geotube
- Reef balls
- Permeable fences
- Geohooks
- Floating breakwater
- Gabions

These alternatives are chosen because they have been or could be used as a detached breakwater with the purpose of mangrove rehabilitation. The alternatives are elaborated in Appendix L.1.

6.2 Groynes

Groynes are cross-shore elements along the coast. The main function of these cross-shore elements is to interrupt the natural longshore current, and thereby decreasing local current velocities, which lead to accretion at the upstream side of the groynes. The sediment transport rate behind the groynes is decreased by the same amount as the amount that is trapped in front of the groynes (Bosboom & Stive, 2015). Therefore, groynes can cause downdrift erosion when their influence on the sediment balance is too large. Nevertheless, these effects will decrease in time when the upstream side gets filled up with sediment and sediment transport will go over and around the structure.
Two different groyne alternatives are elaborated in Appendix L.2:

- Rubble-mound groynes
- Permeable groynes

6.3 Soft measures

Soft measure alternatives are made from sand (or mud) and their functionalities are based on natural processes. The main purpose of these measures is to enlarge the sediment input. If there is enough sediment available, more sedimentation can take place. Therefore, these measures can help to decrease erosion and can even cause accretion. Due to the natural process, the functionality will decrease after several years. The described soft measures for this project are:

- Longshore sandbar
- Direct nourishment
- Mud Engine

These are further explained in Appendix L.3

7. Scenario research

Based on the research before, two different scenarios are described in this chapter. After a description of the scenario, the corresponding multi criteria analysis (MCA) is executed for the alternatives described in chapter 6. The purpose of these MCA's is to determine which alternatives are best applicable for each scenario. After this, the alternatives which score best in the MCA are used to draft different designs. In this chapter, the choice is made to first work out the three steps above for scenario 1, before switching to the second scenario. The difference of scenario 1 and 2 is given in Figure 26. The rehabilitation of scenario 1 takes place between the red lines and the rehabilitation of scenario 2 takes place between the blue lines.

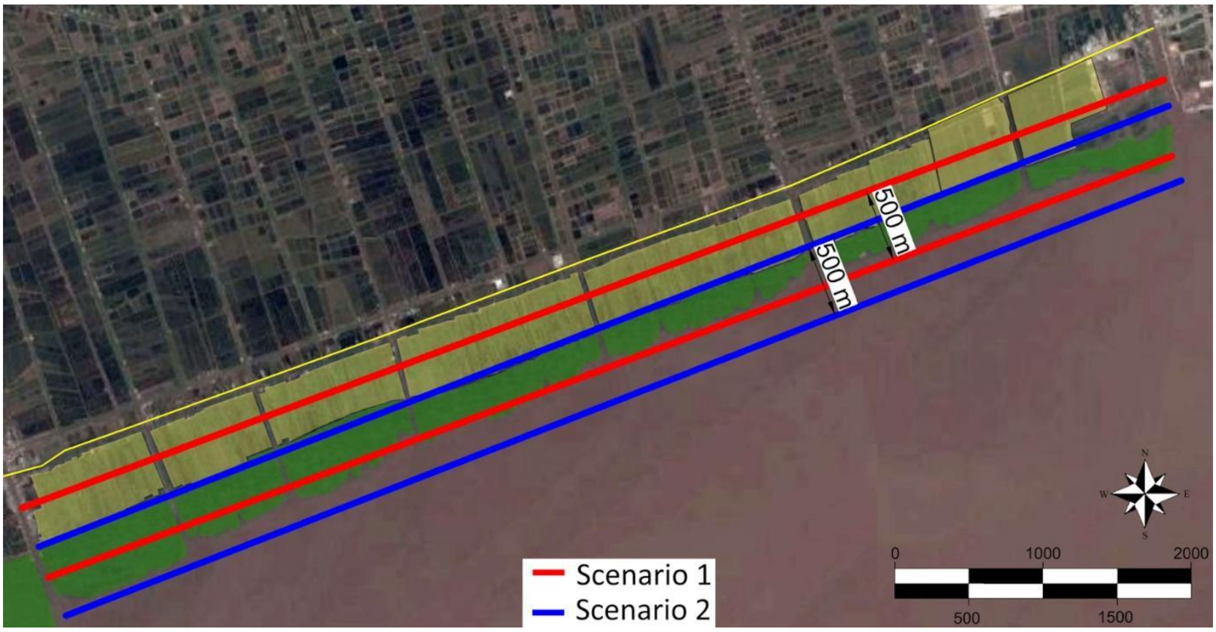


Figure 26: Difference between scenario 1 and 2

The scenarios differ in layout of the shrimp farms that are present in front of the sea dyke. Each scenario has its pros and cons, therefore for this project, it is decided to consider them both. The pros and cons of each scenario are summarized at the end of this chapter. A very important assumption for both scenarios is that the mangrove belt in its current state is not sufficient to protect the hinterland. Nowadays, the government counts the mangrove plants that are in the shrimp ponds in front of the dyke, as a part of the desired 500 m belt to protect the hinterland. In this project, it is advised not to do so, because of the reasons summarized below:

1. There are large gaps between the rows of mangrove plants in different shrimp ponds.
2. The mangrove plants in the shrimp ponds probably will be much weaker than the mangrove plants in the mangrove forest at the seaside because in the shrimp ponds no sedimentation takes place, so these mangrove plants cannot consolidate soil to have their roots firmly into the ground.
3. The mangrove plants in the shrimp ponds therefore also do not contribute to counteract sea level rise. This is an important function of the desired 500 m mangrove forest. At some points in the considered area, only 150 m of mangrove forest is present to fulfil this function.

4. The mangrove plants in the shrimp ponds are not part of the ecosystem which normally exists in the mangrove belt at the seaside. In case this would become one whole, the mangrove forest would be healthier.

7.1 Scenario 1: Optimised land use

7.1.1 Introduction

The first scenario is based on the desirable layout of the shrimp farms in front of the sea dyke, which is the result of the 'land use in the ideal situation' from paragraph 3.2.2.2. Most important for the design of the coastal protection is that the 40% shrimp part of the farm is fully located directly in front of the dyke. In this way, the 60% mangrove plants can already be part of the required mangrove belt of 500 m. This layout will result in optimal land use, and less land reclamation seawards is needed as shown in Figure 27. Rehabilitation of mangrove at the front side of the mangrove forest is difficult, but with appropriate site works to create good hydrological conditions for mangrove plants, mangrove rehabilitation is possible in former shrimp ponds (Tas, 2016).

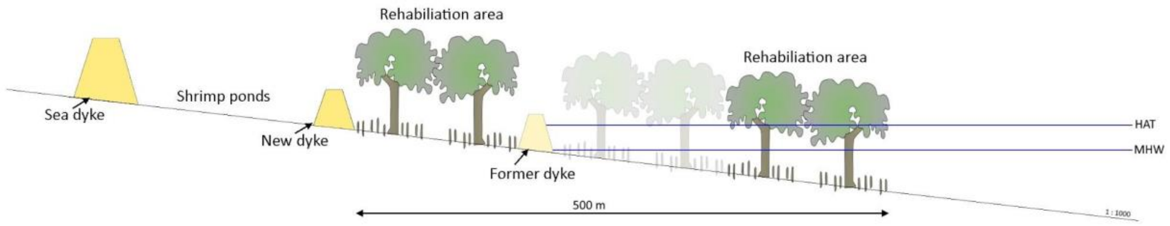


Figure 27: Cross-section scenario 1

The total area of mudflat which has to be rehabilitated into mangrove forests is approximately 39 ha in this scenario, which is shown in figure 28.

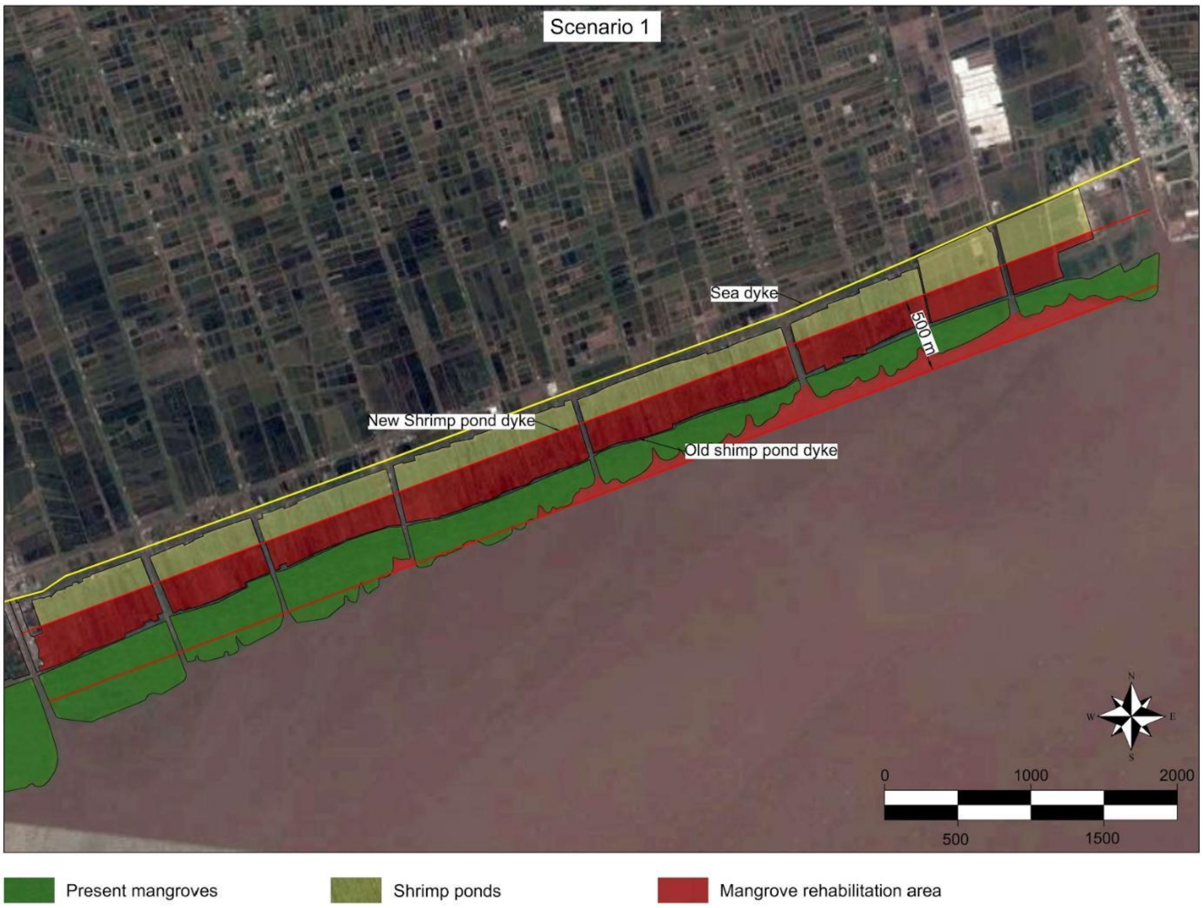


Figure 28: Overview of rehabilitation area scenario 1

The figure also reveals that only some relatively small measures will be sufficient to obtain the required mangrove belt of 500 m in case the shrimp farms are changing their layout. However, the implementation and the total change in land use might be hard to achieve. The government has to implement measures to force land use adjustments. The farmers have to change their way of thinking about the land use and might get the feeling that they lose a large part of their property to grow mangrove forest outside their ponds. Without intensively informing and educating the farmers about the opportunities this plan can create, this scenario will probably lead to a negative attitude towards the new land use. Besides that, the government is focused on land reclamation and planting new mangroves seawards, thus their attitude is probably not positive towards this scenario in the first place. Figure 28 is an overview of the area to rehabilitate.

7.1.2 Multi Criteria Analysis (MCA)

For both scenarios, a multi criteria analysis (MCA) is executed. A description of the used method, the explanation and estimation of the criteria and the rating of the alternatives can be found in Appendix M. The results of the MCA for respectively scenario 1 is as follows. The results for scenario 1 are shown in Figure 29.

Scenario 1: Alternatives

	Rubble mount breakwater	Prefabricated emerged wavebreakers	Concrete breakwater	Geotube	Reef balls	Permeable fences	Geohooks	Floating breakwater	Gabions	Rubble-mound groynes	Permeable groynes	Longshore sandbar (Chenier)	Direct nourishment	Mud engine
Totaal	-59	-67	-30	-5	19	80	53	38	-56	-62	77	16	16	12

Figure 29: Multi Criteria Analysis (MCA) results for scenario 1

It can clearly be seen that hard and expensive structures have low scores, while the cheaper permeable natural fences got high scores. In the design, every option above 30 points is taken into consideration for our variants. These are shown in Table 12.

Table 12: Top results MCA scenario 1

Permeable fences	80
Permeable groynes	77
Geohooks	53
Floating breakwater	38

The permeable fences and permeable groynes are often part of the same structure, but they have different main functions. In Vietnam U- or T-shaped fences are widely used. Between the T-fences there are gaps, allowing a free flow between the fences, whereas the U-fences are closed, obstructing the cross-shore flow. Both fences seem to work well in trapping sediment and reducing waves, however, the differences in effectivity are not known. To guarantee wildlife is not hindered by the fences we will use T-fences, as they have an open arrangement. This resulted in three options for the variants. These variants will be further elaborated in the next section.

7.1.3 Designs scenario 1: Optimised land use

This scenario includes the new layout of the shrimp farms. As mentioned before only some relatively small scale measures are needed to achieve the desired mangrove belt with a width of 500 m. Therefore, in this scenario, the chosen alternatives are worked out to achieve local accretion instead of considering a large coastal area.

7.1.3.1 Permeable fences

Permeable groynes made of locally available materials such as brushwood and bamboo- or melaleuca-poles, are suggested as the measure to enhance trapping of fine sediments on mudflats in a natural way (Winterwerp, Erftemeijer, Suryadiputra, van Eijk, & Zhang, 2013). Permeable dams mimic the natural functions of mangrove forests to dissipate waves and thereby enable natural mangrove regeneration to occur. The combination of a permeable groyne and permeable breakwater are often built as T-fences. In Vietnam, often fields of 50x50 meter are used to induce accretion with permeable fences Albers & von Lieberman (2011).

Permeable structures are easier to construct on soft muddy soils than hard impermeable structures, because the materials are relatively light and easily manageable. Furthermore, the permeable structures are less likely to enhance scour and downdrift erosion than impermeable structures. Bamboo is extensively used in constructions in developing countries based on its strength and year-round availability at a minimum cost (Halide, Brinkman, & Ridd, 2004). In Bạc Liêu bamboo is also used as low cost construction material for example in the U-fences at the Nhà Mát community. The permeable fences are very good applicable at the project location.

7.1.3.2 Geohooks

Geohooks are still a new product and not much experience is gained yet for this innovation, especially not in rehabilitating mangroves. Although Geohooks can be applied in different interesting ways, they are rated in the MCA as a permeable breakwater. In this variant, the Geohooks are placed as a kind of artificial reef, as is done before in a pilot project in the Netherlands, see Figure 30.

Figure 30: (l) Pilot project Geohooks; (r) shape single Geohook (Geohooks BV, 2015)

A Geohook has a shape that follows seven ribbons of a cube of about 40 cm and is made of biodegradable material. An example is shown in Figure 30. Thus, the hooks cling into each other and the pile forms a strong and steady breakwater. If it is designed well, accretion will occur behind the breakwater, which in the end can result in a salient or tombolo. Downdrift erosion will be limited because the Geohook-breakwater is permeable and thereby does not block the total sediment and water currents. The breakwaters should be located not too far offshore and there must be gaps between the breakwaters. The costs of a Geohook-breakwater are unknown.

7.1.3.3 Floating breakwater

The concept of using a floating breakwater for mangrove rehabilitation is very attractive assuming that the structure can be moved and reused at multiple locations. In this way, the floating breakwater is a temporary structure which can be removed when the mangrove forest, at a certain location, is wide and strong enough to retain waves and prevent erosion. A floating breakwater can have many different shapes and can be constructed with a wide variety of materials. For this scenario, the floating breakwater is considered as a solution constructed of locally available materials like bamboo or tires, as shown in Figure 31.

Figure 31: Floating tire breakwater (Unknown. (n.d.))

A large difference between the Geohook breakwater and the floating breakwater is that the floating breakwater does not block any currents. This is not beneficial for the accretion behind the breakwater, what probably is the reason why floating breakwaters are rarely applied as an anti-erosion measure. Nevertheless, a floating breakwater creates a more tranquil environment behind the structure, which leads to extra settlement of sediments. Thus, using only floating breakwaters to induce accretion is possible, but takes a lot more time. The effects are hard to predict and modelling is required. A more attractive option might be to use the floating breakwater in combination with other solutions in case the wave conditions are too extreme. The costs depend heavily on the used materials, equipment and additional measures, if needed.

7.1.4 Conclusion

There are a lot of uncertainties and very few experiences for Geohook-breakwaters and floating breakwaters used to prevent erosion or to rehabilitate mangroves. The permeable bamboo fences are widely used and tested in Vietnam and have proven to be successful. The bamboo-fences have a low carbon-footprint and are a good example of a building with nature approach. Furthermore, they are relative easy to build and the costs are low. When the fences are built as T-fences, they trap sediment and create tranquil conditions at the same time. U-fences also seem to be a good solution, but less experience is gained yet with this configuration of the permeable bamboo fences. Therefore T-fences will be further elaborated in the final design.

7.2 Scenario 2: Current land use

7.2.1 Introduction

The second scenario is based on the current layout of the shrimp farms. This means the farmers still should obey the 40/60-rule of shrimps and mangrove plants, but they can arrange their farm in their own way. During the fieldwork was observed that this resulted in shrimp ponds with a more longitudinal mapping, as can be seen in Figure 32. The open shrimp-part generally is located at the seaside of the sea dyke and the secondary dykes, that separate the different farms. Due to this division, there are large gaps between the mangrove plants of different farms, whereby these cannot be seen as a part of the mangrove forest that should reduce the wave impact on the dyke during floods. Therefore, in this scenario, the full 500 m of desired mangrove belt should be realized in front of the current shrimp farms to provide sufficient protection. This results in a total rehabilitation area of 170 ha which is about 5 times the area of scenario 1. As can be seen in Figure 32, in this situation a large width of reclaimed land is needed.

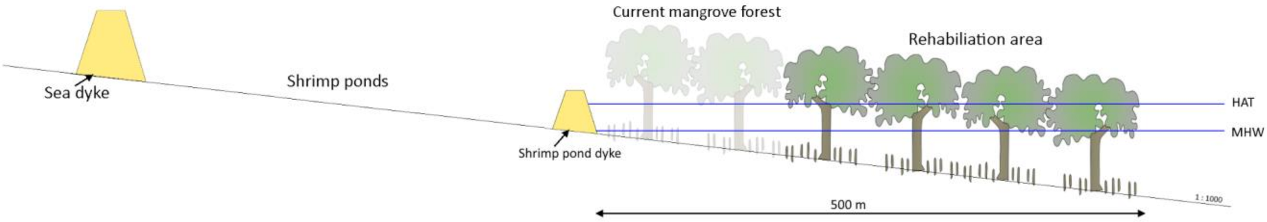


Figure 32: Cross-section scenario 2

This scenario does not change the current situation by means of the land use in front of the dyke, but mangrove rehabilitation this far seawards is hard and costs a lot of time. Shrimp farmers have a more positive attitude towards this scenario and the government is already trying this kind of expansion in other areas of the Mekong Delta. However, from an engineering point of view, expanding more seawards can lead to serious problems in terms of changes in local currents and downdrift erosion. An overview of the area to reclaim is given in figure 33.

Figure 33: Rehabilitation are in scenario 2

7.2.2 Multi Criteria Analysis (MCA)

The results for the MCA executed for scenario 2 are shown in Figure 34

Scenario 2: Alternatives

	Rubble mount breakwater	Prefabricated emerged wavebreakers	Concrete breakwater	Geotube	Reef balls	Permeable fences	Geohooks	Floating breakwater	Gabions	Rubble-mound groynes	Permeable groynes	Longshore sandbar (Chenier)	Direct nourishment	Mud engine
Totaal	-64	-72	-37	-16	17	37	14	12	-81	-60	38	37	34	19

Figure 34: MCA results scenario 2

Scenario 2 consists of a much bigger area where mangroves have to be planted and mudflats have to be created. It is clearly visible that in this situation the big nourishment solutions become more interesting. The figure shows also that the differences between the alternatives become smaller. Again, the options with a score above the 30 points are taken into account. These are shown in Table 13.

Table 13: Top results MCA scenario 2

Permeable groynes	38
Permeable fences	37
Longshore sandbar (Chenier)	37
Direct nourishment	34

The permeable fences and permeable groynes will be combined. The three structures are further elaborated in the next paragraph.

7.2.3 Designs scenario 2: Current land use

In Vietnam, no experiences are gained yet with mangrove rehabilitation projects of this size. Therefore, the designs sketched below contain uncertainties considering the feasibility, constructability, and reliability.

7.2.3.1 Permeable fences

The first option to reclaim this area is to repeatedly apply the T-fences, which are also used for scenario 1. For example, theoretically, it is possible to build a row of permeable T-fences in front of the land that was already reclaimed with an earlier T-fence project. In this manner, more and more land can be reclaimed in different phases. If the same dimensions, 50 m cross-shore and 50 m longshore elements, are used there are a lot of T-fences required to obtain the desirable 500 m mangrove belt. Furthermore, reclaiming the full width, with all the different phases, will probably takes a time-lapse of several decennia. An option to speed up the rehabilitation and apply the T-fences for scenario 2, is to upscale the dimensions of the fences. It has to be noticed that this is not modelled and the effects are uncertain.
The permeable bamboo fences are still a well proven method to rehabilitate mangroves, but never done before on this scale. Furthermore, the original T-fences are designed to be constructed in between two headlands. When the T-fences are built to reclaim land outside these headlands, it is unsure if this design with these dimensions will still be the best solution and suitable here.

7.2.3.2 Longshore sandbar

At many places worldwide, longshore sandbars are naturally present at gently sloped coasts with mangrove forests. These longshore sandbars, also called cheniers, are dynamic sand lenses lying on the muddy subsoil. Furthermore, at the East Mekong Delta shoreline cheniers are locally present (Wölcke, Albers, Roth, Vorlaufer, & Korte, 2016). During an earlier mangrove rehabilitation project near Bạc Liêu, the presence of an offshore sandbar resulted in an accumulation of mud and therefore fastened the sedimentation process inside the build permeable fences considerably. Moreover, part of the waves will break on the chenier, whereby the permeable fences are subjected to smaller wave forces.

In this variant, creating a longshore sandbar is not a standalone solution. The constructed chenier should be combined with smaller onshore solutions like the permeable fences. Without the use of permeable fences, probably also some natural mangrove rehabilitation will take place, but this might not be sufficient because the lifetime of a longshore sandbar is limited. The fences are needed to accelerate the sedimentation process to be able to gain land within the lifetime of the chenier and consolidate the gained land with the growth of new mangrove forest.

The constructed longshore sandbar will break part of the waves and will keep sediment into the system that normally would be lost offshore. Despite these advantages of a chenier, a disadvantage is that it needs careful and accurate modelling to achieve the desirable effects. In case the sandbar is too high, too many waves break and therefore not enough wave force is left to bring the sediments towards the shore. If the sandbar is too low, it will not have the desirable effects mentioned above. Even in the case the chenier is modelled carefully, its effectiveness remains quite uncertain on the long term because the conditions at the Bạc Liêu shoreline are very dynamic.

7.2.3.3 Direct nourishment

In case of a direct nourishment, the entire area where mangrove rehabilitation takes place is man-made. The soil will be directly supplied on the shore. An ideal bathymetry must be created where the new mangrove plants can grow. The newly created land has to be protected with a surrounding dyke, to prevent fast erosion. This dyke can be from bamboo, geotubes or other material. In front of the dyke, the mudflat will be much lower than behind the dyke and the natural bathymetry will be extremely disturbed.

The setting time of small sediments is higher than for coarser ones. Therefore, it takes a lot more time to fill the dredging ship, or much more mud and water has to be dredged than necessary. Next, when the mud is supplied to its destination, it will spread out over a large area, whereby it takes even more time to settle and compact. Thus, the direct nourishment has to be done in multiple phases.

7.2.4 Conclusion

The alternatives of this scenario contain a lot of uncertainties and should be investigated and modelled much further to get to a feasible design. Because there is no single best option, a combination of different alternatives is made. In the final design for scenario 2, chapter 9, the permeable fences are used to trap sediment and dissipate waves. It is not practical to construct the small T-shapes that are used in scenario 1, because of the enormous number that is required. Therefore, the design of the T-fences has different dimensions than in scenario 1. In scenario 2 more sediment is needed. To speed up the sedimentation process, the T-fences will be combined with a longshore sandbar, a chenier. This chenier keeps sediment in the system that normally would be lost offshore and decreases the intensity of the wave attack on the fences. If the chenier does not work sufficiently, one could decide to execute agitational dredging, which also increases the sediment input in the system. A chenier is favourable over direct nourishment because it is a less extreme measure and it fits better the vision of building with nature.

7.3 Comparison scenarios

Table 14 shows the benefits of both scenarios.

Table 14: Comparison of the two scenarios

Scenario 1	Scenario 2
Less reclaimed land needed - Cheaper - Less negative impact on downdrift sediment balance - Less uncertainty - Shorter period to build	Layout shrimp farms does not have to be changed - Farmers don’t “lose” land / property - No legislation needed to change the land use

8. Final design scenario 1

For scenario 1 the permeable fences are chosen as the best solution as described in paragraph 7.1.4. In this chapter, the final design is elaborated. The final design consists of a layout description, a design of the structure, the mangrove plant zonation, a risk analysis, an implementation plan, and a cost estimation.

8.1 Layout

The final design consists of permeable T-fences made with bamboo, which protect the newly planted mangroves at the seaside of the already existing mangrove belt. As described in paragraph 7.1.1 the current dyke between the mangrove forest and the shrimp farms is relocated more landwards. In the area between the old and new shrimp farm dyke, rehabilitation of the mangrove forest takes place.

8.1.1 Compartments

Albers & von Lieberman (2011) did physical and numerical modelling on bamboo fences to mitigate coastal erosion in the Sóc Trăng Province where these fences appeared to be a good solution. Different combinations and dimensions of longshore and cross-shore bamboo fences were modelled with wave data and tidal data from Vĩnh Châu. These data are similar to the situation at Bạc Liêu. The modelling of Albers and Von Lieberman resulted in bamboo T-shaped fences with dimensions shown in Figure 35. Due to the similarity in hydraulic boundary conditions, the same dimensions of the T-Fences are assumed to be optimal for this location. The cross- and longshore compartments form fields of around 50 x 50 m.

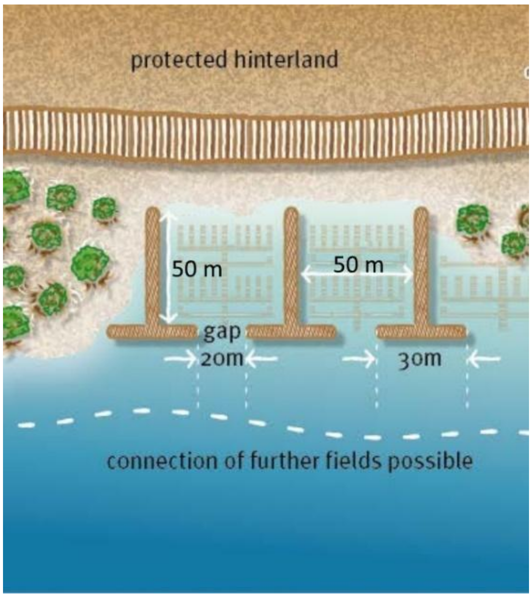


Figure 35: Dimensions T-fences (Albers, San & Schmitt, 2013)

During flood and ebb tides, different flow patterns occur in a compartment. To increase the sedimentation in a compartment it is important to create tidal flats. During flood tide, the flow velocity in the gap is higher than the flow velocity which flows through the permeable fences. Therefore, more water and sediment flows through this gap than through the voids of the permeable fences. Behind the permeable fences, the flow spreads out and the flow velocity decreases significantly. Settlement of sediment starts when the flow velocities are low enough. During ebb tide, the flow velocity is also higher through the gap than through the permeable fences. Therefore, the water flows converge to the gap. Due to the acceleration of the flow towards the gap, a channel is formed naturally. To improve the flow patterns and speed up the settlement on floodplains, one could build a network of drainage ditches. It is important that the flow velocity on the floodplains is low enough to prevent the sediment from flowing outside the fences again.

8.1.2 Phasing

The length of the cross-shore fence is 50 metre while the largest cross-shore length which has to be rehabilitated in case of scenario 1 is 150 metre. Therefore, at some locations, these T-fences should be constructed in three phases. First, the fences closest to the shore are constructed and when there is enough accretion in the enclosed fields the second row of fences can be constructed. Appendix N shows the three phases of the design of these bamboo T-fences applied at the Bạc Liêu coast divided into three sections. The following lengths of fence should be constructed in each phase.

Table 15: Amount of fence construction and planted mangrove scenario 1

	Fence construction	Planted Mangrove
Phase 1	1142 m	4 ha
Phase 2	4550 m	12 ha
Phase 3	6729 m	23 ha
Total	12421 m	39 ha

8.1.3 Design overview

For a clear description of this design, the project area is divided into three sections as shown in Figure 36. The design and phasing of each section can be found in Appendix P.

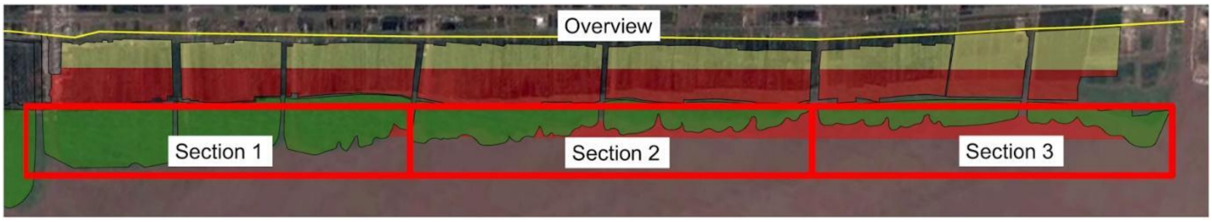


Figure 36: Section overview

Section 1 is the southwestern part, there is only a small shortage of mangrove forest. An area of 10 000 m^2 needs sedimentation in section 1. For these T-fences, 290 m of bamboo fence is needed which can be constructed in one phase.

Section 2 is the middle part of the project area. 145 000 m^2 of this section has to rehabilitated using 4850 m of bamboo fence. Parts of this section are being constructed in three phases.

Section 3 is the northwest part of the project area, this is the largest rehabilitation area with an area of 232 760 m^2. A total length of bamboo fences of 7270 m is needed in this section.

Enough sedimentation has taken place when the bottom height in the compartments is elevated to the same height as the currently present mangrove border. The mangrove coastline eroded until a distance of 150 m from the shrimp pond dyke. At that location, the bottom height is 0.65 m above MSL. Therefore, 0.65 m above MSL is assumed to be the intended bottom height in the compartments. A cross-section with the intended bottom height is presented in Figure 37.

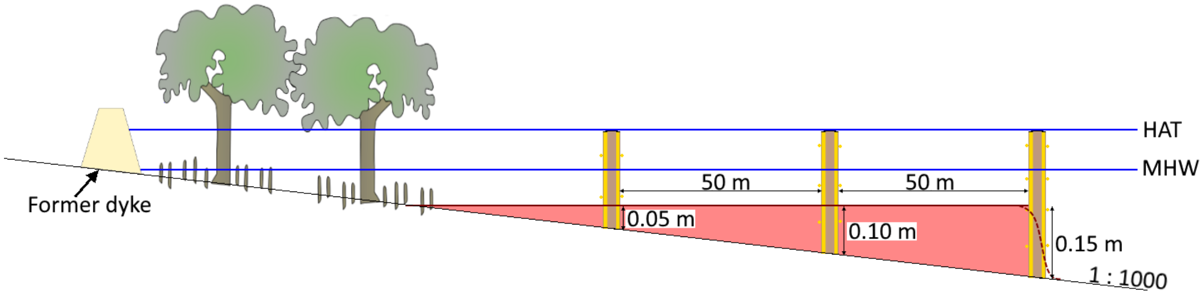


Figure 37: Sedimentation scenario 1

A numerical study on T-fences by Albers & von Lieberman (2011) showed sedimentation rates between 0.044 kg/m²/tide and 0.067 kg/m²/tide. An average value of 0.050 kg/m²/tide leads to 36 kg/m²/year. According to the consolidation approach of (Migniot, 1981) a suspension of 300 kg/m^3 is necessary to establish plants. This results in a yearly accretion of approximately 0.12 m/year.

In the first phase the bed level elevation at the fence has to be five centimetres as can be seen in Figure 37. With a sedimentation rate of 0.12 m/year it will take five month to reach a bed level of 0.65 m above MSL. After these five months, the mangrove plants can be planted and the next row of fences can be built. In phase two the bed level difference at the second fence has to be 10 cm. After ten months, there is expected to be enough bed level rise to plant the mangroves. Phase three must have a bed level elevation near the fence of 15 cm. Therefore, after fifteen months the mangroves can be planted in phase three.

8.2 Structure

A permeable fence usually consists of two rows of poles with brushwood in between. In more severe circumstances one or two extra rows of poles can be added for more stability and strength. Because the brushwood is added to damp the wave action, the biggest force will be on the back row of poles. It is advised to connect the rows to each other and/or strengthen the back row of poles by adding more, stronger or reinforced poles. To prevent the brushwood from washing out and as a scour protection, Nypa palm leaves are placed on the bottom and at the top between the rows of poles.

The fences reduce the flow velocity of water and sediment, after which the sediment can settle in the lee area between the fences. This can be done by combining groynes and breakwaters into different arrangements.

The front row of poles need to be able to withstand the (breaking) waves, and the back row of the poles must be able to withstand the absorbed wave energy from the brushwood. This is where the largest forces are present. Therefore, the back row of poles is made of stronger bamboo poles. It is assumed that the forces of the breaking waves in the brushwood are well distributed to the back poles and a calculation of this complicated process is not made. The forces on the back row of poles are therefore calculated by using a modified Goda formula for permeable vertical walls. Too much displacement of the poles can result in brushwood washing out, so the maximum displacement at the top is chosen as 10% of the length of the pole above ground level.

8.2.1 Material

Bamboo is a cheap building material, readily available in most parts of Asia, and therefore also in Vietnam. It is widely used for many applications such as scaffolding, furniture, beauty products, and now also in mangrove rehabilitation. Bamboo is chosen to construct the vertical poles, which are embedded in the soil, and as horizontal bars to connect the poles to each other. This makes the structure more stable, and keeps the vertical poles in their right position. Nypa leaves are placed in the bottom between the poles as a scour protection, and on the top to prevent the brushwood from washing out. The connections of the vertical and horizontal bars are made with jute rope or steel wire. For a structure made with completely natural materials, jute rope is preferred as connection material. For a more comprehensive explanation on the material choice, the reader is directed to Appendix O.

8.2.2 Loads

Because the wave-breaking (longshore) fences need to endure higher loads like breaking waves and tidal currents, they are built with larger diameter poles than the sediment-trapping (cross-shore) fences, which main task is to reduce the (slow) longshore current. The forces on the front poles can be calculated with Morison's formula for a fixed body in an oscillating flow and breaking waves. For the back row, calculations with Goda and Minikin are made in Appendix P.

The normative depth in front of the last row of fences in phase 3 is 0.9 m. The design wave for the structure is a breaking wave of 0.70 m. At this location, the fences in phase one can be constructed with smaller poles to withstand the smaller wave loads and moments. The designs can be found in Appendix P. They have been verified with the calculations, and have been found to be of sufficient strength. The wave loads on the fence are shown in Figure 38.

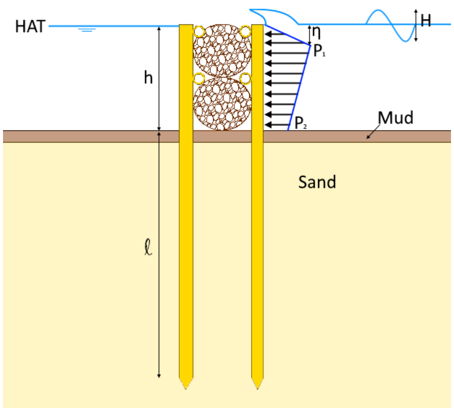


Figure 38: Wave loads on fences

Wave action on the structure is a dynamic force, this means fatigue and liquefaction of the soil might cause problems. The bamboo fences have proved to work quite well already in protecting the mangrove plants for the first years. Fatigue is therefore not considered as a cause of failure. The fences are not build to guarantee safety or to be able to withstand earthquakes or tsunamis. They are built to last around 10 years with frequent maintenance. Therefore, no safety factors are applied and only conservative values are estimated.

8.2.3 Maintenance

When the fences are placed, it will take a few years to accomplish accretion. In the meantime, the filling of brushwood can wash out, poles can become unstable or connections can be broken. The fences have to be monitored every 6 months and after every storm and be restored where needed. In a worst-case scenario, the fences need to be rebuilt completely.

8.3 Zonation

In order to make a proper coastal design, it is important to consider the ideal zonation for mangrove species. Selecting species that are suitable for the location is important for successful rehabilitation. The zonation is discussed in paragraph 3.2.1.4. Each zonation and mangrove species have its own inundation time. In scenario 1, in which the dyke in front of the shrimp farms will be replaced, there are several options to increase the diversity. In the front line of the forest, zone 2, the Avicennia Marina is the most suitable species to plant in the Bạc Liêu Province (Clough, Hoang, To, & Phong, 2016). This species grows fast, is resistant to long inundation times and is very good in retaining sediment. At the landward side of the forest where the current dyke is, an open and well-protected area creates more opportunities to create diversity in mangrove species. The wave attack is very small due to the existing mangrove belt in front of it and there is no chance of erosion. The survival chances for planted mangroves are also very high due to the mild circumstances. One could allow nature to go its own way here. The mangrove forest will restore itself and planting is not necessary. However, it is likely that different mangrove plants, zone 3 or even zone 4 species, could habitat in that area. If these species will not grow naturally because these species are currently not available in the area, one could plant a few different species to increase the diversity. Mangroves can even be planted as seedlings in this protected area.

8.4 Risks

In this paragraph, the risks of the final design for scenario 1 are determined. Good risk management can make a significant difference in the end result of a project. A risk can be defined as the probability of an event from occurring and its associated consequences. These consequences have mostly a negative effect on the functions that the system should perform, or on the production process of the system. Projects anticipate more efficiently on risks if these are known beforehand.

An overview of the risks for the final design of the two scenarios is given in Appendix Q. An analysis is done for every risk, by determining the consequences and likelihood of the event. Also, there is a mitigation strategy elaborated.

The mitigation strategy contains four categories; avoid, reduce, transfer, and accept. The risks are described from the viewpoint of the main contractor. The contract that the contractor has with the client includes managing the project, supply of materials and equipment, production of the designed system, monitoring of the system, and maintenance. Figure 39 shows the risk matrix with all the risks. Further elaboration of the top risks, which are shown in red and orange, is given below.

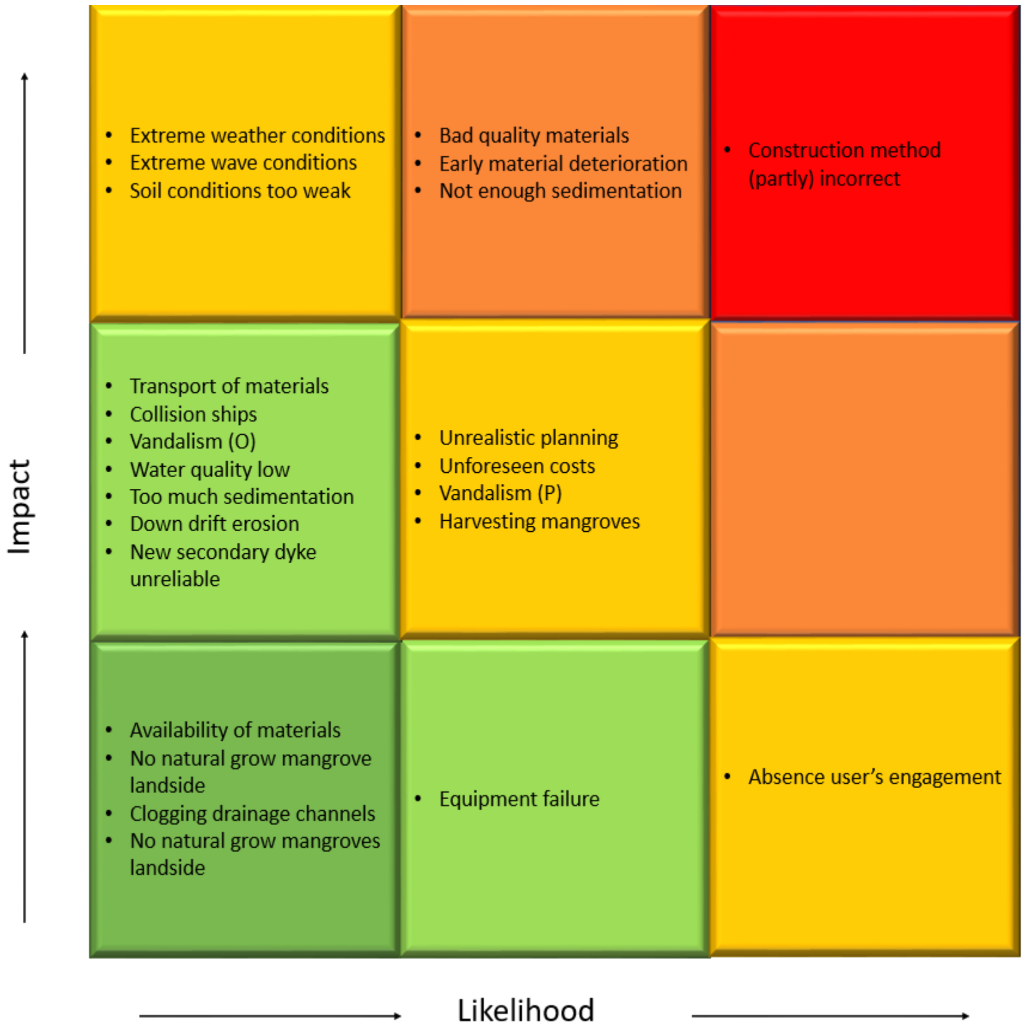


Figure 39: Risk matrix scenario 1

Top risks both scenarios

1. Construction method (partly) incorrect: During the production phase, a proper execution is very important. Construction mistakes, like for example applying wrong centre-to-centre distances between the vertical poles, can have huge consequences for the structure. The mitigation strategy for this risk is to always have a supervisor during the production phase on the project site.
2. Bad quality materials: Almost all used materials are natural resources. Therefore, it is possible that they do not have the strength that is expected during the design phase. The mitigation strategy for this risk is a selection procedure before the materials are used in the system.
3. Early material deterioration: At the end of the project the fences will not be deconstructed because they eventually decline and merge with the natural environment. If this already happens when it still needs to fulfil its functions, this has a big impact on the project. The mitigation strategy is strict monitoring the structure for early detection and maintenance.
4. Not enough sedimentation; Sedimentation is a natural process. If the sedimentation is not sufficient, the mangrove rehabilitation cannot take place. The fences create a tranquil environment in which sedimentation occurs, but it is uncertain how fast this happens. The mitigation strategy is to create a bigger sediment input manually.

8.5 Implementation plan

Execution of a project like this is quite complex. Therefore, it needs coordination of several activities, but also managing the budget, overseeing the planning, and many other matters. The aim of an implementation phase or plan is to achieve the goals of a project by planning and carrying out the activities that it requires. In order to accomplish that, a Work Breakdown Structure (WBS) should be made. In this implementation plan the necessary activities, expected constraints, and assumptions are listed. Besides that, an overall planning, and the required materials are given.

Planning

This planning is based on a Work Breakdown Structure (WBS), which is shown in Figure 40. A Work Breakdown Structure represents all the subgoals in the project. It is important that all potential bottlenecks are identified. For every detail layer, the tasks for achieving this sub goal are identified. Based on this WBS the planning is made. Some activities from the WBS are combined for planning purposes, which is elaborated in Appendix R. In this Appendix, the tasks that are given in the WBS, are further elaborated. The critical path is essential to identify because delay of tasks on this critical path will cause immediate delay of the whole project.

The project planning for scenario 1 starts in April, with the construction of 1142 m fences (phase 1) and changing the land use. A project year will last from April until March. Figure 41 shows the planning of both scenarios. The construction of the fences will take approximately five months including the collection and transportation of materials. After building a minimum waiting time of five months is needed for the bed to be elevated sufficiently to plant mangroves in the first phase. In the meantime, the mangrove seedlings can be collected and the plants can mature in a nursery. For the first planting phase (4 ha) 80 000 seedlings are necessary. June is the best month to collect fruits from the Avicennia Marina (Thinh, Thoi, Tran, Hai, & Schmitt, 2009). The fruits have to planted and grow for 8 months until they are suitable to be planted at the foreshore. The mangrove plants should be planted in March or April at the foreshore as these are the months with the best growing conditions for the mangrove plants. After constructing phase 2 of the bamboo fences a minimum of ten months of waiting time is necessary before mangroves can be planted. Because the mangrove trees must be planted in March or April, and sediment-trapping takes time, the second phase of constructing bamboo fences will start in December of the first year. Construction of the second phase of bamboo fences 4550 m has to be finished in April of the second year at the same time as planting the first phase of mangrove trees. In June 240 000 seedlings must be collected to mature and be planted at the foreshore in March of year three. At this time the last phase of bamboo fences 6729 m is built. This will be finished in October of year three. In June of year four, 460 000 seedlings will be collected for the last planting phase (23 ha). These will be planted at the foreshore in March of year five, 17 months after building the last phase of fences. From year one till year 13 maintenance and monitoring. If the trees are fully developed the fences lose their function. This is no issue because they are made of natural resources, so they will decay eventually. The project is terminated in 2029.

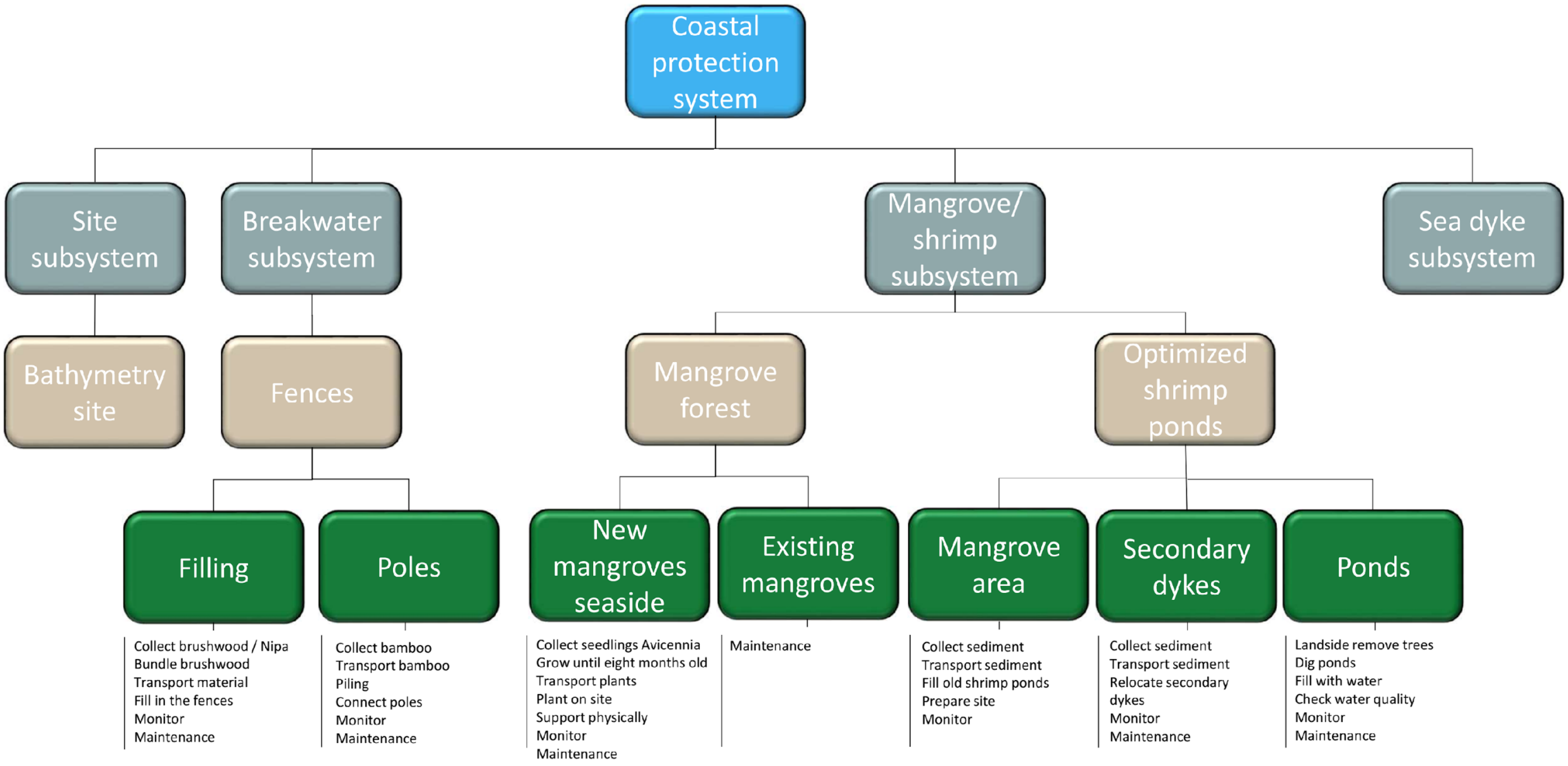
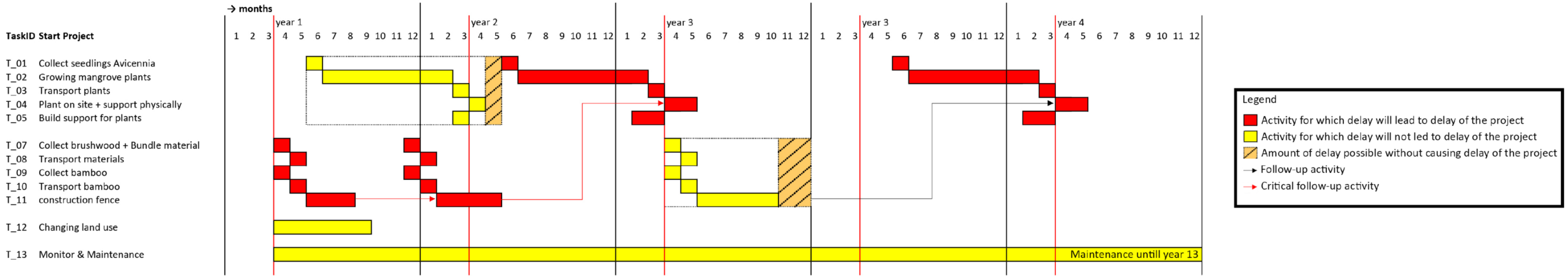


Figure 40: Work Breakdown Structure (WBS) scenario 1

Scenario 1



Scenario 2

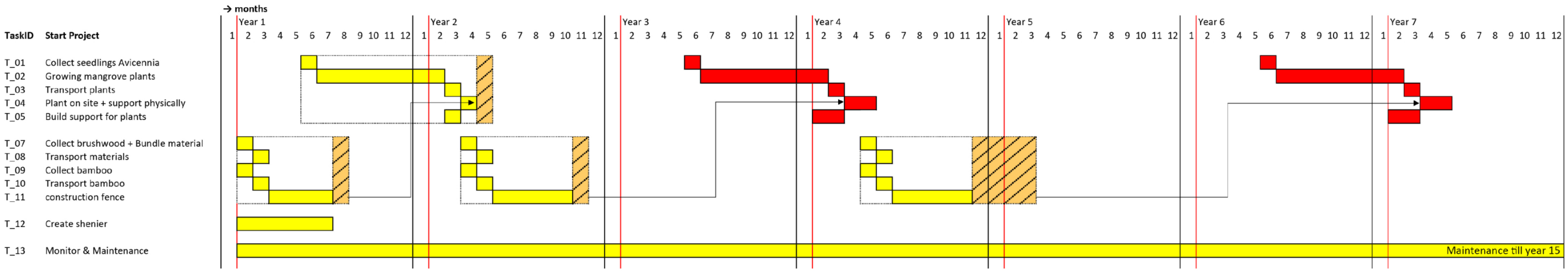


Figure 41: Planning diagram scenario 1 and 2

8.6 Cost estimation

For Scenario 1, the costs consist of construction of Bamboo Fences, Changing land use, Planting mangroves, Maintenance, and monitoring. In appendix S, the cost estimation is defined. The cost estimation is based on previous projects executed in the Bạc Liêu province by SIWRR and GIZ. Table 16 shows the cost estimated for each year according to the planning. A net present value calculation shows what an investment is worth today based on the principle that money today is worth more than money tomorrow. To calculate the net present value a discount rate of 5.0% is used. This is approximately the current yield on Vietnam government bonds maturing in 5 years. At 16-01-2017, 24 028 VND was equal to 1,- EU. The net present value is negative since the benefits of this project are not transferred into money.

Table 16: Cost estimation scenario 1

Year	Costs (in Vietnamese Dong)	Costs (in euro)
0	26 000 000 000 VND	€ 1 100 000
1	3 500 000 000 VND	€ 140 000
2	19 000 000 000 VND	€ 780 000
3	3 800 000 000 VND	€ 160 000
4	5 400 000 000 VND	€ 220 000
5	880 000 000 VND	€ 37 000
6	660 000 000 VND	€ 28 000
7	460 000 000 VND	€ 19 000
8	440 000 000 VND	€ 18 000
9	210 000 000 VND	€ 8 600
10	190 000 000 VND	€ 7 900
11	53 000 000 VND	€ 2 200
12	32 000 000 VND	€ 1 300

Total costs	VND	61 000 000 000	€ 2 500 000
NPV	VND	-56 000 000 000	€ -2 400 000
VND 24 028 = 1 EU (16-01-2017)			

9. Final design scenario 2

In this chapter, the final design of scenario 2 is elaborated. First, a description of the layout is given. After this description, the zonation, a cost estimation, the risks and finally an implementation plan are described.

9.1 Layout

The design consists of permeable T-fences which dissipate the wave energy and trap the sediment at the location where later the mangroves can be planted. The natural process of sedimentation would take a lot of time, therefore a chenier will be placed in front of the fences. The chenier keeps sediment into the system that normally would be lost offshore and breaks part of the waves that could affect the permeable fences. The chenier accelerates the sedimentation and the permeable fences are less subjected to waves.

In this paragraph, the dimensions of the compartments created by the permeable fences are described, as well as the dimensions of the chenier. Then the phasing is further explained and at last a design overview is given.

9.1.1 Compartments

In paragraph 8.2.1 the ideal dimensions for the permeable fences are explained. If the same dimensions for the fences were used as in scenario 1, the rehabilitation project would take several decades. Furthermore, a lot of bamboo would be used. Therefore, larger dimensions for the permeable fences are used in the final design of scenario 2. In this design, the area of the compartments is upscaled linearly by a factor 4. The length and width of a compartment are upscaled from 50x50 m to 100x100 m and the gap between the fences is assumed to be 40 m wide instead of 20 m. The purpose of the gap is to improve the sediment input in the compartment. Using these dimensions, the ratio between breakwater length and gap is equal to scenario 1. It is assumed that the sediment input is enough to facilitate accretion. The settlement of sediment is equal to the principles explained in scenario 1. For further improvement of the sediment input and minimisation of the sediment output, a drainage system of ditches could be added to the design if monitoring shows insufficient sedimentation. The dimensions for this drainage system should also be upscaled because larger volumes of water enter, and leaves, the compartments. The ideal dimensions for this drainage system should be further investigated.

9.1.2 Chenier

If the design would only consist of permeable fences, it would take a very long time before enough sedimentation takes place to plant the mangroves. To speed up this process, a chenier can be placed more offshore in front of the permeable fences. This chenier improves the sediment availability in the system and reduces the wave attack. The design of the chenier is based on a reference project in Java, Indonesia (Tonneijk, et al., 2015). The chenier is placed 1000 m offshore and the width in cross-shore direction is 400 m. In longshore direction, the cheniers are separated by gaps. During ebb, water can flow relatively easy between these gaps which prevents fast erosion of the cheniers. The ratio between cheniers and gaps is roughly 1000 m chenier, and 500 m gap between the two islands. These are reliable dimensions compared with an emerged detached breakwater where the dimensions to create a salient have to be $0.5 < \frac{L_b}{D_s} < 1.3$ and gap smaller than $\frac{L_{gap}}{L} < 1$. In which L_b is the length of the breakwater, D_s is the distance to the shoreline and L_{gap} is the distance between two breakwaters.

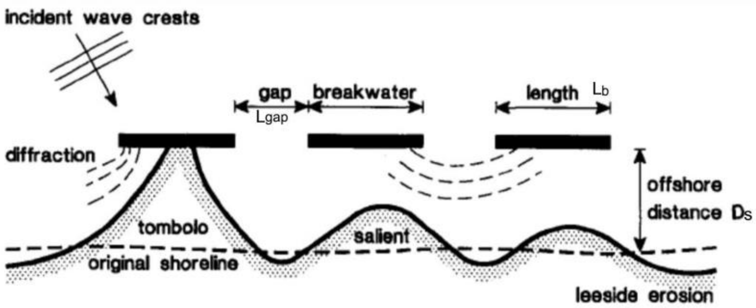


Figure 42: Salient and tombolo (Bosboom & Stive, 2015)

The crest of the chenier is assumed on mean sea level (MSL) with a height of 0.70 m. In that case, half of the time the chenier is under the water level. During flood tide, waves will break on the chenier and sediment will be transported landwards. The chenier creates a tranquil environment where sediment can settle easily. As soon as ebb conditions occur, the chenier runs dry and keeps the imported sediments into the system. Water levels can decrease due to the gaps between the cheniers which prevents erosion of the cheniers. A cross section of scenario 2 with the chenier can be found in Figure 43.

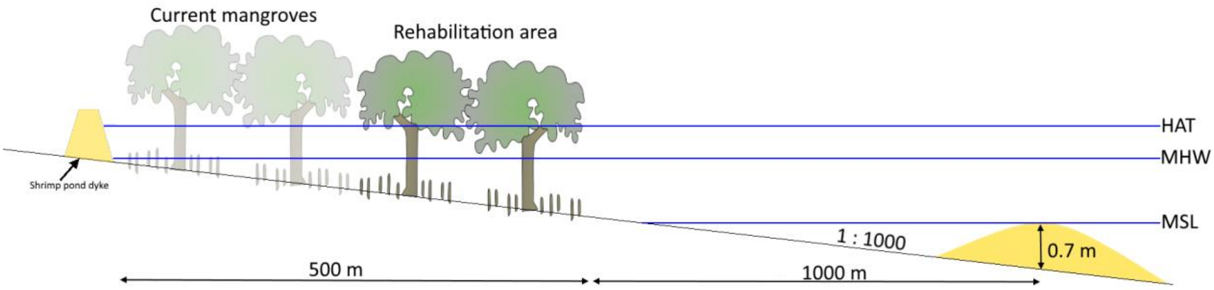


Figure 43: Cross-section scenario 2

9.1.3 Phasing

For a rehabilitation project of this size, it is inefficient or even impossible to construct everything at once. This would probably lead to severe downdrift erosion. A better solution is to spread the rehabilitation over a longer period. Risks can be reduced by working in different phases, and the land reclamation and mangrove rehabilitation takes place in a more natural way which increases the chances of success.

Based on the dimensions proposed in the previous paragraph, it is possible to rehabilitate the forest in three phases. The timeline of this scenario is as follows. The first row of T-fences is constructed and at the same time, the chenier is built offshore. It is very important to monitor the chenier, so unforeseen fast erosion of the chenier can be observed immediately. After enough sedimentation took place in the first row of T-fences, young mangroves can be planted here. When the mangroves are planted the next row of T-fences can be built and so on. An overview of the design in these phases can be found in Appendix U.

9.1.4 Design overview

In total 170 ha mangrove forest has to be rehabilitated for scenario 2. The design is executed in three phases as explained before. The total number of fences for each individual phase and area of planted mangroves are shown in Table 17.

Table 17: Amount of fence construction and planted mangrove scenario 2

	Fence construction	Planted Mangroves
Phase 1	6188 m1	32 ha
Phase 2	9630 m1	63 ha
Phase 3	11083 m1	75 ha
Total	**26901 m1**	**170 ha**

The crests of the cheniers are located at MSL, therefore the height of the cheniers in the middle is 70 cm. The width of the cheniers are 400 m and they are placed as a heap of sand. The total volume of one chenier with a length of 1000 m is estimated to be 140 000 m^3. To construct six cheniers a volume of about 840 000 m^3 sand is needed.

In Figure 44 an overview of the total final design is given. The design of each phase can be found in Appendix T.

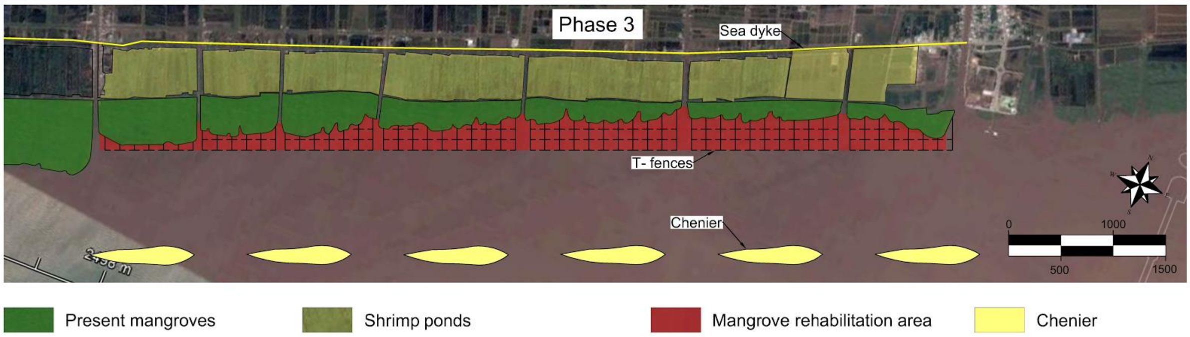


Figure 44: Overview scenario 2

For scenario 1 a clear description of the sedimentation estimation is given. For this scenario, a lot more sediment is needed. If the same approach as for scenario 1 is used, with an accretion rate of 0.12 m per year, it would take at least 6 years to achieve the needed amount of sediment. Phase 1 would take 1 year, the next phase two years and phase 3 three years. It is expected that the chenier will accelerate sedimentation, an increase of 25% is assumed which results in an accretion rate of 0.15 m per year. With this assumption, the sedimentation takes 8, 16 and 24 months respectively for the three phases. A cross-section of the sedimentation in each phase is presented in Figure 45.

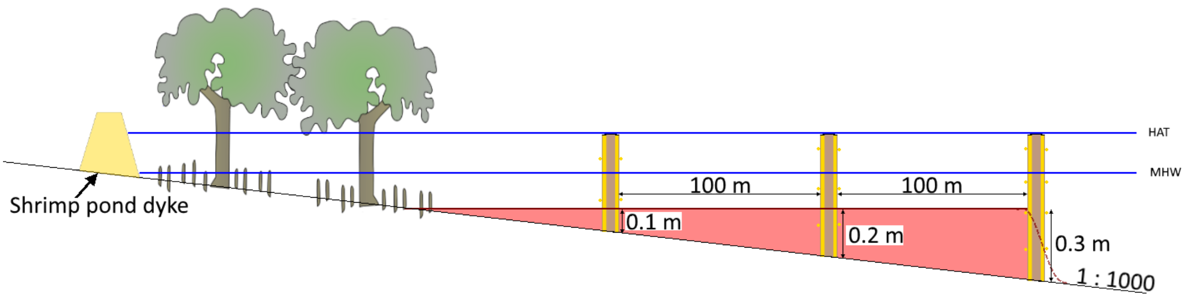


Figure 45: Sedimentation scenario 2

The chance of downdrift erosion is high with extreme measures like this. North of the rehabilitation

zone, in the Nhà Mát community, a hard dyke revetment is present and a mangrove rehabilitation project is ongoing. South of the project area, a healthy mangrove forest of more than 500 m is present. In case too much downdrift erosion occurs during the project of scenario 2, it is therefore expected that the mangrove forest at that location will recover naturally. These effects are very uncertain and should be monitored well to assure the safety against flooding of the hinterland.
If the effectiveness of the chenier is not sufficient, one could consider agitational dredging or a mud nourishment. Both measures increase the amount of sediment in the water and in the system.

9.2 Structure

The structure of the permeable fences is approximately the same as explained in chapter 8.3. The main differences are the size and the location of the structure. In this scenario, the fences are located more seawards, therefore, the water levels are higher in front of the fences and the wave attack is more severe. The normative depth in front of the last row of fences in phase 3 is 1.05 m, compared to the 0.90 m for scenario 1. The design wave for the structure is a breaking wave of 0.82 m. At this location, the fences will be constructed with more and stronger poles to withstand the higher wave loads and moments. The verification calculation can be found in Appendix P.

9.3 Zonation

In scenario 2, in which the present shrimp farm layout stays untouched, it is more challenging to create diversity in the mangrove forest as there is no area landward of the existing forest for mangrove rehabilitation. As mentioned in paragraph 3.2.1.4, the front side of mangrove forests has to consist of zone 2 species like the Avicennia, because only pioneer mangrove species can be planted seawards. A possible solution to create diversity is mixed-species cluster planting devised by GIZ. This close to nature mangrove rehabilitation approach makes a mix of Avicennia and Rhizophora mangroves. The mangroves plants are planted in clusters in which one Rhizophora tree is surrounded by four Avicennia trees as shown on the left in Figure 46. These clusters are planted alternately as shown on the right in Figure 46. By making use of this distribution, the Avicennia takes care of trapping the sediment and protecting the Rhizophora. It is important to plant more mature seedlings with this method because this increases the survival rates significantly (Wölcke, Albers, Roth, Vorlaufer, & Korte, 2016).

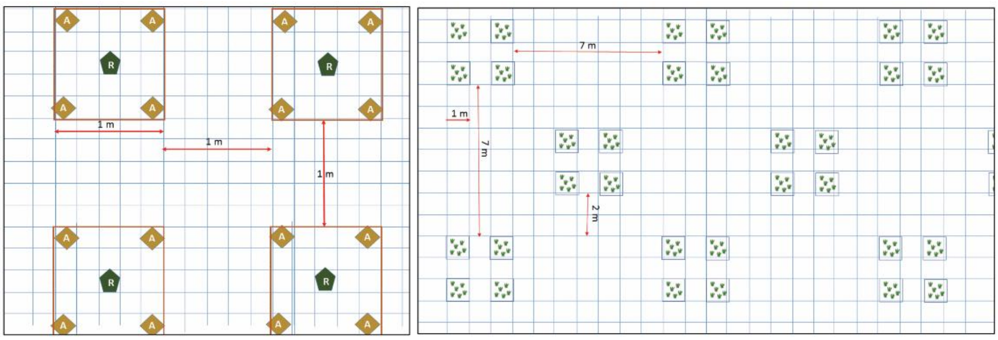


Figure 46: Mixed species clusters (Wölcke, Albers, Roth, Vorlaufer, & Korte, 2016)

9.4 Risks

In this paragraph, the risks of the final design for scenario 2 are determined. The same method as in paragraph 8.6 is used for this scenario. Figure 47 shows the risk matrix with all the risks for scenario 2. Most of the top risks are similar to scenario 1, which is already elaborated in paragraph 8.5. Further elaboration of the top risks of just scenario 2, which are shown in red and orange, is given below.

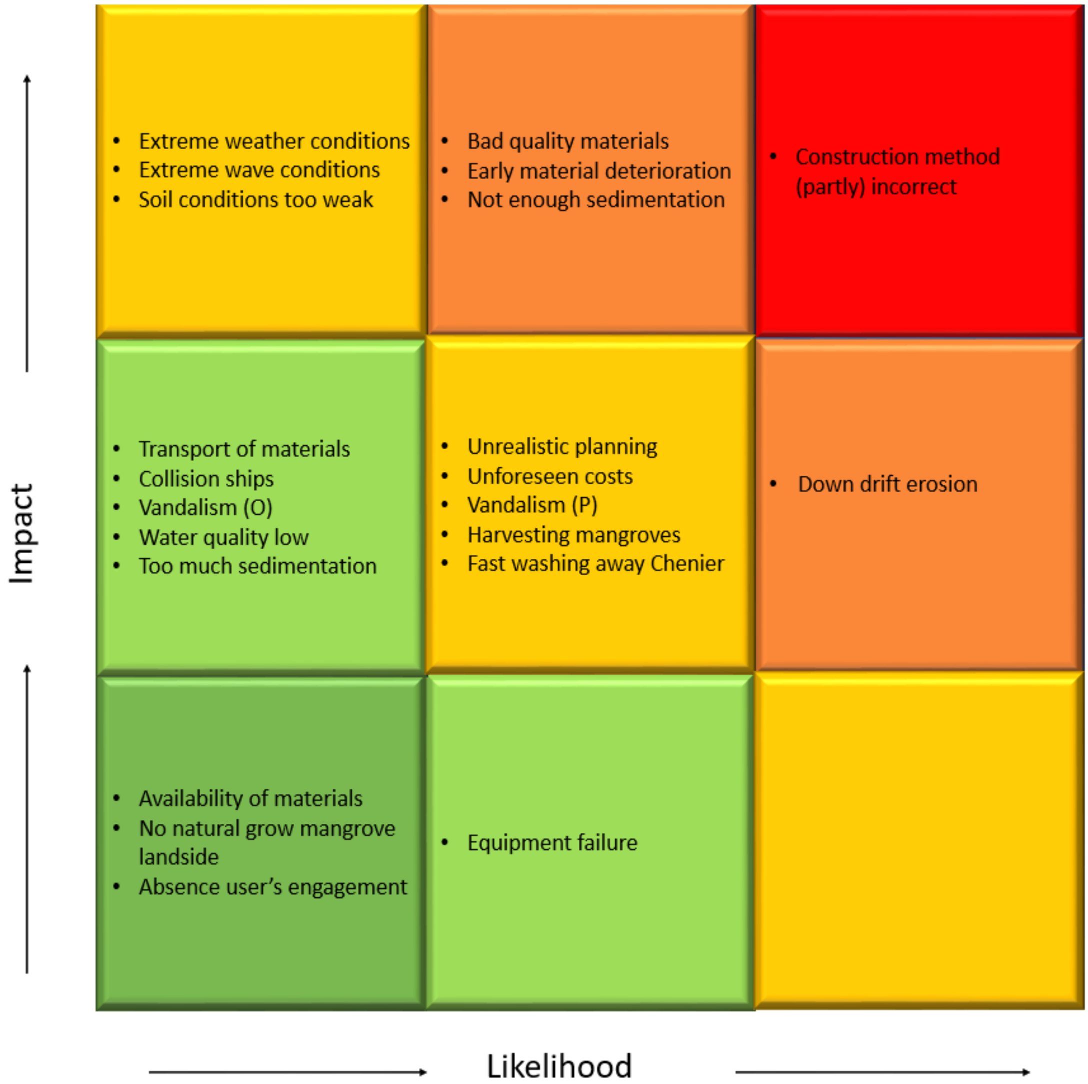


Figure 47: Risk matrix scenario 2

Top risks Scenario 2

- Downdrift erosion: For scenario 2 a lot of sediment has to be trapped with the fences. Therefore, the longshore sediment transport will be affected considerably. It is very likely that with this scenario more downdrift erosion occurs. This risk will be accepted; but the consequences will be monitored.

9.5 Implementation plan

This planning is based on a Work Breakdown Structure (WBS), which is shown in Figure 48: Work Breakdown structure scenario 2. The project planning for scenario 2 starts in February, with the construction of 6188 m fences (phase 1) and creating a chenier. Therefore, a project year will last from February until January. The construction of the fences will take approximately six months including the collection and transportation of materials. After building the fences a minimum waiting time of eight months is necessary for the elevation of the bed level. For the first planting phase (32 ha) 640 000 seedlings must be collected in June of the first year and mature for eight months until they are suitable to be planted at the foreshore. In March, year two, the first phase of planting mangroves will start and the construction of phase two 9630 m bamboo fences starts and must be finished in November, year two. After building a minimum waiting time of 16 months is needed for the second planting phase of mangroves. In June 1 260 000 seedlings must be collected to mature for planting phase 2 (63 ha) at the foreshore in March of year 4. At this time the last phase of bamboo fences 11083 m is built. After building a minimum waiting time of 24 months is needed for the last planting phase of mangroves. In June of year 6, 1 260 000 seedlings will be collected for the last planting phase (63 ha). These will be planted at the foreshore in March of year 7, 26 months after building the last phase of fences. From year 1 till year 15 maintenance and monitoring is executed. The project is terminated in 2031.

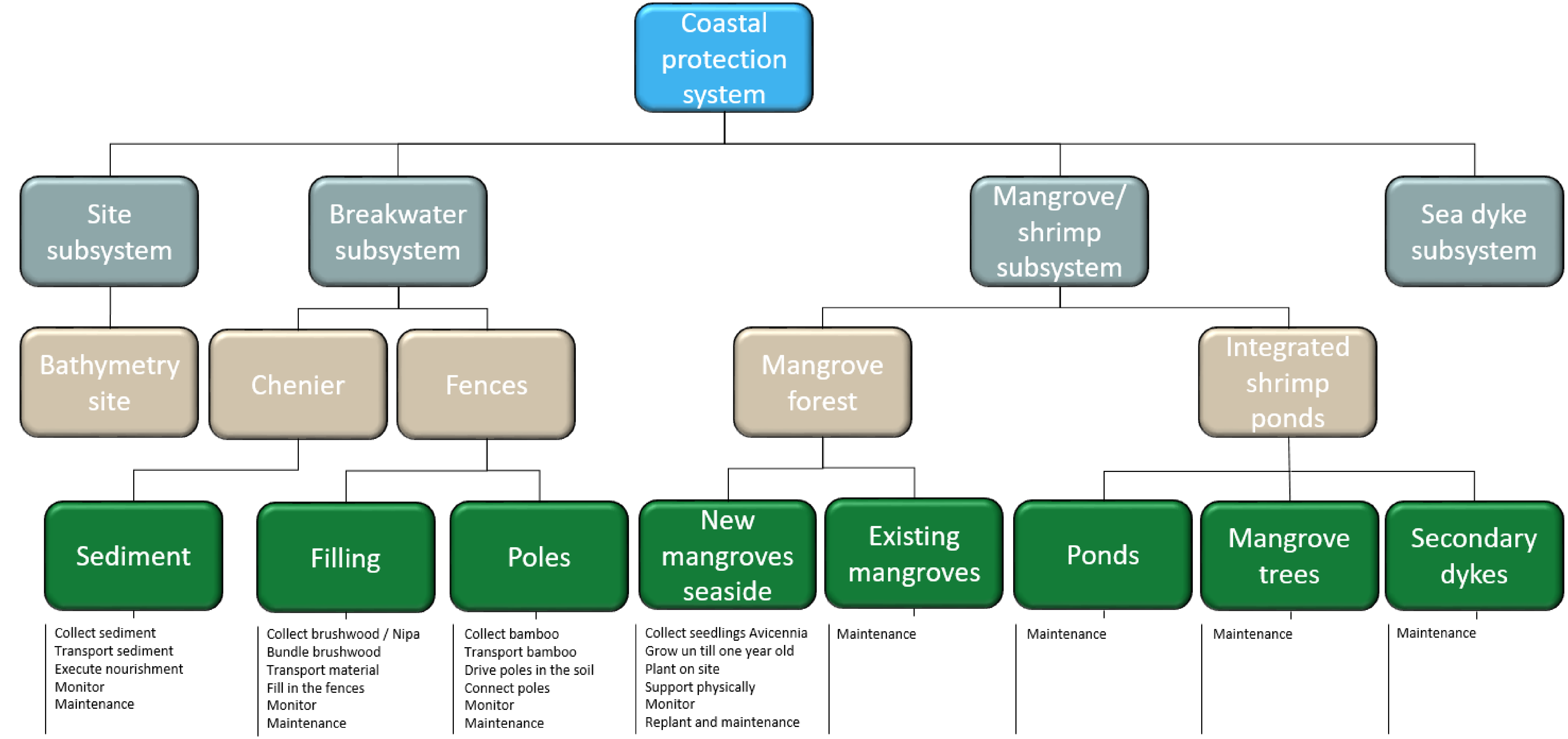


Figure 48: Work Breakdown structure scenario 2

9.6 Cost estimation

For Scenario 2, the costs consist of the construction of bamboo fences, construction chenier, planting mangroves, maintenance and monitoring. An overview of the estimated cost is given in Table 18. In Appendix S, the cost estimation is defined.

Table 18: Cost estimation scenario 2

Year	Costs (in Vietnamese Dong)	Costs (in euro)
0	160.000.000.000VND	€6.700.000
1	33.000.000.000VND	€1.400.000
3	12.000.000.000VND	€500.000
4	41.000.000.000VND	€1.700.000
5	5.700.000.000VND	€240.000
6	5.000.000.000VND	€210.000
7	16.000.000.000VND	€670.000
8	3.300.000.000VND	€140.000
9	2.300.000.000VND	€96.000
10	910.000.000VND	€38.000
11	620.000.000VND	€26.000
12	460.000.000VND	€19.000
13	170.000.000VND	€7.100
14	170.000.000VND	€7.100
15	110.000.000VND	€4.400
Total costs	VND 280.000.000.000	€ 12.000.000
NPV	VND -260.000.000.000	€ -11.000.000

VND 24 028 = 1 EU (16-01-2017)

10. Discussion

The aim of this report was to make a coastal protection system for part of the Bạc Liêu Province in which mangrove forests play a vital role in protecting the hinterland against flooding. The design should be sustainable and carried by both government and the local community. In this chapter the limitations and uncertainties of the design are discussed.
Limitations are the subjects which are not captured in this report. These subjects were out of the scope or not included in this report due to the time schedule, lack of data and lack of experience or knowledge.

10.1 Data

The biggest limitation during this project was the limited available data. During the analysis of the current situation, most values are based on data from other locations than Bạc Liêu Province. This is further elaborated per subject.

Bathymetry
The bathymetry for the project location is very dynamic and can vary a lot over short distances. For our project, an average homogeneous slope for the whole area is assumed. The design should be adapted to the present bathymetry and be measured before and monitored during construction.

Soil conditions
The soil conditions are important for the stability of the construction. The soil conditions in Bạc Liêu are unknown, but a silt-sand subsoil is assumed. Assumptions for the soil conditions are made in order to execute the calculation of the permeable fences.

Wave conditions
Significant wave height of Bạc Liêu were not available, therefore, significant wave height from other provinces are used. If the significant wave height in Bạc Liêu deviates, higher waves can occur on which the permeable fences are not designed. For the design, water levels and their corresponding height of a breaking wave are used to validate the strength of a design.

Tidal regime
The local tidal regime is based on data from a measurement station in Vung Tau. These measurements are calibrated to an approximation of the local tidal data with local observations in Bạc Liêu. The tidal regime in Bạc Liêu can differ quite a bit from the measurements from Vung Tau. More accurate and actual data from Bạc Liêu is needed to make modelling possible. Creating computer models can be very useful for predicting the effects of a mutation in hydraulic engineering. Especially for functions like dissipating wave energy, decreasing currents and improving sedimentation, modelling is essential to be able to make a detailed design. Without modelling it is difficult to predict what the precise effects of different alternatives are on currents, sediment transport and erosion.

Material
The loads and soil conditions were mostly based on assumptions, and so were the material properties of bamboo. Structural calculations were made as a preliminary design and comparison between designs. More accurate values on the used bamboo's strength and stiffness need to be determined by tests. Many reports are already written on material properties of bamboo but it can vary a lot with growing circumstances, species and treatment. The bamboo used in the fences, for example, is not dried as is normally the case for structural bamboo.

10.2 Experience and knowledge

Ecology
In this project, there are interfaces between hydrodynamic, morphodynamic and ecological conditions for mangrove forests. To improve mangrove rehabilitation and create ideal conditions for mangrove plants to grow, it is important to know more about these ideal conditions. With more ecological knowledge, there might be less uncertainty about the functions and possibilities for mangrove plants to grow and more knowledge to optimize the shrimp farming is needed.

Stakeholders
A stakeholder analysis is made to identify different important stakeholders. For these stakeholders, a stakeholder engagement plan is made. However, it was not possible to have interviews with all the stakeholders. Before executing a design, it is important to identify the core values of all stakeholders.

Innovative alternatives
Some of the alternatives are relatively new or never used for mangrove rehabilitation before. These alternatives have proven that they can fulfil their functions. However, it is uncertain if they also work well for mangrove rehabilitation in the Bạc Liêu Province, since the soil, wave, and tidal conditions are different than where these alternatives are constructed usually.

Final design scenarios
The uncertainties differ for both scenarios. The T-fences of scenario 1 are an often-applied design in Vietnam but the performances of the fences differ. The effectiveness of the fences depends on the local bathymetry and amount of sedimentation, which is an uncertain factor. The size of a project like scenario 2 has never been executed before and contains a lot of uncertainties and assumptions. The design of scenario 2 might have negative side effects. Large amounts of sediment are trapped, which can cause downdrift erosion.
The amount of erosion and the possibility to counteract this downdrift erosion are uncertain and not further investigated. In scenario 2 chenier is included in the design. A chenier can be a good solution for improving the sedimentation but more research is necessary for a reliable design. If a natural chenier is present, which is unknown, one can nourish this for better functionality. If there is no natural chenier present, the risk exists that a man-made chenier erodes fast.
10.3 Further research
This report gives a design for different scenarios in which the Bạc Liêu Province is protected against floods. It is highly recommended to collect more local data and model the designs to improve both designs.

Collect more data
To make a design for the Bạc Liêu Province and other locations one should have a lot more data. The most important data to collect is the bathymetry, soil conditions, tidal regime, currents, strength properties of the used bamboo and sediment concentrations.

Influence wind turbine park
In recent years, a wind turbine park was constructed close to the coast in Bạc Liêu. Coastal erosion occurred during the construction due to removal of mangrove forest, obstruction of currents and placing of the poles in the soil. It is unclear what the effect of the wind turbine park is on coastal erosion on the long-term.

Modelling
In order to improve the alternatives and designs, modelling is very important. The effects of mutations can be predicted with accurate models.

Applicability of melaleuca

There are two types of material that can be used for the structure: Melaleuca and bamboo. Both are easy to find in Vietnam and very cheap. Due to experience with degrading Melaleuca, bamboo is used in the final design. However, Melaleuca can be 2-5 times cheaper than bamboo.

Configuration of fences

Two types of permeable fence structures are used in practice, the U-shaped fence and the T-shaped fence. Which of these two hold better results and under which conditions should be further investigated.

Implementation shrimp ponds

Further research is needed on how to implement the optimised shrimp pond to create ideal conditions for shrimp farming.

Effect drainage ditches

Drainage ditches in the compartments can improve the sedimentation. The dimensions and locations of these channels should be further investigated.

Finance

How should the project be financed, taking the restructuring of the fish ponds into account. The optimised shrimp ponds might hold more benefits.

Upscaling T-fence design

In scenario 2, the original T-fence design with sedimentation sections of 50x50 m is upscaled to a T-fence design with sedimentation sections of 100x100 m. It should be investigated if this is possible and if the upscaled design will induce a comparable amount of accretion.

11. Conclusion

This design project was based on the main design question, which is stated in chapter two:

'What is the best design for the coastal system, including mangrove rehabilitation, which protects the hinterland of the Bạc Liêu province against flooding?'

This main question was divided into sub-questions:

1. What is the current physical and socio-economic situation?
2. What is the ideal physical and socio-economic situation?
3. How does the current situation deviate from the ideal situation?
4. What are the requirements for the system?
5. Which alternatives meet the requirements?
6. What are the best alternatives?
7. What is the final design?
    - Which measures should be taken to implement the solution?
    - Which risks are foreseen for the final design?

The first second and third sub-questions are answered in chapter 3, in which paragraph 3.1 answers the first question, 3.2 explains the second question, and 3.3 elaborates on the third question. The fourth question is answered in chapter four and five. The fifth question is explained in chapter six. The best alternatives are determined by means of an MCA in chapter seven. Chapters eight and nine are elaboration of the seventh sub-question. This research have led to the following design on the main question.

There are problems with erosion and loss of mangrove forest in the Bạc Liêu province. Several rules are implemented to protect the mangrove forest. Of which the requirements of 500 m mangrove forest and 60% mangrove forest coverage of shrimp farms are the most important. At the moment, the mangrove belt does not satisfy the 500 m rule and the coastal protection system does not provide sufficient safety against flooding. To create a sustainable coastal protection system that is carried by both government and the local community, where mangrove forests play a vital role, requirements are set up from both the technical and the stakeholder domain. Two scenarios are made which lead to two final designs.

In scenario 1, the shrimp farms in front of the sea dyke are optimised, whereby a part of the shrimp ponds becomes part of the required mangrove belt. Due to this optimisation, only a relatively small amount of land has to be reclaimed at the seaside of the present mangrove belt. The rehabilitation of the mangrove belt is done by use of permeable bamboo fences. These fences have proven to be successful. The bamboo fences have a low carbon-footprint and are a good example of a building with nature approach. Furthermore, they are relatively easy to build and the costs are low. When the fences are built as 50x50 m T-fences, they trap sediment and create tranquil conditions at the same time.

In scenario 2 the land use in front of the sea dyke remains unaffected. The layout of the current shrimp ponds will not be changed; therefore, the total rehabilitation of the mangrove forest has to take place at the seaside of the present mangrove belt. This results in a significantly larger area that has to be reclaimed. In this scenario T-fences and a chenier are the best alternatives according to the MCA. The T-fences for this scenario are scaled up (100x100 m), because of the size of the area that needs to be reclaimed and rehabilitated. Despite these large sedimentation areas, still three project phases are needed to achieve the desired situation. To speed up the accretion process and reduce the wave attack on the large permeable fences, in the design of scenario 2 also the construction of six cheniers are included. These sand lenses will be built about 1 km offshore and have a length of 1000 m, a width of 400 m and a height of 0.70 m.

12. References

Albers, T. (2011). *Detailed design of breakwaters*.

Albers, T. (2012). *Construction supervision of bamboo fences in Bac Lieu Province, Vietnam*.

Albers, T., San, D. C., & Schmitt, K. (2013). *Shoreline management guidelines. Coastal protection in the lower Mekong Delta*. Hanoi: GIZ.

Albers, T., & von Lieberman, N. (2011). *Current and Erosion Modelling Survey - coastal zone of Soc Trang*.

Alsem, D., Kamerman, J., van Leeuwen, C., van Ruijven, L., den Toom, T., & Vos, M. (2013). *Guidelines for Systems Engineering within Civil Engineering sector*.

Angsupanich, & Havanond. (1996). *Effects of bamacles on Mangrove seedling transplantation at Ban Don Bay, Southern Thailand.*

Anthony, E. J., Brunier, G., Besset, M., Goichot, M., Dusouillez, P., & Lap, N. V. (2015). *Linking rapid erosion of the Mekong River delta to human activities*.

Balke, T., Bouma, T. J., Horstman, E. M., Webb, E. L., Erftemeijer, P. L. A., & Herman, P. M. J. (2011). Windows of opportunity: thresholds to mangrove seedling establishment on tidal flats. *Marine Ecology Progress Series*.

Bartolomei, J., & Miller, T. (2001). *Functional Analysis Systems Technique (FAST) as a group knowledge elicitation method for model building.* Paper presented at the Proceedings of 19th International Conference of the System Dynamics Society, Atlanta, GE, USA.

Bergmann, H., & Oumeraci, H. (1999). Wave pressure distribution on permeable vertical walls *Coastal Engineering 1998* (pp. 2042-2055).

Bosboom, J., & Stive, M. J. F. (2015). *Coastal Dynamics I*. Delft: Delft University of Technology.

Bosma, R. H., Nguyen, T. H., Siahainenia, A. J., Tran, H. T. P., & Tran, H. N. (2016). *Shrimp-based livelihoods in mangrove silvo-aquaculture farming systems*.

Burbridge, P. R., & Koesoebiono. (1984). *Management of mangrove exploitation in Indonesia.* Paper presented at the Asian Symposium on Mangrove Environment: Research and Management, Kuala Lumpur.

Burger, B. (2005). *Wave attenuation in Mangrove forests*.

Clough, B., Hoang, P. V., To, H. H., & Phong, L. T. (2016). *Mangrove Rehabilitation in the Mekong Delta in the period 2008--2014. Good Practices and Lessons Learned.*

Cuong, T. P., & Vuong , L. Q. (1996). *Rehabilitation of mangrove ecosystem and shrimp culture in the coast of Minh Hai Province*.

Deltares (Producer). (n.d.). Building Block - Habitat requirements for mangroves. *Deltares*. Retrieved from https://publicwiki.deltares.nl/display/BWN1/Building+Block+-+Habitat+requirements+for+mangroves

Duke, N. (2012). *Mangroves of the Kien Giang Bisphere Reserve Vietnam*. Hanoi: GIZ.

Dung, L. C., Vinh, N. N. G., & Bousquet, F. (2005). *Economic differentiation of rice and shrimp farming systems and riskiness: a case of Bac Lieu, Mekong Delta, Vietnam*.

Dung, N. T. (2012a). *Approving a program to strengthen and upgrade the sea dyke system (667/QD-TTg)*.

Dung, N. T. (2012b). *APPROVING THE MASTER PLAN ON SOCIO-ECONOMIC DEVELOPMENT OF BAC LIEU PROVINCE THROUGH 2020 (221/QD-TTg)*.

Ellison, J. C. (1998). Impacts of Sediment Burial on Mangroves. *Marine Pollution Bulletin,* 420-426.

Geohooks (Producer). (2015). Retrieved from www.geohooks.nl

Giang, G. K. (2012). Coastal rehabilitation and Mangrove restoration using Melaleuca fences: Practical experience from Kien Giang province. *Deutsche Gesellschaft fur Internationale Zusammenarbeit (GIZ) GmbH*.

GIZ. (2012). *Coastal Erosion Bac Lieu Summary*

GIZ. (2014). *Integrated Coastal Management Programme*.

Graauw, A. d. (n.d.). Fajaihah breakwater under construction. Retrieved from http://www.ancientportsantiques.com/wp-content/uploads/2011/07/FujairahBW.jpg

Ha, T. T. P., van Dijk, H., & Visser, L. (2014). Impacts of changes in mangrove forest management practices on forest accessibility and livelihood: case study in mangrove-shrimp farming system in Ca Mau Province, Mekong Delta, Vietnam. *Elsevier*.

Hai, T. N., & Yakupitiyage, A. (2005, April 29). The effects of the decomposition of mangrove leaf litter on water quality. *Elsevier,* 700-712.

Halide, H., Brinkman, R., & Ridd, P. (2004). Designing bamboo wave attenuators for mangrove plantations. *Indian Journal of Geo-Marine Sciences*, 33.

Hien, L. T. (2016). *The effect of foreshore lowering on Bac Lieu sea dike*.

Hong, P. N., & San, H. T. (1993). *Mangroves in Vietnam*. Bangkok: The International Union for Conservation of Nature and Natural Resources (IUCN).

Hung, N. S. (2009). *Approving a program to strengthen and upgrade the sea dyke system From Quang Ngai to Kien Giang (667/QD-TTg)*.

Hutchings, P., & Saenger, P. (1987). *Ecology of Mangroves*. St. Lucia: University of Queensland Press.

ICEM. (n.d.). About MARD - Mandate. Retrieved from http://www.mard.gov.vn/en/Pages/mandate.aspx?TabId=AboutMARD

Janssen, J. J. (2000). *Designing and building with bamboo*: International Network for Bamboo and Rattan Beijng, China.

Janssen, M. P. J. (2016). *Flood Hazard reduction by mangroves*.

Johnson Popp, J. (Producer). (2008). SMART requirements. *The practical project manager*. Retrieved from https://jessica80304.wordpress.com/2008/08/04/smart-requirements/

Kathiresan, K., & Bingham, B. L. (2001). Biology of Mangroves and Mangrove Ecosystem. *Elsevier*.

Kramer, V. (2013). *Stappenplan van projectmanagement tot Vraagspecificatie*.

Mannion, M., & Keepence, B. (1995). *SMART Requirements*.

Marchand, M. (2008). *Mangrove restoration in Vietnam, Key considerations and a practical guide*.

Matsui, N., Songsangjinda, P., & Wodehouse, D. (2014). *Longevity of simultaneous operation of aquaculture and mangrove forestry as explained in terms of water and sediment qualities*.

McIvor, A., Spencer, T., Möller, I., & Spalding, M. (2013). *The response of mangrove soil surface elevation to sea level rise*.

MoNRE. (2009). *Climate change, sea level rise scenarios for Vietnam*.

Murray-Webster, R., & Simon, P. (2006). Making sense of stakeholder mapping. *PM World today*, 1-5.

Nguyen, T. T. (2009). *Surface sediment caracteristics and sediment transport from Bassac River mouths to Ca Mau Peninsula (Mekong Delta)*. Germany: Institute of Geoscienses.

Nong, T. Q. (2016). Office of the Bac Lieu People's Committee. Retrieved from http://eng.baclieu.gov.vn/pages/office-of-the-bac-lieu-people%E2%80%99s-committee.aspx

Othman, M. A. (1994). Value of mangroes in coastal protection. *Hydrobiologica,* 277-282.

Postma, M. G., Dunnewolt, J., Hanssen, J., Bouziotas, D., & Stoop, B. (2015). *Integrated Coastal Management in Ca Mau*.

Russell, M., & Michaels, K. (2012). Effectiveness of Melaleuca: ed.

Schiereck, G. J., & Booij, N. (1995). *Wave Transmission in Mangrove Forests.* Paper presented at the International Conference on Coastal and Port Engineering in Developing Countries, Delft.

Scurlock, J., Dayton, D., & Hames, B. (2000). Bamboo: An overlooked biomass resource? *Biomass and bioenergy, 19*(4), 229-244.

Soerianegara, I. (1986). *The width of mangrove green belt as coastal zone protection forest.* Paper presented at the In proceedings of the Symposim on New Perspectives in Research and Management of Mangrove Ecosystems, Colombo.

Spalding, M., McIvor, A., Tonneijck, F., & van Eijk, P. (2014). *Mangroves for coastal defence, guidelines for coastal managers and policy makers*.

Stieglitz, T., Ridd, P., & Müller, P. (2000). Passive imigration and functional morphology of curstacean burrows in a tropical mangrove swamps. *Hydrobiologia*, 69-76.

Tas, S. (2016). *Wave load and overtopping of sea dikes as function of their location in the cross-section, for different foreshore geometries*.

Temmerman, S., Meire, P., Bouma, T. J., Herman, P. M., Ysebaert, T., & De Vriend, H. J. (2013). *Ecosystem-based coastal defence in the fac of global change*.

Thao, N. D., Takagi, H., & Esteban, M. (2013). *Coastal Disasters Risk in Southern Vietnam, The problems of coastal development and the need for better coastal planning*. Retrieved from UNISDR:

Thinh, P. T., Thoi, H., Tran, H. M., Hai, L. T., & Schmitt, K. (2009). *Tool Box for Mangrove Rehabilitation and Management*.

Tomlinson, P. B. (1994). *The Botany of Mangroves*. Cambridge: Cambridge University Press.

Tonneijk, F., Winterwerp, H., van Weesenbeeck, B., Bosma, R., Debrot, D., Noor, Y. R., & Wilms, T. (2015). *Building with Nature Indonesia. Securing Eroding Delta Coastlines*.

Tran, N. D. (Producer). (n.d.). Forest And Forestland Management in Vietnam. [PowerPoint slides] Retrieved from http://www.ksla.se/wp-content/uploads/2013/04/Nghia-Dai-Tran.pdf

Urbanska, K. M., Webb, N. R., & Edwards, P. J. (1997). *Restoration Ecology and Sustainable Development*.

van Lamsweerde, A. (2002). *Goal-Oriented Requirements Engineering: A Guided Tour*.

van Loon, A. F., Dijksma, R., & van Mensvoort, M. E. F. (2007). Hydrological classification in mangrove areas: A case study in Can Gio, Vietnam. *Elsevier,* 80-82.

Vien, T. D. (2008). *Forestland Management Policies in Vietnam: An Overview*.

Visser, M., & Vreman, C. (2011). *Klant Eisen Specificatie: Zeetoegang IJmond*.

Vrijling, J., Kuijper, H., van Baars, S., Bezuyen, K., Molenaar, C., van der Hoog, W., Hofschreuder, B., & Voorendt, M. (2011). Manual Hydraulic Structures CT3330. *TU Delft*.

Wahyudi, I., Ishiguri, F., Aiso, H., Tyas Istikowati, W., Sutiya, B., Takashima, Y., Ohkubo, T., Iizuka, K., & Yokota, S. (2014). Anatomical characteristics and wood properties of Melaleuca leucadendron naturally growing in secondary forest in Indonesia. *Australian Forestry, 77*(3-4), 168-172.

Walden, D. D., Roedler, G. J., Forsberg, K. J., Hamelin, R. D., & Shortell, T. M. (2015). *System engineering Handbook; a guide for system life cycle processes and activities*. Hoboken: John Wiley & Sons Inc.

Wasson, C. S. (2006). *System Analysis, Design, and Development*. John Wiley & Sons, Inc.: Hoboken.

Watson, J. G. (1982). Mangrove forests of the Malay Peninsula. *Malayan Forest Records*.

Webb, J. (2015). Aerial photograph of artificial reef offshore breakwater sea Palling on the Norfolk coast. Retrieved from http://medias.photodeck.com/191cc356-53bd-4be1-9c5d-139b95415063/artificial_reef_breakwate_rjc17860_uxga.jpg

Winterwerp, J. C., Erftemeijer, P. L. A., Suryadiputra, N., van Eijk, P., & Zhang, L. (2013). Defining Eco-Morphodynamic Requirements for Rehabilitating Eroding Mangrove-Mud Coast. *Wetlands*, 515-526.

Wölcke, J., Albers, T., Roth, M., Vorlaufer, M., & Korte, A. (2016). *Integrated Coastal Protection and Mangrove Belt Rehabilitation in the Mekong Delta*.

Wolfowitz, P. (2006). *World Bank Group, Working For A World Free Of Poverty*.

Zavalloni, M., Groeneveld, R. A., & van Zwieten, P. A. M. (2014). *The role of spatial information in the preservation of the shrimp nursey function of mangroves: a spatially explicit bio-economic model for the assessment of land use trade-offs*.

Appendices

Table of content

Appendix A: List of figures

Appendix B: List of tables

Appendix C: Assumptions

Para. #	Assumption	Value	Unit
	Tidal range	3.5	m
	HAT Bạc Liêu	1.4	m
	MHW Bạc Liêu	0.9	m
	Dyke toe	0.8	m
	MSL Bạc Liêu	0	m
	MLW	-1,5	m
	Slope	1:1000	-
	Significant wave height	0.65	m
	Wave period	5-6	s
	Sea level rise	0.33	m
app	Design wave height scenario 1	0.70	m
app	Design wave height scenario 2	0.82	m
app	Inner radius of bamboo (d)	d=0.75D	-
app	Tensile strength bamboo (f_t)	15	N/mm^2
app	Compression strength bamboo (f_c)	4	N/mm^2
app	Bending strength (f_b)	7.6	N/mm^2
app	E modulus bamboo	18 000	N/mm^2
	The bamboo poles are slender and react as Euler-Bernoulli beams		
	Buckling and fatigue are neglected.		
	E modulus Melaleuca	8000	N/mm^2
	Minimal forest width	500	m
	Longshore current	0.50	m/s
	Elevation to counteract SLR	1-10	mm/year
	Median grain diameter D50	0.003-0.007	mm
	Soil stiffness k_s	0.045	N/mm^3
	The soil is homogenous		
	The pile is geometrically straight		
	Eccentric loads are not considered		
	Transverse deflections of the pile are small		
	Deflections due to shearing stresses are small.		
	Piles are not influenced by each other		

Appendix D: Systems Engineering

In this appendix the approach based on Systems Engineering is explained. The design project is based on a Systems Engineering (SE) approach. According to the Guidelines for Systems Engineering within the civil engineering sector, version 3 the definition is as follows:
'Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing and disposal. SE considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs'(D. Alsem et al., 2013).
In practice this implies that the project is based on system thinking, which means that each system is part of a bigger system. All parties and the total life cycle of the system will be taken into account. Other important aspects for Systems Engineering are developing from abstract to concrete (a top-down development), explicit working and optimisation for the whole life cycle of the system(D. Alsem et al., 2013).
The application of SE is important for a project because costs and timescales can be managed more effectively by having more control and attention for the requirements, interfaces and risks.

The technical processes in the life cycle of a system, which are given by ISO 15288, are shown in figure D1. A brief explanation is stated below:

- Stakeholder Requirements Definition Process; Determining involved stakeholders during the system's entire life cycle, and their interests and wishes.
- Requirement Analysis Process; Analysing the customer (stakeholders) requirements and defining these wishes into system requirements.
- Architectural Design Process; Considering several alternatives to develop a solution that meets the system requirements.
- Implementation Process; Parts of the system are put together in this process.
- Integration Process; Creation of a product that meets the system requirements.
- Verification Process; Verify the system if it meets the system requirements.
- Transition Process; The system is activated. The functions described in the customer requirements will be performed by the system.
- Validation Process; Confirmation if the customer requirements specification is done correctly
- Operation Process; The system is used.
- Maintenance Process; Maintenance in order that the system can perform its functions.
- Disposal Process; Demolition of the system, handling of waste material and returning the project site to its original state.

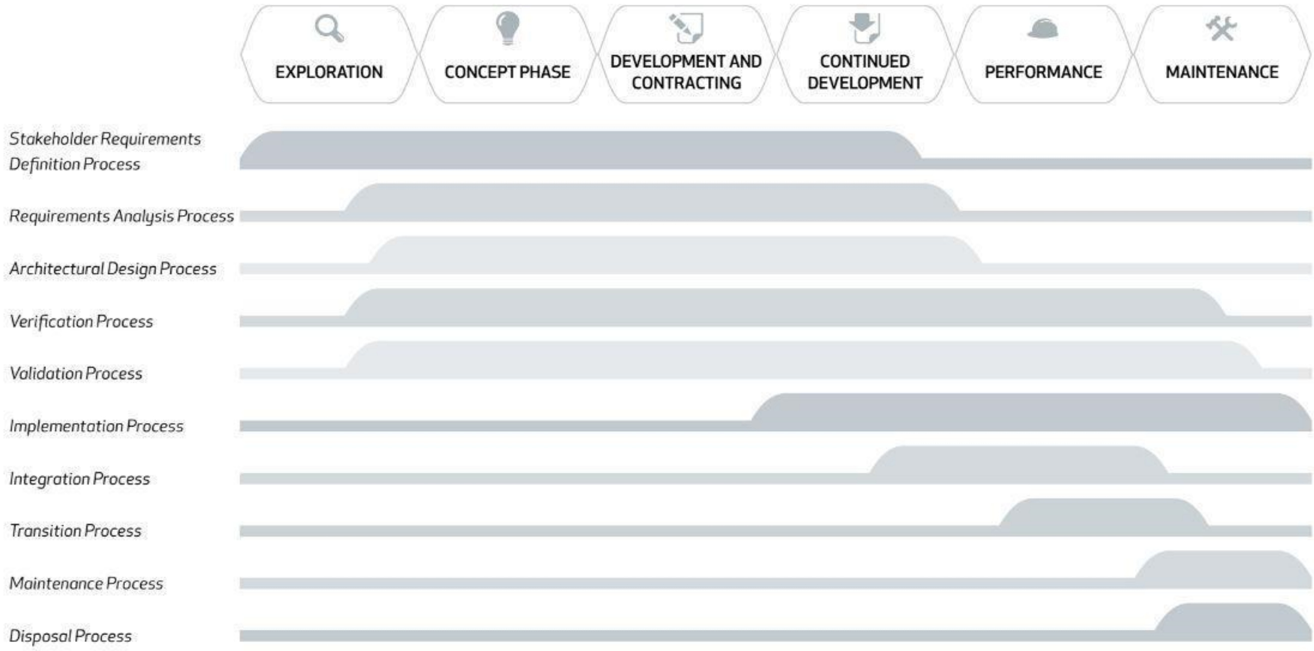


Figure D1: Overview of technical processes in project's lifetime

During the exploration life cycle phase the stakeholder requirements definition process takes place. In this project the stakeholders are determined by doing literature study and conversations with the local community. During the concept phase their wishes are analysed, and the customer requirements can be turned into system requirements. Besides this process, an environmental analysis is executed, which means that the current and ideal situation are determined by using literature study, measurement data and a project site visit. Since accurate measurements of the considered area are not available, data of these neighbouring areas are projected to the Bạc Liêu shoreline. Comparing satellite images of the last decades gives an indication of the severity of the erosion. During the project site visit, it is determined which mangrove species are present at the location and the soil conditions are taken into account.

The outcome of this research are the natural and human interfaces of our project. In chapter 5 the requirement specification is documented, which contains all the information necessary for the system. This includes a structured overview of the available solution space, the internal and external interfaces, and the requirements for the system. In this document the requirements are divided into functional, interface and aspect requirements. Another important process is the verification and validation process. There are several methods to verify if the requirements are met by the design. In table D1 these methods are elaborated.

Table D1: Verification methods

Verification method	Explanation
Inspection	Visual or dimensional examination of an element. It can use easy measurement methods.
Analysis	Mathematical or probabilistic calculation, logical reasoning, modelling, and simulation.
Demonstration	Shows correct operation of the system, observations will show that the system response as expectedly.
Test	Shows functional, operability, or performance capability of the system quantitatively.
Analogy or similarity	Shows evidence based on similar elements or experience.
Simulation	This method is done based on models or mock-ups.
Sampling	This method is based on samples.
Through child requirements	Method only used for requirements, which have child requirements that are measurable and have their own verification method.

Retrieved from (D.D. Walden et al., 2015)

Next the requirements are converted into several alternatives, which are verified using the requirements specification. The SE processes are based on an iterative process between functions, requirements and the alternatives, this is shown in figure D2. The solution space is determined by the requirement specification, which is based on the functions of the system. The design alternatives are again based on which functions it has to perform and what the solution space is.
For complicated and/or immense project this iterative process has to be done on several layers, which is represented in figure D3 the V-model. The V-model represents a top-down / bottom-up process, which start at the upper left corner and ends in the upper right corner. The top-down process is the specification and decomposing process, the bottom-up process represents producing and combining process.

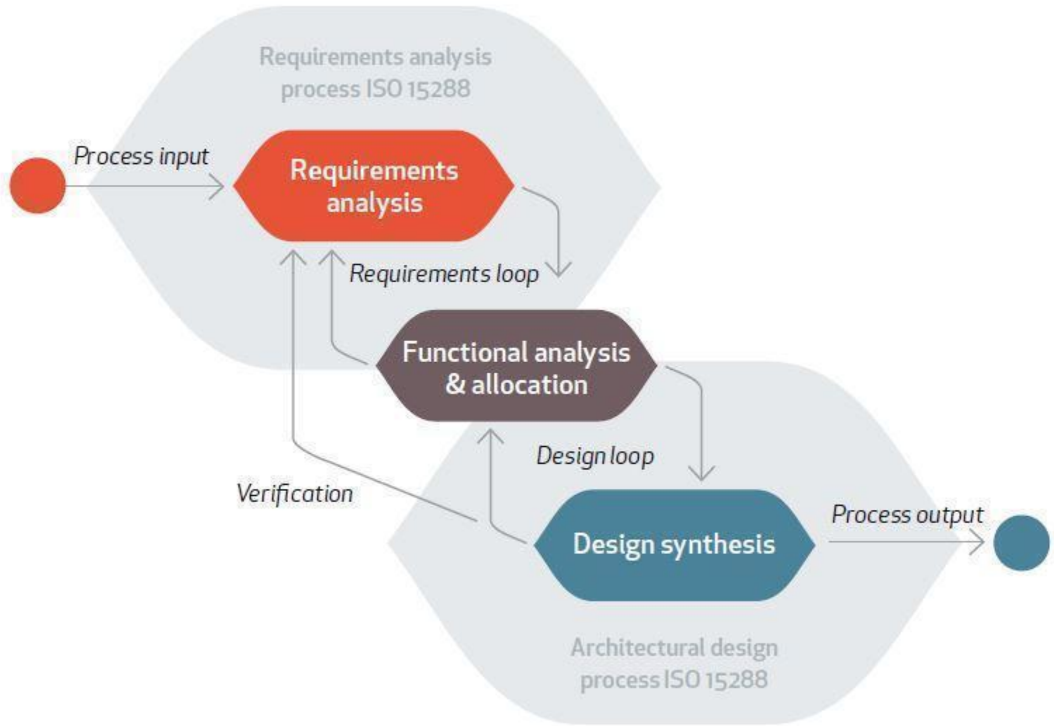


Figure D2: Iterative process for specification (D. Alsem et al., 2013).

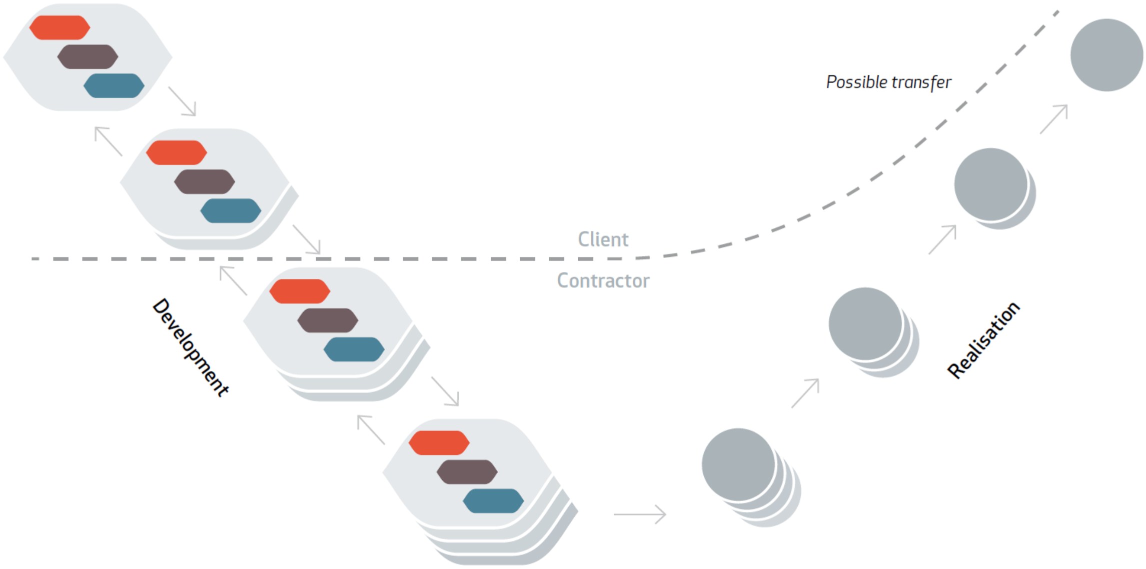


Figure D3: V-model (D. Alsem et al., 2013)

The alternative that meets the requirements best is further elaborated in chapter 7 & 8. The final design is validated to the project's objective, mission, vision and demand. Finally, the project's implementation plan and our recommendations are described. All these processes are documented traceable and explicitly.

Appendix E: Field visit report

In this appendix the field visit is described. The date, location, and delegation are given first. Afterwards, the objectives of the visit are further elaborated.

E.1 Date & Location

Table E1: Project visit objectives and methodology.

Date: **20-22 December**	Location: **Bạc Liêu Province, Nhà Mát Community**
Objectives of the visit: 1. Inspection of the pilot project of WIP. 2. The collection of information about stakeholders and the current land use in front of the dyke. 3. Mapping the project area.	**Methodology:** - Interviewing - Photography - Video Recordings - Flight cam

E.2 Delegation

Table E2: Delegation

Name	Title	Organisation
Mr. Roman Sorgenfrei	Development Advisor	GIZ
Mr. Tinh Phan Thanh	Project Coordinator	GIZ
Ms. Hannah Honsel	Bsc Environmental Engineering	GIZ
Representative of WIP		WIP
Representative of MARD		MARD
Mr. Remco Oudshoorn	Bsc Technical Innovation Science	TU Delft
Mr. Maurits Enschedé	Bsc Civil Engineering	TU Delft
Mr. Harm van Oorschot	Bsc Civil Engineering	TU Delft
Ms. Roos van der Meer	Bsc Civil Engineering	TU Delft
Mr. Thieu Stevens	Bsc Civil Engineering	TU Delft
Ms. Zoë van Looij	Bsc Civil Engineering	TU Delft

E.3 Main findings

Objective 1: Inspection of the pilot project of WIP.

Currently, WIP is doing a project in the Nhà Mát community. During the first day, the pilot area of WIP in front of the Nhà Mát community is visited. At this location, a hard structure is present to protect the hinterland against the sea. Rehabilitation of mangroves is not necessary to create flood safety here but several measures to improve mangrove rehabilitation are tested at this location. Last May they built U-fences and planted new mangrove plants. Figure E1 shows the fences and the planted young mangrove trees at this pilot location. The submerged breakwaters that are present at the locations are from a previous failed pilot project.

Figure E1: Young mangroves with permeable fences

Figure E2: Preparations to refill the fences

Figure E2 shows the preparations to refill the brushwood in the U-fences. At this location WIP contracted a maintenance company for the U-fences which check the U-fences every 6 months. During the visit a time lapse of the incoming tide is made and we inspected the U fence (figure E3). The fences looked robust and steady especially at the left side of the pier.

Figure E3: The project group in front of the U-fences

<u>Objective 2: The collection of information about stakeholders.</u>
By visiting the area with the representatives, it was possible to ask different questions about the stakeholders in the area (See figure E4).

Figure E4: L: Asking question to different stakeholders R: Complete group picture

MARD
The government has stated the policy that all shrimp farms have to meet the 40/60 rule. This means that shrimp farms are only allowed in the mangrove forest area when the farm has a mangrove coverage of at least 60% of the total farm area. Whether the farmer meets this requirement is checked once a year. Only trimming of the mangrove forest is allowed.

Bạc Liêu Provincial People's Committee (PPC)
According to the MARD official the goal of the PPC is to maintain the 500 m of mangroves in front of the dyke. At the moment, most of the sea dyke 500 m of mangrove forest is present if the mangrove forest planted within the fishponds are included. But at several locations the required 500 m is not met. Besides that, according to the MARD official the width of the mangrove forest was 700 m in 2012. At locations where the 500 m is not met projects are carried out to restore the mangrove forest at the sea side.

Small businesses Nhà Mát
Nhà Mát is a small community with small shops and eateries (small businesses). In a conversation with the representative of WIP and MARD it emerged that the people that are living there, think that the government is responsible of the wet area of the project site since they own the land.

Tourists
In the surroundings of the pier there is a resort and a Ferris wheel. The area is not often visit by non-Vietnamese tourists.

Locals
Approximately 8 km south of Nhà Mát a small harbour with residential area is location. Figure E5 shows this area. Unfortunately, it was not possible to contact these locals because the MARD official did not want to provoke conflict. The people in this area do not like the land use restrictions.

Figure E5: Small harbour 8 km South of Nhà Mát

Shrimp farmers
South of Nhà Mát there are shrimp ponds in front of the dyke, the farmers are not always pleased with the government because of the (new) policies around shrimp farms. The shrimp ponds are of the type integrated shrimp pond. The shrimp ponds are protected with small dykes build by the farmers. At most locations, the width of the mangrove forest in front of these small dykes is approximately 150 m.
In front of the dyke a lot of contamination was present. Shrimps are harvested every two weeks, every two months approximately 20 cm of the water is pumped out of the ponds are replaced by seawater.

GIZ GIZ is a research institute concerned with the coastal protection of Vietnam. GIZ is consulting the governmental coastal protection institutes of Vietnam on how to deal with coastal erosion. With the use of flight cams, the monitoring of coastal erosion is improved.
<u>Objective 3: Mapping the project area.</u> During the visit the project area would be mapped using a flight cam, but after the first flight it unfortunately was too windy for the flight cam so it was too risky to map the entire coastline.

Appendix F: Data verification Vung Tau

This appendix is about the verification between the data from Vung Tau and Canh Hao station. Vung Tau is a measurement station where a lot of data is available about water levels from 2007 till now. To verify whether the data from Vung Tau station can be applied to the Bạc Liêu province, the measurement data between Vung Tau and Ganh Hao station is compared. Gang Hao station is a measurement station near Bạc Liêu, this is shown in figure F1 (L.T. Hien, 2016).

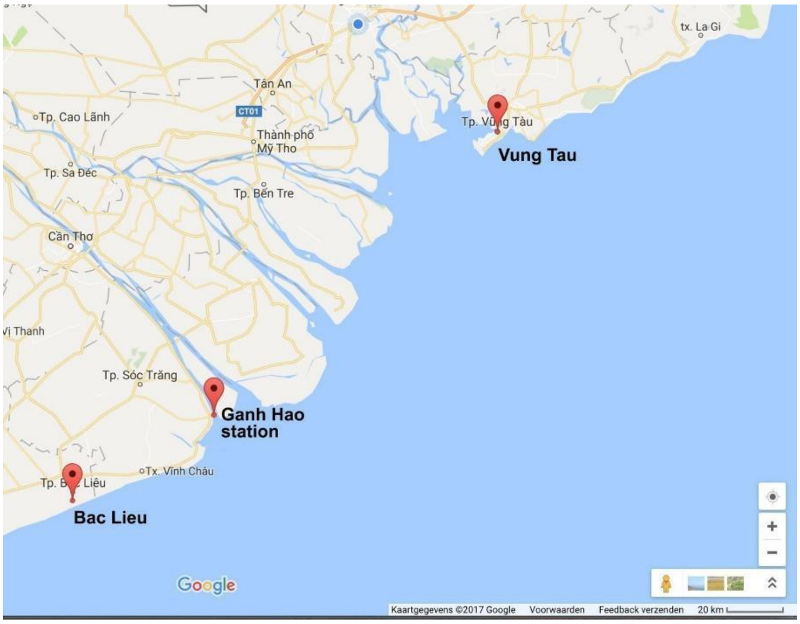


Figure F1: Positions of measurement stations

From Ganh Hao station is data available from 01-10-2009 till 16-10-2009. However, there is a time difference in measuring data. The specific time that a data point is registered, local time or GMT, causes these time differences. Figure F2 gives the comparison of data measured during this period in Vung Tau and Ganh Hao after the time differences are resolved.

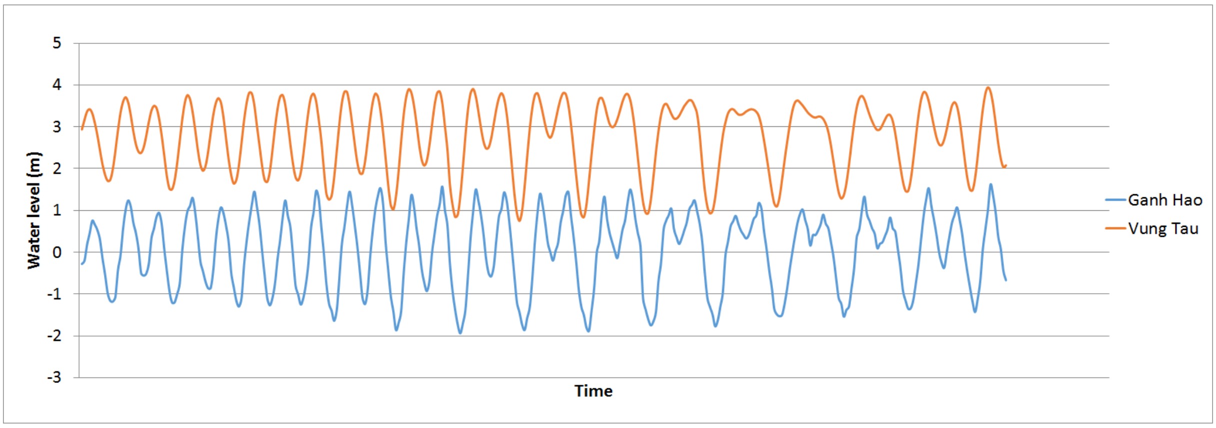


Figure F2: Comparison measurements after time differences

Furthermore, the measurement stations do not have the same base point. Therefore, a (constant) difference in water elevation is visible. The average difference between the two lines is 2.74 m and is therefore assumed as the difference in base point. By subtracting 2.74 m from each Vung Tau data point the lines fits best. Figure F3 is the comparison after time scaling, and base point difference change have been adopted.

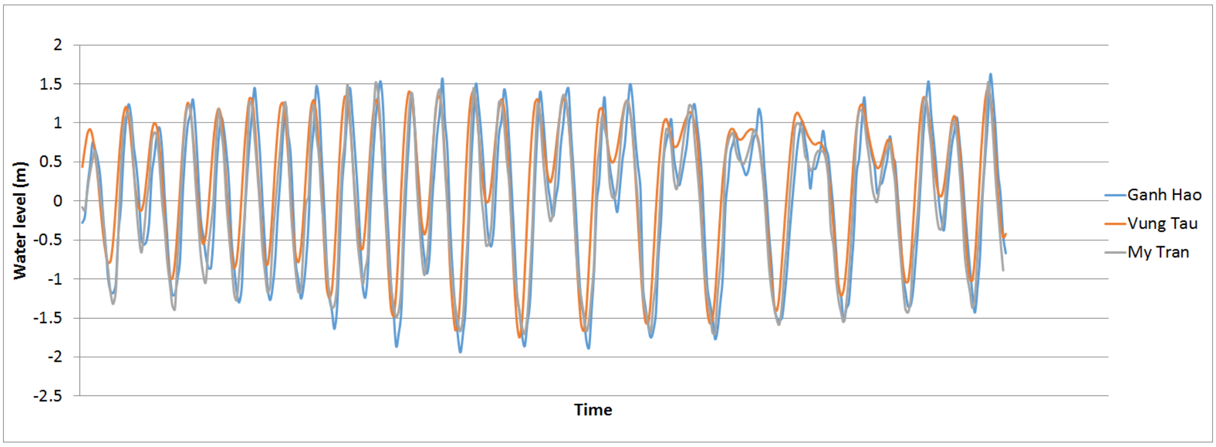


Figure F3: Comparison measurements after time scaling and base point difference

It is clearly shown in figure G3 that there is a small difference in time scale. This difference in time and elevation is caused by tidal propagation.

In conclusion, there is no significant difference between the water elevation measured in Ganh Hao and Vung Tau. Furthermore, the distance between Bạc Liêu and the Ganh Hao station is assumed as negligible. Therefore, it can be concluded that the data from Vung Tau is applicable for the Bạc Liêu Province.

Appendix G: Applicable laws with regards to mangrove forests in the Bạc Liêu Province

Table G1: Applicable laws

Date Decision	Title of regulations	Implication
6-3-1985 **57/QD.UB**	Temporary regulations about mangrove management, protection with relation to aquaculture technical management in Forestry-Fisheries Enterprises and households.	Households were allocated mangrove land for re-plantation and protection from destruction
8-11-1988 **389/QD.UB**	Temporary regulations on allocation of mangrove land to households for production and protection.	Farmers have to cover at least 80% with the mangroves and limit the area to 20% for pond aquaculture. Mangroves must be planted at a density 20,000 trees ha−1.
28-3-1991 **64/QD.UB**	Decision on implementing methods for management, protection and uses of forest, forestry land and water surface in forest land. To replace the Decision 389/QD.UB.	Households have less than 20 ha of mangrove forest or 10 ha of empty mangrove maintain at least 80% of mangroves. Farmers were allowed to open ponds by hand and had to plant 20,000 trees per ha. The renewable land-use rights were granted for 20 years to individual HHs under contract with FEs.
12-9-2002 **24/QD.UB**	Decision on reforming structure and management regimes of forest and forestry lands in Ca Mau province.	Converts the use-right contracts from green to red certificates. Allows farmers to gain more benefits from timber marketing, to dredge or excavate the ponds using machines. For an entire, mangroves should cover 70% of the area; however, for HHs, mangrove could covers 50%, 60% or 70% of total area of farms having less than 3 ha, 3–5 ha, or more than 5 ha, respectively.
22-9-2010 **10/QD.UB**	Decision on the implementation of policies on forest development and protection in Ca Mau province. To replace Decision 24/QD.UB	To encourage all economic and private sectors involved in forest protection, development, production and market. Mangroves should cover at least 60% of total allocated area to farmer.

Appendix H: Inundation times

In this appendix the inundation times from measurements in Vung Tau are shown. All 2015 measurement points from Vung Tau are taken into account. First, it is determined how many minutes a day the water level reaches at least a certain point each month. This result is shown in figure H1. This figure shows clearly that higher water levels appear during the NW-monsoon. For determination of the ideal zonation, March is taken as a representative month.

	Water level																		
Month	**-0,3**	**-0,2**	**-0,1**	**0**	**+0,1**	**+0,2**	**+0,3**	**+0,4**	**+0,5**	**+0,6**	**+0,7**	**+0,8**	**+0,9**	**+1,0**	**+1,1**	**+1,2**	**+1,3**	**+1,4**	**+1,5**
jan	1061	1022	972	917	865	795	701	614	521	461	368	300	213	124	60	29	14	0	0
feb	992	941	889	834	774	686	587	508	424	362	281	225	163	88	47	19	4	0	0
mrt	941	892	848	786	734	668	592	499	399	315	223	153	97	50	31	14	0	0	0
apr	924	876	816	764	716	634	560	482	410	318	224	134	68	40	12	2	0	0	0
mei	857	799	730	645	577	503	443	379	304	232	157	87	39	15	0	0	0	0	0
jun	876	774	688	628	560	500	426	364	296	216	160	102	44	2	0	0	0	0	0
jul	848	772	708	625	544	480	395	331	265	192	116	46	12	2	0	0	0	0	0
aug	830	784	724	660	571	492	424	345	286	230	155	103	56	29	4	0	0	0	0
sep	856	798	750	700	640	554	478	388	322	250	204	138	96	54	32	18	10	0	0
okt	975	927	871	819	763	693	612	552	466	393	333	261	201	153	101	58	25	8	0
nov	1020	976	930	880	838	770	692	592	530	448	370	320	212	122	70	46	20	4	0
dec	1086	1049	1005	972	906	809	716	637	573	488	412	339	261	180	97	27	2	0	0

Figuur H1: Inundation times

To meet the exact inundation times for each individual zone, an interpolation is done between the water levels. The result of this interpolation for the inundation time per zone is shown in table H1.

Table H1: inundation times

Zone	Duration of inundation (min/day)	Water height (m)	Width zone for slope 1:1000 (m)	Vegetation (species)
1	>800	-0,02	-	None
2	400–800	0,5	520	*Avicennia*, *Sonneratia*
3	100–400	0,89	390	*Rhizophora*, *Ceriops*, *Bruguiera*
4	10–100	1,22	330	*Lumnitzera*, *Bruguiera*, *Acrostichum aureum*
5	<10	1,3	-	*Ceriops*, *Phoenix paludosa*

The ideal widths for each zone are adapted in *table H1.*

Appendix I: Stakeholder description

Governance

National Assembly

The National Assembly is the Parliament of Vietnam and is 'the highest organ of state power'. Responsibilities include approving laws, determining state budget and contribution to the development of the economy, society, culture and education. One of its functions is expanding the external relations with other countries. They are a member of the International Parliamentary Union (IPU), the ASEAN Inter-Parliamentary Organization (AIPO), the Association of Francophone Parliamentarians (APF) and several others. Two ministries have an influence on this project, the ministry of Natural Resources and Environment (MoNRE) and the ministry of Agriculture and Rural Development (MARD).

Ministry of Natural Resources and Environment (MoNRE)

The responsibilities of the Ministry of Natural Resources and Environment (MoNRE) can be divided into two sections. The first section is implementing education programs on legislations on land, this to create awareness of policies among companies, communities and individuals (T.P. Cuong & L.Q. Vuong 1996).

The second section is the implementation of the planning of land use on national level in accordance with the 5-year plan of land use (2016-2020). This includes monitoring the implementation by provinces and other local authorities, approving of planning of land use at district level and reviewing the planning of provincial-level land use according to the Land Code elaborating the 5-year plan. (T.P. Cuong & L.Q. Vuong 1996)

Ministry of Agriculture and Rural Development (MARD)

The responsibilities of the Ministry of Agriculture and Rural Development (MARD) lay in different areas: Agriculture (crop production and animal husbandry), veterinary for animals, forestry, salt production, fishery, water resources, rural development, the quality of food and hygiene safety for imported agro-forestry, fishery and salt products. In these areas, the main tasks are guiding implementation of legal documents and policies, governing and approving strategies and master plans, issuing, monitoring and evaluating these master plans according to national (technical) standards, processes and socio-economic cost norms (ICEM, n.d.).

Bạc Liêu Provincial People's Committee (PPC)

Bạc Liêu People's Committee is the executive body and fulfils the following duties and tasks. The first task is the execution of general advisor, which includes monitoring and supervising departments, People's Committees in districts and cities, and other relevant organizations. Besides that, controlling administrative procedures, making drafts of legal documents and providing information for the public are tasks of the People's Committee (T.Q. Nong, 2016). The Department of Agriculture and Rural Development (DARD) Bạc Liêu of the People's Committee are in charge of the mangrove forest management.

Forest Management Boards (FMBs)

The forests and forestland are managed by the Forest Management Boards (FMBs), which is an organization that holds a significant proportion of forestland and supposed to be a kind of semi-government agency. The FMB makes it easier to plant and manage the forestland and its production, because the agencies have a lack of resources to invest in forest plantation and protection (N.D. Tran, n.d.)

Users

Locals and small businesses Nhà Mát

The locals and small businesses in Nhà Mát are represented by the local people's committee. Some local households who meet the criteria can use a part of the mangrove forest to improve their livelihood (aquaculture). Most of the locals are working in rice production or aquaculture.

Shrimp farmers

Integrated shrimp-mangrove ponds are present in the coastal zone of the Bạc Liêu province. The shrimp ponds in the mangrove forest create economic value in the Bạc Liêu province.

Energy and water suppliers

The energy and water companies supply the users with resources to do business. The energy companies must be able to deliver the energy demand for the locals. The building of a thermo-power plant and a high-voltage power grid in the following decades is planned (N.T. Dung, 2012a). In the Bạc Liêu province Asia's first offshore wind farm is recently developed. The windmills are placed outside the mangrove area and are not in the scope of this project.

Tourists

The Bạc Liêu Provincial People's Committee planned to have two million tourists visits to Bạc Liêu in 2020. This is an increase of approximately 1 million tourists visits in five years (N.T. Dung, 2012a). Three main tourist activities can be distinguished, eco-tourism, cultural-historical relics and festival tourism.

Partners

Vietnamese Organizations

Different Vietnamese Organizations are involved with mangrove rehabilitation in the Mekong Delta. For example, the Southern Institute of Water Resources Research (SIWRR) is occupied with the salinity intrusion forecast, the flooding forecasts and the erosion of riverbanks and coastal areas in the Mekong Delta.

Another organization is the Institute of Ecology and Works Protection (WIP). They do scientific research about hidden dangers in dykes and dams, implementation of measures based on growing plants against wave attack to protect sea dykes.

International Organizations

There are several international organizations involved in mangrove rehabilitation projects. Since 2011 the Gesellschaft für Internationale Zusammenarbeit (GIZ) is working together with the Vietnamese Ministry of Agriculture and Rural Development in order to protect the coastline. In five provinces of the Mekong Delta local people are replanting and managing the mangrove forests.

Another international organization is Royal Haskoning DHV. They led the consortium which developed the Mekong Delta Plan, as a part of the Strategic Partnership Arrangement on Climate Change Adaptation and Water Management between Vietnam and The Netherlands. The objective of this plan is to be a strategic guidance document for the long-term development of the Mekong Delta.

Most of the flood protection projects are financed partly or whole by the World Bank. The mission of this organization is ´working for a world free of poverty´. It finances projects all over the world in different sectors (P. Wolfowitz, 2006).

J. Customer requirements specification (CRS)

In this appendix the complete Customer Requirements Specification (CRS) is given, this includes the short summary that can also be found in chapter 4, and all customer requirements (CR) itself. At the end of this appendix the excel document is included.

J.1 Objective and CRS process

The aim for the CRS (Customer Requirements Specification) process is two-jointed. The first part is to support and structure the interaction with stakeholders. Secondly, it is to collect input for the system developments, such as the requirements and design alternatives. This contributes to make a structured and complete inventory of all the input of the active stakeholders (M. Visser & C. Vreman, 2011). The CRS process has several steps to finalize the specification, which are shown in figure J1.

Figure J1: CRS process steps

Starting with identifying the stakeholders based on a stakeholder analysis, which is done in chapter 3, the CRS is based on wishes from these stakeholders. Mostly, these wishes are unstructured, solution focused, conflicting and they can be interpreted in several ways. Therefore, it is important to find the relevant information and to translate that into system requirements. When these customer requirements are conflicting or not feasible, they need to be rejected. (V. Kramer, 2013). The analysis from the CRS to the SRS is shown in figure J2.

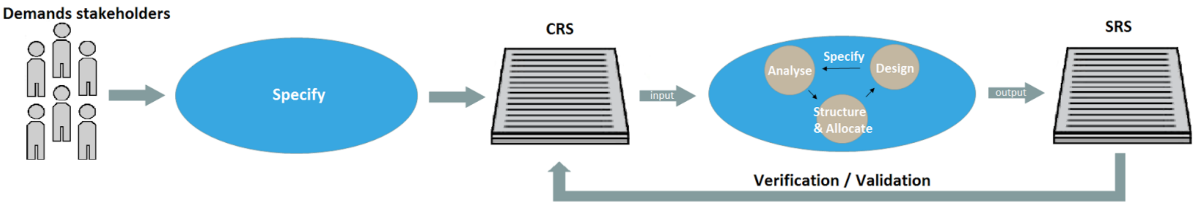


Figure J2: Analysis from CRS to SRS

The CRS is not a static document, this means that during the project it constantly changes, because of the feedback loop between de CRS and SRS. Validation and verification is an important process during the whole life cycle of the project. The several verification methods that are explained in paragraph 2.5 and appendix D.

In paragraph J.2 the customer requirements are given. The requirements are categorized by stakeholder category, which are described in chapter 3. The requirements in the following paragraph all have the same format as shown in table J1. This format includes a code, a title, a description, a verification method, the source document, the stakeholder that contributed the requirement, and the status of the requirement. The code for every customer requirement is a unique number that is generated automatically. There are four statuses for CR: honoured, partially honoured, rejected, and secured. When a CR is honoured, the wish of the stakeholder will be translated into a system requirement. A partially honoured CR means that with a few adjustments the requirement is honoured. If a CR is secured, the wish of the stakeholder is already secured into a national policy or the implementation plan. When the CR is rejected, the wish will not be accepted. When a customer requirement is honoured or partly honoured it is defined into one of the system requirements, which are elaborated in chapter 5 and appendix K.

Table J1: Format customer requirements

CR_xxxx – [Title]	Status:	Defined in SR
[description]	[honoured / partially honoured / rejected / secured]	SR_xxxx
Stakeholder: [stakeholder that contributed the requirement]		**Source document:** [reference document]
Verification Method: [Inspection / Analysis / Demonstration / Test / Analogy / Simulation / Sampling / Through child requirements]		

J.2 Customer requirements

In this paragraph the customer requirements are documented. These are divided into the stakeholder categories: governance, users, and partners.

J.2.1 Governance

CR_001 – Preservation of forest	Status:	Defined in SR
Stabilize the forest area in the Bạc Liêu province at around 8,300 ha, including 389 ha of Bạc Liêu bird special-purpose forests, protection forest range outside the sea dikes, and zone off for tending 2,780 ha of coastal submerged forests.	Partially honoured	SR_019
Stakeholder: Bạc Liêu Province People's Committee		**Source document:** *667/QD-TTg* (N.T. Dung, 2012a)
Verification Method: Inspection		

CR_002 – Location of the dyke	Status:	Defined in SR
Select dykes that pass to high terrain areas, geological background is relatively good to ensure stability and far from eroded areas.	Partially honoured	SR_010
Stakeholder: National Assembly		**Source document:** *667/QD-TTg* (N.T. Dung, 2012a)
Verification Method: Analysis		

CR_003 – Minimum amount of mangroves	Status:	Defined in SR
In front of sea dyke, it requires having planted mangroves area with minimum of 500 m width.	Honoure d	SR_019
Stakeholder: National Assembly		**Source document:** *667/QD-TTg* (N.T. Dung, 2012a)
Verification Method: Analysis		

<table>
<tr><th>CR_004 – Sustainability dyke</th><th>Status:</th><th>Defined in SR</th></tr>
<tr><td>Established dyke should not affect to flooding releasing, and far away from eroded river bank.</td><td>Partially honoured</td><td>SR_010</td></tr>
<tr><td colspan="2">Stakeholder: National Assembly</td><td>Source document:
667/QD-TTg
(N.T. Dung, 2012a)</td></tr>
<tr><td colspan="3">Verification Method: Analysis</td></tr>
</table>

<table>
<tr><th>CR_005 – Road transport on dyke</th><th>Status:</th><th>Defined in SR</th></tr>
<tr><td>The Dyke should integrate with transportation service and must comply with standards and guidelines of transport sector.</td><td>honoured</td><td>SR_011
SR_034</td></tr>
<tr><td colspan="2">Stakeholder: National Assembly</td><td>Source document:
667/QD-TTg
(N.T. Dung, 2012a)</td></tr>
<tr><td colspan="3">Verification Method: Inspection</td></tr>
</table>

<table>
<tr><th>CR_006 – Land reclamation</th><th>Status:</th><th>Defined in SR</th></tr>
<tr><td>Steps can be arranged to build extra dykes in front of the main dyke for land reclamation for socioeconomic development.</td><td>Secured</td><td></td></tr>
<tr><td colspan="2">Stakeholder: National Assembly</td><td>Source document:
667/QD-TTg
(N.T. Dung, 2012a)</td></tr>
<tr><td colspan="3">Verification Method: -</td></tr>
</table>

<table>
<tr><th>CR_007 – Land use on eroded areas</th><th>Status:</th><th>Defined in SR</th></tr>
<tr><td>Consider to remove residential areas to behind of the dike on eroded areas. When this solution is impossible, it requests to build infrastructures to prevent erosion, artificial deposition and site keeping.</td><td>Secured</td><td></td></tr>
<tr><td colspan="2">Stakeholder: National Assembly</td><td>Source document:
667/QD-TTg
(N.T. Dung, 2012a)</td></tr>
<tr><td colspan="3">Verification Method: -</td></tr>
</table>

<table>
<tr><th>CR_008 – Priority of protection</th><th>Status:</th><th>Defined in SR</th></tr>
<tr><td>Based on the importance of protected areas to determine the appropriate design standards, but at least against the storm level 9 and tidal level with 5% frequency, in order: the urban and the concentrated residential areas; security and defence facilities; the economic, cultural and important infrastructure areas and agricultural production areas.</td><td>Partially honoured</td><td>SR_017
SR_031
SR_036</td></tr>
<tr><td colspan="2">Stakeholder: National Assembly</td><td>Source document:
667/QD-TTg
(N.T. Dung, 2012a)</td></tr>
<tr><td colspan="3">Verification Method: Analysis</td></tr>
</table>

CR_009 – Dyke stability		Status:	Defined in SR
Ensure stability in accordance to the design of existing sea dikes, easy to make higher for sea level rise.		Partially honoured	SR_025
Stakeholder: National Assembly			**Source document:** *667/QD-TTg* (N.T. Dung, 2012a)
Verification Method: Analysis			

CR_010 – Bridges and culverts		Status:	Defined in SR
Improvement of old culverts, building new bridges and culverts must be ensured: prevent water; suitable for agricultural production plan, aquaculture; control salinity intrusion; can be combined with the avoiding storm area for boats and ships.		Partially honoured	SR_018
Stakeholder: National Assembly			**Source document:** *667/QD-TTg* (N.T. Dung, 2012a)
Verification Method: Inspection			

CR_011– Monitoring		Status:	Defined in SR
Strengthening monitoring, research to evaluate seasonal erosion of sea dike, the adverse effects of nature or negative effects of human		Rejected	
Stakeholder: National Assembly			**Source document:** *667/QD-TTg* (N.T. Dung, 2012a)
Verification Method: -			

CR_012 – Dyke revetment		Status:	Defined in SR
Create planting area in front of the dike against waves. It must be planted grass on 2 sites of the dike or protect by stable materials to prevent erosion.		Partially honoured	SR_023
Stakeholder: National Assembly			**Source document:** *667/QD-TTg* (N.T. Dung, 2012a)
Verification Method: Inspection			

CR_014 – Agriculture development		Status:	Defined in SR
Developing hi-tech agriculture in association with development of industries and services		Partially honoured	SR_035
Stakeholder: Bạc Liêu Provincial People's Committee			**Source document:** *221/QD-TTg* (N.T. Dung, 2012b)
Verification Method: Inspection			

CR_015 – Economy	Status:	Defined in SR
To restructure the economy through gradually increasing the proportions of non-agricultural sectors; the proportions of agriculture-forestry-fisheries and non-agricultural sectors will be 36.4% and 63.6% by 2015 and 31% and 69% by 2020.	Rejected	
Stakeholder: Bạc Liêu Provincial People's Committee		**Source document:** *221/QD-TTg* (N.T. Dung, 2012b)
Verification Method: -		

CR_016 – Upgrading of rainwater drainage	Status:	Defined in SR
Complete the renovation and upgrading of rainwater drainage and wastewater treatment systems of the city and townships, and implement the national target program on rural clean water and environmental sanitation	Partially honoured	SR_026
Stakeholder: Bạc Liêu Provincial People's Committee		**Source document:** *221/QD-TTg* (N.T. Dung, 2012b)
Verification Method: Analysis		

CR_017 – Allow new production models	Status:	Defined in SR
Change production models, grow rice and rear shrimp or grow rice and plant forests alternately suitable to the ecosystem of each sub-zone	Rejected	
Stakeholder: Bạc Liêu Provincial People's Committee		**Source document:** *221/QD-TTg* (N.T. Dung, 2012b)
Verification Method: -		

CR_018 – Aquaculture	Status:	Defined in SR
Expand the area under aquaculture	Rejected	
Stakeholder: Bạc Liêu Provincial People's Committee		**Source document:** *221/QD-TTg* (N.T. Dung, 2012b)
Verification Method: -		

CR_019 – Ship traffic	Status:	Defined in SR
To develop road and waterway transportation services in combination with building warehouses, storing yards and wharves.	Partially honoured	SR_033
Stakeholder: Bạc Liêu Provincial People's Committee		**Source document:** *221/QD-TTg* (N.T. Dung, 2012b)
Verification Method: Analysis		

CR_020 – Road transport	Status:	Defined in SR
Upgrading road infrastructure, especially the systems of "horizontal" axial roads, coastal roads, rural roads and bridges, to ensure uninterrupted transport in the whole province.	Rejected	
Stakeholder: Bạc Liêu Provincial People's Committee		**Source document:** *221/QD-TTg* (N.T. Dung, 2012b)
Verification Method: -		

CR_021 – Multi-purpose irrigation system	Status:	Defined in SR
Multi-purpose irrigation system to gradually adapt to climate change and sea level rise in combination with transport development and natural disaster prevention and mitigation; to control salinity, drain alum and retain and supply fresh water for specialized rice sub-zones; to study the building of appropriate water supply and drainage systems for preventing and limiting the spread of epidemics and ensuring environmental sanitation for sustainable aquaculture.	Partially honoured	SR_026
Stakeholder: Bạc Liêu Provincial People's Committee		**Source document:** *221/QD-TTg* (N.T. Dung, 2012b)
Verification Method: Inspection		

CR_022 – Shrimp infrastructure	Status:	Defined in SR
Infrastructure facilities for 15,000 ha of industrial shrimp rearing.	honoured	SR_035
Stakeholder: Bạc Liêu Provincial People's Committee		**Source document:** *221/QD-TTg* (N.T. Dung, 2012b)
Verification Method: Analysis		

J.2.2 Users

CR_023 – Retain local functions	Status:	Defined in SR
Retaining of performing functions for locals	honoured	SR_002
Stakeholder: Local community		**Source document:**
Verification Method: Inspection		

CR_024 – Retain shrimp farmers functions	Status:	Defined in SR
Retaining of performing functions for shrimp farmers	honoured	SE_002
Stakeholder: Shrimp farmers		**Source document:**
Verification Method: Inspection		

CR_025 – Hindrance locals	Status:	Defined in SR
No hindrance for the Nhà Mát community	Secured	
Stakeholder: Local community		**Source document:**
Verification Method: -		

CR_026 – Hindrance resort	Status:	Defined in SR
No hindrance for the Nhà Mát resort	Secured	
Stakeholder: Tourists		**Source document:**
Verification Method: -		

Appendix K: System requirement specification (SRS)

This appendix provides the complete SRS (System requirements specification). In the introduction the objective of this document, the process, including analyses, and how to specify the requirements is explained. The next paragraphs contain the requirements, starting with the top requirements. Next the more detailed requirements concerning the system is divided into functional, aspect, and interface requirements.

K.1 Objective and analyses

The aim of this document is to make a structured collection of all requirements, which have to be met by the system. Mostly, the discipline of requirements analysis and management is underrated, which is odd because starting with adequate requirements can reduce or totally eliminate most issues during a project (J. Johnson Popp, 2008). These issues include project delays, a final scope that does not please the client, and budget exceedance (J. Johnson Popp, 2008).
The system requirement specification is based on several analysis. First of all it is partly based on the customer requirement specification. Secondly, a function analysis is done, to check the completeness of the specification. The function analysis is done based on the FAST method, which means that the system is looked at by asking three different questions. The 'how'-question ensures the arrangement of the functions. The 'why'-question confirms the necessity of the functions in the diagram, and the 'if-then'-question finds supporting functions. (J. Bartolomei & T. Miller, 2001). For the functional analysis the system is split into two main goals of the system: 'mangrove forest restoration' and 'protection of the hinterland'. In figure K1 and K2 the FAST method for these two goals are shown.

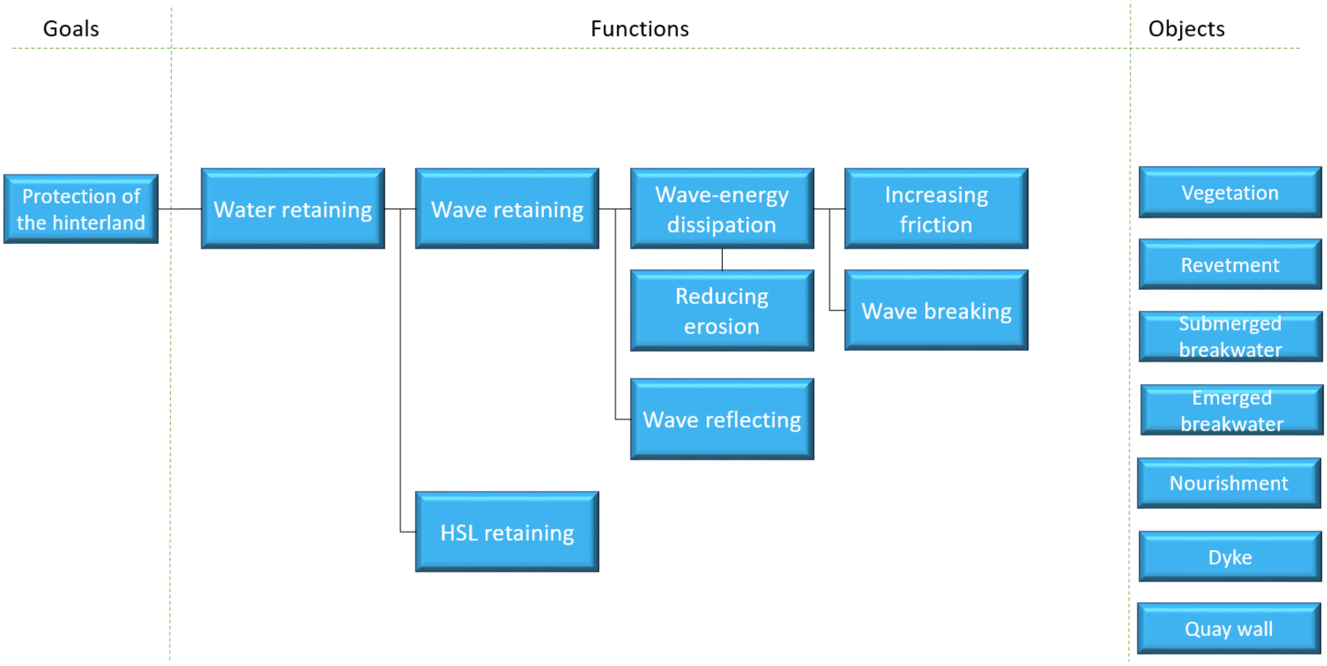


Figure K1: FAST method for primary goal: 'protection of the hinterland'.

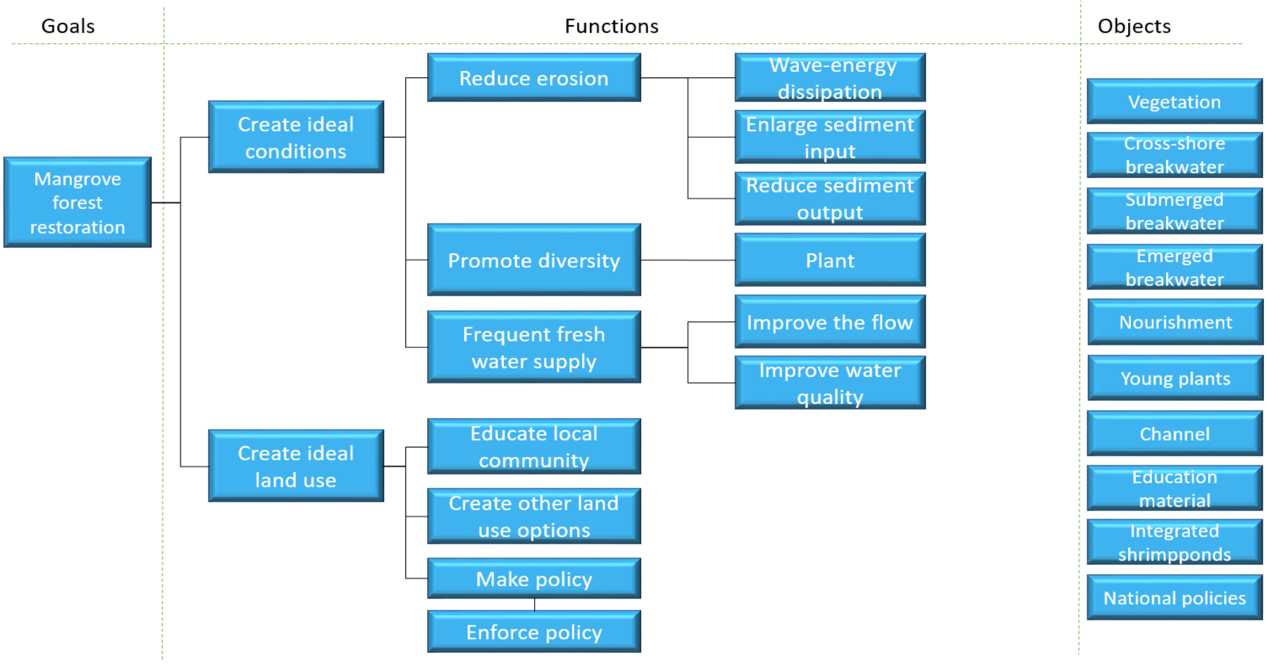


Figure K2: FAST method for primary goal 'Mangrove forest restoration'.

K.2 Requirements specification

Requirements specification is a careful assessment of the needs that a system is to fulfil (A. van Lamsweerde, 2002). Normally, requirements are defined by the client in cooperation with the project team. However, defining these requirements is not that easy. Common mistakes in defining the specification are duplicated, missing or misplaced, and conflicting requirements (C.S. Wasson, 2006). Therefore, it is essential to have requirements how to specify the system requirements. The primary rule is the acronym 'SMART', which stands for specific, measurable, attainable, realisable and time-bounded (M. Mannion & B. Keepence, 1995). An explanation of these conditions is listed in table K1. Besides this rule, a requirement has to be necessary, verifiable, unique, solution free, and traceable.

Table K1: Requirement conditions (M. Mannion & B. Keepence, 1995)

Requirement concept	Explanation
Specific	Requirements should represent exactly what is required, this involves multiple areas: - Clear; - Consistent; - Simple, so avoid double requirements.
Measurable	It should be clear when the objective of the requirement is reached.
Attainable	The requirement should be accomplishable in terms of the social status.
Realisable	The requirement should be physically and theoretically possible, is it feasible.
Time-bounded	It should be clear when a requirement needs to be executed.
Necessary	Requirements should be crucial.
Verifiable	Requirements should have a verification method, so it is possible to check if the requirement is achieved.
Unique	Not two or more requirements that mean the same.
Solution free	Requirements cannot already describe the solution.
Traceable	Requirements includes for example a title and a source document

The requirements in the following paragraphs all have the same format as shown in table K2. This format includes a title, parent and/or child requirements, a description, a verification method, and the source text.

Table K2: Format requirements

SR_xxxx – [Title]	Parent requirements	Child requirements
[description]	SR_xxxx	SR_xxxx
Verification Method: [Inspection / Analysis / Demonstration / Test / Analogy / Simulation / Sampling / Through child requirements]		**Source text:** [reference text]

K.2.1 Top requirements

In this paragraph the top requirements are documented. The whole coastal protection system has to meet these requirements and they are based on the primary functions of the system.

SR_001 – Life time	Parent requirements	Child requirements
All functions of the coastal protection system must be reliable until at least 2050.		SR_008 SR_010 SR_025
Verification Method: Simulation		**Source text:** para. 2.4.3

SR_002 – Preservation interface functions	Parent requirements	Child requirements
The coastal protection system must preserve the interface functions.		SR_003 SR_011 SR_026 SR_034 SR_037
Verification Method: Through child requirements		**Source text:** CRS

SR_013 – Protection hinterland	Parent requirements	Child requirements
The coastal protection system must protect the hinterland of Bạc Liêu against floods.		SR_004 SR_005 SR_016 SR_038
Verification Method: Through child requirements		**Source text:** para. 2.3

K.2.2 Functional requirements

Functional requirements are requirements that defines a function of the system or subsystem. A function is a service or activity, which the system has to achieve or provide to reach the objectives of the system. This is described in the format of verb + noun + performance indicator.

SR_004 – Reducing erosion	Parent requirements	Child requirements
The coastal protection system must prevent erosion.	SR_013	SR_039 SR_046
Verification Method: Analysis		**Source text:** para. 3.3.2.5

SR_005 – Water level	Parent requirements	Child requirements
The sea dyke system must retain storm surge of 1 m.	SR_0013	SR_006
Verification Method: Simulation		**Source text:** para. 3.1.2.1

SR_006 – Coastal protection wave height	Parent requirements	Child requirements
The temporary protection system must retain a significant wave height of 0.65 m.	SR_005	SR_041 SR_048
Verification Method: Analysis		**Source text:** para. 3.1.2.2

SR_007 – Coastal protection wave period	Parent requirements	Child requirements
The temporary protection system must retain waves for at least the significant wave period of 5.5 s.	SR_005	
Verification Method: Analysis		**Source text:** para. 3.1.2.2

SR_010 – Stability dyke	Parent requirements	Child requirements
The dyke must be on ground that is not eroding according to figure 4, paragraph 2.5	SR_001	
Verification Method: Analysis		**Source text:** CRS

SR_014 – Slope	Parent requirements	Child requirements
The average bottom slope at the mangroves must have a slope of at least 1:1000.	SR_016	
Verification Method: Analysis		**Source text:** paragraph 3.1.2.3

SR_015 – Storm protection	Parent requirements	Child requirements
The coastal protection system must withstand storm conditions level 9.	SR_005	SR_017 SR_030
Verification Method: Through child requirements		**Source text:** CRS

SR_016 – Mangroves	Parent requirements	Child requirements
The coastal protection system must include mangroves.	SR_013	SR_014 SR_019 SR_020 SR_022 SR_024 SR_040 SR_047
Verification Method: Through child requirements		**Source text:** CRS

SR_017 – Storm wind speed	Parent requirements	Child requirements
The coastal protection system must retain a storm with wind speed 75–88 km/h.	SR_015	
Verification Method: Simulation		**Source text:** CRS

SR_018 – Salt intrusion	Parent requirements	Child requirements
The coastal protection system must control salt intrusion.	SR_026	
Verification Method: Inspection		**Source text:** CRS

SR_019 – Mangrove belt width	Parent requirements	Child requirements
The mangrove belt must have a width of at least 500m after 5 years.	SR_016	
Verification Method: Inspection		**Source text:** CRS

SR_020 – Dissipate wave height	Parent requirements	Child requirements
The mangrove forest must reduce the wave height till a maximum of 0.20 m.	SR_016	
Verification Method: Analogy		**Source text:** (M.P.J. Janssen, 2016)

SR_022 – Mangrove density	Parent requirements	Child requirements
The mangrove forest must have a sparse density or more than 0.1 stems/m2 and 45 roots/m2 after 5 years.	SR_016	
Verification Method: Inspection		**Source text:** (M.P.J. Janssen, 2016)

SR_024 – Variety mangrove forest	Parent requirements	Child requirements
The mangrove forest must have a diversity of at least 2 species.	SR_016	
Verification Method: Inspection		**Source text:** para. 3.2.1.4

SR_026 – Drainage system	Parent requirements	Child requirements
The coastal protection system must contain a drainage system.	SR_002	SR_018
Verification Method: Analysis		**Source text:** CRS

SR_030 – Storm tidal level	Parent requirements	Child requirements
The coastal protection system must retain a storm tidal level with 5% frequency.	SR_015	
Verification Method: Analysis		**Source text:** CRS

SR_038 – Stability temporary protection	Parent requirements	Child requirements
The temporary protection system must be stable for at least ten years.	SR_013	SR_042 SR_043 SR_044 SR_045 SR_049 SR_050
Verification Method: Through child requirements		**Source text:** appendix O

Scenario 1

SR_039 – S1 sediment trap	Parent requirements	Child requirements
The temporary protection system of S1 must trap sediment to a height of 0.65 m above MSL within five years.	SR_004	
Verification Method: Analysis		**Source text:** para. 8.2

SR_040 – S1 mangrove rehabilitation	Parent requirements	Child requirements
The mangrove forest of S1 must be rehabilitated for 37 ha at the seaside of the current mangrove forest.	SR_016	
Verification Method: Analysis		**Source text:** para. 8.2

SR_041 – S1 wave height	Parent requirements	Child requirements
The fences system of S1 must retain a design wave height of 0.70 m.	SR_006	
Verification Method: Analysis		**Source text:** para. 8.3.2

SR_042 – S1 fence height	Parent requirements	Child requirements
The fences system of S1 must have a height of at least HAT.	SR_038	
Verification Method: Analysis		**Source text:** Appendix O

SR_043 – S1 fence top displacement	Parent requirements	Child requirements
The fence system of S1 must have a maximum displacement at the top of 10% of the length of the pole.	SR_038	
Verification Method: Analysis		**Source text:** Appendix O

SR_044 – S1 fence porosity	Parent requirements	Child requirements
The fences system of S1 must have a porosity of 0.35.	SR_038	
Verification Method: Analysis		**Source text:** para. 8.3

Scenario 2

SR_046 – S2 sediment trap	Parent requirements	Child requirements
The temporary protection system of S2 must trap sediment to a height of 0.65 m above MSL within five years	SR_004	
Verification Method: Analysis		**Source text:** para. 9.2

SR_047 – S2 mangrove rehabilitation	Parent requirements	Child requirements
The mangrove forest of S2 must be rehabilitated for 170 ha at the seaside of the current mangrove forest.	SR_016	
Verification Method: Analysis		**Source text:** para. 9.2

SR_048 – S2 wave height	Parent requirements	Child requirements
The temporary protection system of S2 must retain a design wave height of 0.82 m	SR_006	
Verification Method: Analysis		**Source text:** para. 9.3.2

SR_049 – S2 fence height	Parent requirements	Child requirements
The fences system of S2 must have a height of at least HAT.	SR_038	
Verification Method: Analysis		**Source text:** para. 9.3

K.2.3 Aspect requirements

Aspect requirements describe specific characteristics, which are not actively involved in the primary function of the system. These requirements can be divided in the RAMS characteristics: Reliability, Availability, Maintainability, and Safety. Besides RAMS, futureproof, sustainability, and design requirements are also aspect requirements.

Both scenarios

SR_008 – Sea level rise	Parent requirements	Child requirements
The coastal protection system must be futureproof for a sea level rise of 0.33 m till 2050.	SR_001	
Verification Method: Simulation		**Source text:** (N.D. Thao, H. Takagi, & M. Esteban, 2013)

SR_025 – Future proof	Parent requirements	Child requirements
The coastal protection system must be upgradeable for worse conditions in the future.	SR_001	
Verification Method: Simulation		**Source text:** CRS

Scenario 1

SR_045 – S1 Fence availability	Parent requirements	Child requirements
The fences system of S1 must be available for at least ten years.	SR_038	
Verification Method: Inspection		**Source text:** para. 8.3

Scenario 2

SR_050 – S2 Chenier availability	Parent requirements	Child requirements
The chenier must be available for at least five years after planting the new mangroves.	SR_038	
Verification Method: Inspection		**Source text:** para. 9.3

K.2.4 Interface requirements

The interface requirements are based on the interfaces determined in the tube model in paragraph 3.3.4.1. It is important to specify these requirements, considering that a lot of mistakes have been made in other flood defence projects. The interfaces for this system are described in table K3

Table K3: Explanation of interfaces

Object 1	Object 2	Explanation
System of interest	Tourism	One of the policies is to get more tourism in the Mekong Delta. Another element of this interface is the Nhà Mát resort and the pier.
System of interest	Road transport	Here the interface is the road that is situated on the dyke within our scope. It is also important that our system is accessible.
System of interest	Mangroves	Mangroves are playing a big role in our system of interest, but there are also mangroves just outside of our geographical scope.
System of interest	Ecology & Nature	In a mangrove forest, ecology is very important to take into account.
System of interest	Aquaculture	The system of interest includes aquaculture like integrated shrimp ponds.
System of interest	Ship traffic	Due to that the system of interest is partly in the ocean, ship traffic have to be taken into account as an interface.
System of interest	Energy & Water supply	This interface involves the electricity cables and water pipes in the area.

Both scenarios

SR_003 – Preservation fauna	Parent requirements	Child requirements
The coastal protection system must preserve the local fauna.	SR_002	
Verification Method: Inspection		**Source text:** para. 1.1

SR_011 – Transportation on dyke	Parent requirements	Child requirements
The coastal protection system must integrate with transportation service, which complies with standards and guidelines of the transport sector.	SR_002	SR_033
Verification Method: Through child requirements		**Source text:** CRS
SR_032 – Water transport	**Parent requirements**	**Child requirements**
The coastal protection must facilitate ship traffic from sea to the canals.	SR_002	
Verification Method: Analysis		**Source text:** CRS

SR_033 – Road transport maximum	Parent requirements	Child requirements
The weight of transport over the dyke must have a maximum of 8 t.	SR_011	
Verification Method: Analogy		**Source text:** CRS

SR_034 – Surface aquaculture	Parent requirements	Child requirements
The coastal protection system must provide at least 2,143 ha surface for aquaculture in front of the dyke.	SR_002	
Verification Method: Inspection		**Source text:** CRS

SR_037 – Shrimp / mangrove ratio	Parent requirements	Child requirements
The shrimp ponds must meet the 60/40% ratio.	SR_002	
Verification Method: Inspection		**Source text:** para. 3.1.3.1

Appendix L: Alternatives

In this appendix the different alternatives are described. These alternatives are determined based on literature research and a brainstorm session. All alternatives are described in the format as described in table L1

Table L1: Alternative description format

Description	A short description of the system.
Purpose	Purpose and method of the system.
Advantages	The main advantages are described.
Disadvantages	The main disadvantages are described.
Maintenance	The maintenance is described as far as known. If unknown an estimation is given.
Total cost estimate	The costs are estimated and categorised in relatively cheap, moderate, expensive and very expensive.
Experience	Previous project are described and there is discussed whether it was successful or not.
Reference	Links to reference projects.

L.1 Detached breakwaters

Rubble-mound breakwater

Description	Emerged or submerged breakwaters built with a gravel or sandy kern and a rock armour layer
Purpose	Structural voids in the armour dissipate wave energy Waves break because of the limited water depth above the breakwater (stormy conditions) Creating a more tranquil environment behind the breakwater to induce accretion
Advantages	• Very effective in dissipating waves • Very effective in dissipating high waves (storm conditions)
Disadvantages	• Foundation needed in muddy coasts • High construction costs • Expensive construction material • Large transport distance and heavy transport • Permanent • Foreign element in coastal zone • Extreme measure for small problem
Maintenance	Low maintenance (inspection after large storms)
Total cost estimate	Expensive
Experience	Very effective for accretion, applied worldwide. For example with the breakwater at Sea Palling on the Norfolk Coast where the detached rubble mound breakwaters result in accretion. In the field of mangrove restoration there is little experience with rubble mound breakwaters because the heavy structure usually cannot be founded on the soft muddy soil. One project where a rubble mound detached breakwater is used with the intention to restore mangroves is Sungai Haji Dorani in Peninsular Malaysia. To prevent this structure to sink in the mud it was founded on a bamboo matrass. This structure is built in 2008 when there were little mangroves left. The study of Hashim et al (2010) found that the DCR breakwater was not effective in protecting planted mangroves, with an almost 100% mortality rate for planted seedlings. This mortality was ascribed to active sedimentation, resource use (fisherman disturbance of site), and barnacle infestation.
Reference	(Thomalia & Vincent, 2001) (Hachim, Kamali, Hashim, & Ismail, 2010)

Figure L1: Breakwater at Sea Palling, Norfolk UK .(J. Webb, 2015)

Prefabricated emerged breakwater

Description	Emerged breakwaters with prefabricated revetment like Xblocks, Tetrapod, Accropode, Akmon, Dolos, Kolos etc.
Purpose	Structural voids in the armour dissipate wave energy Creating a more tranquil environment behind the breakwater to induce accretion
Advantages	• Very effective in dissipating waves
Disadvantages	• Expensive material • Hard to execute but sound execution essential • Foundation needed in muddy coasts • High construction costs • Nearby construction site preferred • Permanent • Foreign element in coastal zone • Extreme measure for small problem
Maintenance	Negligible (inspection after large storms)
Total cost estimate	Very expensive
Experience	Big prefab concrete blocks as used as a breakwater revetment all over the world, for example in Cadzand, The Netherlands and Fregate Island, Seychelles. Although breakwaters with this kind of revetment are very effective in breaking waves, they usually are applied to create a sheltered area for harbours and other crowded high-value areas.
Reference	(Delta Marine Consultants, sd) (CLI, 2016)

Figure L2: Breakwater at Fujairah (A.d. Graauw, n.d.)

Concrete breakwater

Description	Hard permeable emerged breakwater
Purpose	Wave breaking Creating a more tranquil environment behind the seawall to induce accretion
Advantages	• Very effective in dissipating wave energy • Can withstand severe weather conditions and storms
Disadvantages	• Expensive high quality materials needed • Hard to execute but sound execution essential • High construction costs • Permanent • Foreign element in coastal zone • Wave reflection • Extreme measure for small problem
Maintenance	Negligible
Total cost estimate	Expensive
Experience	Proven to be very effective at for example Tran Van Thoi and U Minh District located at the West Coast of the Mekong Delta. Important difference with the East Coast, and therefore also the Bạc Liêu shoreline, is that at the West Coast the wave conditions are more severe and the slope is much steeper. Due to these characteristics much heavier constructions are needed. At the West Coast these heavy concrete breakwaters seems to be successful in reclaiming land and protecting mangrove areas.
Reference	(Wölcke, Albers, Roth, Vorlaufer, & Korte, 2016)


Figure L3: Concrete breakwater as build along the West Mekong Delta shoreline(J. Wölcke et al., 2016)

Geotube

Description	A large bag of geotextile filled with sand or other locally available material (preferably with bamboo mat foundation to minimize settlements)
Purpose	Emerged breakwater, forming a local wave barrier or creating local shallowness to induce wave breaking
Advantages	• Easy to install • Can be filled with locally available material
Disadvantages	• Foundation needed when bearing capacity is not sufficient • Vulnerable to vandalism • Wide structure needed to gain enough height • Foreign element in coastal zone • Not biodegradable
Maintenance	Only when failure occurs
Total cost estimate	Moderate
Experience	In Nhà Mát (Vietnam) a geotube of 1 000 m was constructed as mangrove protection. (Figure L4). This project was not successful and the geotube has been replaced by bamboo U-fences. Other geotube projects did show good results with geotube protections for mangroves. In Sungai Haji Dorani (Malaysia) the geotubes resulted in a stabilization of the shoreline and in rehabilitated mangrove forest. In Langkawi, Malaysia, geotubes were placed to protect young mangroves, on a foundation of bamboo and with a scour apron. According to Russel et al, a study concluded that geotubes were not effective in mangrove reforestation and coastal protection.
Reference	(ISME, 2012) (TenCate Geosynthetics Asia) (Lee, Hashim, Motamedi, & Song, 2014) (Russell, Michaels, 2012)

Figure L4: Geotube at Nhà Mát (Unknown. (n.d.). [Photograph]. Retrieved from http://www.lienphat.com.vn/en/Projects/project-list/)

Reef balls

Description	Submerged breakwater in the form of an artificial reef made of reefballs shown in figure L5 & L6
Purpose	Dissipate wave energy by creating a shallow and rough area
Advantages	• Environmentally friendly • No maintenance • Can be cast in all sizes • Can be made of biodegradable material • Easy construction • Protects small wildlife
Disadvantages	• Expensive (licence needed) • Anchorage needed • Foundation might be needed • Little experience in muddy intertidal coasts • Permanent • Not destined for mild slopes • Not destined for muddy coasts • Small scale mangrove restoration
Maintenance	No maintenance needed
Total cost estimate	Depends on the quantity. Expensive
Experience	Reef balls are designed to last at least 500 years, made of a concrete mixture. They can be cast in different sizes and shapes. They have proved to be stable in deeper water, even during storms. They can be placed by boats of any size. Mostly used at locations where there once was a natural reef that disappeared as a replacement. Over 500.000 reef balls are placed at 3400 different projects worldwide.
Reference	http://www.reefbeach.com/ http://www.artificialreefs.org/ScientificReports/ReefBallProjectPlanning.htm http://clean.ns.ca/programs/water/reef-balls/ http://escaribbean.com/cayman-islands-mangrove-restoration http://www.mangrovesolutions.com/Projectsummary.php http://www.reefball.com/reefballcoalition/mangroves.htm http://www.reefball.org/pricing.htm

Figure L5: L: Reef balls to create oyster bars for shoreline stabilization (Unknown. (n.d.). [Photograph]. Retrieved from http://www.reefbeach.com)

Figure L6: Oyster reef breakwater (FCIS staff. (n.d.). [Photograph]. Retrieved from http://fl.audubon.org/news/oyster-reef-breakwater-lengthened-protect-major-tampa-bay-nesting-rookery)

Permeable fences

Description	Permeable structures made of local material like bamboo (see figure L6 & L7)
Purpose	Emerged nearshore breakwater forming a permeable obstacle for waves and currents
Advantages	• Environmentally friendly • No foundation needed • Biodegradable • Low material costs • Low construction costs • Renewable material • Easy maintenance • Ecologically attractive, building with nature
Disadvantages	• Needs careful monitoring and maintenance • Sensitive to rotting and shellfish • Limited strength and durability
Maintenance	Frequent maintenance: • Inspection connections • Substitution/addition of brushwood • Substitution/addition of poles
Total cost estimate	Relatively cheap
Experience	Along the Mekong Delta shoreline already a lot of experience is collected in the last years with permeable fences. GIZ and WIP have had successes with their T- or U-shaped bamboo fences, which are for example placed at the coast of Soc Trang and Ca Mau in Vietnam. First, the fences are used to trap sediment and to create a mudflat. When enough sediment is gathered, the mangrove trees are planted and the fences protect them against wave attack. When the mangroves are matured, the fences will eventually rot away or disappear under the newly reclaimed land. The fences have proved to be successful when the erosion problems and wave attack are not too severe. However, due to the used materials, their strength is limited and already quite some fences were destroyed by heavy weather.
Reference	(Schlegel, 2014) (Russell, Michaels, 2012)

Figure L7: Left: Bamboo fences at Nhà Mát - Right: Melaleuca fences (M. Russell & K. Michaels, 2012)

Geohooks

Description	Packages of interlocking ground consolidator hooks. Comparable with the roots of mangroves.
Purpose	Capture sediment, prevent erosion, reduce waves and currents
Advantages	• Natural materials - Environmentally friendly • No foundation needed (normally) • Temporary structure • Easy construction • Can be made of slowly biodegradable material • Protects small wildlife
Disadvantages	• Temporary structure - no longer than 5 years or even less • Vulnerable to strong wave attack • Sensitive to rotting, fungi and oysters • May not be applicable in very soft mud • Little experience
Maintenance	Periodic checks
Total cost estimate	Unknown, Intermediate
Experience	Ground Consolidation Hooks are a relatively new product with little experience. Several physical modelling experiments and pilot projects have carried out such as the Artificial reef in the Marker Meer (The Netherlands) and a Gas pipe Protection in the Wadden Sea (The Netherlands) . The GC-Hooks seem to work but the results are not unambiguous.
Reference	http://www.geohooks.nl/ http://www.anomeprojects.com/News%2020150615,%20Order%20from%20Gasunie%20for%20engineering.php

Figure L8: Geohooks (Unknown. (n.d.). [Photograph]. Retrieved from http://www.geohooks.nl)

Floating breakwater

Description	Floating structure anchored to the ground. There are four categories of floating breakwaters: Box, pontoon, mat and tethered float.
Purpose	Dissipate wave energy
Advantages	• Applicable on soft coastal bottoms • Minimum interference with water circulation and fish migration • Can be reused / rearranged easily • Minimum visual impact
Disadvantages	• Only effective in mild wave conditions • Only effective in conditions with limited wavelengths. • Only effective when the natural period of oscillation is much longer compared to the wave period • Uncertain performance, limited experience
Maintenance	Periodic inspection
Total cost estimate	Unknown, depends what kind. Intermediate
Experience	Many floating breakwaters have been constructed all over the world. Most of these floating breakwaters are meant to shelter harbours and are constructed in areas with mild wave conditions. In Port of Richards Bay a floating breakwater system is used to prevent erosion of a mangrove forest. This however is in very sheltered area which is not comparable with the Bạc Liêu project area. In literature is found that floating breakwaters can be used to prevent coastal erosion.
Reference	http://www.fdn-engineering.nl/floating-breakwater-in-monaco (Tholet, 2012) (Drieman, 2011)

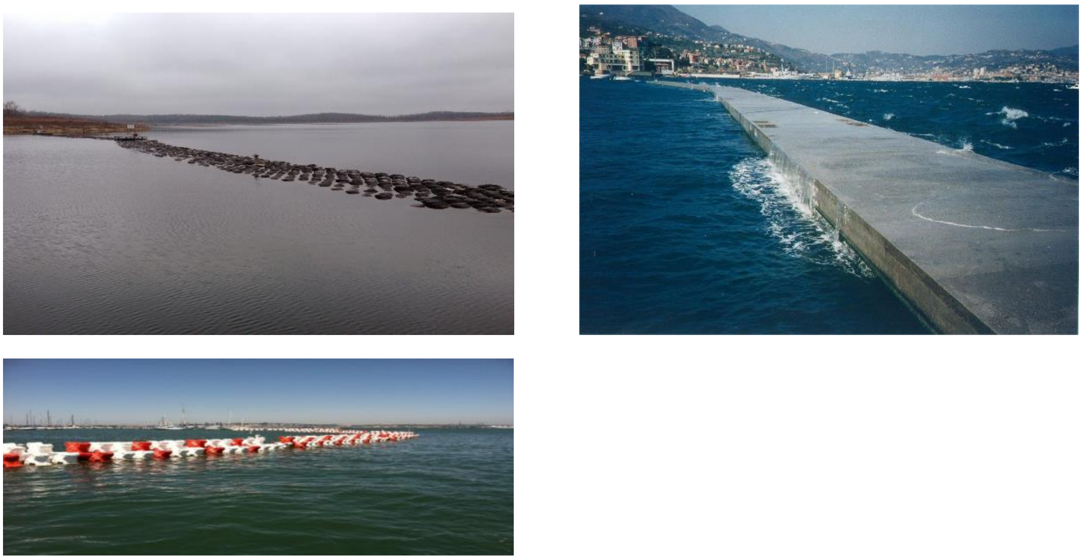


Figure L9: Different floating breakwaters (Unknown. (n.d.). [Photograph]. Retrieved from http://www.whisprwave.com/photos/wave-attenuators/, http://www.coastalwiki.org/wiki/File:FBimage006.JPG, http://pontiaccove.blogspot.com/2015/01/the-breakwater.html)

Gabions

Description	Stones held together in a basket or cage, allowing the material to have a vertical slope. It is the same principle as riprap, but used with smaller stones held together with wire mesh. Can be placed as a mattress on a slope or as blocks.
Purpose	Dissipate wave energy, block currents, trap sediment.
Advantages	• Can be used with all kinds of rocky material • Easy to construct
Disadvantages	• Needs foundation when placed on soft soil • Foreign element in coastal zone • Expensive material costs (stones, good quality steel) • Large transport distance and heavy transport, expensive • Vertical structure can cause more erosion • When there is strong wave attack the wire mesh can't hold the moving stones
Maintenance	yes
Total cost estimate	Intermediate
Experience	In Vam Kenh Moi (Vietnam) gabions stopped the erosion and degradation of the mangrove forest. Gabions were here a good solution to stop the wave attack and therefore the erosion. However, the gabions were placed very close to the edge of the remaining mangrove forest and no additional new mangroves were reclaimed. Furthermore, gabions are only recommended at fairly protected locations (Bron 82). In Vietnam gabions are often used as revetment, but many of these gabions show damage and endangered stability.
Reference	(Albers, Dinh, Schmitt, 2013) http://www.snh.org.uk/publications/on-line/heritagemanagement/erosion/appendix_1.8.shtml http://www.gcbarges.com.au/gabion-baskets http://accord.org.ph/node/514


Figure L10: Gabions (Bá Lục. (2013, September 28). [Photograph]. Retrieved from Google Earth)

L.2 Groynes

Rubble-mound groynes

Description	Stone cross-shore elements that (partly) interrupt the longshore current
Purpose	Increase local sediment settlement, decrease local current velocities
Advantages	• Very effective in trapping sediment • Much experience
Disadvantages	• Causes downdrift erosion • Heavy foundation needed in muddy coasts. • High construction costs • Expensive construction material • Large transport distance and heavy transport • Permanent • Foreign element in coastal zone
Maintenance	Low maintenance (inspection after large storms)
Total cost estimate	Expensive
Experience	In the Can Gio District (Vietnam) rubble-mound groynes were built to retain and extend the beach. Google earth pictures shows this measure has been effective. Overall experiences with rubble-mound groynes show that they are very effective in inducing local accretion but they often worsen the erosion problems further downstream quite severe.
Reference	https://www.google.com/maps/place/C%E1%BA%A7n+Gi%E1%BB%9D,+H%E1%BB%93+Ch%C3%AD+Minh,+Vietnam/@10.3989926,106.9569973,2426m/data=!3m1!1e3!4m5!3m4!1s0x31753f89f9cd22e5:0x9b3c0cf29b5dcb1a!8m2!3d10.5083266!4d106.8635004!6m1!1e1

Figure L11: Rubble-mound breakwaters L: Stacey, A. (2011) [Photograph]. Retrieved from http://www.stacey.peak-media.co.uk/Highcliffe/800-10210015.jpg R: Unknown. (n.d.) [Photograph]. Retrieved from http://wikivisually.com/wiki/File:Sea_Bright_Beach_Jetty.jpg

Permeable groynes

Description	Permeable groyne made of local material like bamboo (see figure …)
Purpose	Main function is to lower local current velocities and create good conditions for the sediment to settle. When placed right, leaving enough sediment in the longshore current to avoid downdrift erosion
Advantages	• Environmentally friendly • No foundation needed • Biodegradable • Low material costs • Low construction costs • Renewable material • Easy maintenance • Ecologically attractive, building with nature
Disadvantages	• Needs careful monitoring and maintenance • Sensitive to rotting and shellfish • Effects on overall sediment transport still quite uncertain • Limited strength and durability
Maintenance	Frequent maintenance: • Inspection connections • Substitution/addition of brushwood • Substitution/addition of poles
Total cost estimate	Cheap
Experience	The last few years a lot of experience was collected with permeable fences. GIZ and WIP have had success with T- or U-shaped bamboo groynes. First, the fences are used to trap sediment, and create a mudflat. When enough sediment is gathered, the mangrove trees are planted, and the fences protect them against wave attack. When the mangroves are matured, the fences will eventually disappear by themselves, since they are made from natural materials. The fences have proved to be successful when the erosion and wave attack are not too severe. However, due to the natural materials, their strength is limited, and some fences were destroyed by heavy weather. Melaleuca fences reduce wave energy up to 65% (Russel et al, 2012), and have been successful in Kien Giang in restoring the mangrove forest. They also retained up to 20 cm of sediment a year.
Reference	(Russell, Michaels, 2012) (Albers, Dinh, Schmitt, 2013)

Figure L12: T-fences (Albers, Dinh, Schmitt, 2013)

Figure L13: Permeable fence with brushwood (Dinh, S. (2016))

L.3 Soft measures (or Elements that enlarge the sediment input)

Longshore sandbar (Chenier)

Description	A bulk of sand placed offshore, causes the waves to break at the low water depth created by the sandbar. Besides this, a chenier forms a barrier for sediment that normally would get lost due to cross-shore currents.
Purpose	Breaking/dissipating waves, Less sediment loss
Advantages	• Minimum environmental impact • No visual impact • Increase available sediment • Minimum interference with water circulation and fish migration • In front of the Bạc Liêu shoreline already some natural migrating sandbars are present every once in a while
Disadvantages	• It is hard for dredging ships to reach the shore due to the shallow water • Desirable sediment might not be locally available • Modelling necessary
Maintenance	Monitoring and additional nourishment when required
Total cost estimate	Expensive
Experience	With a mangrove rehabilitation project on Java (Indonesia) cheniers were restored to break waves. Monitoring has to show whether this was effective. In Suriname large mud banks migrate along the mangrove forest coasts. This migrating mud banks result in accretion and erosion depending on whether a mud bank passes by or not.
Reference	(Tonneijck, Winterwerp, Weesenbeeck, Bosma, Debrot, Noor, Wilms, 2015) (Antony, 2015)

Figure L14: Offshore sandbar (Unknown. (s.d.). [Photograph]. Retrieved from http://www.plumislanderosion.com/2013-03-05-13-05-49/the-problem-in-a-nutshell.html)

Direct nourishment

Description	Elevate the foreshore by dumping sediment straight on it
Purpose	Supply sediment
Advantages	• Fast results • No visual impact • Mangroves can be planted right after
Disadvantages	• Mud is hard to dredge and dump • It is hard for dredging ships to reach the shore due to the shallow water • Expensive • Does not stop the erosion
Maintenance	Every (few) year(s)
Total cost estimate	Expensive
Experience	Using sand, there is a lot of good experience with direct nourishment and creating new land like Maasvlakte 2 (The Netherlands) and Palm Jumeirah (Dubai) projects. Creating new mudflats is a whole other story. Fine sediment needs much more time to settle and therefore it is important to create a calm environment around the nourishment area. In the Netherland there is a project going on in which artificial islands are made of slib and fine sediment (Marker Wadden). The experience with creating a new muddy foreshore by direct nourishment is still very limited.
Reference	http://www.coastalwiki.org/wiki/Shore_nourishment https://www.maasvlakte2.com/ https://boskalis.com/csr/cases/marker-wadden.html

Figure L15: Direct nourishment (Cecconi, G. (2009) Beneficial Reuse and Morphological Restoration, SedNet Conference 2009, Hamburg, Germany)

Mud engine

Description	A large amount of sediment is placed at a single location, which will be transported by the longshore current and supplies sediment to the coastal zone in a natural way.
Purpose	Supply sediment
Advantages	● Constant long term sediment supply ● Prestigeproject ● Ecologically attractive, building with nature ● Environmentally friendly
Disadvantages	● Mud is hard to dredge and dump ● It is hard for dredging ships to reach the shore due to the shallow water ● High construction costs ● Low experience
Maintenance	No maintenance Monitoring required
Total cost estimate	Expensive
Experience	One of the first and biggest building with nature project is the Sand engine in Delfland (The Netherlands)(Figure 33). This project runs for five years now. However the experiences with the sand engine in Delfland are quite good, there is still a lot research to do and there are a lot of uncertainties about the performances. Besides the sand engine in Delfland there is a sand engine pilot project in the IJsselmeer. Both these 'engines' provide the coast of extra sand. Nevertheless, at the project location in Bạc Liêu a much more fine sediment is prefered. This year a pilot project is started in the Netherlands, a Mud Motor near Harlingen. A great hump of fine sediment is dumped at one location and the idea of this project is that the fine sediment will be transported, distributed and form new mudflats by natural currents. Unfortunately there are no results about that pilot project yet.
Reference	http://www.dezandmotor.nl/en/ https://www.ecoshape.org/en/projects/sand-engines-in-the-ijsselmeer/ https://www.ecoshape.org/en/projects/mud-motor/

Figure L16: De Zandmotor (Unknown. (s.d.). [Photograph]. Retrieved from http://www.dezandmotor.nl/nl/actueel/nieuws/zandmotor-succesvolle-aanjager-van-innovatief-kustonderhoud/)

Appendix M: Multi Criteria Analysis

In the Multi Criteria Analysis (MCA) for each scenario different alternatives are compared. The alternatives scores points at different criteria. The total score which an alternative achieves at a criterion is the result of the weightage, of that specific criterion, multiplied with the score. The weightage of the criteria is distributed from 1 till 10 and the scores are classified in five categories (--, -, 0, +, ++) as is shown in table M1. Figure M1 gives an example of the MCA.
`

Rating	Points
++	2
+	1
0	0
-	-1
--	-2

Criteria	Weight (1 to 10)	Alternative A	Alternative B	Score A	Score B
Criterium XX	7	-1	2	-7	14

Figure M1: Example of MCA

M.1 Criteria

The alternatives are judged by different criteria in the MCA. Not all the criteria are equally weighted. In table M1 the different criteria and an explanation about their rating is given.

Table M1: Overview of criteria in the MCA

Building with nature	6	Building with nature is an important objective in nowadays projects. The goal of this project is rehabilitation of the mangrove forests and at the end, protect the hinterland making use of mangroves. This final goal is already a great example of building with nature. To restore the mangrove forest it is preferable to do this also by the building with nature principles, but this is not a hard requirement. Therefore this criterion is rated with a 6.
Carbon footprint	3	The final goal of the project is to rehabilitate a healthy mangrove forest. This forest contributes very positive to the carbon footprint. At the end all the different alternatives aim this mangrove forest. The final purpose of a healthy mangrove forest is rated higher than the way to achieve this forest. Nevertheless the carbon footprint is still taken into account and therefore rated with a 3.
Temporary	7	The aim of this project is to rehabilitate the mangrove forest. It is unfavourable that there remain parts of the construction in the forest. It is desirable for the structure to be easily recycled or naturally degraded when the function (let the mangroves grow back) is fulfilled. Therefore this criterion is rated with a 7.
No down drift erosion	7	To rehabilitate the mangroves it is important to hold extra sediment at that location. A disadvantage of trapping sediment at one location is that there arises a shortage of sediment at another location. One of the requirements of our system is that our solution does not causes, or minimise, erosion but hard to determine if it occurs as a consequence of the structure.
Robustness	4	In Vietnam some structures are pretty vulnerable to vandalism. Sometimes even parts of the construction got stolen and the structure is not able to

		fulfil its function anymore. It is therefore important that the structure is a robust one. But, on the other side, if the structure gets damaged or breaks down, no one will get harmed. There will be only material damage which could be fixed easily. At the end, robustness is therefore not a very important factor in our MCA and is rated with a 4.
Constructability	9	Constructability is a very important criterion. The area where the design will be constructed is hard to reach and poor to work in, because of the tidal range and muddy soil. If the construction is very hard and difficult to make, the costs will increase enormously. Furthermore it is also important to take a look at the equipment that is needed to build the construction. Constructability is one of the most important criteria and therefore rated with a 9 in this MCA.
Construction time	2	Construction time is not of big importance in this design. There is no hindrance for any kind of traffic and there are no other activities in the building are like recreation, fisheries or business. Because of the low hindrance for anyone, the construction time is rated with a weightage of 2.
Maintainability	4	Maintenance and maintainability can be a high cost. Less maintenance has an advantage, but on the other hand the labour costs are very low in Vietnam which makes the amount of labour maintenance less important. Maintenance that is easy but has to be done more regularly is therefore preferable over difficult maintenance that appears less often. Maintainability is rated with a 4.
Settlement sensitivity	6	There is a muddy soil at the project location and no information about the soil characteristics is available. Building in mud is very uncertain. Sometimes extra constructions, like a foundation, are needed. Due to the uncertainties and possible extra costs this criteria is given a medium score, a 6.
Costs	9	In Vietnam, budget is low, and costs therefore have a high priority in the MCA. The total costs of a project are of great importance. These costs consists material, equipment, transport and labour costs. The costs are rated with a 9 in this MCA.
Aesthetics	2	The final goal of this project in to restore the nature. It is undesirable to 'build' this nature back with a not so well looking construction in front of the mangroves. But at the end it is not that important in this project and therefore it is given a low weightage in this MCA, a 2.
Reliability	6	Reliability is important in the design. One does not want to waste money with an experimental project which does not work, but on the other hand there should also be room for innovation. And, as also mentioned at the maintenance criterion, the structure will be used for reforestation and not for safety. A failure won't lead to disastrous consequences. Therefore a 6 was given.
Efficiency	4	Efficiency means the time that it takes to grow the mangroves back. For some alternatives it takes a lot more time than other alternatives. Besides, some alternatives have to be built in phases, which takes many years to achieve the final result. On the other hand, at this moment there is still a reasonable mangrove belt present. Therefore this criterion is rated with a 4.

M.2 Results

In table M2 and M4 the results for the two scenarios is shown.

Table M2: Results MCA scenario 1

Criteria	Weight (1 to 10)	Rubble mount breakwater	Prefabricated emerged wavebreakers	Concrete breakwater	Geotube	Reef balls	Permeable fences	Geohooks	Floating breakwater	Gabions	Rubble-mound groynes	Permeable groynes	Longshore sandbar (Chenier)	Direct nourishment	Mud engine
Environment															
Building with nature	6	-	--	--	-	+	++	++	0	--	-	++	++	-	++
Carbon footprint	3	--	--	--	0	-	++	0	0	0	--	++	+	0	0
Temporary	7	--	--	--	-	0	+	++	++	--	--	+	++	++	++
Side-effects															
No down drift erosion	7	-	-	-	-	+	+	+	++	-	--	0	++	++	++
Robustness	4	++	++	++	-	+	-	+	-	--	++	-	0	0	+
Construction															
Constructability	9	--	--	0	+	+	++	+	+	+	--	++	-	--	--
Construction time	2	--	--	-	+	0	+	++	+	0	--	+	-	-	-
Maintenance	4	++	++	+	++	++	-	0	0	--	++	-	-	-	+
Foundation	6	--	--	0	0	0	++	+	+	--	--	++	++	++	++
Costs	9	--	--	-	0	0	++	+	+	0	--	++	--	--	--
Aesthetics	2	-	--	--	--	-	0	-	-	--	-	0	++	++	++
Reliability	6	++	++	++	0	-	+	-	-	0	++	+	-	++	-
Efficiency	4	0	0	0	+	-	0	-	-	0	+	+	-	++	--
Totaal		-59	-67	-30	-5	19	80	53	38	-56	-62	77	16	16	12

It can be clearly seen that hard and expensive structures scores bad. While cheaper permeable natural fences got high scores. In the design every option above 30 points is taken into consideration for our variants. These are shown in table M3.

Table M3: Top results MCA scenario 1

Permeable fences	80
Permeable groynes	77
Geohooks	53
Floating breakwater	38

The permeable fences and groynes are the same structure, except with different purposes. In the design these will be used combined in a structure like T- or U-fences. This leaves 3 options for the variants. These variants will be further elaborated in chapter 7.

Table M4: Results MCA scenario 2

Criteria	Weight (1 to 10)	Rubble mount breakwater	Prefabricated emerged wavebreakers	Concrete breakwater	Geotube	Reef balls	Permeable fences	Geohooks	Floating breakwater	Gabions	Rubble-mound groynes	Permeable groynes	Longshore sandbar (Chenier)	Direct nourishment	Mud engine
		Alternatives													
Environment															
Building with nature	6	-	--	--	-	+	++	++	0	--	-	++	++	-	++
Carbon footprint	3	--	--	--	0	-	++	0	0	0	--	++	+	+	0
Temporary	7	--	--	--	-	0	+	-	++	--	--	+	++	++	++
Side-effects															
No down drift erosion	7	--	--	--	--	+	+	+	+	--	--	-	++	++	++
Robustness	4	++	++	++	-	+	-	-	-	--	++	-	0	0	+
Construction															
Constructability	9	--	--	0	+	+	-	+	0	-	--	0	+	-	-
Construction time	2	-	-	-	+	+	--	++	+	0	-	--	+	+	+
Maintenance	4	++	++	+	++	++	-	0	0	--	++	-	-	+	+
Foundation	6	--	--	0	0	0	++	+	+	--	--	++	++	++	++
Costs	9	--	--	-	0	0	++	+	+	0	--	++	-	--	--
Aesthetics	2	-	--	--	--	-	0	-	-	--	-	0	++	++	++
Reliability	6	++	++	++	0	-	0	--	--	0	++	+	--	+	--
Efficiency	4	0	0	0	0	--	-	--	--	0	+	-	--	++	--
Totaal		-64	-72	-37	-16	17	37	14	12	-81	-60	38	37	34	19

Scenario 2 consists of a much bigger area where mangroves and mudflats have to be created. It is clearly visible that in this situation the big nourishment solutions become more interesting. It can also be seen that the differences between the alternatives becomes smaller. It is harder to rate variants which are never used before on this scale or on a project like this. Again the options with a score above the 30 points are taken into account. These are shown in table M5.

Table M5: Top results MCA scenario 2

Permeable groynes	38
Permeable fences	37
Longshore sandbar (Chenier)	37
Direct nourishment	40

The permeable fences and groynes will be combined again. The three structures are further elaborated in chapter 7.

Appendix N: Phasing overview scenario 1

In this appendix an overview of the phasing of scenario 1 is given. In figure N1 the phasing of section 1, the south eastern part of the project location, is given.

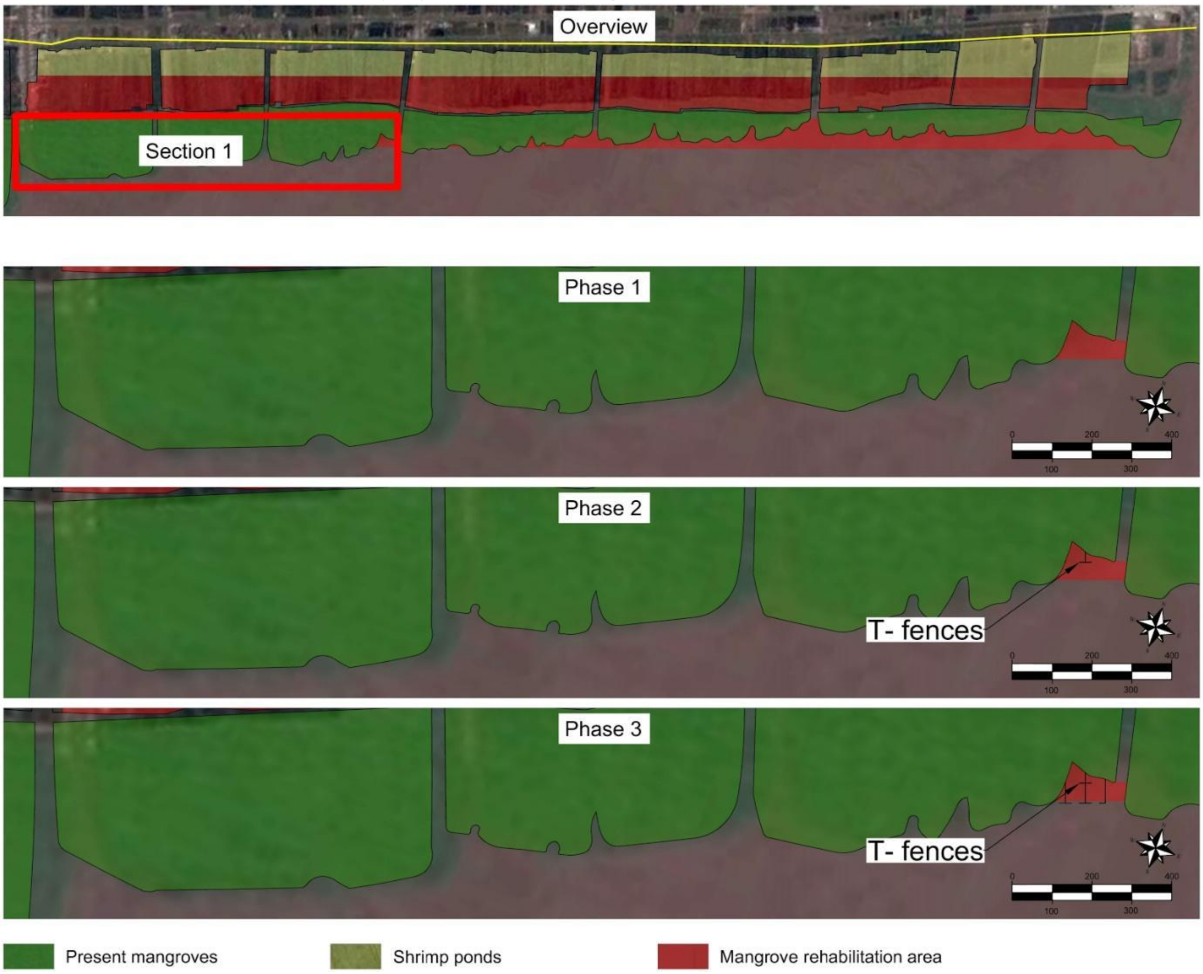


Figure N1: Phasing scenario 1 section 1.

In figure N2 the phasing of section 2 of scenario 1 is given.

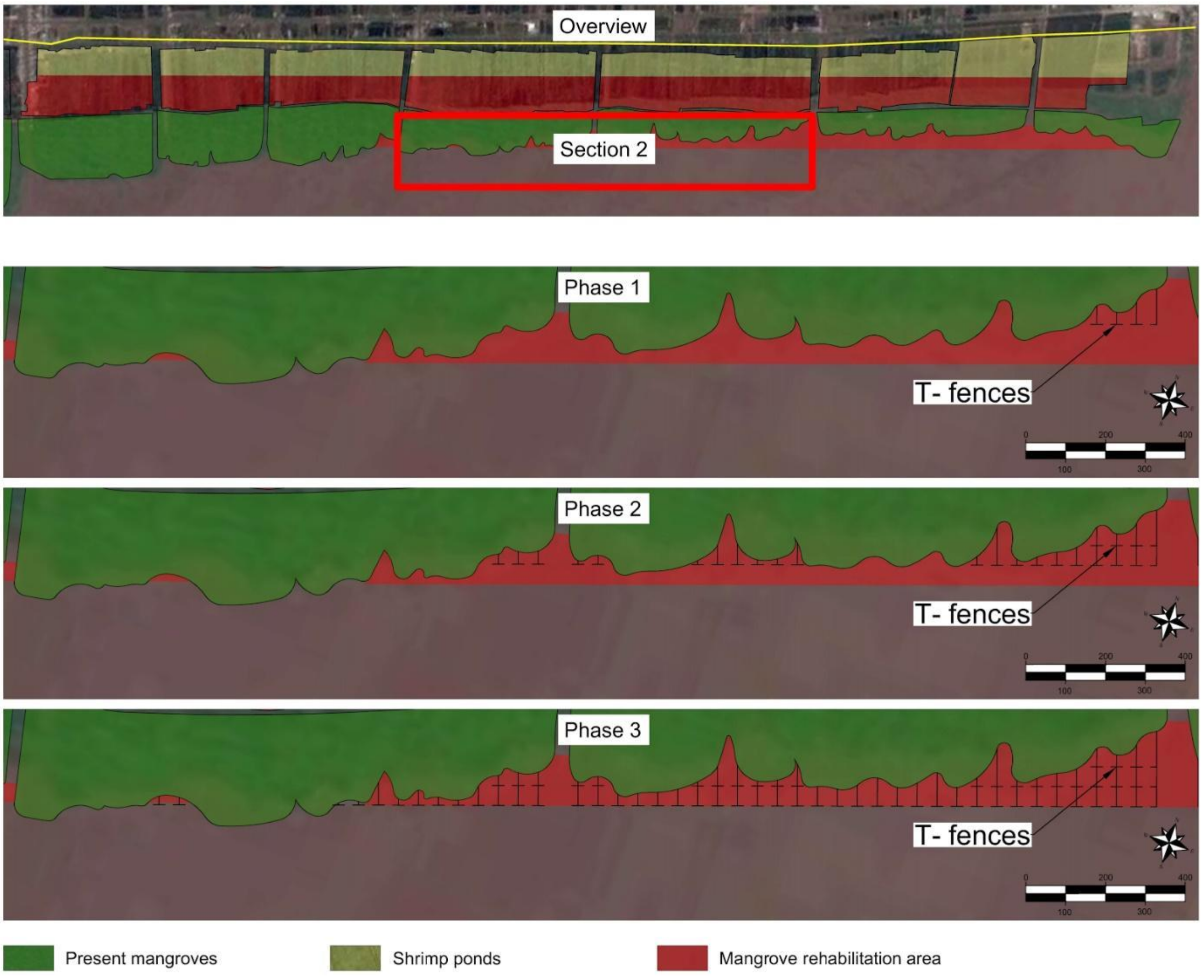


Figure N2: Phasing scenario 1 section 2

In figure N3 the phasing of section 3 in scenario 1 is given

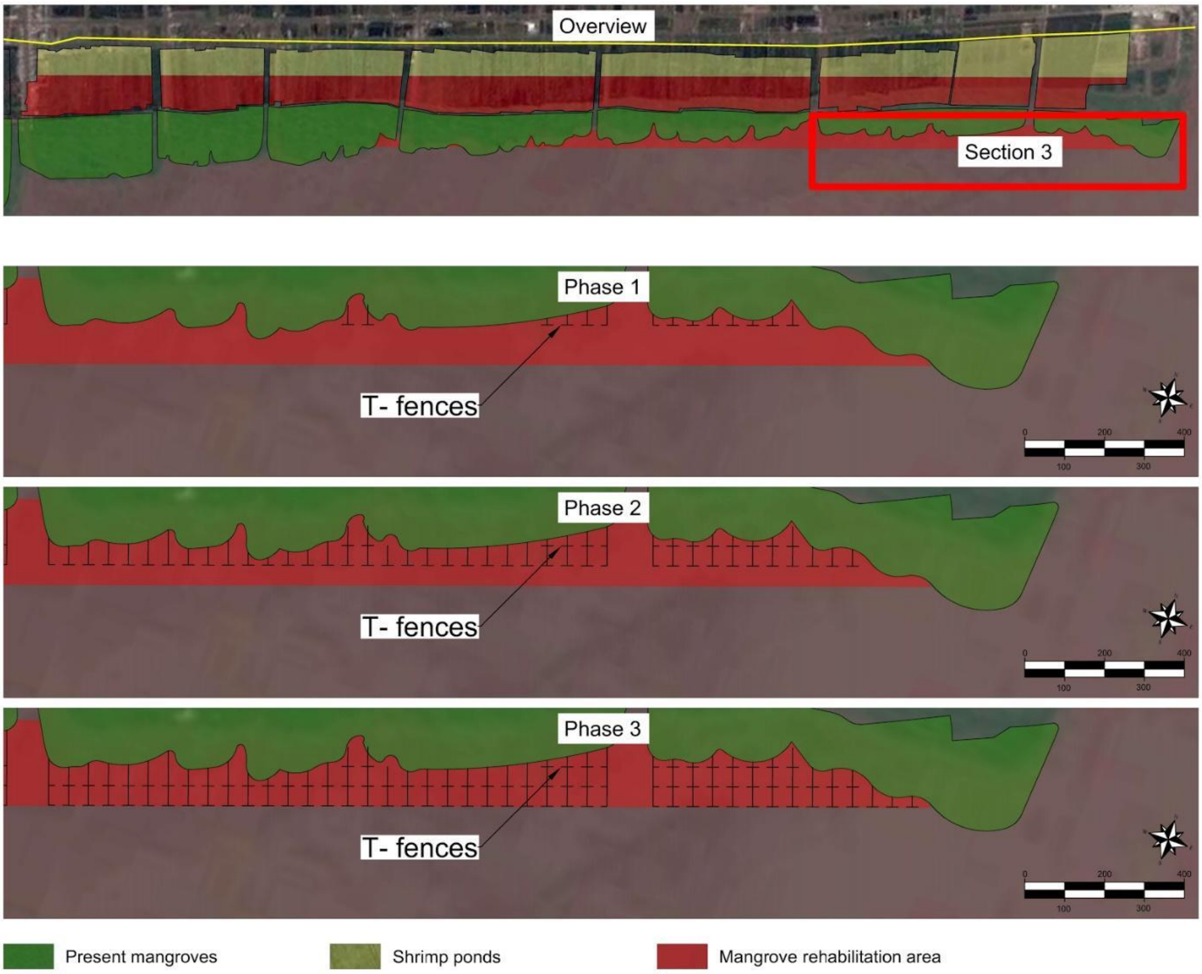


Figure N3: Phasing scenario 1 section 3.

Appendix O: Structure calculations

The fences reduce the speed of flow and sediment, after which the sediment can settle in the lee area between the fences. This can be done by combining groynes and breakwaters into different arrangements. In Vietnam U- or T-shaped fences are widely used. The difference is that between the T-fences there are openings, allowing a free flow between the fences, whereas the U-fences are closed, obstructing the cross-shore flow. Both fences seem to work well in trapping sediment and reducing waves, however, the differences in effectivity are not known.

A permeable fence usually consists of 2 rows of poles, with brushwood in between. In more severe circumstances one or two extra rows can be added for more stability and strength. Because the brushwood is added to damp the wave action, the biggest force will be on the last row of poles. It is advised to connect the rows to each other and/or strengthen the back row of poles by adding more, stronger of reinforced poles for more efficiency. To prevent the brushwood from washing out and as a scour protection, Nypa palm leaves are placed on the bottom and at the top between the rows of poles.

The wave-break (longshore) fences need to endure higher loads like breaking waves and tidal currents, they are built with larger diameter poles than the sediment-trapping (cross-shore) fences, which main task is to reduce the (slow) longshore current. The front row of poles need to be able to withstand the (breaking) waves, and the back row of the poles must be able to withstand the absorbed wave energy from the brushwood. Too much displacement of the poles can result in brushwood washing out, so the maximum displacement at the top is chosen as 10% of the length of the pole above ground level.

For the maximum moment, we consider the pole clamped at bed level. To determine the maximum deflection, we use the Winkler model in combination with the Euler-Bernoulli beam. Wave action on the structure is a dynamic force, and this means fatigue and liquefaction might cause some problems. The bamboo fences have proved to work quite well already in protecting the mangrove plants for the first few years, after which they are not needed anymore because the plants are matured enough to withstand the waves alone. Fatigue is therefore not considered as the main cause of failure. The fences are not build to guarantee safety or to withstand earthquakes or tsunamis. They are built to last around 10 years with frequent maintenance. Therefore, no safety factors are applied and only conservative values are estimated. Findings of a structural model based on so many assumptions cannot be accurate, but it can give a good idea on the forces and strength for a preliminary design.

Material choice

Bamboo

Bamboo is a cheap building material, available in most parts of the tropical countries and therefore also in Vietnam. It is estimated that there are more than 1000 species of bamboo in the world (J. Scurlock, D. Dayton, & B. Hames, 2000). Bamboo is a natural product, and therefore subjected to large differences in strength, flexibility, durability and so on. It depends heavily on the age and environment the bamboo grew in, empirical measurements are used for different diameters and species. It grows relatively fast and is strong, flexible and light. It naturally makes use of a high stiffness/weight ratio because of air-space in the segments. It is, however, sometimes seen as an inferior material because of its vulnerability to fungus and moisture expansion. With the right treatment, these problems are no longer an issue, but it is still seen as a cheap reputation.

The use of bamboo in hydraulic engineering is not very common because of the durability, fungi, insects and shells that weaken the structure. In the scope of this project, we use only the whole poles of the bamboo, not cut or laminated. Also, because the fences are temporary structures, durability of the bamboo might not really be an issue. A found optimum diameter for the use of the fences is 80 mm (T. Albers, 2011), but in designs of GIZ and SIWRR mostly diameters of 100-120 mm are used. We can consider these 3 diameters for the designs. The outer diameter D can easily be measured, but for the strength of the pole, the inner radius and therefore the wall thickness contribute to the strength. The average inner radius d of a bamboo pole can be estimated at $0,75 * D$.

Assumptions made on bamboo

The chosen tensile stress for bamboo is $f_t = 15\ N/mm^2$ (T. Albers, 2011).
The chosen compression stress for bamboo is $f_c = 3.9\ N/mm^2$ (T. Albers, 2011).
Chosen bending strength is $f_b = 7.6\ N/mm^2$ (T. Albers, 2011).
Elasticity modulus for bamboo is chosen as $E = 18\,000\ N/mm^2$ (J.J. Janssen, 2000).
Although it varies with species and diameters (larger diameters have a lower elasticity modulus due to the outer fibers (strongest fibers) compared to smaller diameters)
In the scope of this project, bamboo poles of significant length are used and failure due to bending will be governing against shear → Euler-Bernoulli model.
The average inner radius d of a bamboo pole is $0{,}75 * D$. (mean value of values found in (J.J. Janssen, 2000) and assumed values of (T. Albers, 2011).
Buckling and fatigue are neglected.

Material properties

In table O1 the material properties of bamboo poles with different diameters is given.

Table O1: Material properties bamboo

Diameter D $[mm]$	80	100	120
Diameter d $[mm]$	60	75	90
Area A $[mm^2]$ $\left(= \pi \frac{(D^2-d^2)}{4}\right)$	2200	3436	4948
Moment of inertia I $[mm^4]$ $\left(= \pi \frac{(D^2-d^2)}{64}\right)$	1 374 447	3 355 583	6 958 137
Elasticity modulus E $[N/mm^2]$	18 000	18 000	18 000
EI $[Nmm^2]$	$2.47 * 10^{10}$	$6.4 * 10^{10}$	$1.25 * 10^{11}$
f_t $[N/mm^2]$	3.9	3.9	3.9
f_c $[N/mm^2]$	15	15	15
f_b $[N/mm^2]$	7.6	7.6	7.6
W $[mm^3]$ $\left(= \frac{I}{0.5d}\right)$	34 361	67 112	115 969
M_r $[Nmm]$ $(= W * f_b)$	261 144	510 048	881 364

Failure of the bamboo pole occurs when the limit moment is reached. The recommended bending strength of 7.6 (T. Albers, 2011) is the lowest found in relevant literature. There is a good chance the bamboo poles have a bending resistance more than 3-4 times the calculated value. “The characteristics of the used bamboo exceeded the values assumed in the design of the structure” (T. Albers, 2012). Since the assumptions made above are similar to the ones Albers used, we can assume they are on the conservative side. As the failure of bamboo poles do not endanger people’s lives, safety factors will not be used, but only conservative values of the structural properties of the bamboo poles.

Melaleuca

Melaleuca fences are also used to rehabilitate the mangrove. “The fences reduce wave energy by up to 63%, retain up to 20 cm depth of sediment each year and up to 700 ton per hectare, and protect up to 100% of planted or naturally recruited mangrove seedlings, even in severe erosion sites.” (G.K. Giang, 2012)
The elasticity modulus of Melaleuca is estimated to be $E = 8\,000\ Mpa$.
(I. Wahyudi et al., 2014). But because bamboo is hollow, poles of the same diameter can be of the same flexural stiffness.
Moment of inertia of melaleuca for a 80 mm diameter pole: $I = \frac{\pi}{4} r^4 = \frac{\pi}{4} 40^4 = 2\,010\,619\ mm^4$.
This means the EI of a 80 diameter pole is 2 010 619 $\times 8000 = 1.61 \times 10^{10}$, which is a little bit less than a bamboo pole with the same diameter.

Conclusion on material

Theoretically, melaleuca is more economically favourable, with flexural stiffness ratios quite comparable with bamboo, but a cheaper solution. However, it is more sensitive to rotting according to some sources, and a trials with different fences showed very good results with bamboo, compared to other materials. (G.K. Giang, 2012). Therefore, bamboo is chosen as material for the fences.

Loads

For the two scenarios, different water depths and waves apply, and the extreme conditions are assumed for the fences. Forces are calculated with a few different approaches. For the first few methods, it is assumed the pole is clamped in the soil. The loadings for both scenarios are given in table O2.

Table O2: loading conditions

Scenario	1	2
Wave period $\boldsymbol{T}$ $[\boldsymbol{s}]$	5.5	5.5
Water depth $\boldsymbol{h}$ $[\boldsymbol{m}]$	0.9	1.05
Wavelength $\boldsymbol{L}$ $[\boldsymbol{m}]$ $(=\boldsymbol{T}*\boldsymbol{gd})$	16.3	17.7
Wave height $\boldsymbol{\eta}$ $[\boldsymbol{m}]$	0.7	0.85
Specific weight seawater $\boldsymbol{\rho}$ $[\boldsymbol{kg/m^3}]$	1025	1025
$\boldsymbol{g}$ $[\boldsymbol{m/s^2}]$	9.81	9.81
$\boldsymbol{P}$ $\left(=\frac{s}{e}\right)$ **(estimated)**	0.35	0.35

The forces on the front poles can be calculated with Morison's formula for a fixed body in an oscillating flow. Because in the past the fences have failed due to strong wave attack, and not due to the tidal or longshore flows, these forces are neglected in the verification of the strength of the poles.

We will use the following formula for breaking waves and assume the forces of normal flow to be insignificant (J. Vrijling et al., 2011):

$$F_{max} = F_D = C_D^* K_D H^2 \frac{1}{2} \rho g D$$

With the maximum moment:

$$M_{max} = F_D h\, S_D$$

$C_D S_D S_I K_D K_I$ can be found in the "Shore Protection Manual" (CERC 1984), and depend on wave phase, period, water depth and the velocity of the water particles. $C_D^* = 2.5 * C_D$

For breaking waves in shallow water we can assume some values (J. Vrijling et al., 2011).

$$C_D = 0.7$$

$$C_D^* = 2.5 * 0.7 = 1.75$$

$$K_D = 1.0$$

$$S_D = 1.11$$

Theory states waves break when $\frac{H}{h} \geq 0.78$ (J. Vrijling et al., 2011).

We now assume a breaking wave so $H = 0.78 \times h$.

Scenario 1

$h = d_b = 0.9$ (at the chosen point for the fence)

$\rightarrow H = H_b = 0.9 * 0.78 \approx 0.7$

$$M_{max} = C_D^* K_D H^2 \frac{1}{2} \rho g D h \, S_D = 1.75 * 1.0 * 0.7^2 * \frac{1}{2} * 1025 * 9.81 * 0.1 * 0.9 * 1.11 = 430.7 \, Nm$$
$$= 430700 \, Nmm$$

$$UC = \frac{430\,700}{510\,048} = 0.84$$

A pole diameter of 100 mm will be sufficient for the front row of poles.

Scenario 2

$h = d_b = 1.05$

$\rightarrow H = H_b = 0.82$

$$M_{max} = C_D^* K_D H^2 \frac{1}{2} \rho g D h \, S_D = 1.75 * 1.0 * 0.82^2 * \frac{1}{2} * 1025 * 9.81 * 0.12 * 1.05 * 1.11$$
$$= 827.4 \, Nm = 827\,400 \, Nmm$$

$$UC = \frac{827\,400}{881\,364} = 0.94$$

The maximum moment of a 120 mm diameter bamboo pole is sufficient for the front row of poles. It must be noted that the poles can be stronger as they are connected to each other.

Breaking waves on the pile wall with Minikin (J. Vrijling et al., 2011).

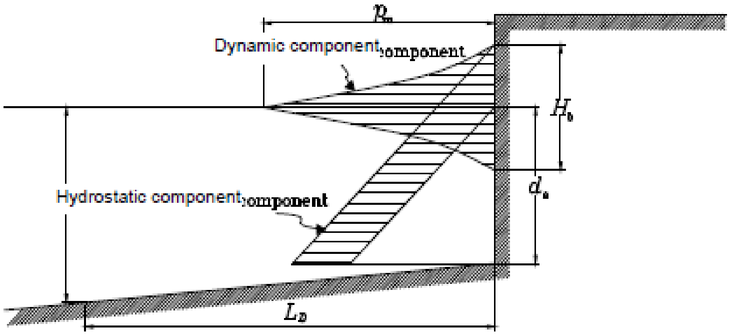


Figure O1: Minikin Broken wave pressure (J. Vrijling et al., 2011)

Minikin maximum wave pressure:

$$p_m = \frac{1}{2} C_{mk} \pi \rho g \frac{H_b}{L_D} \frac{d_s}{D} (D + d_s)$$

Resultant force (at still water level):

$$F = \frac{p_m H_b}{3} + \frac{\rho g H_b}{2} \left(\frac{H_b}{4} + d_s \right)$$

Scenario 1

$C_{mk} = 2, \quad H_b = 0.7m, \quad d_s = h = 0.9, \quad D \approx 1.06 \, m, \quad L_D = 16.3 \, m$

$$p_m = \frac{1}{2} * 2 * \pi * 1025 * 9.81 * \frac{0.7}{16.3} \frac{0.9}{1.06} (1.06 + 0.9) = 2257.6 \, N/m^2$$

$$F = \frac{2257.6 \; * 0.7}{3} + \frac{1025 * 9.81 * 0.7}{2} \left(\frac{0.7}{4} + 0.9 \right) = 526.8 + 3783.3 \, N/m$$

Where the second term is from the increased hydrostatic pressure, which, since the fence is permeable, is present on both sides of the pole, this means only the force 526.8 N/m is taken into account. If a single pole takes up 1/3 of that force, which attacks at 0.9 m (still water) the maximum moment in the pile is $526.8/3 * 900 = 158\,040 \, Nmm$. All poles will be strong enough to take up this force. If we also take the hydrostatic pressure into account without a permeability reduction, we get an additional $3783.3/3 * 0.5 * 1060 = 668\ 383\ Nmm$. A diameter of 120 mm will be sufficient to take up both forces. But is assumed this value will not be present completely.

<u>Scenario 2</u>

$C_{mk} = 2, \quad H_b = 0.82m, \quad d_s = 1.05, \quad D \approx 1.46\ m, \qquad L_D = 17.7\ m$

$$p_m = \frac{1}{2} * 2 * \pi * 1025 * 9.81 * \frac{0.82}{17.7} * \frac{1.05}{1.46}(1.46 + 1.05) = 2642\ N/m^2$$

$$F = \frac{2642\ * 0.82}{3} + \frac{1025 * 9.81 * 0.82}{2}(\frac{0.82}{4} + 1.05) = 723 + 5174\ N/m$$

If a single pole takes up 1/4 of that force, which attacks at 1.05 m(still water) the maximum moment in the pile is $\frac{723}{4} * 1050 = 189\ 788\ Nmm$, all diameter poles will be strong enough.

If we also take the hydrostatic pressure into account without a permeability reduction, we get an additional $\frac{5174}{4} * 0.5 * 1460 = 944\ 255\ Nmm$. A diameter of 120 mm will not be sufficient to take both forces. But is assumed this value will not be present completely.

Another method to calculate the forces on the back row is the modified GODA formula for permeable structures (H. Bergmann & H. Oumeraci, 1999). In figure O1 a schematisation of the wave and water forces on the fence is given.

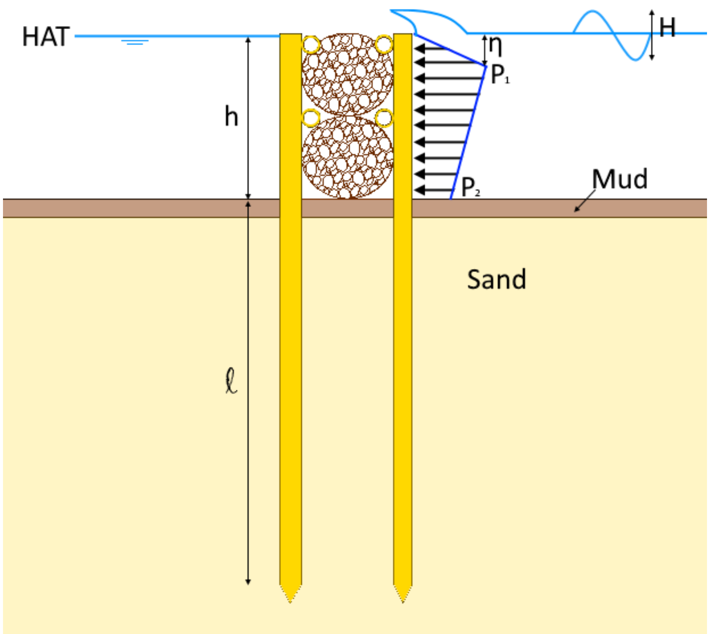


Figure O2: Schematization of the Goda wave pressure on the bamboo poles.

The modified Goda formula yields (H. Bergmann & H. Oumeraci, 1999):

$p_{1,res} = p * g * H^*$

where

$H^* = \alpha_1^* * \Psi_e * \Psi_p * H_i$

And

$$\alpha_1^* = 0.6 + 0.9 * \left(\frac{\left(\frac{a\pi h}{L}\right)}{\sinh\left(\frac{4\pi h}{L}\right)} \right)^2$$

$\Psi_e = \left(1 - 0.5\sqrt{P}\right)$

$\Psi_p = \left(1 - \sqrt{P}\right)^a$

Where

$$a = \sqrt{\frac{1}{6}\frac{h}{Hi}}$$

And

$$p_{2,res} = 0.85 * \frac{1}{\cosh\left(\frac{2\pi h}{L} * \frac{1}{\Psi_p}\right)} * p_{1,res}$$

$$\eta^* = \Psi_e\left[2 - tanh\left(\frac{a\pi h}{L}\right)\right] * H_i$$

With the values, we obtained from literature we can calculate P1 and P2 with the modified Goda formula.

$$a = \sqrt{\frac{1}{6}\frac{h}{Hi}}$$

<u>Scenario 1</u>

$\boldsymbol{T}\ [\boldsymbol{s}]$	Wave period		5.5
$\boldsymbol{L}\ [\boldsymbol{m}]$	Wavelength (shallow water)		16.3
$\boldsymbol{d}\ [\boldsymbol{m}]$	Depth		0.9
$\boldsymbol{H_d}\ [\boldsymbol{m}]$	Design wave height		0.7
$\boldsymbol{\rho}\ [\boldsymbol{kg/m^3}]$	Specific weight seawater		1025
$\boldsymbol{g}\ [\boldsymbol{m/s^2}]$	Gravitation constant		9.81
$\boldsymbol{P}\ \left(=\frac{s}{e}\right)$ **(estimated)**	Porosity		0.35
$\boldsymbol{p_{1,res}}$		1998	N/m2
$\boldsymbol{H^*}$		0.20	M
$\boldsymbol{\alpha_1}^*$		0.61	-
$\boldsymbol{\psi_e}$		0.70	-
$\boldsymbol{\psi_p}$		0.66	-
$\boldsymbol{a}$		0.46	-
$\boldsymbol{p_{2,res}}$		1489	N/m2

Pressure on one bamboo pole is taken as ⅓ of the pressure as there are +-3 poles per linear meter. The pressure from the modified Goda reaches over the top of the pole. Therefore the modified eta is not used, but half a wave height.

$$\frac{1489}{3} = 496.3\ N/m$$

The first pressure works over a height of 0.9 m, with a resultant force of $496.3 * 0.9 = 446.7\ N$ at ½ of this height 0.45 m.

The second pressure works over a height of 0.9 m, with a resultant force of:
$0.5 * 0.9 * \frac{(1998.4-1488.8)}{3} = 76.44\ N$ at ⅔ of the length 0.60 m.

The third pressure works on the top (or over) the pole and has a height of half the wave, 0.35 m. Its resultant force is $0.5 * 0.35 * \frac{1998.4}{3} = 116.6\ N$ and works at $0.9 + \frac{1}{3} * 0.35 \simeq 1\ m.$

The resulting moment is then:
$496.3 * 0.45 + 76.44 * 0.6 + 116.6 * 1.0 = 385.799\ Nm = 385\ 799\ Nmm$

$$UC = \frac{385799}{881\ 364} = 0.44$$

A bamboo pole of 120 mm will be sufficient according to this formula (with a little modification for eta).

Scenario 2

$T\ [s]$	**Wave period**	**5.5**
$L\ [m]$	Wavelength (shallow water)	17.7
$d\ [m]$	Depth	1.05
$H_d\ [m]$	Wave height	0.82
$\rho\ [kg/m^3]$	Specific weight seawater	1025
$g\ [m/s^2]$	Gravitation constant	9.81
$P\ \left(=\frac{s}{e}\right)$ **(estimated)**	Porosity	0.35

$p_{1,res}$	2342	N/m2
H^*	0.23	M
$\alpha_1{}^*$	0.61	-
ψ_e	0.70	-
ψ_p	0.66	-
a	0.46	-
$p_{2,res}$	1712	N/m^2
η	1.11	m

Pressure on one bamboo pole is taken as ¼ of the pressure as there are 4 poles per linear meter. The pressure from the modified Goda reaches over the top of the pole. Therefore, the modified eta is not used, but half a wave height.

$\frac{1712}{4} = 425.5\ N/m$

The first pressure works over a height of 1.05 m, with a resultant force of $425.5 * 1.05 = 446.7\ N$ at ½ of the height 0.525 m.

The second pressure works over a height of 1.05 m, with a resultant force of $0.5 * 1.05 * (2342 - 1712)/4 = 82.7\ N$ at ⅔ of the length 1.05 m.

The third pressure works on the top (or over) the pole and has a height of half the wave, 0.42 m. Its resultant force is $0.5 * 0.42 * 2342 = 164\ N$ and works at $1.05 + \frac{1}{3} * 0.42 \simeq 1.19\ m$.

The resulting moment is then:

$425.5 * 0.525 + 229.3 * 2/3 * 1.05 + 164 * 1.19 = 579\ Nm = 579\ 000\ Nmm$

$UC = \frac{579\ 000}{881\ 364} = 0.66$

A bamboo pole of 120 mm will be sufficient according to this formula (with a little modification for eta).

Calculation with an Euler-Bernoulli beam in soil

This calculation is made in addition to the forces calculated for the maximum moment with Goda and Menikin, which assumes a clamped beam and no soil-structure interaction.

To model the soil as a spring system, we can use the Winkler model:
Definition of coefficient of subgrade reaction according to Winkler:

$$k_s = \frac{q}{\delta}$$

Where ks is the soil stiffness, q is the applied (distributed) force, and is the displacement.
The soil layers in Nhà Mát were not investigated, but it is assumed to be 0,10 m of silt/mud, and the sublayer of semi-compact more sandy layer. The k_s values chosen are 0.01 (N/mm3) for the top layer of 0.10 m, and 0.05 (N/mm3) for the sublayer. For the calculation with the domains the soil is assumed to be homogenous.

Horizontal modulus of subgrade reaction for piles

This value can be given by Menard (J. Vrijling et al., 2011).

$\frac{1}{k_h} = \frac{1}{3 * E_{menard}} \frac{4.0 * (2.65)^2 + 3\alpha}{18}$ for piles smaller than 0.6 m.

$$E_{menard} = q_c * f$$
$$E_{dynamic} = 3 * E_{static}$$

We can use the mean empirical values for sand/silt. From the table of empirical relationships (J. Vrijling et al., 2011) we can choose a to be ⅖ and f to be 1.5. A q_c (cone resistance) of 15 (MPa) for moderately loose sand is chosen.

$$E_{menard} = q_c * f = 15 * 15000000 = 27500000$$
$$\frac{1}{k_h} = \frac{1}{3 * 27500000} \frac{4.0 * (2.65)^2 + 3 * \frac{2}{5}}{18} = 2.21 * 10^{-8}$$
$$k_h = \frac{1}{2.21 * 10^{-8}} = 45 * \frac{10^6 N}{m^3} = 0.045\ N/mm^3$$

This is comparable with the values assumed earlier.

Displacement and maximum moment in a single pile calculation

An estimation of the top displacement using the differential equation of the Euler-Bernoulli beam in soil.
Assumptions:
1. The pile is geometrically straight,
2. Eccentric loads are not considered,
3. Transverse deflections of the pile are small,
4. Deflections due to shearing stresses are small.
5. Piles are not influenced by each other

To determine the displacement at the top of the bamboo fence, also the possible movement in the soil is taken into account. For this calculation the model below is used:

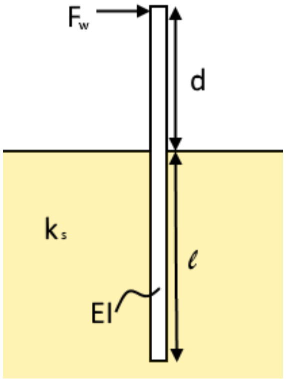
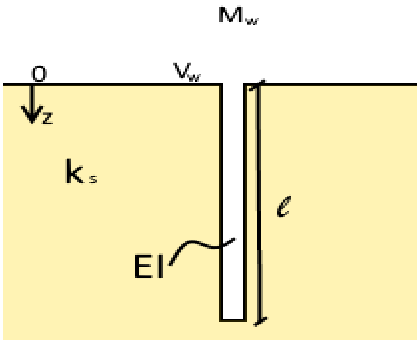


Figure O4

(Where d in the drawing is the water depth h)

Within this model, the bamboo pole is split up in two parts; one part that surrounded by soil and the other part above the soil. For each part a differential equation is posed. First the lower part of the pole is considered, according to the model below.



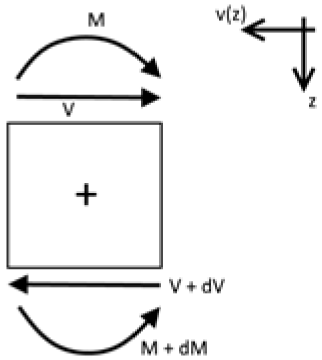


Figure O5

Figure O6

The corresponding differential equation is: $EI\frac{d^4v}{dz^4} + kv = 0$.

This can be rewritten as: $\frac{d^4v}{dz^4} + 4\lambda^4 v = 0$ in which: $\lambda = \sqrt[4]{\frac{k}{4EI}}$.

The general solution of this equation is given by:

$$v(z) = e^{-\lambda z}(C_1 cos\,(\lambda z)\ + C_2 sin\,(\lambda z)\,) + e^{\lambda z}\left(C_3 cos\,(\lambda z) + C_4 sin\,(\lambda z)\right)$$

<u>Scenario 2</u>

As we are using the same diameter pole in both scenarios, we checked the displacement due to the largest moments of the two scenarios, which occurs in case of scenario 2. If the bamboo poles appear to have sufficient stiffness, the poles of scenario 1 will also be stiff enough.

In general, the beam is considered to be semi-infinite when $\lambda l > \frac{3}{2}\pi$.

The embedded depth should then be at least:

$$l > \frac{\frac{3}{2}\pi}{\lambda} = \frac{\frac{3}{2}\pi}{\sqrt[4]{\frac{k}{4EI}}} = \frac{\frac{3}{2}\pi}{\sqrt[4]{\frac{5,4}{4*1,0*10^{11}}}} = \frac{\frac{3}{2}\pi}{1,92*10^{-3}} \approx 2458\ mm \approx 2,5\ m$$

The later determined stiffness of the bamboo is even larger, but this will not affect the results of this calculation. In this project the embedded length is chosen to be about 2,0m. Still, for this calculation is chosen to consider the beam as if it was semi-infinite, because the displacements at the top of the bamboo pole are expected to be negligible. Due to this assumption, only three boundary conditions are required. These boundary conditions are:

1. $v(l) \rightarrow 0 \quad for \quad z \rightarrow \infty$
2. $M(0) = 1 * 10^6 \; Nmm$
3. $V(0) = 1000 \; N$

Filling in the first boundary condition results in the elimination of two integration constants; $C_3 = C_4 = 0$.
The formula's for M and V can be derived from the remaining part of the general solution in the following way:

$$v(z) = e^{-\lambda z}(C_1 cos\,(\lambda z) + C_2 sin\,(\lambda z))$$

$$\varphi(z) = \frac{dv}{dz} = -\lambda e^{-\lambda z}(C_1 cos\,(\lambda z) + C_2 sin\,(\lambda z) + C_1 sin\,(\lambda z) - C_2 cos\,(\lambda z))$$

$$M(z) = -EI\frac{d^2 v}{dz^2} = -2EI\lambda^2 e^{-\lambda z}(C_1 sin\,(\lambda z) - C_2 cos\,(\lambda z))$$

$$V(z) = -EI\frac{d^3 v}{dz^3} = 2EI\lambda^3 e^{-\lambda z}(C_1 sin\,(\lambda z) - C_2 cos\,(\lambda z) - C_1 cos\,(\lambda z) - C_2 sin\,(\lambda z))$$

Now the other two boundary conditions can be used.

$$M(0) = -2 * (1{,}0 * 10^{11}) * (1{,}92 * 10^{-3})^2 * e^0 * (C_1 sin\,(0) - C_2 cos\,(0)) = 1 * 10^6 \; Nmm$$

$$\rightarrow \; C_2 \approx 1{,}356$$

$$V(0) = 2 * (1{,}0 * 10^{11}) * (1{,}92 * 10^{-3})^3 * e^0 * (C_1 sin\,(0) - C_2 cos\,(0) - C_1 cos\,(0) - C_2 sin\,(0)) = 1000 \; N$$

$$\rightarrow \; C_1 \approx -2{,}063$$

The solution for the bamboo part that is in the soil therefore is:

$$v(z) = e^{-\lambda z}\left(-2{,}063 * cos\,(\lambda z) + 1{,}356 * sin\,(\lambda z)\right)$$

With this formula, the displacement and rotation at the boundary from the lower part and the part above ground level, can be determined.

$$v(0) = e^0\left(-2{,}063 * cos\,(0) + 1{,}356 * sin\,(0)\right) = -2{,}063 \; mm$$

$$\varphi(0) = -(1{,}92 * 10^{-3}) * e^0(-2{,}063 * cos\,(0) + 1{,}356 * sin\,(0) - 2{,}063 * sin\,(0) - 1{,}356 * cos\,(0)) \approx 6{,}56 * 10^{-3} \; rad$$

The displacement of the upper part of the beam can be determined with help of the so called "forget-me-not", that fits the model below. Next the displacements that already occurred in the soil, should be added.

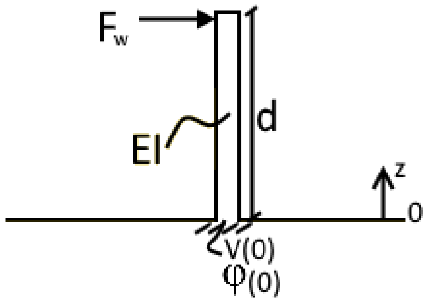


Figure O7

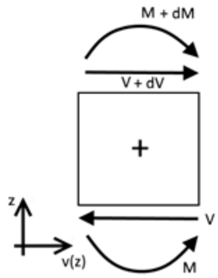


Figure O8

The formula for the displacement corresponding to this model is: $v(z) = -\frac{F_w * d^3}{3EI}$.
The total displacement at the top of the bamboo pole can be calculated with:

$$v(z) = v(0) - \varphi(0) * d - \frac{F_w * d^3}{3EI}$$

$$v(z) = -2{,}063 \; - 6{,}56 * 10^{-3} * 1000 - \frac{1000 * 1000^3}{3 * (1{,}0 * 10^{11})} \approx -12\ mm$$

So, in case of a wave load of 1kN at the top of the bamboo pile, the expected displacement is about 12mm. The allowed displacement is 10% of the pole length above ground, which for this design results in an allowed displacement of $0{,}10 * 1000 = 100\ mm$. It can be concluded that the used poles in both designs satisfy this requirement.

Appendix P: design overview (9.2.4)

In this appendix the design drawings of the bamboo fences with its dimensions are given. In figure P1 cross section A-A is given.

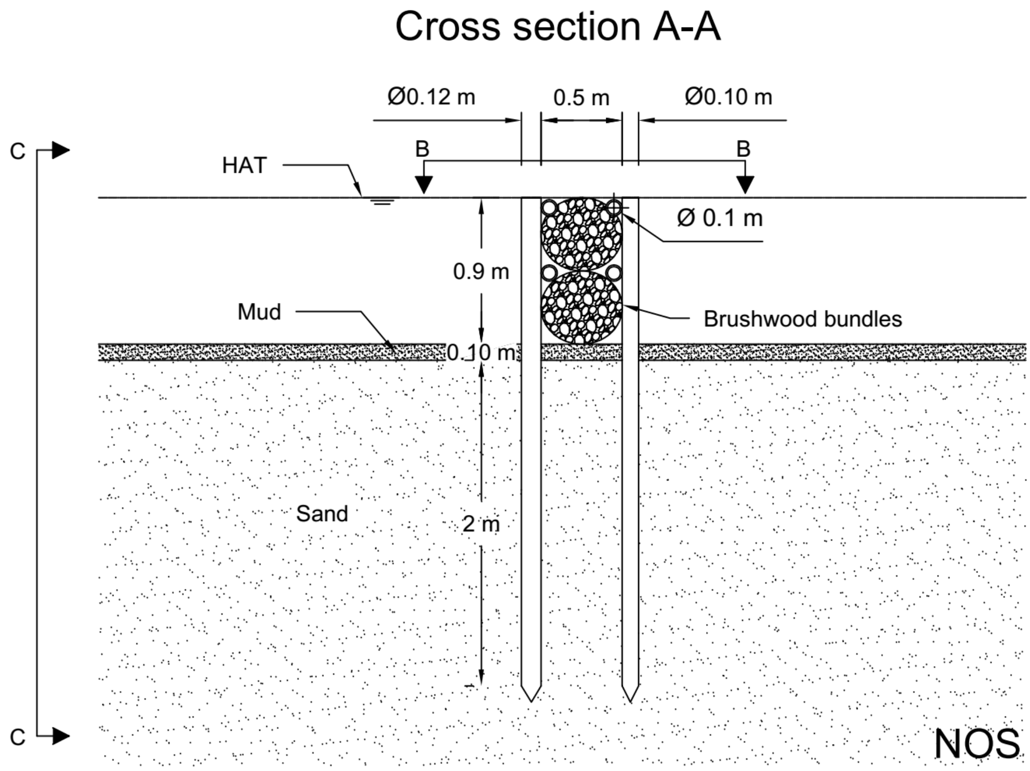


Figure P1: Cross section A-A

In figure P2 the top view of a part of the bamboo fence with its dimensions is given.

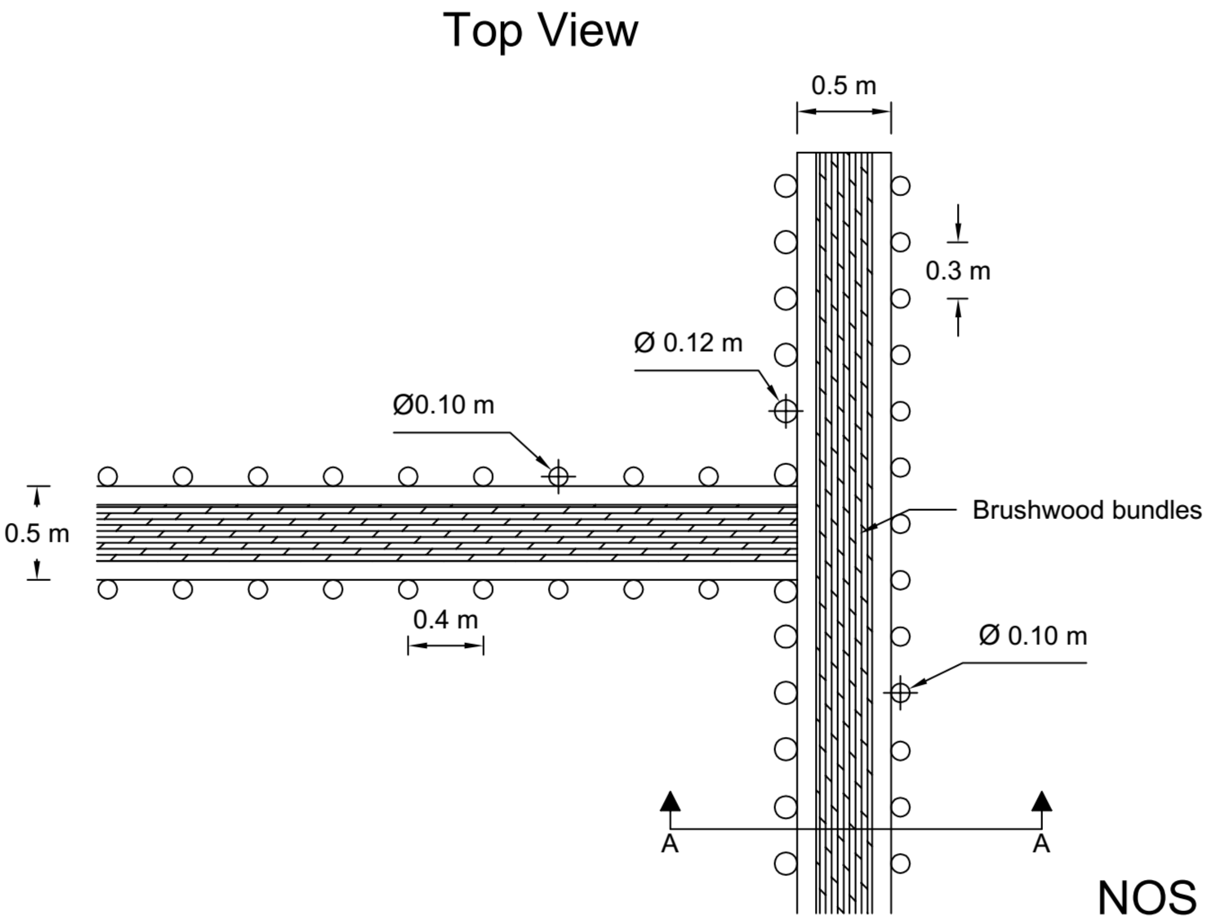


Figure P2: Top view

In figure P3 cross section C-C is given.

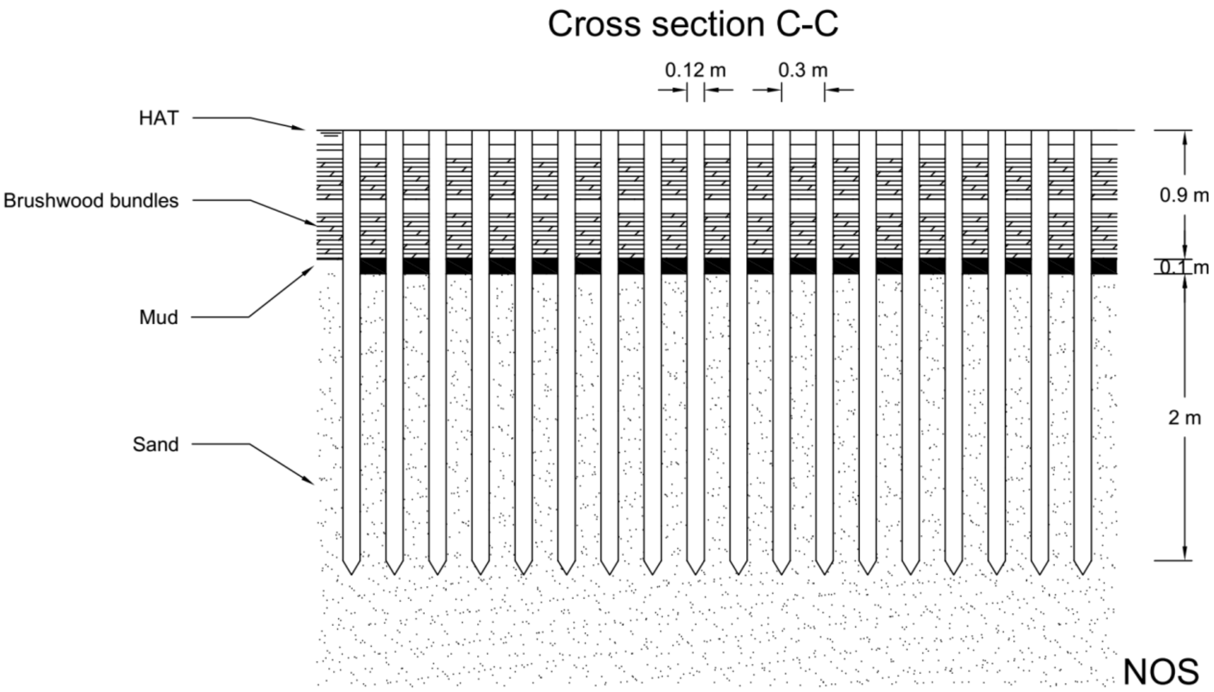


Figure P3: Cross section C-C

Appendix Q: Risk assessment

In this appendix the risks of the final design for both scenarios is determined. Good risk management can make significant difference in the end result of a project. A risk can be defined as the probability of an event from occurring and its associated consequences. These consequences have mostly a negative effect on the functions that the system should perform, or on the production process of the system. Projects anticipate more efficiently on risks if these are known beforehand.

An overview of the risks for the final design of the two scenarios is given in table Q1. In the first column the risk is described. The second and third column are elaborating about the consequences and the likelihood of the risk. The last column explains the mitigation strategy. The mitigation strategy contains four categories; avoid, reduce, transfer, and accept. Avoiding the risk means that the mitigation strategy takes place before the risk can happen. Transferring the risk means that the responsibility will be handed over to a willing third party, for example, this can be done by means of a contract. Risk reduction implies that the risk will be lower through a mitigation strategy beforehand, but not entirely solved. If the risk is accepted, the mitigation strategy takes place after the risk has happened or there is no mitigation strategy at all in a case of such a low risk that it does not matter for the project.
The risks are described from the viewpoint of the head contractor. The contract that the contractor has with the client includes managing the project, supply of materials and equipment, production of the designed system, monitoring of the system, and maintenance.

Table Q1: Overview risks

ID	Risk	Impact (L/M/H)	Likelihood of event	Mitigation strategy (Av/Ac/Tr/Re)	Sc.
	Project management				
1	Absence user's engagement	L; User's do not have much influence	High possibility	Reduce; beforehand education	1
2	Absence user's engagement	L; User's do not have much influence	Low possibility	Reduce; beforehand education	2
3	Unrealistic planning estimation	M; Delay of the project	Medium possibility	Avoid; taking slack time into account	B
4	Unrealistic cost estimation	M; the budget has a lot of influence	Medium possibility	Reduce; unforeseen costs are taken into account	B
	Production process				
5	Availability of materials	L; material not available	Low possibility	Transfer; contract with suppliers	B
6	Transport of materials / equipment	M; possible that roads / trucks are not available	Low possibility	Avoid; Materials already at project site a week before production phase	B
7	Vandalism during production process	M; Materials / equipment not available	Medium possibility	Avoid; Good security	B
8	Extreme weather conditions	H; with T-storms it is not possible to work	Low possibility	Accept; Keep an eye on weather forecast	B
9	Extreme wave conditions	H; with bad wave conditions it is not possible to work	Low possibility	Accept; Keep an eye on wave forecast	B
10	Soil conditions are not as expected	H; Soil too weak not possible to build the fences	Low possibility	Accept; Soil improvements or design adaptation	B
11	Equipment failure	L; Cannot work	Medium	Accept; Easy to replace	B

		further	possibility	equipment	
12	Construction method (partly) incorrect	H; Reliability structure insufficient	High possibility	Reduce; Supervisor during construction	B
13	Bad quality material	H; bad quality leads to a less reliable structure	Medium possibility	Avoid; Selection process beforehand	B
	Operation process				
14	Collision ships	M; Reliability structure decreases	Low possibility	Accept; maintenance	B
15	Vandalism during operation process	M; Reliability structure decreases	Low possibility	Accept; maintenance	B
16	Early material deterioration	H; Reliability structure decreases	Medium possibility	Accept; monitoring structure → maintenance	B
17	Heavy wave conditions	H; Structure collapse	Low possibility	Accept; maintenance after storm	B
18	Not enough sedimentation	H; Conditions mangroves not optimized	Medium possibility	Accept; enlarge sediment input manual	B
19	Too much sedimentation	M; Mangroves suffocate	Low possibility	Accept; plant new mangrove plants	B
20	Water quality low	M; Small survival rate mangroves	Low possibility	Transfer; find source	B
21	Harvesting of mangroves	M; Reliability coastal protection decreases	Medium possibility	Reduce; policies	B
22	Fast flushing away chenier	M; sedimentation decelerates	Medium possibility	Reduce; monitoring and nourishment	2
23	Clogging drainage channels	L; slower sedimentation	Low possibility	Accept; monitoring and maintenance	1
24	Downdrift erosion	M; mangrove forest disappears on the leeside	Low possibility	Accept; monitoring	1
25	Downdrift erosion	M; mangrove forest disappears on the leeside	High possibility	Accept; monitoring	2
26	No natural grow mangrove trees on landside	L; no storm wave reduction	Low possibility	Accept; manually plant new trees	1
27	New secondary dyke not reliable	M; shrimp ponds flood	Low possibility	Reduce; good design, monitoring during construction	1

The risks that are determined can also be represented by means of a matrix, which is shown in figure Q1 and Q2 risk matrix for scenario 1 and 2. The risks that are in the orange or red areas have the biggest priority.

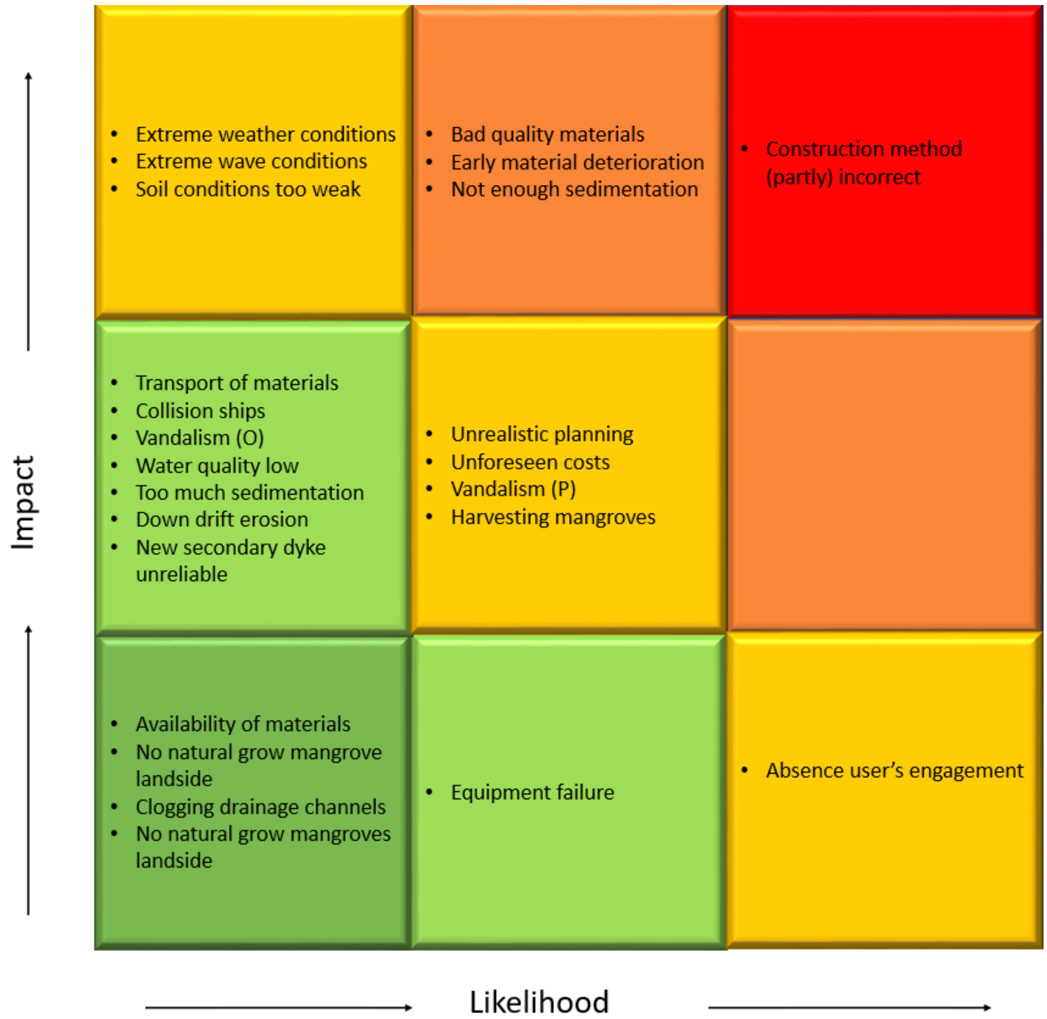


Figure Q1: Risk matrix scenario 1

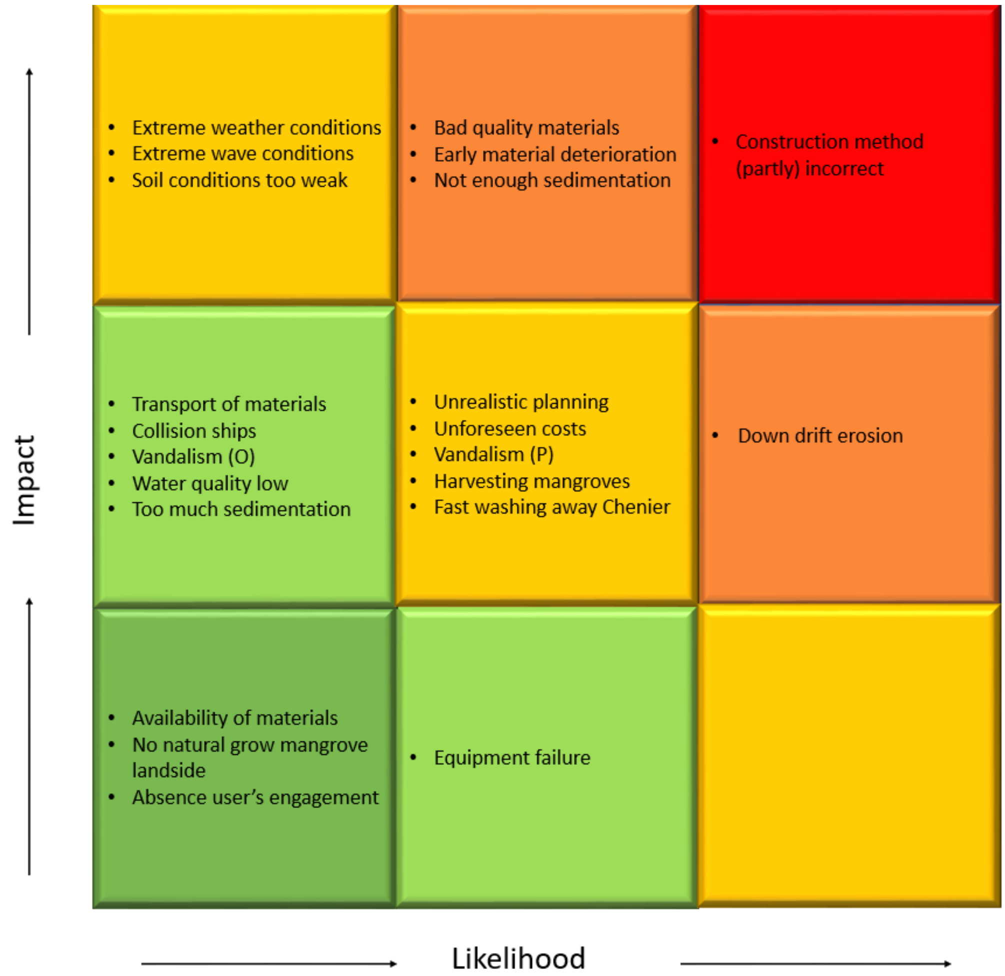


Figure Q2: Risk matrix scenario 2

Top risks both scenarios

- Construction method (partly) incorrect; During the production phase it is important that the construction method is done correctly. Construction mistakes can have huge consequences for the structure. The mitigation strategy for this risk is to always have a supervisor during the production phase on the project site.
- Bad quality materials; Almost all materials are natural resources. Thus, it is possible that these materials do not have the strength that is expected during the design phase. The mitigation strategy for this risk is a selection procedure before the materials are used in the system.
- Early material deterioration; At the end of the project the fences will stay in place, because the fences will rot away eventually. But if this already happens when it still needs its functions this has a big impact on the project. The mitigation strategy is strict monitoring the structure for early detection and maintenance.
- Not enough sedimentation; Sedimentation is a natural process. If the sedimentation is not sufficient, the mangroves cannot rehabilitate. The fences create a tranquil environment in which sedimentation occurs, but it is uncertain how fast this happens. The mitigation strategy is to create a bigger sediment input manually.

Top risks Scenario 2

- Down drift erosion; For scenario 2 a lot of sediment is trapped in the fences. Therefore the longshore sediment transport is blocked extremely. It is likely that down drift erosion occurs. This risk will be accepted; except for monitoring the consequences.

Appendix R: Planning and implementation

Execution of a project like this is quite complex. Therefore, it needs coordination of several activities, managing its budget, overseeing the planning, and many other matters. The aim of an implementation phase or plan is to achieve the goals of your project by planning and carrying out the activities that it requires. In order to accomplishing that a Work Breakdown Structure (WBS) should be made, which is based on the System Breakdown Structure (SBS). In this implementation plan the necessary activities, an overall planning, and the required materials are given.

R.1 Scenario 1

Based on the SBS a WBS is made, which is shown in figure R1. For every layer in the SBS the activities for achieving this subsystem are identified. A WBS represents all these activities in the project. A further elaboration of these activities conducts the description, and duration. There after the planning is made to identify the critical path. This path is essential to determine, because delay of activities on this critical path will cause immediate delay of the whole project.

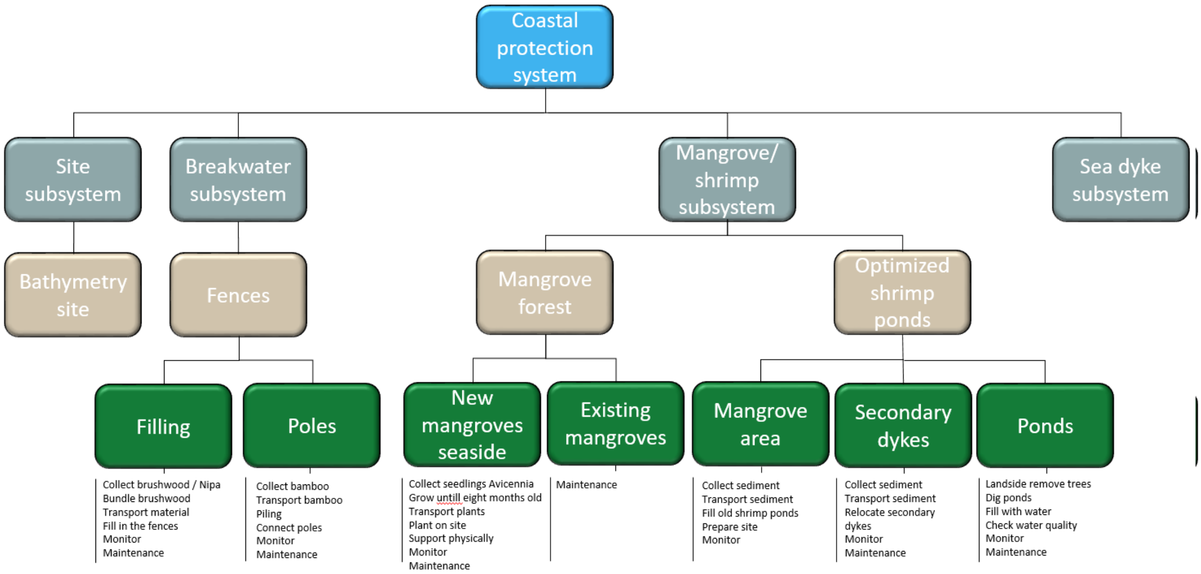


Figure R1: WBS scenario 1

As shown in the SBS the coastal protection system is divided into four subsystems; site, breakwater, mangrove/shrimp, and sea dyke subsystem. The site and sea dyke subsystems are within the scope, however, these will not be changed compared to the current situation. The breakwater subsystem exists of fences, which is divided into the filling and the poles. The mangrove/shrimp subsystem is divided into the mangrove forest and the optimized shrimp ponds. The mangrove forest is broken down into the new mangrove forest on the seaside and the already existing mangroves. The optimized shrimp pond is subdivided into the new mangrove rehabilitation area, the new secondary dykes, and the shrimp ponds directly on the seaside of the sea dyke. The side view of the scenario is given into figure 27 in paragraph 7.1.1.

The activities that are given in figure R1 are necessary to achieve the total coastal protection system, and are used in the planning. These activities are described in table …, the duration for every activity is completed in months.

From the WBS the following activities can be combined for planning and cost purposes:
Collect brushwood/ Nipa leaves and Bundle Brushwood. (Collect + Bundle material)
Fill in the fences, piling, connect poles (construction fence)
Fill old shrimp ponds, dig new shrimp ponds, prepare site, relocate secondary dyke, fill with water,
Check water quality and remove trees landside. (Changing land use)
Collect sediment + Transport sediment + drop sediment (create chenier)

The total production time for the final design of scenario 1 will be13 years. After these years the new planted mangrove trees are matured and the fences lose their function. This is no issue because they are made of natural resources, so they will rot away eventually.

S.2 Scenario 2

This paragraph describes the implementation plan, including the planning and necessary materials, of scenario 2. The realization of scenario 2 has a few differences compared to scenario 1. The shrimp ponds are not changed which makes The structure of the fences are the same in both scenarios, but the scale of scenario 2 is 2 times bigger than in scenario 1.

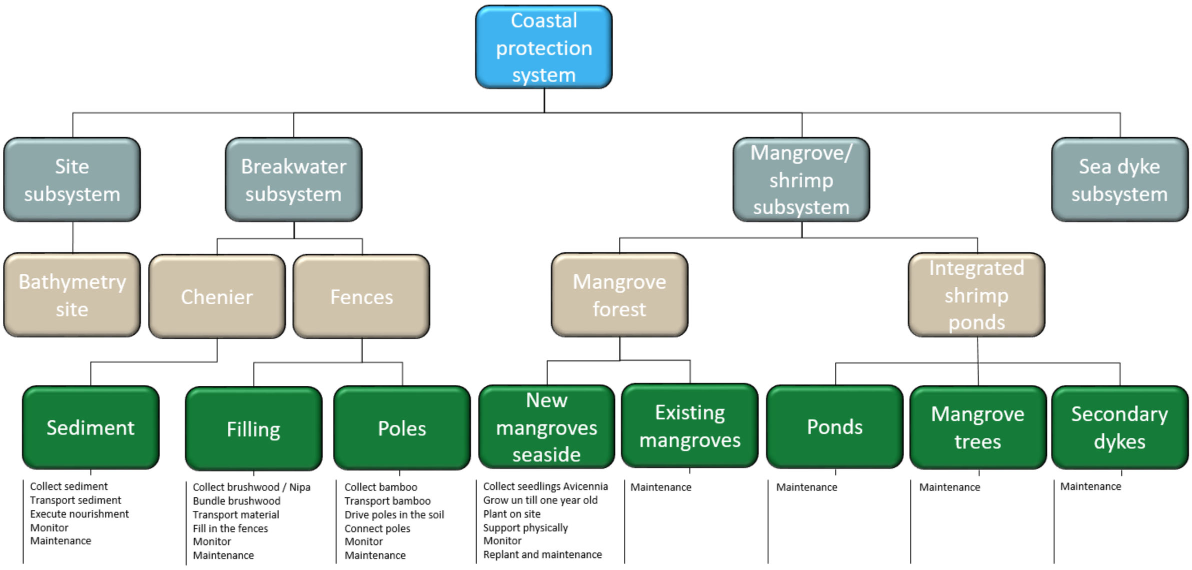


Figure R2 WBS scenario 2

As shown in the SBS the coastal protection system is divided into four subsystems; site, breakwater, mangrove/shrimp, and sea dyke subsystem. The site, integrated shrimp ponds and sea dyke subsystems are within the scope, however, these will not be changed compared to the current situation. The breakwater subsystem exists of a chenier and fences, which is divided into the filling and the poles. The mangrove/shrimp subsystem is divided into mangrove forest and the integrated shrimp ponds. The mangrove forest is broken down into the new mangrove forest on the seaside and the already existing mangroves. The integrated shrimp pond is subdivided into ponds, mangrove trees and secondary dykes directly on the seaside of the sea dyke.

Appendix S: Cost estimation

In general, the costs of mangrove rehabilitation are hard to determine since it depends on the location of the rehabilitation. The rehabilitation of mangroves in this report consist of four parts. Creating bamboo fences, site preparation, planting mangroves at the land side and planting mangroves at the seaside. A cost estimation is made using a previous cost estimation for bamboo fences by the Cà Mau sub department of water resources provided in Table S2. This cost estimation is based on a T fence barrier construction of 555m. The vertical poles are for 2.1 to 2.3 meter piled into the ground. Horizontal bars overlap 30cm. Stainless steel rope is used to connect the horizontal and vertical poles and keep the brushwood in place. The vertical bars are 3.5m high and have a diameter of 0.1. The horizontal bars have a length of 4m and a diameter of 0.1. The bundle material has a length of 2m a width of 0.5m and a height of 0.4m. The amount of material required to build one meter bamboo fence is summarized in table S1.

Table S1: Amount of material per meter fence

Material	Length (m)	Width (m)	Height (m)	Diameter (m)	material per meter fence
Vertical bamboo poles			3.5	0.1	5
Horizontal bamboo poles	4			0.1	1.08
Bundle	2	0.5		0.4	1
Kg of Steel				0.03	1.3

The cost of the bamboo fence construction consists of direct and indirect costs. The construction supervision fee is adjusted to 2,8%. Besides that, the manufacturing overhead costs are combined and transferred into a percentage of the direct cost in order to make an estimation of other projects possible. The manufacturing overhead contains all costs that cannot directly be traced to the bamboo fence such as the equipment needed to construct and transport the material. Transferring the cost led to a manufacturing overhead estimation of 3.5% of the direct cost. Note that this is just a rough estimation since the direct costs do not have a perfect correlation with the indirect since the real cost depend on the amount of equipment that is used. With small projects, indirect cost will be relatively high which increases the percentage of the manufacturing overhead.

GIZ conducted projects in the Bạc Liêu to rehabilitate mangroves at abandoned shrimp ponds areas in the Bạc Liêu Province. At these locations site preparation was needed because these areas have high elevation and are rarely flooded (B. Clough et al., 2016). Site preparation mainly consists of digging channels of 2-3 m wide and 0.5 meter deep. Rearranging a shrimp pond consists of similar activity. Therefore the average costs estimation of land preparation per ha is set on 57 000 000 VND based on the mangrove reforestation projects of GIZ (B. Clough et al., 2016). This report is not planning to plant mangroves at the new prepared land side since there are a lot of seedlings of mangroves present in the area.

At project sites in the Bạc Liêu Province GIZ planted 31 500 seedling at 4.1 ha (B. Clough et al., 2016). This is 7682 seedlings per ha. The average cost per ha seedling was 36 834 677 VND (B. Clough et al., 2016). At the seaside a higher density of seedlings is needed. At a comparable seaside GIZ planted approximately 20 000 seedlings per ha. This is 2,6 times more seedlings per ha. To give a cost estimation for this higher density the costs of the average cost per ha seedling GIZ is multiplied by 2.5 and rounded to the nearest million number. This results in 92 000 000 VND per ha. The same is done for the planting of mangroves this results in 140 000 000 VND per ha.

Table S2: Cost estimation of 555m t-fence construction by the the Cà Mau sub department of water resources

DETAIL COST ESTIMATION FOR 555 m T-FENCES

No.	DESCRIPTION	UNIT	QUANTITY	LABOUR (VND)		MATERIAL (VND)		TOTAL
	Ea x L x W x H			UNIT	AMOUNT	UNIT	AMOUNT	(VND)
I	**DIRECT COST**							
1	Vertical bars: bamboo poles have diameter around 0.08~0.1 m and length of 3.5 m.	bar	3.058,00		-	98.000	299.684.000	299.684.000
	7 x 59,00 x 2,00 x - x -							
	7 x 45,00 x 2,00 x - x -							
	1 x 801,00 x 2,00 x - x -							
2	Horizontal bars: bamboo poles have diameter around 0.08~ 0.1 m and length of 4 m.	bar	1.000,26		-	112.000	112.029.120	112.029.120
	7 x 30,00 x 6,00 x 0,25 x 1,20							
	1 x 345,70 x 6,00 x 0,25 x 1,20							
3	Bundle type A 0,2m x 0,3m x 2m (bamboo, mangrove,…), including stainless steal rope	cluster	735,00		-	220.000	161.700.000	161.700.000
	7 x 15 x 7,00 x x							
4	Bundle type B 0,2m x 0,2m x 2m (bamboo, mangrove,…), including stainless steal rope	cluster	1.218,00		-	200.000	243.600.000	243.600.000
	1 x 174,00 x 7,00 x x -							
5	Stainless steel rope Φ3	kg	684,75		-	67.000	45.878.560	45.878.560
	3 x 3.058,00 x 1,00 x 0,055 x 1,20							
	2 x 555,00 x - x 0,055 x 1,20							
6	Stake bamboo poles 2.1-2.3m.	pole	3.058,00	30.000	91.740.000		-	91.740.000
	1 x 3.058,00 x - x - x -							
	SUB-TOTAL							**954.631.680**
II	**OTHERS**							
1	Construction supervision fee (2.744% of direct cost, based on decision 975/QĐ-BXD, signed on 29/09/2009)	1						26.195.093
2	Stationery	l.sump	1,00	-	-	5.000.000	5.000.000	5.000.000
3	Canoe and car rental							
	Canoe 5 x - x x - x -	trip	5,00	-	-	3.700.000	18.500.000	18.500.000
	Car 7 x - x x - x -	trip	7,00	-	-	1.400.000	9.800.000	9.800.000
	SUB-TOTAL							**59.495.093**
	TOTAL							**1.014.126.773**

Defining the costs for creating a Chenier are difficult to define. An educated guess is used of 130 000 VND per m^3 Chenier.

When the fences are placed, it will take a few years to accomplish accretion. One year after the fences are placed the conditions behind the fences should be sufficient for mangroves to grow. At first the conditions are severe which results in more maintenance costs. When the mangroves mature the amount of sediment that traps in the roots increases. According to previous projects after 9 years, no maintenance is needed anymore. Because of this an infant mortality failure pattern is used. Based on previous projects an estimated guess that the maintenance cost is 30% of the total costs of the first year.

The function used for the cost estimation is: $y = \frac{30}{x^{1.8}}$. The percentage of maintenace costs over the years is given in figure S1.

Years	% maintenance costs of total costs (excl. maintenance costs)
1	30
2	9
3	4
4	2
5	2
6	1
7	1
8	1
9	1
10	0

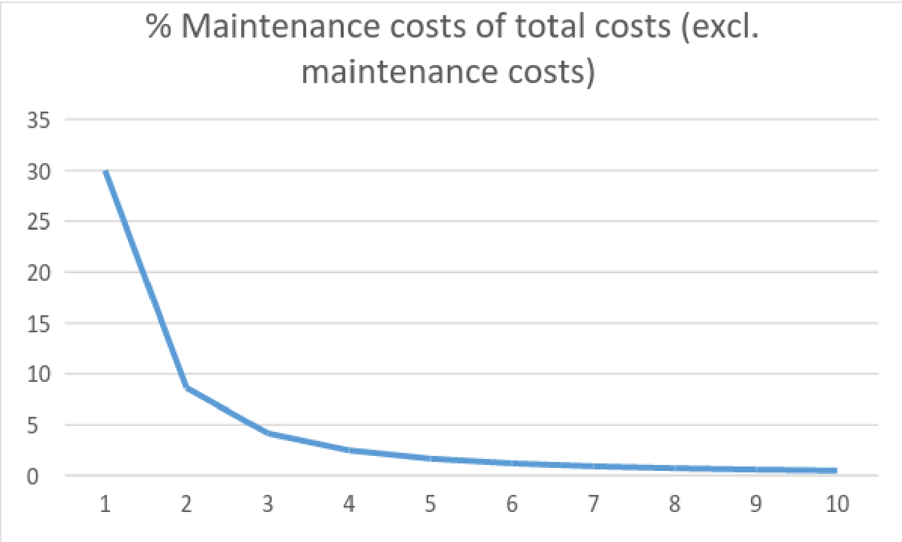


Figure S1: percentage maintenance cost of total costs after years of construction

This results in the following total cost estimation used for both scenarios. The project is divided into project year starting in august. To give an overview of the total costs of the project the expenses per year will be calculated.

To calculate the net present value a discount rate of 5,0% is used. This is approximately the current yield on Vietnam government bonds maturing in 5 years at January 2017. The project of Scenario 2 takes to year more to execute. In table S3 the NPV of scenario 1 and scenario 2 are provided note that this is not a fair comparison since the project for scenario 2 takes two more years to accomplish.

Table S3 NPV Scenario 1 and 2.

Scenario 1

Year	Costs (Vietnamese Dong)		Costs (in euro)	
1	VND	26.000.000.000	€	1.100.000
2	VND	3.500.000.000	€	150.000
3	VND	19.000.000.000	€	790.000
4	VND	3.800.000.000	€	160.000
5	VND	5.400.000.000	€	220.000
6	VND	880.000.000	€	37.000
7	VND	660.000.000	€	27.000
8	VND	460.000.000	€	19.000
9	VND	440.000.000	€	18.000
10	VND	210.000.000	€	8.700
11	VND	190.000.000	€	7.900
12	VND	53.000.000	€	2.200
13	VND	32.000.000	€	1.300
14			€	-
15			€	-
TC	**VND**	**61.000.000.000**	€	2.500.000
NPV	**VND**	**-56.000.000.000**	€	-2.400.000

VND 24028 = 1 EU

Scenario 2

Year	Costs (Vietnamese Dong)		Costs (Euro)	
1	VND	160.000.000.000	€	6.700.000
2	VND	33.000.000.000	€	1.400.000
3	VND	12.000.000.000	€	500.000
4	VND	41.000.000.000	€	1.700.000
5	VND	5.700.000.000	€	240.000
6	VND	5.000.000.000	€	210.000
7	VND	16.000.000.000	€	670.000
8	VND	3.300.000.000	€	140.000
9	VND	2.300.000.000	€	96.000
10	VND	910.000.000	€	38.000
11	VND	620.000.000	€	26.000
12	VND	460.000.000	€	19.000
13	VND	170.000.000	€	71.000
14	VND	170.000.000	€	71.000
15	VND	110.000.000	€	4.400
TC	**VND**	**280.000.000.000**	€	12.000.000
NPV	**VND**	**-260.000.000.000**	€	-11.000.000

Table S4 Average costs GIZ projects for mangrove rehabilitation in former shrimp ponds (B. Clough et al., 2016).

Average cost per hectare of planting at Sites 1 and 3 in 2011. A total of about 31,500 seedlings were planted.

Item	VND ha^{-1}	USD ha^{-1}*
Site preparation (mainly canal construction)	57,245,161	2,600
Seedling costs (propagule + nursery costs)	36,834,677	1,670
Planting costs (transport + labour)	56,193,548	2,550
Total cost	15,273,387	6,830

* Based on an exchange rate of USD 1 = VND 22,000 and rounded up or down to the nearest USD 10

Appendix T: Phasing scenario 2

In this appendix an overview of scenario 2 is given with its three phases.

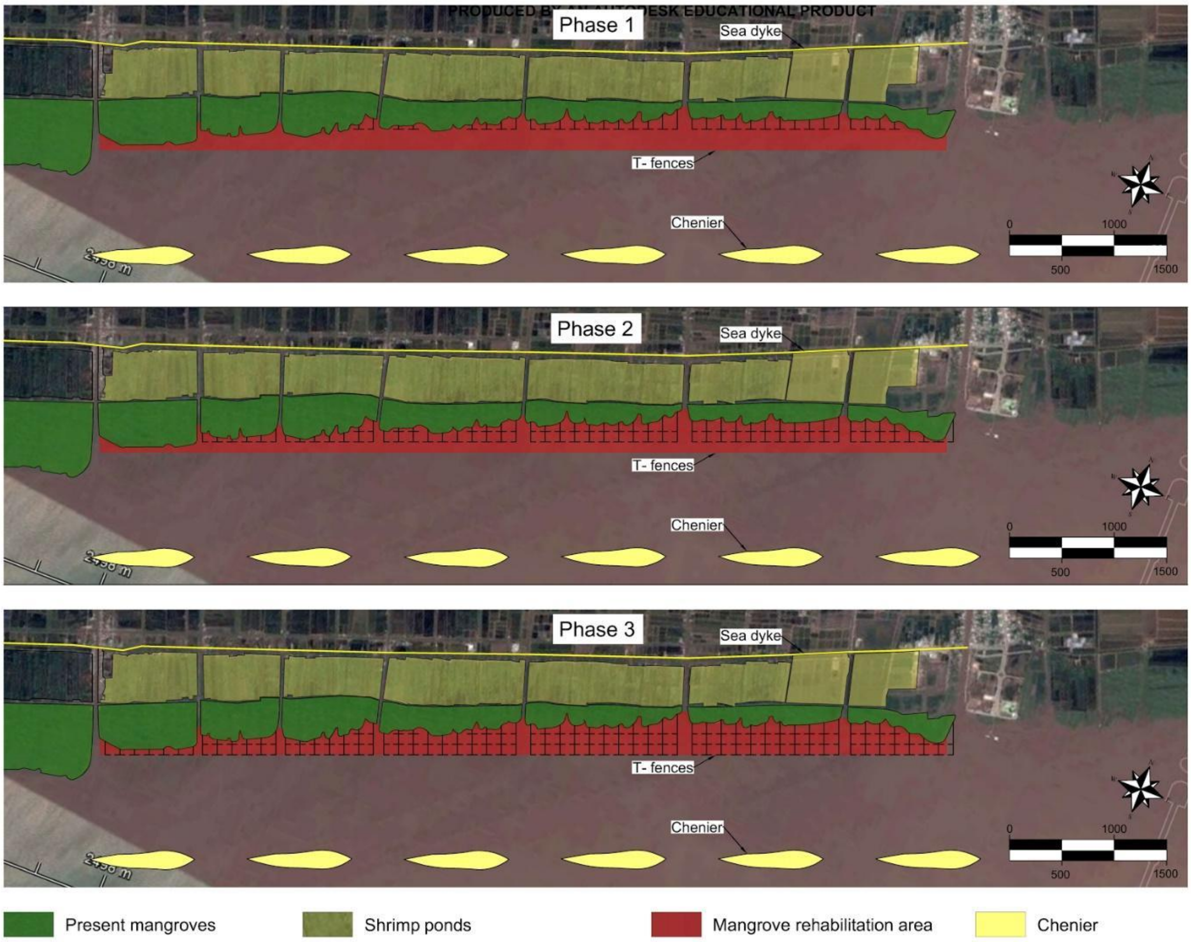


Figure T1 three phases of scenario 2