Coastal erosion management in Cha-am & Hua Hin, Thailand

Evaluation of the current situation
& recommendations for the future

February, 2017

Sustainable Shores

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Sustainable Shores

Preface

In April 2016 our team was formed consisting of two Construction Management and Engineering students and three Hydraulic Engineering students. Although we were a little apprehensive about the project and its contents at first, we started this adventure with great enthusiasm. Now, almost eight months later, we can look back on a great and interesting time. We have learned to know the culture of the country of smiles. We have learned what it is to work in a country like Thailand, which is not always as easy as in the Netherlands. And we have learned to work in a multidisciplinary group.

All of this would not have been possible without the help of Dr. Ir. H.J. Verhagen, who arranged the project together with Dr. A. Ashakul and Mrs. Juthamas Ashakul. Many thanks especially to Dr. A. Aphinat who arranged our project room, our apartment and many more.

Mr. J. Laksanalamai was our contact from the Thai Marine Department. We are grateful for his great effort in helping us. Many thanks for arranging all the data, setting up all meetings and for the guided tour around the project area. Also, thanks for providing valuable feedback.

We would also like to acknowledge Mr. B. Huijsman for helping us with our many UNIBEST questions. Without his help we would not have come this far. We want to thank Mr. M. Zijlema for his comments on our SWAN model and Peter Groenewoud from waveclimate.com for granting us access to waveclimate.com and helping us with our questions.

We are indebted to Dr. A. Jotisankasa from Kasetsart University for letting us borrow the Kunzelstab penetrometer and to Dr. W. Kongkitkul for arranging the Kunzelstab and arring our soil tests. Many thanks to Ms. S. Khamsoy for all her time and help with the soil tests and Ms. M. Thananant for helping with the interviews and further translation.

Lastly, we would like to thank the KMUTT for accommodating us, we experienced a very welcoming atmosphere from both the students and the teachers and other staff for which we are very grateful.

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Summary

This report is a documentation of the analyses and conclusions on the erosion problem along a coastal stretch in the Cha-am and Hua Hin area. It starts with an introduction (chapter 1) and a problem analysis (chapter 2), which form Part I of the report. The problem was defined in chapter 2 as:

Beach erosion on the coastal stretch of Cha-am to Hua Hin has unwanted effects. Tourism is being threatened by the declining beach width and at some points the coastline retreat causes problems for non-tourism related stakeholders. Performed beach nourishments to tackle the problem have had a much lower lifetime than was expected prior to construction. Some hard structures have been constructed at certain points along the coastline, which have met some local success, but the overall problem has not been solved.
A sustainable, long term and integral plan is necessary to cope with the on-going beach erosion. This plan should incorporate managerial aspects such as the stakeholders, risk management, time management, budget planning and decision-making.

To solve this problem in a structured way a method for solving the problem was made first (chapter 2). This approach was the following: After the problem was analysed an economical and technical analysis would be made of the coastal stretch and a stakeholder analysis would be performed. After these were concluded its findings were to be combined in a system analysis, which would conclude Part II. In Part III a structured way was to be provided on how to perform beach nourishments. Part IV would set up possible solutions, which would then be calculated in the UNIBEST model. Then in Part V a risk assessment would be made and the solutions would be assessed with a MCA (Multi Criteria Analysis). Finally in Part VI conclusions would be drawn and the project and possible future research would be discussed.

Part II analyses the coastal area and prepares the found information for later parts of the report:

In chapter 3, an overall analysis of Thailand was made, including its geographical and typological characteristics, climate, history, economy, environment, society, culture and government. The chapter includes all the relevant information for the project and is necessary to ensure a complete overview of the situation and the problem at matter, as the context of a problem greatly impacts the type of solution.

Chapter 4, Coastal analysis, describes the technical aspects of the analysis of the coastal stretch under research. The coast was characterised as a sandy coast, with a strong northward longshore current with a mixed mainly diurnal tide. There are two monsoon periods, mid-May to September and November to mid-March. The wave climate consists of medium to small waves, with the dominant direction being north northeast during the northeast monsoon (November-March), south southwest during the southwest monsoon (May-September) and south in other months. The monsoon periods cause a highly variable sand transport and a corresponding highly variable coastline.
From the initial coastal analysis it was concluded that the most probable causes for the erosion are human interventions and hard structures along the coastline. Information about the most important hard structures and projects from the Marine Department have been listed here.

A stakeholder analysis was performed in chapter 5 to identify and categorize all the involved stakeholders. The stakeholders were identified based their interests, powers and attitude, to determine their roles in the project and their criticality. Furthermore, their involvement during the different phases of the project was also established, all of which is used for the stakeholder engagement plans for each alternative.

The chapter System engineering (chapter 6), combines all information gathered from the previously separately made analyses to provide a systemic overview from the problem and its context. The stakeholders and their roles in the system are described and the mission and objectives of the project are analysed. The end result is a comprehensive system architecture useful for a suitable solution as it is a framework that supports and enables the integrated elements of the system to provide the system's capabilities and perform missions.

In Part III, chapter 7, previous nourishments and their shortcomings have been described. Better values for amounts of sand required for future nourishment, and the way to calculate this have been given. And finally a roadmap, with design practices has been made for future nourishments to be executed by the Marine Department.

Chapter 8, Part IV, describes the coastal model that was made in UNIBEST. The model proved to be unable to provide correct results for the project. The most plausible causes for why the model did not work are: Faulty wave conditions, sinks and/or sources that were no modelled, and limitations of UNIBEST-CL+. The failure of the model has some implications for the project, but it was still possible to come up with solutions to the defined problems.

Chapter 9, describes the scenarios which were taken into account for the project. The first scenario, do nothing, was used as a necessary reference for the second and third scenario. The second scenario consists of several possible solutions, groynes, T-groynes, beach nourishment and a beach nourishment with coarser material. In the third scenario all existing structures were removed, to test an hypothesis by some NGO´s that removing all structures would improve the situation.

The stakeholder engagement plans are elaborated in chapter 10, after the stakeholder analyses and the establishments of the solutions. The plans show a proposed method for each solution to engage the stakeholders in the solution to minimize their opposition and maximize their cooperation. The plans for T-groynes and groynes show some similarities, as their design and construction are similar, as is with the beach nourishment and coarse nourishment.

Part V, Chapter 11, consists of two parts, namely the risk management and the multi-criteria analysis. The risk management included an assessment of the solutions based on their risks. The risks for each solution were established together with risk responses. The risk management established that the T-groynes have the highest risks, while the beach nourishment alternative has the lowest. The second part assesses the scenarios qualitatively and the proposed solutions with an MCA. It was concluded that removing the existing structures would not solve the erosion problems. The conclusion of the MCA analysis was that a beach nourishment would be the best solution for the current project.

Part VI, concludes the project with an advice plan for the Marine Department and a discussion with the limitations of the research. Since the research is conducted in a short amount of time, by a team with limited expertise and without expert judgements, the research needs to be further extended to result in more comprehensive and objective conclusions and a more thorough and reliable advice plan.

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PART I
Starting Phase

1. Introduction

Beach erosion is a common phenomenon all around the world and can have disastrous consequences (e.g. Dunn, Friedman, & Baish, 2000). Erosion itself is not necessarily a problem, but when the interests of important stakeholders are threatened it does become a serious issue. These interests can be monetary while flood safety can also be an important reason to take measures against erosion. Coastal erosion management requires a multidisciplinary approach in which knowledge of coastal physical processes is combined with social and physical structures (Saengsupavanich, Chonwattana, & Naimsampao, 2009). This multidisciplinary approach is used in this research in which solutions are presented for the erosion problem near Cha-am and Hua Hin, Phetchaburi Province and Prachuab Khiri Khan Province respectively in Thailand.

The Thai coast suffers from significant erosion in many areas (Nuttalaya. 1996; Saengsupavanich et al., 2009; SEATEC, 2003). In response, individuals along the Cha-am and Hua Hin coastline have built large amount of structures to counter these problems with, unfortunately, little to no avail. The problems are being shifted from one location to another instead of being solved. Furthermore, the self-made structures are expected to collapse due to shortcomings. This structural erosion problem has led to a thorough analysis of a coastal section stretching from the Phetchaburi River-Mouth in the Phetchaburi Province to the Pranburi River-Mouth in the Prachuab Khiri Khan Province, which was carried out by SEATEC in the year 2003. The analysis resulted in a prioritised list of erosion areas in which the area in front of the Mrigadayavan Palace was most critical according to the used criteria. In response to the analysis, measures were designed to protect the area around the Mrigadayavan Palace. Jetties, groynes, submerged offshore breakwaters and emerged offshore breakwaters were built in the first phase (Figure 1.1). Latest phases mostly consisted of beach nourishments, which are so called soft measures. Due to developments, such as building regulations and interference of NGOs, these soft measures are the preferred measures nowadays.

a. b. c. d.

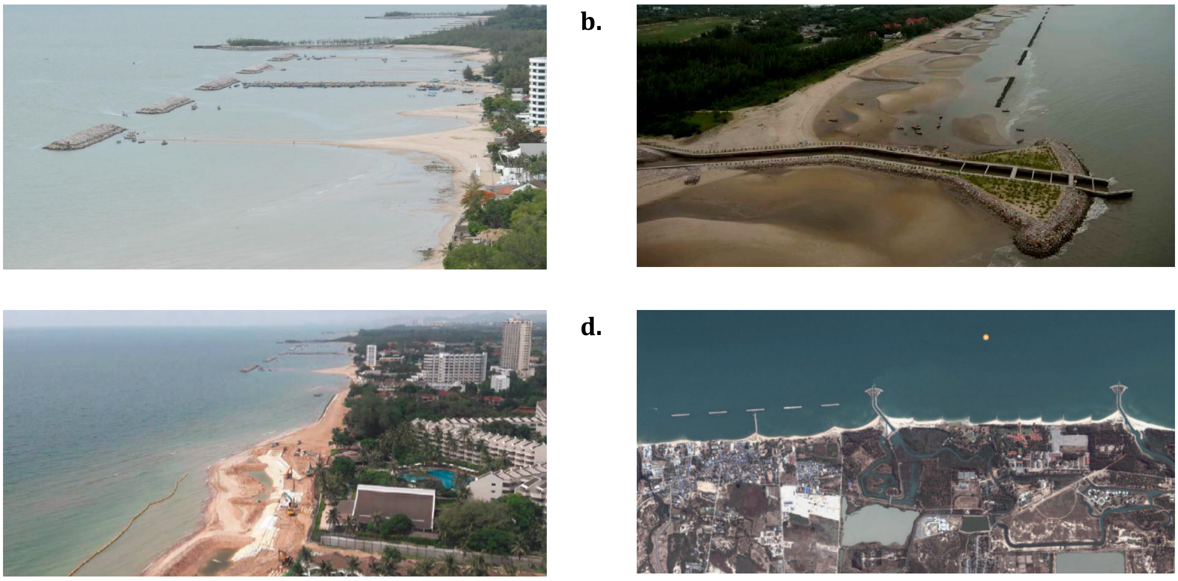


Figure 1.1 | Protection measures around the Mrigadayavan Palace. (a) Emerged breakwaters and a groyne north of the Mrigadayavan Palace constructed in 2007. (b) Jetty, groynes and submerged breakwaters in front of the Mrigadayavan Palace constructed in 2005. (c) Construction of a nourishment north of the emerged breakwaters in 2015. (d) Satellite imagery of the area around the Mrigadayavan Palace in 2008 (Personal communication, J. Laksanalamai, July, 2006).

The new collaboration between the Delft University of Technology and the King Mongkut's University of Technology Thonburi resulted in the contact between the multidisciplinary team Sustainable Shores and the Thai Marine Department. This resulted in the assignment for the team of which the goal was to advise on the erosion problem, meaning, recommending measures that should be considered to deal with the erosion problem. The project location was specifically the location in front of the Mrigadayavan Palace. The effectivity of the structures was doubted by local NGO's. Furthermore the team got the idea that there was severe erosion in that area. The problem definition has however shifted to a more integral approach, which will be explained in chapter 2. It was concluded that the hard structures have solved the problem in front of the Mrigadayavan Palace more or less successfully. However, they resulted in more severe problems outside the project area. Therefore, a thorough study is necessary to determine the extent of the problem and to design an integral plan to counteract the erosion problem.

1.1. Vision

This project was carried out with a vision, which is also presented in the name of the team. The Sustainable Shores team finds that sustainability in all its aspects is extremely important. In our perspective, sustainability is the key to a design that will not only be beneficial to the present generation but also to many future generations. Therefore, we have the responsibility as a team to ensure that the sustainability aspect is incorporated in all of our proposed solutions and recommendations.

In order to appropriately integrate sustainability into our project, it is important to know its definition. Multiple definitions exist, but in our opinion the definition of Our Common Future, also known as the Brundtland Report (World Commission on Environment and Development, 1987) is the most comprehensive. According to the Brundtland Report, sustainability can be defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". By using this definition, we acknowledge three different aspects, namely planet, people and prosperity (Figure 1.2). Our solution must take environmental issues into account. The beach is an ecosystem, which is an important habitat for many species. Therefore, we have a certain responsibility towards these species. The ecosystem has a direct link with the second aspect, being 'people'. The project area involves a fishing community, which is strongly dependent on a healthy ecosystem. Moreover, the local community strongly depends on the tourism sector, which links the people aspect to the third aspect, being 'prosperity'.

1.2. Content

In order to increase the readability, the report is subdivided into five parts, starting with an introduction to the problem (chapter 1 and 2). In the second part, the analyses, the current situation will be analysed. It contains the socio-economic situation (chapter 3), the state of the coast (chapter 4), the involved stakeholders (chapter 5), and the project as a system (chapter 6). The third part addresses the first mission of the problem (chapter 7, beach nourishments), and part four addresses the second mission of the problem. This fourth part contains the coastal model (chapter 8), different scenarios (chapter 9), and the assessment of the scenarios (chapter 10). In part five, the conclusion, the report is wrapped up. In this part an advice on both the technical and the management aspects will be provided (chapter 11). Moreover, the results and possible future research will be discussed (chapter 12).

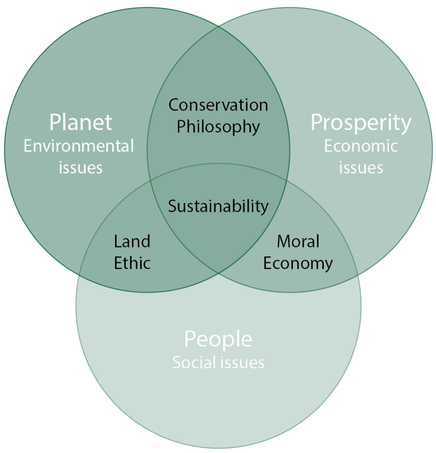


Figure 1.2 | The aspects of sustainability (Yates, 2012)

2. Problem analysis
In order to provide a complete and comprehensive overview of the problem, the problem will be analysed in this chapter. Firstly, an extensive problem description is given, followed by the boundaries of the system and the project. Afterwards, the mission of this project, interpreted by the members of the team, will be discussed. Lastly, the project methodology will be explained with the approach of how to tackle the search for the suitable solutions and de most suitable solution.

2.1. Problem definition
The problem definition for this project is not a straightforward result from how the client defined the problem. It is a result of the problem as stated by the client in combination with an analysis of the coast. As stated in chapter 1, the problem that the client defined concerned the erosion in front of the Mrigadayavan Palace. A site visit, however, showed us that there was no serious erosion problem in front of the palace. After further meetings with the Marine Department, they also acknowledged that there was no problem at the palace site[1]. The site visit and new information from the Marine Department determined that the problems were mainly at Cha-am (Figure 2.1 and Figure 2.2) and an area south of the palace in front of a military base. A revetment and beach nourishment is now being constructed in front of the military base, to deal with that problem. A revetment however is not the ideal solution for this type of situation and it became clear there were procedural issues with the EIA (Environmental Impact Assessment), which made a revetment the preferred solution instead of more functional solutions. Furthermore, beach nourishment seems unnecessary in front of a military base, seeing as there is no tourism. This example calls for a more structural approach to solving the erosion problems and for revising the procedures used for the EIA. For Cha-am, the beach erosion seems to cause concern for most locals in the affected areas, some locals even place their own sandbags at the beach to try and stop the beach erosion (Figure 2.1). Interviews were taken at Cha-am (see Appendix I), which leads us to conclude that locals are affected by the narrowing of the beach mostly in terms of reduced profits from the tourism industry, which is an important source of income for Cha-am.

a.

b.

Figure 2.1 | Problems at Cha-am. (a) Narrow beach at Cha-am, locals have placed sandbags along the beach in an effort to stop the erosion. (b) Steep beach at Cha-am with sandbags emplaces by locals visible, the situation around the tree shows that the beach is receding. Some waste is also visible, which is a problem at Cha-am beach (own pictures).

[1] The current state of the structures preventing the erosion is however doubtful, but as stated in paragraph 2.2 this is not within the scope of this project.

a.

b.

c.

Figure 2.2 | Problems at Cha-am. (a) Beach north of the offshore breakwaters, below in the picture the beach is wider due to a recent nourishment. (b) Farther away it is visible that the beach has completely eroded away. (c) Even further away there are exposed sandbags. These sandbags were placed as part of a recent nourishment, the sand layer covering them has been completely eroded already (own pictures).

The Marine Department has already tried to address the problem with beach nourishments at certain areas south of Cha-am, however the performed nourishments had a much shorter lifetime than was expected prior to construction. The nourishments that were performed seemed to have been performed without a proper design, which might have added to the severity of the problem. This problem has resulted in a subdivision of the problem into:

1. **Large beach nourishment losses.** The executed beach nourishments have been washed away much quicker than was anticipated by the Marine Department, the cause of which is currently unknown. This makes new nourishments necessary much earlier than planned. The Marine Department was concerned that the short lifetime of the beach nourishment is caused by a higher net cross-shore transport than expected. SEATEC concluded in 2001 that net cross-shore transport is negligible.

2. **Erosion.** As stated in the introduction, beach erosion itself is not a problem. However, the impact of the beach erosion can be a problem, as is the case on the coastal stretch between Cha-am and Hua Hin. At this location, the impact of beach erosion has an undesirable effect. The economy in the cities of Cha-am and Hua Hin is for a significant part focused on tourism and the beaches are used to attract both Thai and international tourists. When these beaches become less attractive due to erosion, it is quite probable that fewer tourists will visit the area, which will have a major impact on the local community and is therefore unwanted.

Problem definition
All aspects are summarized in the following problem definition:

Beach erosion on the coastal stretch of Cha-am to Hua Hin has unwanted effects. Tourism is being threatened by the declining beach width and at some points the coastline retreat causes problems for non-tourism related stakeholders. Performed beach nourishments to tackle the problem have had a much lower lifetime than was expected prior to construction. Some hard structures have been constructed at certain points along the coastline, which have met some local success, but the overall problem has not been solved.

A sustainable, long term and integral plan is necessary to cope with the on-going beach erosion. This plan should incorporate managerial aspects such as the stakeholders, risk management, time management, budget planning and decision-making.

2.2. System boundaries

In order to ensure a manageable size of the research project, it was necessary to determine the scope of the project with its boundaries. The determination of the system boundaries gives a clear overview of the problem area and thus of the area which needed to be researched. With a scope that is too broad, it would have been impossible to provide a report with sufficient depth to tackle the problems. With a scope that is too limited, the project would have only solved some local problems and could have caused problems in neighbouring areas. The definition of a clear scope was necessary to outline the objectives of the project and the goals that had to be met to achieve a satisfactory result.

Physical boundaries
The project area, which is illustrated in Figure 2.3, stretches from the Cha-am breakwaters in the north to the rock formation south of Hua Hin and is ca. 30km long. This area is chosen because in the north the longshore transport is mostly blocked by the breakwaters and in the south it is mostly blocked by the rock formation. The current projects around the Mrigadayavan Palace are within the light green box (see Figure 2.3). A much larger area was taken into account, to make it possible to check for new problems which could be created elsewhere by the solutions and either alleviate them or select different solutions. This integral approach is necessary to rebalance this coastal system.

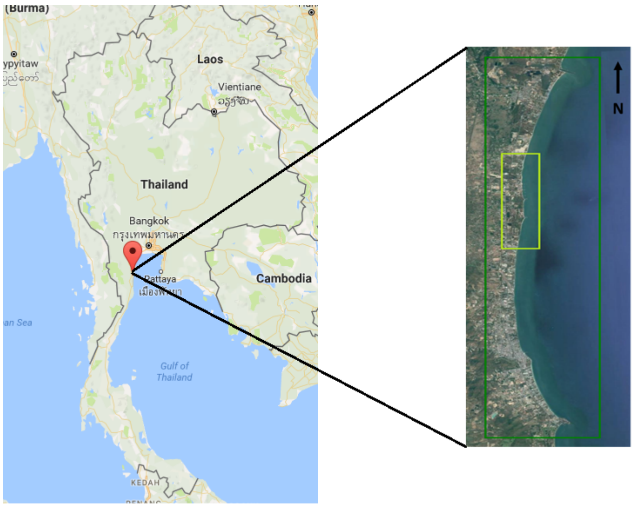


Figure 2.3| The system boundaries (dark green) **and the current project area of the Marine Department** (light green) **(Google Maps, 2016)**

Project management boundaries
From a management point of view, the focus of this research will be on

- the identification of the requirements
- the management of the stakeholders
- the balance of a few of the competing project constraints:
    - scope
    - quality
    - risk

It has to be clear that the results of this research are solely recommendations and need further elaboration, when deciding on implementing them. The first focus, the identification of the requirements, is done in collaboration with the multi-criteria analysis, in which the criteria on which the solutions will be assessed are set up using the requirements. The MCA will also be a way to measure the quality of each solution. Regarding stakeholder management, a general assessment of the involved stakeholders will be made, to end with an advice on how to engage the involved stakeholders. The risk management in this research will consist of a basic identification, analysis and response planning, based on the ATOM methodology. This research will not elaborate on the budget and planning of the alternatives, as the available time for the research is limited as well as the expertise of the team. Furthermore, since the solutions will be in their very early stages of definition and proper research into implementation is not yet done, the given estimates have thus a higher chance of being inaccurate. However, the economic feasibilities of the solutions will be discussed while conducting the multi-criteria analysis (MCA), based on very rough estimates. This research will also not elaborate on Thai legislation and the organizational structure of the Thai government, since the research is conducted by Dutch students with lack of knowledge on this subject. At most, recommendations will be made regarding potential adjustments or legal aspects that might need further research.

2.3.Mission

The mission of this project is to give an advice to the Marine Department on how to manage the coastal erosion occurring on the coastal stretch between Cha-am and Hua Hin. This is a sustainable, long term and integral plan which contains the following items:

- **Mission 1 Beach Nourishment**: An advice on how to perform nourishments and with what return period, as this was specifically requested from the Marine Department.
- **Mission 2 Erosion Solutions**: An advice on how to deal with the erosion problems, a stakeholder management plan on how to involve and engage the stakeholders to limit resistance against measurements and a risk management plan on how to deal with certain risks and their occurrence.

2.4. Methodology

In this paragraph the methodology is explained. The methodology is subdivided in the following objectives:

1. Make a complete problem definition
2. Socio-economic analysis
3. Determine the current state of the coastal stretch.
4. Identify the stakeholders and their involvement.
5. Establish a framework for a suitable solution.
6. Provide a structured way to perform beach nourishments for the Marine Department.
7. Build a model that represents the coastal stretch.
8. Define alternatives and assess them.
9. Assess the alternatives on various aspects.
10. Establish the best alternative(s) to deal with the erosion problem.

The research method to answer the problem can be divided into various phases, they are linked to the parts in which the project is divided.

Part I: Starting phase

In the starting phase, which is the introduction and the problem analysis, the problem is introduced, investigated and a methodology is defined on how to tackle the problem. This part is essential to make a well-structured report, in which all problems are discussed.

Objective 1: Make a complete problem definition

The first objective is to define the problem and clear boundaries. This is important to be able to clearly solve the investigated problem, without a clear definition a clear conclusion cannot be reached. This has been done in the beginning of this chapter.

Part II : Orientation phase

In the orientation phase objectives 2, 3 and 4 form the analysis of the situation and of the context of the problem, which have been performed with the help of a literature study, an analysis of the available data, previously completed researches and interviews/questionnaires with experts and stakeholders. This phase provides a comprehensive understanding of the situation, the problem at hand and the stakeholders involved.

Objective 2: Socio-economic analysis

The socio-economic analysis is conducted to determine the context of the situation and the problem. It will ensure a better understanding of the problem, its history and current state. Literature studies were done on the areas geographical and typological characteristics, climate, history, economy, environment, society, culture and government.

Objective 3: Determine the current state of being of the coastal stretch

In order to determine the current state of the coastal stretch the project team first went on a three-day site visit. During this site visit the project team analysed the coast and conducted interviews to get to know the opinion of the local citizenry and other stakeholders. The project team was guided by the contractor of the current project and officials from the Marine Department along on-going construction operations. Also, the project team took soil samples from which the relevant parameters were determined. The current state was further evaluated using data analysis, a literature research and expert interviews. The data analysis consists of an analysis of (satellite and aerial) images from 1984 up to 2016 (Google Earth, 1984-2016; SEATEC, 2003), an analysis of wave and wind data from the Hua Hin buoy and BMT ARGOSS (2016) and an analysis of the soil samples.

Objective 4: Identify the stakeholders and their involvement

The identification of the stakeholders is done by assessing previously completed researches and similar projects in the area as well as in other countries. Interviews with stakeholders are conducted to gain their perspectives and ideas on the area, problem and possible solutions. Once all the stakeholders are identified, their criticality, typology, power, interest and attitude are determined, in order to finally create a comprehensive overview of the involved stakeholders.

Objective 5: Establish a framework for a suitable solution

In order to ensure a more comprehensive and integral recommended solution, it is important that both the technical and managerial part are integrated. Therefore, the previous objectives are to be combined in an overview that will have the function of a framework regarding the recommended solution. As both the technical and managerial part, but also the operating environment will be involved, the framework should contribute to a solution that is the most suitable for this project.

Part III: Design phase - Mission 1, Beach Nourishment

The design phase is divided into two parts, each with a different mission. The first part includes an analysis on the application of beach nourishments, which gives an approach to perform beach nourishments in the area.

Objective 6: Provide a structured way to perform beach nourishments for the Marine Department
It is expected that a structured approach regarding performing beach nourishments has already been made in other countries, where more experience is available with regard to executing nourishments. Thus a literature study has been performed in order to come to a structured approach regarding beach nourishments for the Marine Department.

Part IV: Design phase - Mission 2, Erosion Solutions

The second part of the design phase contains the building of the model and the definition of the various possible solutions for the problem. Based on the results of the orientation phase, a model is built to create a reproduction of the reality, after which the defined alternatives can be tested in the model. The results of the UNIBEST run show the most technically suitable solution for the problem.

Objective 7: Build a model that represents the coastal stretch
The model was built in the modelling program UNIBEST-CL+. The parameters are based on the results of objective 1. SWAN was used to determine the near shore wave climate. The input for SWAN was the offshore wave climate, which is defined in objective 1. UNIBEST was calibrated and validated with erosion rates as presented in the report of SEATEC (2003), which are based on aerial photographs.
It should be noted that this objective strongly depends on objective 3. When building and running the model, earlier conclusions are tested and when unexpected results occur a new hypothesis is made which is then tested again.

Objective 8: Define alternatives and run them in the model
To come up with alternatives a brainstorm session was organised. The options that were determined during the brainstorm session were subsequently evaluated based on an estimation of their costs and effectiveness, on this basis some alternatives could be eliminated. For the MCA (Multi Criteria Analysis) it was necessary to only have a limited list of options to be able to compare them effectively. Narrowing down our options had to be done in a systemic way, in order to come to the most relevant options. A SWOT (Strength, Weaknesses, Opportunities and Threats) analysis was chosen to shorten the list of options. It was applied to the remaining solutions and was able to distil a few options that have been assessed in later phases.

Part V: Assessment phase - Mission 2, Erosion Solutions

The assessment phase only contains objective 7, in which the various alternatives determined in the previous phase are assessed on other aspects than their technical effectiveness, using risk management and a multi-criteria analysis. The phase's outcome is the most suitable alternative for the problem.

Objective 9: Assess the alternatives on various aspects
The assessment of the alternatives consists of two parts: the risk management and the multi-criteria analysis. The risk management identifies the risks for each solution and determines its probability and impact to finally propose responses to deal with those risks. The results of this parts are the risk registers and conclusions on the severity and acceptability of the risks for each solution, which will be used in the multi-criteria analysis to assign scores for the criteria concerning risks. After the risk management, the solutions were tested based on their functional, sustainable, economic-feasible and social-cultural aspects in the evaluation phase. The multi-criteria analysis is used to determine the most suitable solution for the problem, since it can be used to assess various alternatives based on a variety of criteria. The outcome of this part is a ranking with the solutions the best to the worst solutions for the problem.

Part VI - Conclusive phase

The final phase is the conclusive phase where the conclusions of the design and assessment phases are combined in a final advice plan for the Marine Department. This part thus contains the conclusions, recommendations and discussions of the whole research.

Objective 10: Establish the best alternative(s) to deal with the erosion problem
Lastly, the conclusions and recommendations have been presented in an advice plan for the Marine Department. This plan contains the considered alternatives and an elaboration of the final best-chosen solution(s) for the coastal stretch.

PART II Orientation Phase

3. Socio-economic analysis

An analysis of Thailand has been made in this chapter, including its geographical and typological characteristics, climate, history, economy, environment, society, culture and government. The chapter includes all the relevant information for the project, however, more information on the mentioned topics and less relevant topics can be found in Appendix A. The analysis is necessary to ensure a complete overview of the situation and the problem at matter, as the context for each problem is different from the other.

3.1. Geographical and typographical characteristics

The Kingdom of Thailand is a country in Southeast Asia with Bangkok as its capital. The kingdom is located in the tropical area between latitudes 5° 37′ N to 20° 27′ N and longitudes 97° 22′ E to 105° 37′ E (Climatological Group, 2015). The total area of the country is around 513.000 km^2 of which 0,4% consists of water. It can be seen in Figure 3.1 that the countries adjacent with Thailand are: Myanmar (north and west), Laos (north and east), Cambodia (east) and Malaysia (south). The country is further surrounded by the Gulf of Thailand (east) and the Andaman Sea (west). Thailand shares a total of 4863 kilometres of borderline with its neighbouring countries and a total coastline of 3219 kilometres (Maps of World, 2016). The highest point of Thailand is Doi Inthanon, its summit peaks at 2.576 meter and the lowest point is the Gulf of Thailand at 0 meter. Thus Thailand does not have any land below sea level.

Figure 3.1 | Thailand in Southeast Asia (own ill.)

Cha-am and Hua Hin in the Southern part of Thailand

The district Cha-am is situated in the province Changwat Phetchaburi and the district Hua Hin is situated in the province Prachuap Khiri Khan, both in the Southern part of Thailand. The part is in its turn situated on the Malay Peninsula (Climatological Group, 2015) and contains the narrowest part of the Peninsula, Kra Isthmus in Prachuap Khiri Khan. The province Changwat Phetchaburi is divided into 8 districts, while the province Prachuap Khiri Khan is divided into 7 districts. The east coast of the Southern part is generally dominated by river plains, while the west coast has steep singular hills, caused by erosion of the limestone. Submerged by the rising sea after the last ice age, they now form many islands, such as the well-known Phi Phi Islands. The two coasts are divided by various mountain ranges, of which the most prominent are the Phuket range and the Nakhon Si Thammarat Range.). Further along the peninsula the land fades into mangrove swamps (World Atlas, 2016). The border with Malaysia is formed by the Sankalakhiri range, also known by the Malaysian people as the Titiwangsa Mountains.

3.2. Climate

Figure 3.2 illustrates the tropical climates of Southeast Asia, where the average temperature throughout the year is above 18 °C. The general pattern of the tropical climate is warm temperatures and humid weather with abundant rainfall and thunderstorms in certain periods and areas (Ecoca, 2016). Depending on the type of tropical climate, humidity is variable. The tropical rainforest climate experiences abundant rainfall all year round, while the tropical wet and dry climate experiences seasonal shifts in rain patterns (The British Geographer, 2016).

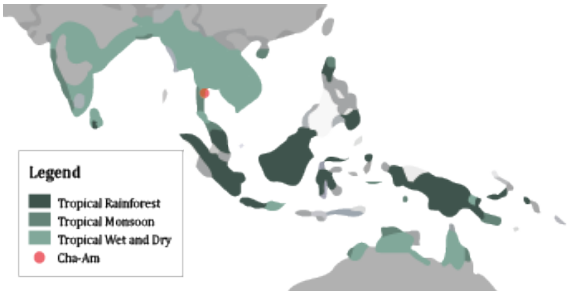


Figure 3.2 | Type of tropical climate areas in Southeast Asia (own ill.)

The Gulf of Thailand experiences two monsoon periods. The southwest monsoon occurs from mid-May to September and the northeast monsoon from November to mid-March (Nuttalaya, 1996). During the monsoon periods, abundant rain occurs. Due to this abundant rainfall, inundation is very common and often causes flooding.

Climate in Cha-am and Hua Hin
As Cha-am and Hua Hin are part of the southern part of Thailand, the climate is generally mild throughout the year. This is mainly due to the region's maritime characteristics. The high temperatures from upper Thailand seldomly occur in the south and the seasonal variations are also significantly less than in upper Thailand. The rainy season in the southern part of Thailand differs from upper Thailand. Both during the southwest and northeast monsoon abundant rain occurs. The abundant rainfall in the southern Thailand east coast peaks in November and remains until January the following year. In most periods during the year, Thailand is covered by warm and moist air. The relative humidity in the southern part of Thailand is relatively higher and reduces during the winter and summer. Moreover, the monsoon system does not only characterize the rainfall and temperatures, but also the pattern of the surface wind. The prevailing winds during the northeast monsoon season are mostly east or northeast in the southern part, while during the southwest monsoon they are south, southwest and west. During the summer, the prevailing wind is mostly south. Moreover, the southern part of Thailand has a relatively high risk of tropical storms and typhoons. By considering the annual mean, tropical cyclones usually move across Thailand about 3-4 times a year (Climatological Group, 2015).

3.3. History

The timeline in Appendix A.3 gives an overview of the history of Thailand, with its different political areas throughout time and important events that occurred. More detailed information on the development of Cha-am and Hua Hin will be given in this section.

Cha-am City
Cha-am City is a city in the Cha-am district, which is part of the Phetchaburi Province. Originally, Cha-am was a fishing village. However, after king Rama VI built his royal palace, Mrigadayavan (which is referred to as "The palace of love and hope"), at the beach of Cha-am, the city received much more attention. The Royal Family and the elite occupied the land in Hua Hin and its surroundings as their holiday destination (Tourism Authority of Thailand, 2003). When the Royal Family commented that Cha-am was just as beautiful as Hua Hin, the city became increasingly popular and developed quickly (Cha-am Homes, 2005). The region has always been very popular among the members of the Royal Family, which is why several other palaces can be found in the region. In the mid '80s, this peaceful fishing village turned into a lively seaside resort, with tall buildings and large resorts arising from the sandy beaches (Thailand Travel, 2016). Nowadays, Cha-am is known among Thai families for being a weekend destination within driving distance from the capital. However, the Thai travellers do not specifically come for the beach but rather for the many good restaurants. Cha-am is also known for the only American International school in Thailand with approximately 300 international students. Also, several national parks including the largest national park in Thailand, Kaeng Krachan, can be found near Cha-am (Reizigersgids, 2012).

Hua Hin
Hua Hin is a city in the Hua Hin District, which is part of the Prachuap Khiri Khan Province. And was also a fishing village from origin. In 1834, some agricultural areas of the neighbouring Province of Phetchaburi were hit by severe drought. A group of farmers moved southward and settled in Hua Hin, which was then

called Samore Riang, meaning "row of anchors", after the fishing boats anchored off the beach (Hua Hin, 2015). Shortly after the World War I, the Southern Railroad was built. This inspired members of the Royal Family and the elite of Bangkok to build bungalows in the area (Tourism Hua Hin, 2016). King Rama VI built the first royal summer palace outside Hua Hin and King Rama VII built another one in Hua Hin, naming it Klai Kangwon Palace (which is referred to as "Far from worries"), which is still in used by the Royal Family (Asia Discovery, 2011). Nowadays, Hua Hin is more popular as ever among Thai and foreign families. Hua Hin has many hotels and resorts and many attractions for the tourists, such as yearly festivals. The locals are extremely proud of their heritage and the town can offer the discerning visitor a glimpse back into Thailand's history with its old colonial buildings and fishing heritage (Tourism Hua Hin, 2016).

3.4. Economy

According to The World Bank (2016a), Thailand is considered an upper-middle economy since 2011 (see Appendix A.4) with a GDP of $395.282 billion. Over the last four decades, Thailand has made remarkable progress in economic development, moving from a low-income to an upper-income country in less than a generation. Also, the annual GDP growth is forecasted to grow to 3.0% in 2018. Thailand has been one of the widely cited development success stories, with sustained strong growth and impressive poverty reduction. Over the last 30 years, the poverty headcount ratio at national poverty lines, as a percentage of the population, has declined from 67% in 1986 to 11% in 2014 (The World Bank, 2016c). However, a revival of domestic demand is necessary. Thailand's economy is operating well below capacity. For example, inflation is far less than the central bank's target and the current-account surplus is strikingly high (about 10% of GDP). The overall shortfall in demand will amount to about 1.4% of GDP at the end of 2016, according to the International Monetary Fund (IMF). As can be seen in the current-account surplus, the gap will be even larger if the foreign tourists' spending is stripped out. Tourism is Thailand's biggest earner of foreign exchange and a major source of employment. In 2013, tourism contributed 9 per cent to GDP and directly employed 2.5 million people, with many more Thais and other industries benefiting indirectly. So, tourism plays a pivotal role in the economy of Thailand and therefore the aim of the government is to boost spending by tourists and urbanites in order to decrease the overall shortfall in domestic demand (Thailand Sustainable Development, 2016a).

Phetchaburi & Prachuap Kiri Khun Provinces

The upper and lower central regions of Thailand are river basins and therefore they are considered as important agricultural societies (OSMEP, 2010). Due to this suitable location not only agricultural activities, such as rice farming and sea and freshwater fisheries, are carried out, but also activities regarding industry and tourism business (Regional Centre of Expertise, 2008). Furthermore, a shift is taking place from agricultural areas in these provinces to industrial areas, because of the proximity to Bangkok. As this is also a possible advantage for investing in other industries, the result is that more and more areas are being turned from agricultural into industrial areas. Additionally, cultural and eco-tourism are present in these provinces. In Cha-am specifically, the Mrigadayavan is an example of the cultural heritage of the country and in Hua Hin the Klai Kangwon Palace. As these palaces are owned by the King, they lead to cultural tourism and related services and souvenir businesses exist. Also, The Sirindhorn International Environmental Park is an example of a business that focuses on eco-tourism, providing several exhibitions regarding energy and the environment (The Sirindhorn International Environmental Park , 2010).

3.5. Environment

Though Thailand is seen as one of the world's top producers of agricultural products, more than 54 per cent of its total land is of a low grade and the amount of soil organic matter is too low nationwide, according to the Land Development Department (LDD). The causes for the poor soil conditions are mostly humans, partially by inexperience and their desire for wealth. Monocropping was a standard in the 1970s, depriving the land of its nutrients. Intensive use of chemical fertilizers also degraded the soil condition. Furthermore, modern farming equipment has compacted the earth and thus prevented penetration of moisture and organic matter. At last, the air pollution, created by coal burning and bunker oil is another contributing factor to degradation. Besides poor soil conditions (The Sirindhorn International Environmental Park, 2016), Thailand also faces soil erosion, indeed caused by the poor soil conditions and the increase in land usage for cultivation. The erosion in turn causes problems for the rivers and streams, as the sedimentation has negative effects for the ecosystems and fisheries. Though coastal erosion mostly has natural causes, other causes than those of the soil erosion, human activities also play a role, e.g. the conversion of mangroves to shrimp and fish farms. Oceans and seas are an important aspect of Thailand, as the country is surrounded by water. Since the Thai seafood industry is one of the biggest of the world and Thailand is loved by the tourists for its aesthetically pleasing beaches and water, its economy thrives on them. Nevertheless, similar to the forests, the oceans and seas are under constant threat of the rapid population growth and economic development (Thailand Sustainable Development, 2016b). Overfishing and pollution are affecting the waters, its flora and fauna and its quality. Water acidification as a result of global warming (oceans absorb carbon emissions) also has an effect on the marine ecosystems, affecting shell-forming animals by for example bleaching the corals and dissolving the animals' shells. This problem also affects the Gulf of Thailand (Olarn & Yu, 2016). Fishing is affecting the waters in various ways (The Sirindhorn International Environmental Park, 2016). There is the problem of competition between fishers, which partly results in overfishing, not letting the ecosystem balance itself out again, and illegal, unregulated and unreported fishing. Another problem are the destructive fishing practices (The Sirindhorn International Environmental Park, 2016)., since these practices affect not only the fish, but also their environment. Bottom trawling has caught other unwanted marine life (by catch), catching endangered species, and destroyed many coral reefs.

3.6. Society

Table 3.1 | Demographics of Thailand (Index Mundi, 2016)

Subject	Numbers
Population	68,200,824
Population growth rate	0.32%
Birth rate	11.1 births/1,000 population
Fertility rate	1.51 children born/woman
Death rate	7.9 deaths/1,000 live births
Life expectancy	74.7 years
Age structure	0-14 years: 17.18% (M: 6.0 mln / F: 5.7 mln)
	15-24 years: 14.47% (M: 5.0 mln / F: 4.8 mln)
	25-54 years: 46.5% (M: 15.7 mln / F: 16.0 mln)
	55-64 years: 11.64% (M: 3.7 mln / F: 4.2 mln)
	65 years and over: 10.21% (M: 3.7 mln / F: 3.9 mln)
Urbanization	Urban population: 50.4% of total population
	Rate of urbanization: 2.79% annual rate of change
Ethnicity	Tai, Malayo-Polynesian, Sino-Tibetan, Hmong-Mien, Austroasiatic
Religions	Buddhist 93.6%, Muslim 4.9%, Christian 1.2%, other 0.2%, none 0.1%
Languages	Thai 90.7%, Burmese 1.3%, other 8%

Public participation

The overall purpose of public participation is to involve those who are affected by a decision in the decision-making process. By involving the public, decision-making is considered to be more sustainable. According to the International Association of Public Participation, public participation is an active, dynamic, process with five key pillars: inform, consult, collaborate, involve, and empower. Up until the 1997 constitution, also People's Charter, the role of Thai citizens in decision-making process had been quite limited. However, nowadays street protests are the main form of public participation. So, both the authorities and Thai people need to learn how to constructively participate in public policy formulation and the decision-making process. The participation process requires reciprocity, communication, conciliation, and respect (Thailand Sustainable Development, 2016b).

Conflict

Currently, Thailand suffers from two key conflicts: one between political fractions known as the red- and yellow shirts, which has resulted in mass street protests the past decade. The other consists of an insurgency in the three deep south provinces of Thailand. Although both of these conflicts generally involve small groups, they have had a serious impact on Thailand's image. Thailand ranked 126 out of 162 countries in the Global Peace Index, with only Myanmar, the Philippines and North Korea below them in the Asian-Pacific region. Nevertheless, Thailand has remained incredibly resilient and even ranked as the world's 10th-most-popular tourist destinations in 2013 and maintained its status as the region's second-strongest economy (Thailand Sustainable Development, 2016c).

Corruption

According to the 2015 Corruption Perceptions Index, Thailand is the 76 least corrupt nation out of 175 countries (Trading Economics, 2016). In Thailand, various forms of corruption exist, ranging from a small bribe of a policeman to the more lavish and infamous form of corruption referred to as "money politics".

The Thai are seemingly tolerant of corruption on a small scale, as 65 per cent of the people surveyed by Transparency International's 2014 Corruption Perceptions Index believe that corruption is okay if they can benefit from it themselves. The "money politics" however, are perceived to trigger public outcry and political instability. This conflict of interest takes place where big money, government and politics intersect and has seriously corroded policy making, governance and arguably the legitimacy of the entire political establishment. The National Anti-Corruption Commission estimates that in certain years almost 30 per cent of the government procurement budget has vanished due to corrupt practices (Thailand Sustainable Development, 2016d).

In order to tackle the on-going corruption, Thailand has set up several agencies, both governmental and independent. Also, the Office Information Act, which is a law aimed at decreasing the corruption, has been enacted since 1997. However, the corruption in Thailand still remains up till this day. In order to eliminate corruption, the private sector and civil society have been taken on the cause as well. For example, the private sector has set up several agencies in order to monitor and implement measures to ensure transparency of procurement projects, raise public awareness and promote actions against corruption (Thailand Sustainable Development, 2016d).

3.7. Culture

Thailand has produced one of the world's richest and most varied cultures with a more than 700-year old history. The ancient capitals of Sukhothai and Ayutthaya are a visible layer of Thailand's ancient past and the remnants of the past can still be witnessed in the rituals maintained by Thailand's monarchy. Preserving such a heritage, while taken into account the globalisation, is a complex matter and both the tangible and intangible cultural heritage will face constant pressure from the new generation Thai who are less interested in the past. Also, more and more businessmen rather look for new opportunities to expand their businesses than preserve the cultural heritage. This results in locals that have to fight to preserve their districts. However, government policies and recognition from international bodies such as UNESCO have helped to keep major cultural landmark from falling prey to developers, while at the local level people have banded together to use the elaboration offered by social media to ensure their voices are heard. This also increased awareness around the need for more people-centred development that also respects cultural heritage (Thailand Sustainable Development, 2016e).

In order to determine how values in the workplace are influenced by culture, we use the study of Geert Hofstede, who defines culture as "the collective programming of the mind distinguishing the members of one group or category of people from others". Together with Gert Jan Hofstede and Michael Minkov, six dimensions of national culture were established, which represent independent preferences for one state of affairs over another that distinguishes countries rather than individuals from each other (Hofstede, Hofstede & Minkov, 2010). The scores on the dimensions are relative, seeing as culture can be only used meaningfully by comparison (Hofstede, 2010a). In order to gain a better understanding, Thailand has been compared to The Netherlands of which the scores can be seen in Figure 3.3 and the explanation can be found in Appendix A.7.

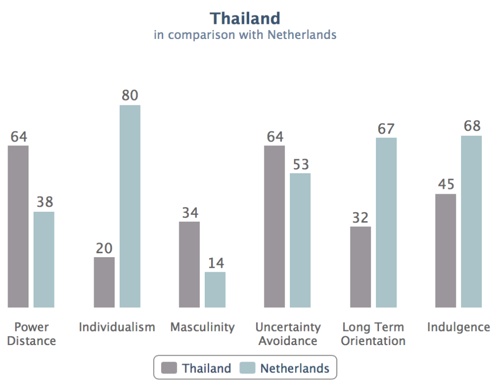


Figure 3.3 | Cross cultural differences of Thailand vs. Netherlands (Hofstede, 2010a)

3.8. Government

The Government of Thailand is composed of three branches: executive, legislative and judiciary.

Executive branch
The executive branch of the Government of Thailand is composed of the Office of the Prime Minister (OPM) and the Cabinet, which in its turn consists of 14 cabinet ministries, each led by its own minister (Thai Law Forum, n.d.).

The ministries and the bureaus are divided into departments and each department is led by a director general. The Cabinet of Thailand, also known as the Council of Ministers of Thailand is the primary organ of the executive branch and chaired by the Prime Minister (Thailand Legal, 2016). It is responsible for the formulation and execution of policies of the government and the administration and management of various government agencies and departments. Furthermore, the cabinet is allowed to submit bills to the National Assembly for consideration, to call and join a joint sitting of the National Assembly to consider an important bill, and to call a national referendum.

The Prime Minister is the head of the government, head of the executive branch, leader of the Cabinet and often the leader of the largest (coalition) party in the lower house of parliament (Thai Law Forum, n.d.). As in accordance with the constitution, the Prime Minister is selected firstly by an election in the lower house, and then officially appointed by the King. As the leader of the Cabinet, the Prime Minister can appoint or remove any minister in the Cabinet. The current Prime Minister is General Prayut Chan-o-cha, the leader of the military coup of 22 May 2014 and is not selected in the lower house nor appointed by the King.

The executive branch of the Government of Thailand can be divided into three levels: central, provincial and local (Thailand Legal, 2016). The central government concerns the ministries, bureaus and departments. The provincial government consists of the provinces, which are led by a governor appointed by the Ministry of Interior. The provinces are divided in districts and for each province there is one capital district. In turn, each district is led by a district chief. Finally, the local governments are the ordinary local government and the special local government, of which the special local government is established in certain areas, such as Bangkok and Pattaya.

Legislative branch (Parliament of Thailand)
The legislative branch of the Government of Thailand was the National Assembly of Thailand (NAT), a bicameral legislature, composed of two houses: the Senate (150 members) and the House of Representatives (500 members) (Hierarchy Structure, 2013). The houses met at the Parliament House of Thailand.

The upper house of the legislative branch is the Senate, which is strictly non-partisan, as members are not allowed to be a member of a party, the House of Representatives, the judiciary or the Cabinet for 5 years (Thai Law Forum, n.d.). Though the Senate has little legislative power, it power lies in advising the appointments of members of the judiciary and independent government agencies. The president of the Senate is also the vice-president of the National Assembly. The Senate sits for a term of six years and can not be dissolved.

The lower house of the legislative branch is the House of Representatives and the primary legislative house of the government of Thailand with seven political parties. Through the vote of no confidence, the house has the power to remove the prime minister as well as the cabinet ministers. The leader of the House is the Speaker of the House, who is also the President of the National Assembly. The House of Representatives sits for a term of four years, but can be dissolved in advance.

After the 22 May 2014 military coup the Senate and the House of Representatives have been abolished according to the interim Constitution of Thailand, composed by NCPO. Its responsibilities are now assumed by the National Legislative Council, appointed by NCPO.

Judiciary branch
The judiciary branch of the Government of Thailand consists of all courts in Thailand and is composed of four systems: the Court of Justice system, the Administrative Court system, the Constitutional Court and the Military Court. These bodies are all independent, intended to check and balance both the Executive and Legislative branches of the government (Thailand Law Forum, n.d.)

The largest court system in Thailand is the Courts of Justice of Thailand and consists of 3 tiers: the Court of First Instance, the Court of Appeals and the Supreme Court of Justice of Thailand. The latter is the highest court of Thailand and thus all its decisions are final and executory (Thailand Legal, 2016). The Court of Appeals handles appeals on the decisions or orders of the lower courts and is mandated to affirm, correct, reverse or dismiss the decisions made by the Court of First Instance. The Court of First Instance is the lowest of the tiers and consists of ordinary courts that decide and adjudicate civil and criminal cases. Courts of the Capital of Bangkok, Provincial Courts, Juvenile and Family Courts, and Specialized Courts are all included in this tier.

The Administrative Court system consists of two layers: the Administrative Courts of First Instance and the Supreme Administrative Court. The system is created to form a connection between the state or an organ of state and the private citizens.

The Constitutional Court (9 positions) was set up to settle matters pertaining to the constitution, including the constitutionality of parliamentary acts, royal decrees, draft legislation, appointment and removal of public officials and issues regarding political parties. Its decisions are final and definite, and bind every state organ.

The Military Court hears cases against the military personnel who committed crimes against the law.

With the new Interim Constitution of 2014, under section 44, it is legal and constitutional for the Prime Minister and NCPO lead to have complete authority to perform any administrative, legislative and judicial action as necessary.

4. Coastal analysis

In this chapter the coastal stretch is analysed. First a general classification of the Thai coast and, more specifically, the project area are given. Secondly, the causes of coastal erosion will be presented. The third paragraph gives a more detailed data analysis of the coast. This will contain information about the size of the coastal stretch, the bathymetry, and sediment, wind, wave and tidal data. Next, the most important coastal features and structures will be discussed. Lastly, the land use of the coast will be given.

4.1. General classification

In this paragraph a coastal characterisation of the Thai coast bordering the Gulf of Thailand is given. Furthermore, information is given regarding the winds and ocean circulation, the tides and the wave climate in the Gulf of Thailand. Also sea level rise in the Gulf of Thailand is discussed.

Coastal characterisation

The project area, which can be found in the black box in Figure 4.1b, lies in a distinct part of the Gulf of Thailand, which is generally known as the Upper Gulf of Thailand. According to Saramul and Ezer (2014) this is a 'shallow estuarine-like system'. The beaches at the Gulf of Thailand consist of mud to sand. Near the project area the beaches can be categorised as sand beaches with further offshore areas of sandy silt, silty sand and clayey silt (Figure 4.1, which is north of our project area) (Negri, Sanflippo, Basso, & Rosso, 2015). Closer to Bangkok extensive mangrove areas are present of which a lot is lost in favour of shrimp farming. The coast at the project area is wave-dominated with a strong longshore current. This can be concluded from the sand spit that is formed north of the project area (Figure 4.1). One can also notice the curved shape of the area, which will result in significant differences in sediment transport (Figure 4.1b).

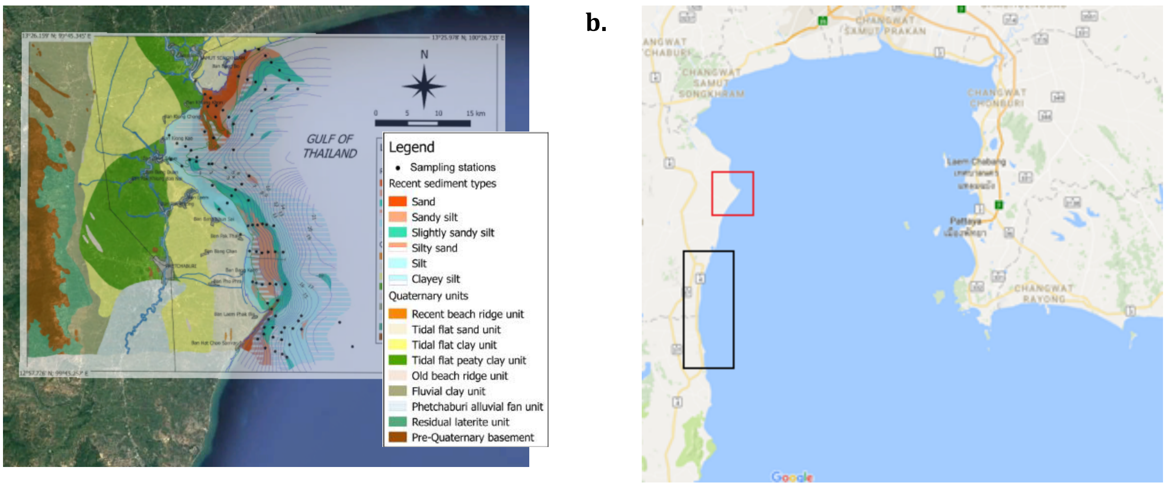


Figure 4.1 | Coastal characterisation. (a) Soil types north of the project site (Negri et. al, 2015). (b) The location of the sand spit (red box) and the project area (black box) in the upper Gulf of Thailand (Google maps, 2016)

Winds and circulation

The Gulf of Thailand knows two monsoon periods. The southwest monsoon occurs from mid-May to September and the northeast monsoon from November to mid-March. This seasonality has an important impact on the coast. Sediment transport will generally switch direction in both monsoon periods (Nuttalaya, 1996). However, sediment transport magnitude differs along the coast since the coastal orientation differs per coastal section (Figure 4.1b).

The circulation in the Gulf of Thailand can be classified as complex. Saramul and Ezer (2014) mention the circulation driven by tides, river runoffs and monsoonal winds. Nuttalaya (1996) extends this with circulation driven by heavy precipitation and density gradients. There also exist locations of upwelling and down welling, which makes the situation even more complex (Nuttalaya, 1996). Pongsapipatt and Sapsomwong (as cited in Nuttalaya, 1996) concluded that due to the different monsoons the circulation of the surface waters change direction. From October the direction is counter-clockwise, but when the water mass of the South China Sea enters the Gulf during the southwest monsoon, the direction becomes clockwise. The water mass follows the western coast and results in a strong northward flow, which changes the direction of the surface circulation. At the eastern side of the Gulf, less saline and cooler water flows out of the Gulf. Besides this, heavy precipitation can result in a layer of fresh water on top of the saltier seawater. The aforementioned 3D effects on the sediment transport are, however, not within the scope of the present research in which we use the model UNIBEST-CL+. The existence of these processes is kept in mind in case the model and reality do not agree. However, further research on these effects is recommended.

Tidal character

The tidal character in the Gulf of Thailand ranges between diurnal tide and a mixed, semi-diurnal tide. The influence of the four major tidal constituents (K_1, O_1, M_2, S_2) can be expressed with a Form Factor (F):

$$F = \frac{(K_1 + O_1)}{(M_2 + S_2)}$$

Where:

- K_1 is the diurnal principal declination tide
- O_1 is the diurnal principal lunar tide
- M_2 is the semi-diurnal principal lunar tide
- S_2 is the semi-diurnal principal solar tide

If F is smaller than 0.25, the tide has a semi-diurnal character, if F is between 0.25 and 1.5 the tide has a mixed, semi-diurnal character. When F is between 1.5 and 3, the tide is classified as a mixed, diurnal tide and if F is larger than 3, the tide has a diurnal character. For fifteen locations along the Gulf of Thailand this form factor was calculated to determine the tidal character (Table 4.1). Location 8 (Hua Hin) is inside the project area, which means we are dealing with a mixed, mainly diurnal tide. In Figure 4.2, measurements of the water level for the month of January 2002 are shown for this location (Aungsakul, Jaroensutasinee, & Jaroensutasinee, 2007). The difference between mean high water (MHW) and mean low water (MLW) at the project site is 1.53m (Department of Marine and Coastal Resources, 2013).

Table 4.1 | Form Factors and tidal types for 15 locations along the Gulf of Thailand. Starting at location 1, the most eastern point bordering the Gulf, following the Gulf counter clockwise and ending at location 15, the most southern point of Thailand bordering the Gulf (Aungsakul et. al, 2007).

No.	Station (City, Province)	Form Factor (F)	Tide Type
1	Laemngob, Trat	4.6	Diurnal
2	Laemsing, Chanthaburi	4.8	Diurnal
3	Paknam Rayong, Rayong	3.6	Diurnal
4	Bangpakong, Chachoengsao	1.3	Mixed, Semidiurnal
5	Royal Thai Navy Headquarters	1.1	Mixed, Semidiurnal
6	Paknam Thachin, Samut Sakhon	1.4	Mixed, Semidiurnal
7	Paknam Maeklong, Samut Songkhram	1.4	Mixed, Semidiurnal
8	Huahin, Prachuap Khiri Khan	2.2	Mixed, Semidiurnal
9	Ko Lak, Prachuap Khiri Khan	16.7	Diurnal
10	Ko Mattaphon, Chumphon	4.5	Diurnal
11	Ko Prap, Surat Thani	2.2	Mixed, Diurnal
12	Pakpanang, Nakhon Si Thammarat	1.0	Mixed, Semidiurnal
13	Songkhla	0.7	Mixed, Semidiurnal
14	Paknam Pattani, Pattani	0.8	Mixed, Semidiurnal
15	Paknam Bangnara, Narathiwat	1.6	Mixed, Diurnal

Wave climate

The Gulf of Thailand is sheltered from large waves due to the presence of land masses (Malaysia, Indonesia and the Philippines) in front of the entrance. Furthermore, the Gulf is also relatively shallow. This means that the wave climate inside the Gulf is mild. The dominant wave directions are dependent on the dominant wind directions. The seasonality of the wind climate results also in seasonality of the wave climate. The dominant wave direction at the project area during the northeast monsoon (November-March) is north northeast, the dominant wave direction during the southwest monsoon (May-September) is south southwest, in the other months the dominant wave direction is south (SEATEC, 2003). The coastal section Cha-am/Hua Hin is sheltered from both directions.

Sea level rise

Sea level rise gets a lot of attention nowadays, however many studies contradict each other regarding absolute sea level rise in the Gulf of Thailand (Saramul & Ezer, 2014). A relative sea level rise is however noticed by Nuttalaya (1996). The land is subsiding due to gas, oil and mainly groundwater extraction.

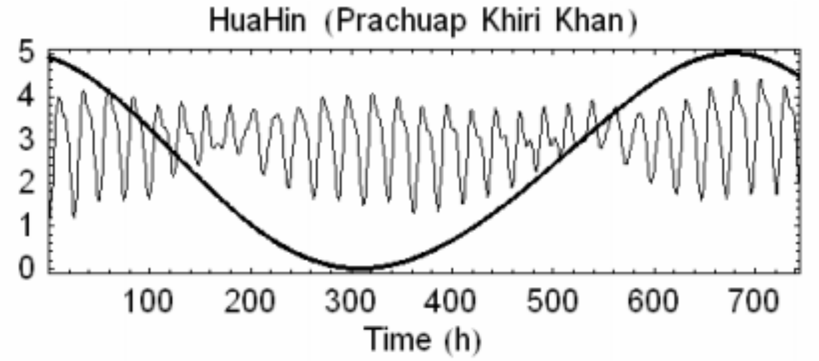


Figure 4.2 | Measurements of the water level (01-2002) at Hua Hin (water level in meters on the y-axis and the moon phase (thick line) (Aungsakul et. al, 2007)

Storms

Tropical storms[2] can enter the Upper Gulf of Thailand in the rainy season; this is in the months October till December when the storms are weakened (Vongvisessomjai, 2009a). Paths of tropical storms are shown in Figure 4.3. Between 1951 and 2014, eighteen tropical storms have been observed. Ten of these had a wind speed lower than 17.5m/s, seven had a wind speed between 17.5m/s and 32.8m/s and one had a wind speed higher than 32.8m/s (Department of Marine and Coastal Resources, 2013). 50% of these storms occurred in October and 33% in November. The maximum measured wave height at the Hua Hin buoy[3] is 2.5m.

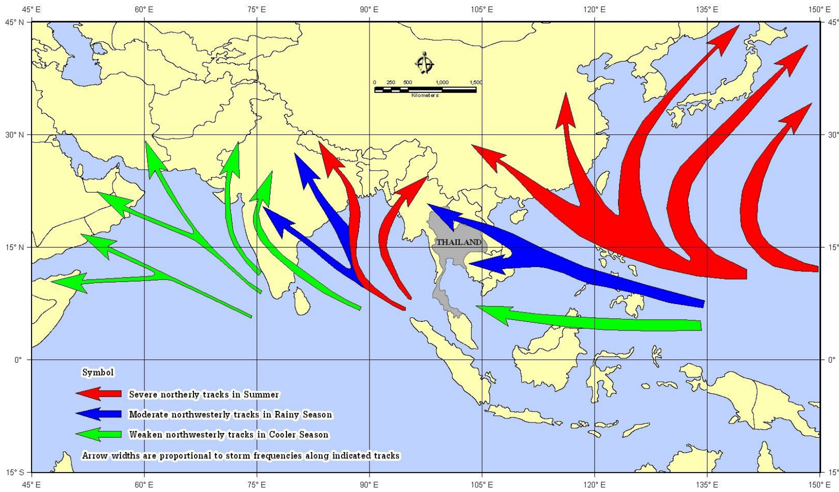


Figure 4.3 | Path of tropical storms (Vongvisessomjai, 2009a)

4.2. Causes of erosion

There are several reasons for coastal erosion in the Gulf of Thailand. Possible causes are the decrease in sediment yield from rivers, coastal structures blocking longshore transport, relative sea level rise and storms (Negri et. al, 2015). One of the major reasons is the disappearing of mangrove forests, but the project area contains no natural mangrove forests, so this is not the cause of erosion in the project area. Dams in rivers can cause a decrease in sediment yield from rivers. Near the project site two main rivers are located, namely the Phetchaburi River and the Pranburi River. Both rivers are however small with a mean discharge of 44.04m^3/s and 14.05m^3/s respectively (SEATEC, 2003). The sediment yield of these rivers is not expected to be high and the rivers are located at some distance from the project area. Therefore the effects on the coastal erosion will be neglected.

[2] In this report we refer to tropical storms in general. Other sources might make a distinction between depression, tropical storm and cyclone (or typhoon).

[3] Location in UTM: 47P, 628206 east, 1385448 north.

In the project area several coastal structures have been built. A lot of these structures block the longshore transport partially. This results in erosion of the downstream coast. This is thought to be one of the major causes of erosion. More information about these structures in the project area is given in paragraph 4.4. Like stated in paragraph 4.1. there is a relative sea level rise in the Gulf of Thailand. Relative sea level rise results in a landward moving coastline, which means that beaches become smaller. Research from Sojisuporn, Sangmanee, and Wattayakorn (2013) shows that in the period 1992-2004 the tide gauge closest to the project area (Pranburi gauge[4], data gathered from 1992 up to 2004) recorded a relative sea level rise of 5cm. On average this is 0.38cm/year. This dataset is however not very long and fluctuates throughout the years. It is therefore debatable if the relative sea level rise has a major influence on the coastal erosion of the project area.

Storms have a large impact on the coastal profile. Storms are often accompanied by a rise in still water level, the so-called storm surge. This increase in still water level plus the heavier wave attack causes the coastal profile to be reshaped. Sediment is carried offshore due to the storm. During milder wave conditions this sediment is slowly transported back onshore. Losses can however still occur, for example when the sediment is transported too far offshore. Another important effect is that the beach becomes smaller which makes the coast more vulnerable for a next storm. The total impact of storms is probably small, because the eroded sand does not leave the system and eventually returns to shore.

4.3. Coastal data analysis

In this paragraph the coastal stretch will be analysed. The data used was obtained through the SEATEC report, the report of the Department of Marine and Coastal Resources, own measurements, data from the Marine Department, data from Navionics (2016), buoy data and data from BMT ARGOSS (2016). Per subject the source of the data will be mentioned.

Orientation and bathymetry

The project area is divided into five main sections (Figure 4.4a). Each section has two subsections, which have more or less the same orientation. The total length is ±34km. Table 4.2 gives the length and orientation per subsection. The bathymetry up to a depth of seven meters that will be used comes from the SEATEC (2003) report and it is extended with the use of Navionics when necessary. This is two or three times the 1/1 year significant wave height (UNIBEST manual, 2011). If a longer time period is simulated, the active profile height is larger. Therefore, three times the 1/1 year significant wave height was taken, which resulted in an active profile height of 6.75m. These profiles are linked to the five sections and are representative for the entire section (Figure 4.4b). In total five cross shore profiles are used. For the rest of the area a detailed bathymetry profile is used which is shown in Figure 4.4c and d.

Table 4.2 | Section orientation and length. Sections are listed in **Figure 4.3**. Orientation and length are determined using Google Earth (2016).

Section	Orientation (w.r.t. °N)	Length (km)
1.a.	19	8.8
1.b.	0.9	3.5
2.a.	2.2	2.0
2.b.	10.3	1.7
3.a.	7.1	5.8
3.b.	357.2	5.3
4.a.	328	1.1
4.b.	5.3	0.3
5.a.	352.6	2.9
5.b.	334.8	2.5

[4] location in UTM: 47P, 607631 east, 1371298 north.

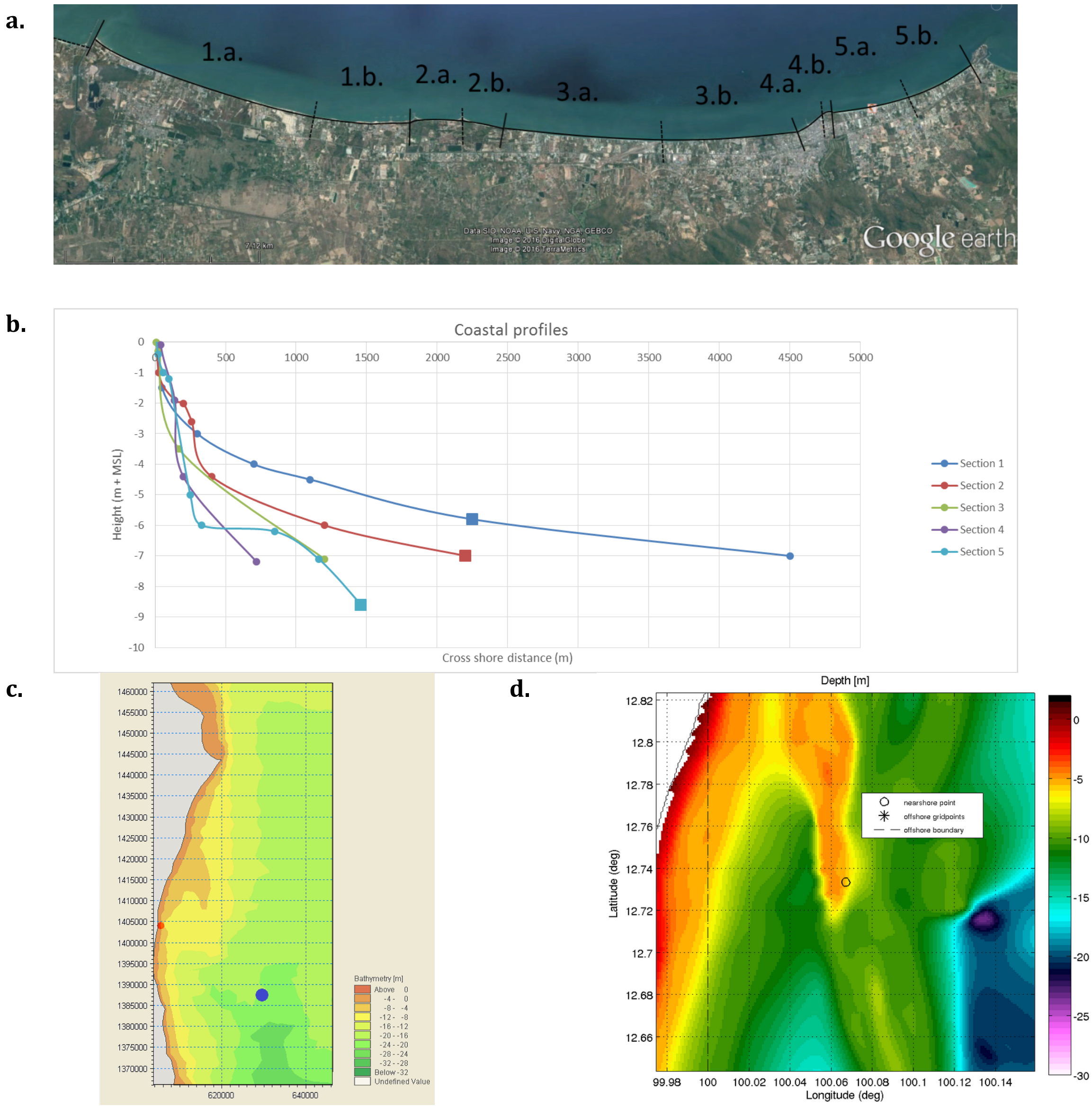


Figure 4.4 | Subsections with their coastal profile and offshore bathymetry. (a) The different subsections (Google Earth, 2016). (b) Representative coastal profiles for the different sections (to square marker: SEATEC (2003) data; from square marker: Navionics (2016) data). (c) Bathymetry data from the Department of Marine and Coastal Resources as used for the simulations, the Hua Hin buoy is located at the blue dot. The red dot represents the palace. (d) The data from BMT ARGOSS (2016) used for comparison.

Sediment transport

Sediment transport occurs due to the fact that the coastal stretch wants to reach an equilibrium situation; this equilibrium angle is however never reached since the conditions always change. Sediment transport can be divided into longshore and cross shore transport and this results in either erosion or accretion (see Appendix F). In Table 4.3 information is given on transport amounts in the project area. A positive value for the net longshore sediment transport stands for net northward transport, a negative value for southward transport. A positive value for the accretion rate means that accretion occurs, a negative value stands for erosion. (SEATEC, 2003). The data from Table 4.3 is in the same order of magnitude as the data from the Department of Natural Resources (2011). They however show that the erosion rate south and north of the jetties increased after construction. The erosion rate north of the jetty in the period 2008-2011 is on average 1.33 m/year; south of the jetty this is 1.75 m/year. Close to the jetty accretion occurs due to the blockage of longshore transport. On the north side of the northern jetty the accretion rate is in the same period on average 3.68 m/year and the accretion rate on the south side of the southern jetty 5.81 m/year.

Table 4.3 | Accretion rate according to SEATEC, 2003. The values from the accretion rate are determined with GIS images over the period 1975-1994

Section	Accretion rate (m/year)
1.a.	North: 4.7 South: -0.41
1.b.	North: -0.44 South: -0.65
2.a.	North: -0.65 South: -1.11
2.b.	-1.11
3.a.	-1.11
3.b.	No data
4.a.	0.50
4.b.	0.50
5.a.	No data
5.b.	-0.28

No cross shore sediment data was available. Cross shore sediment transport is dependent on the velocities caused by different processes. In the surf zone undertow, bound and free long waves, and the short wave skewness in combination with breaking-induced turbulence are important. In the middle and lower shoreface boundary layer streaming, bound long waves and short wave skewness are important (see Appendix F). Upwelling and down welling due to stratification and Ekman currents can also have an effect. During extreme conditions the undertow and boundary layer processes are dominant and cause an offshore directed transport. During mild conditions the wave skewness is dominant, which results in an onshore directed transport. When averaged over time, the transport will be more or less zero. This means that the sediment will not leave the active zone of the profile (Bosboom & Stive, 2015). It is however possible that continual retreat (due to storms) of the upper beach face occurs (Tilmans, Klomp, & de Vroeg, 1993). Therefore it is advised to use a numerical model to calculate the cross shore transport rates. Examples of models are the TC-module of UNIBEST (Delft Hydraulics, now Deltares) and SBEACH developed by the US Army Corps of Engineers. The sediment data was mainly obtained through own measurements (see Appendix F), and complemented with data obtained from the report of SEATEC (2003). For each subsection (Figure 4.4a) 3 diameters are determined (Table 4.4). Also the suspended sediment diameter is determined. This diameter is calculated with:

$$D_{ss} = \begin{cases} D_{50}, & D_{50} < 150\mu m \\ 0.8D_{50}, & D_{50} \geq 300\mu m \end{cases}$$

For a D_{50} between 150 and 300µm a gradual scale was used to determine the D_{SS}.

Table 4.4 | Sediment diameters determined from sieve tests and the diameters used in the model (see Appendix F)

Section	$D_{10,\,model}$ (µm)	$D_{50,\,model}$ (µm)	$D_{90,\,model}$ (µm)	D_{SS} (µm)
1a	280	430	820	334
1b	205	340	560	272
2a	168	270	500	226.8
2b	210	360	510	288
3a	153	250	426	217.5
3b	153	250	426	217.5
4a	153	250	426	217.5
4b	153	250	426	217.5
5a	153	250	426	217.5
5b	153	250	426	217.5

Wave parameters are the most important parameters in determining the magnitude and direction of the sediment transport. The wave data is strongly dependent on the wind data and the bathymetry. Therefore every dataset is translated into a sediment transport magnitude and direction and compared with the data of Table 4.3. The translation into sediment transport magnitude and direction is done using simple calculations but also using a more extensive calculation with UNIBEST-CL+. The dataset that describes the sediment transport on the coastal section best is the wave and wind data of the Hua Hin buoy[5] in combination with a detailed bathymetry dataset from the Department of Marine and Coastal Resources (Figure 4.4c). The dataset from BMT ARGOSS (2016) is summarised in the roses of Figure 4.5**.** This dataset did not deliver satisfactory sediment transport results, possibly because it did not contain storm data and possibly because no clear link between wave and wind data could be made. Since the wave evolution in the Gulf is strongly dependent on the wind conditions this link is very important. Storms can also be of significant influence in sediment transport as explained in paragraph 4.1.

Table 4.5 shows the data from the Hua Hin buoy (for location see Figure 4.4c, depth at the location is 20 meters), which is used for further calculations. This data delivered the best results on sediment transport. Since the wave direction was not measured by the buoy, further calculations are based on the assumption that waves come from the same direction as the wind. This assumption is generally true but Figure 4.5 also shows waves coming from a direction, which does not correspond with a wind direction. New buoy measurements including wave directions could overcome this problem. What is remarkable in both datasets is that only half of the wave conditions come from a direction, which is relevant for the coastal section (0 up to 180 degrees). The other half comes from the direction of the coast and is thus generated by winds coming from land (see Table 4.6). Vongvisessomjai (2009b) used the data from the Hua Hin buoy to conclude that during the northeast monsoon period waves come from the NE (12%, NNE (11%) and ENE (5%). During the southwest monsoon waves originate from WSW (15%), W (12%) and SW (9%). During the southwest monsoon period 98.5% of the waves is lower than 0.5 meter. The waves of this monsoon period are not taken into account in the present research since their direction is offshore.

Table 4.5 | Wave and wind data for relevant directions. Data from Hua Hin buoy years 1996 and 1998. The direction in the table is the middle of the directional bin (for example 0 is middle of bin 350-10 degrees), direction is given in nautical convention, 0 is north, and 180 is south. The displayed significant wave height is the averaged value in the bin. For the wave height the bins were 0-0.5, 0.5-1.0, 1.0-1.5, 1.5-2.0, >2.0. The displayed wind speed is the averaged winds speed in the bin based on direction and significant wave height. The buoy did not measure the wave period, the wave period is therefore determined using an educated guess based on BMT ARGOSS (2016).

Direction (degrees)	Average H_{sig} in bin (m)	Wind speed (m/s)	Duration (%)	T (s)	Direction (degrees)	Average H_{sig} in bin (m)	Wind speed (m/s)	Duration (%)	T (s)
0.0	0.3	3.5	2.5	3.5	80.0	0.4	2.4	0.9	3.5
0.0	0.7	5.5	2.3	3.5	80.0	0.8	2.8	0.1	3.5
0.0	1.2	8.0	1.0	3.8	100.0	0.3	2.9	1.1	3.5
0.0	1.7	8.6	0.3	4.0	100.0	0.9	0.9	0.1	3.5
20.0	0.3	3.4	2.3	3.5	100.0	2.0	6.1	0.1	4.0
20.0	0.8	5.5	1.7	3.5	120.0	0.3	3.5	2.0	3.5
20.0	1.1	8.4	0.5	3.8	120.0	0.7	1.9	0.2	3.5
20.0	1.6	9.1	0.1	4.0	140.0	0.3	3.7	3.0	3.5
40.0	0.3	3.5	1.5	3.5	140.0	0.7	5.2	0.7	3.5
40.0	0.8	6.1	1.0	3.5	160.0	0.4	4.7	6.7	3.5
40.0	1.2	6.3	0.3	3.8	160.0	0.7	5.7	2.4	3.5
40.0	2.0	7.5	0.1	4.0	160.0	1.2	4.2	0.1	3.8
60.0	0.3	3.3	1.3	3.5	180.0	0.4	4.3	7.0	3.5
60.0	0.8	5.5	0.2	3.5	180.0	0.7	5.6	7.2	3.5
60.0	1.3	8.2	0.1	3.8	180.0	1.1	5.3	0.3	3.8
60.0	1.7	6.1	0.1	4.0					

[5] Location in UTM: 47P, 628206 east, 1385448 north.

Table 4.6 | Wind data from the Hua Hin buoy in the year of 1996.

Wind direction (degrees)	Average wind speed (m/s)	Occurrence (%)
0	4.8890	11.3450
45	4.2968	5.2361
90	2.4954	2.4641
135	3.7856	7.7515
180	4.7170	26.2320
225	3.9447	25.5133
270	3.7351	15.6571
315	3.2855	5.8008

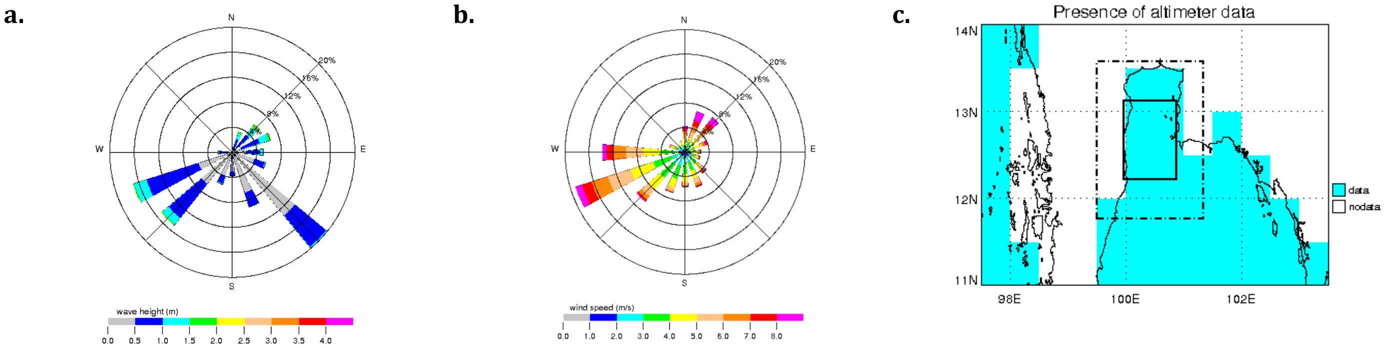


Figure 4.5 | Wave and wind rose from BMT ARGOSS (2016). (a) Wave rose (b) Wind rose (c) Location of data.

Table 4.7 | Tidal elevation information (Department of Marine and Coastal Resources, 2013)

	Water level w.r.t MSL (m)	
Tidal elevation	Pranburi station	Ban Laem
Highest high water (HHW)	+1.70	+2.59
Mean highest high water (MHHW)	+0.85	+1.19
Mean high water spring (MHWS)	+0.83	+1.25
Mean high water (MHW)	+0.80	+1.01
Mean high water neap (MHWN)	+0.76	+0.90
Mean lowest high water (MLHW)	+0.38	+0.70
Local mean sea level (MSL)	+0.10	+0.11
Mean tidal level (MTL)	+0.04	+0.12
Mean highest low water (MHLW)	-0.12	-0.10
Mean low water neap (MLWN)	-0.61	-0.79
Mean low water (MLW)	-0.73	-0.78
Mean low water spring (MLWS)	-0.95	-1.07
Mean lowest low water (MLLW	-0.82	-1.19
Lowest low water (LLW)	-1.81	-2.29
Mean range (MN)	1.53	1.79

Tide data

As stated in paragraph 4.1 the tidal type in the project area is mixed, mainly diurnal. The data of both the tidal elevation as the current velocities is retrieved from the report of the Department of Marine and Coastal Resources. Two stations were used to determine the elevation of the different tides (Table 4.7). The tidal currents were measured by the Department of Marine and Coastal resources in a ten-day measurement campaign 600 meters offshore. The depth of measurements was 0.8 times the water depth, which was 4.5m. The measurements were thus executed on a depth of 3.6m. Also, the water level elevation was measured during the same period (Figure 4.5).

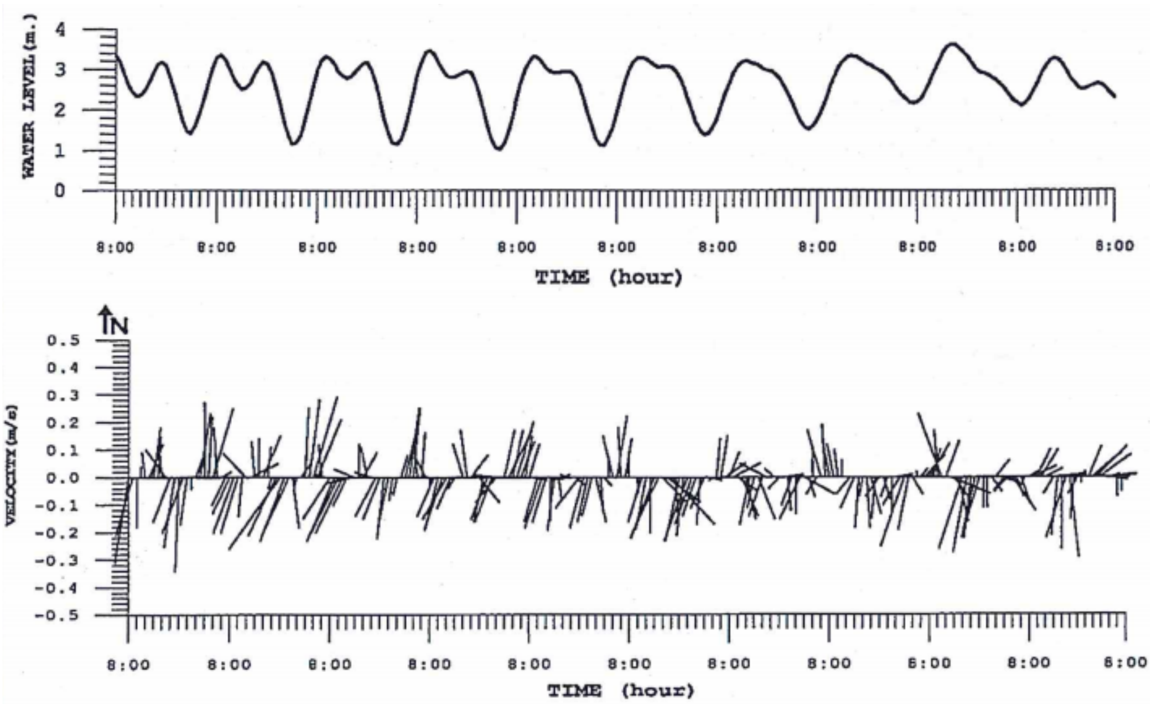


Figure 4.6 | Water level elevation and current velocities and directions (Department of Marine and Coastal Resources, 2013)

4.4. Coastal features and structures

Along the coast several constructions have been built and some nourishments were performed. First the most remarkable coastal features are described after which the interventions before 2005 (the start date of the current project) are discussed. Then the interventions of the on-going project are presented. The current state of these structures is discussed in Appendix B.3.

Coastal features

In the area there is one coastal feature that stands out. This is the, sort of, headland just south of the fish pier at Hua Hin. When the headland would be removed, a nice smooth coastline would be the result (Figure 4.7a). Therefore this feature is analysed more detailed. This is done using photographs from Google Earth (2016) and the Marine Department (2016), both aerial as land based. The photographs show quite a lot of rocks in the water (Figure 4.7band c). These rocks look like they are there naturally. Behind some rocks a salient is formed (Figure 4.7c). This shows that the rocks cause dissipation of wave energy. It is also possible that these rocks block part of the longshore transport, which results into accretion. This alone should not result in such a headland. Therefore we believe that underneath the sand there is a rock layer that cannot be eroded. We also believe that the bathymetry might be such that the waves refract towards the headland. Either extra care has to be taken when modelling this part of the coast, or a straight coastline can be used as simplification.

a.

b.

c.

Figure 4.7 | Photos of the headland (Google Earth, 2016). (a) Aerial photograph of the headland, showing a smooth coastline when the headland is removed. (b) Aerial photograph during low tide showing rocks in front of the coast. (c) Photograph of a tombolo/salient formed behind the rocks.

Interventions before 2005

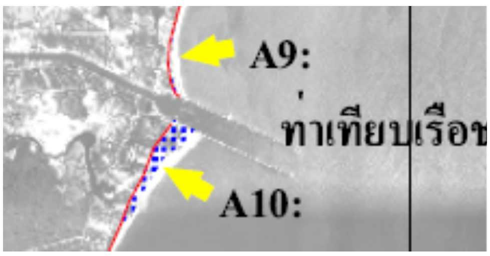
The structures that have been built before 2005 are breakwaters, piers, revetments and seawalls. Per structure the implementation in UNIBEST-CL+ is also discussed. The breakwaters for the fishing port of Cha-am were constructed in 1968. These long breakwaters have a significant effect on the area, cutting off longshore transport at that point (Figure 4.8a). Very significant accretion is found at the south side of the breakwaters and also some at the northern site. These breakwaters will serve as the end point for our model, since longshore transport past it is thought to be zero. The breakwaters extend 1200 m into the sea. These breakwaters will be modelled in UNIBEST-CL+. There is a fish pier at Hua Hin; it is a very open structure (Figure 4.8a and b). There is a small amount of accretion at the location of the fish pier. No data can be found on the year of construction of the pier. From aerial photography it has been ascertained it was constructed somewhere between 1954 and 1974. The construction year has been estimated at 1968. The structure is not thought to be of major influence for the system, because of the limited accretion. The pier is approximately 200 m long. Despite that the structure is not thought to have much influence, it is implemented in UNIBEST-CL+. In 1992 a simple revetment, consisting of loose rock was constructed by the military at the site of the Naresuan Camp (Figure 4.8c). The revetment did not have any filter layer and was thus not able to stop the erosion. It will not be modelled in UNIBEST-CL+ because of the lack of a filter layer and bed protection. It is currently being replaced by the phase 4 construction works. Many structures along the coast have seawalls in front of them to protect them. These seawalls are built by the owners and not the government. It is therefore hard to ascertain when these were constructed and where they are exactly and where not. These structures are neglected due to the lack of information and because a seawall cannot be adequately modelled in UNIBEST-CL+. There is a monument at Cha-am extending a couple of meters into the water, the structure does not stop longshore transport however and is relatively small. It is uncertain when this structure is built, and because the influence seems limited to its immediate vicinity, this structure is not modelled in UNIBEST-CL+.

Interventions of the current project

The current project consists (up to now) of four phases. In the first phase the structures were constructed. In phases two, three and four, nourishments were executed. Phase three and phase four were combined with a revetment underneath the nourishment.

In 2005 two jetties, six submerged offshore breakwaters and eight groynes were constructed at the Mrigadayavan Palace site (Figure 4.8d, Figure 4.9 and Figure 4.10). The jetties were constructed to keep two water channels from silting up. These water channels are a vital water source for the mangrove forest behind the palace. The jetties are both 387 m long, which leads the Thai experts to belief the project site, which is in between both jetties is a closed system. The groynes are 74-101 m long and evenly spaced. Four submerged breakwaters are 125 m long, and the larger breakwater is 460 m long. The spacing between the breakwaters is 75 m (Google Earth, 2016; Department of Marine and Coastal Resources, 2013). Between groynes two and three and groynes four and six also revetments were built to protect the palace. Lastly the beach was also nourished.

a.



b.

c.

d.

Figure 4.8 | Structures along the coastal section. (a) Cha-am breakwaters (SEATEC, 2003). (b) Hua Hin fish pier, (SEATEC , 2003). (c) Revetment at military camp, source: (SEATEC, 2003). (d) The first part of phase 1 finished.

The second part of phase 1 was executed in 2007. Five offshore breakwaters of 135 m long with even spaces of 135 m long[6] were built to the north of the project site of phase 1. One makeshift groyne built for the construction of the offshore breakwaters is still in place at the middle offshore breakwater, because the local fishermen requested this.

Phase 2 was executed in 2014; it was a beach nourishment at the location of the second part of phase 1. In this project 77,300 m^3 of sand was nourished, over a length of 825 m. Approximately 20 to 40 m of land was reclaimed.

In 2015 a second nourishment was executed north of the previous project site (phase 3). Behind the nourishment lies a revetment built with sandbags and geotextile. Over a length of 400 m, 50 m of land was reclaimed for which 55,500 m^3 of sand was nourished.

Phase 4 is currently under construction. North of the phase 3 site a third nourishment is being executed, again with a sandbag and geotextile revetment behind it. Over a length of 600 m 110,000 m^3 of sand is nourished. South of the southern jetty, in front of the military camp the revetment is replaced by a new revetment with a nourishment in front of it. This site is 1300 m long and 210,000 m^3 of sand is nourished there.

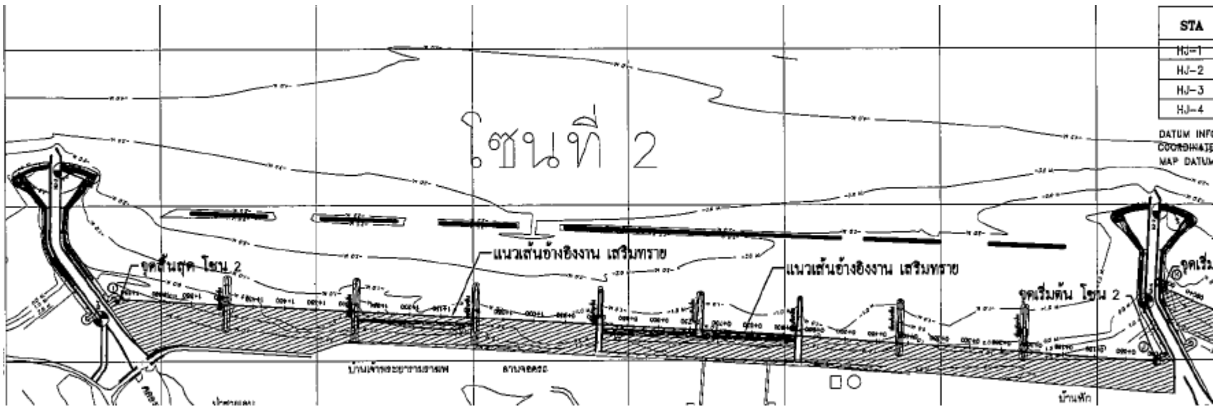


Figure 4.9 | Phase 1 (Department of Marine and Coastal Resources, 2013). First of part Phase 1 (note six submerged offshore breakwaters and the revetments between groynes two and three and groynes four and six.

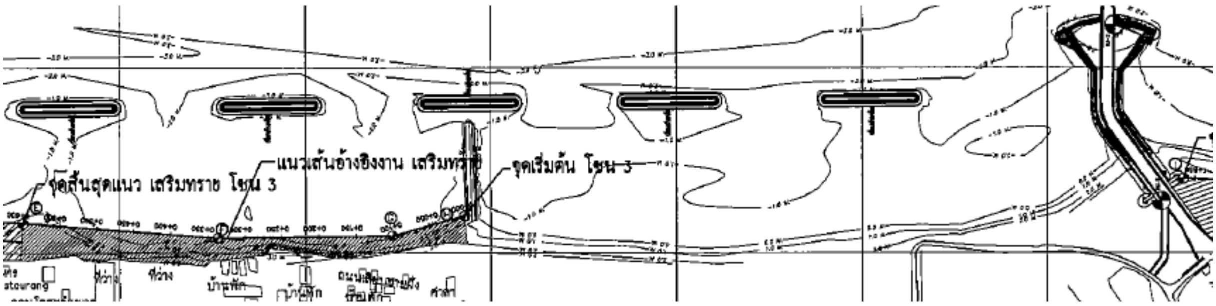


Figure 4.10 | Phase 1 (Department of Marine and Coastal Resources, 2013). Second part of Phase 1 (note that this the jetty on the right side of the picture is the same as the jetty on the left side of **Figure 4.9**.

[6] Note that the difference in length is probably not a design choice but a result from the execution of work and our interpretation of sources.

4.5. Land use

In this section the land use immediately behind the beach is described. The land use is important for the stakeholders. This can be of influence on the decision making process on which solution to choose per section. Five different uses are distinguished, namely build up area, nature, resorts, palaces, and the Hua Hin airport (Figure 4.11).

Colour	Land use
Red	Build up area
Green	Nature (with some structures)
Blue	Resorts
Purple	Palace
White	Airport

Figure 4.11 | Land use directly behind the beach (Google Earth, 2016).

The areas have been reviewed using Google Earth. The labels of each section give an idea about the level of importance of these areas when erosion does occur. It would probably only be allowable to have some erosion in the nature areas (green). The other areas have a significant amount of structures and/or important buildings. This overview shows that when erosion occurs, it would pose a direct issue for a lot of stakeholders.

4.6. Conclusion

In this chapter the coastal characteristics of the project are have been researched. First the general characteristics were determined. The most important findings were that the tidal type is mixed, mainly diurnal. The wave climate in the Gulf of Thailand is sheltered and the coast at the project area is mainly sandy. The main cause of erosion is believed to be human interventions. Due to hard structures the longshore sediment transport has been disrupted causing down drift areas to erode. Other possible causes are the reduction of sediment yield of the nearby rivers, storm erosion and relative sea level rise. It is however debatable how significant the effects of these phenomena are. Some data of the coastal stretch have been analysed. This data analysis is used for the UNIBEST-CL+ model. Information about the orientation and the bathymetry of the coastal stretch was given. Sediment transport and sediment characteristics have also been discussed and data about waves, wind and tides have also been treated. Information about the coastal features and structures has been collected. The locations and the construction year of the human interventions have been determined and some structures have also been evaluated. Special attention was paid to the current project near the Mrigadayavan palace. It was concluded that some structures, as the jetties, are not constructed properly and may need maintenance in the near future. Lastly, the land use of the coastal stretch was analysed. Regular build up area is most dominant, followed by resorts. Other land uses were nature, an airport and two palaces.

5. Stakeholder analysis

To ensure a successful problem analysis and solution implementation, a stakeholder analysis has been made. In this analysis the relevant stakeholders are identified and classified to be able to design stakeholder engagement plans for the different alternatives. These plans will assure certain inclusion of the stakeholders in the project to take their interests into account and prevent great opposition.

Nowadays, stakeholder analyses are more important than ever as the interconnected nature of the world continues to increase. Almost any public problem, ranging from economic development to global warming, encompasses or affects many stakeholders. Bryson (2011) defines a stakeholder as 'any person, group, or organization that can place a claim on an organization's (or other entity's) attention, resources, or output, or is affected by that output'. In order to properly define the problem and come up with suitable solutions, stakeholders are a crucial aspect of public problem solving, which has to be taken into account (Bryson, Patton & Bowman, 2011). The evaluation of potential solutions involves linking the technical rationality with political rationality in order to gain support for the subject at matter. To be able to produce this link, both technical skills and people skills need to be combined, where the people skills include the capacity of working with diverse groups of different cultures and of different occupations. To increase this capacity, it is important to have a good understanding of different aspects of the involved stakeholders.

In order to gain a good understanding of the involved stakeholders in this project, a stakeholder analysis has been conducted. First we will make a stakeholder description of all the involved stakeholders, which can be found in Appendix C.1. It describes who the stakeholders are, what they do, and what they are responsible for. Then the interests, problem perceptions, goal definitions and responsibilities of each stakeholder will be identified. After that, the criticality of each stakeholder will be determined, based on his or her replaceability, resource importance and dependency. Lastly, the stakeholders will be mapped regarding their power, interest and attitude followed by a participation-planning matrix, in which the level of participation of each stakeholder is determined. The results of the stakeholder analysis will be used to develop a stakeholder engagement plan for the different scenarios that will be established later on. Subsequently, the stakeholder engagement plans will be one of the aspects on which the alternatives will be assessed in order to recommend our final solution.

5.1. Stakeholder identification

This section identifies the stakeholders by establishing their interests, problem perceptions, goal definitions and responsibilities (see Appendix C.2). The interests describe what each stakeholder wants to get out of the project, the problem perception describes the problems that each stakeholder encounters regarding the project, the goal definition describes what each stakeholder wants to achieve through the project, and the responsibilities describe the tasks that are assigned to each stakeholder.

5.2. Key Stakeholders

This section determines which of the stakeholders are the most critical. The criticality of the stakeholders is based on their replaceability, their resource importance, and their dependency (see Table 5.1), which all range from low to high. Also, the most important resources from each stakeholder are identified.

5.3. Typology

This section identifies the typology of each stakeholder, based on their power to influence the project, their level of interest and their attitude towards the project, which can either be supportive, neutral or resistant. According to Hillson and Simon (2007), stakeholders can be mapped into eight different positions with regard to their power, interest and attitude. The eight positions, which will be further explained in Appendix C.3, are: acquaintance, friend, irritant, saboteur, saviour, sleeping giant, time bomb, and trip wire. In Figure 5.1, the power of the stakeholders is mapped against their interest. The gradient of their colour indicates their attitude towards the project, which is also illustrated in the legend of the figure.

Table 5.1 | Stakeholder criticality

	Stakeholder	Important resources	Replaceability	Resource importance	Dependency	Critical actor
EIG	Environmental Interest Groups	Lobbying, power/influencing public opinion, sustainability expertise	Moderate	Moderate	Moderate	Yes
FM	Fishermen	Demonstration, protest	High	Low	Low	No
GO	Government	Decision making, legislative power, allocating budgets	Low	High	High	Yes
HR	Hotels & Resorts	Protest, non-cooperation	High	Low	Low	No
IH	Inhabitants	Demonstration, protest	High	Low	Low	No
LO	Landowners	Protest, non-cooperation	Low	Moderate	Moderate	No
LA	Local authorities	Decision making, legislative power, investments	Low	High	High	Yes
LB	Local Businesses	Demonstration, protest	High	Low	Low	No
MD	Marine Department	Prioritising requests, expertise, decision making, overseeing construction and maintenance	Low	High	High	Yes
ON	Other NGOs	Demonstration, protest, expertise, power/influencing public opinion	Moderate	Moderate	Low	No
PD	Project Developers	Investments, expertise, decision making, construction	Moderate	High	High	Yes
PI	Project Investors	Investments	Moderate	High	Moderate	No
RE	Researchers	Expertise	Moderate	High	High	Yes
RF	Royal Family	Setting boundaries	Low	High	High	Yes
TO	Tourists	Abstain from visiting	High	Low	Low	No

Table 5.2 | Stakeholder Typology

	Stakeholder	Power	Interest	Attitude	Role	Description
EIG	Environmental Interest Groups	+	++	-	Irritant	Insignificant active blocker
FM	Fishermen	0	+++	+	Friend	Insignificant active backer
GO	Government	+++	++	++	Savior	Influential active backer
HR	Hotels & Resorts	+	+++	+	Friend	Insignificant active backer
IH	Inhabitants	0	++	0	Friend/irritant	Insignificant active backer/blocker
LO	Landowners	+	++	0	Friend/irritant	Insignificant active backer/blocker
LA	Local Authorities	++	+++	+	Savior	Influential active backer
LB	Local Businesses	0	+++	+	Friend	Insignificant active backer
MD	Marine Department	++	+++	++	Savior	Influential active backer
ON	Other NGOs	+	+	-	Tripwire	Insignificant passive blocker
PD	Project Developers	+	+	++	Acquaintance	Insignificant passive backer
PI	Project Investors	+	+	+	Acquaintance	Insignificant passive backer
RE	Researchers	+	+	0	Acquaintance/tripwire	Insignificant passive blocker/backer
RF	Royal Family	+++	+	+	Sleeping giant	Influential passive backer
TO	Tourists	0	0	0	Acquaintance/tripwire	Insignificant passive backer/blocker

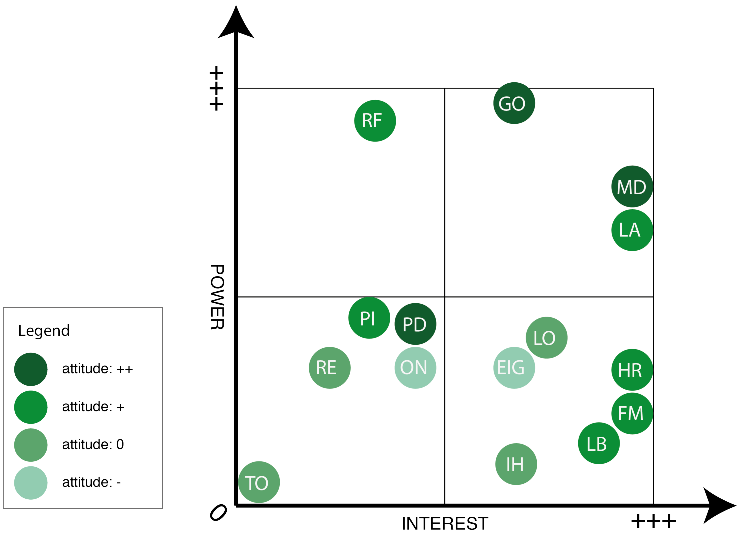


Figure 5.1 | Stakeholder typology mapping (own ill.)

Participation-planning matrix
This section illustrates the different roles of each stakeholder in each consecutive phase of the project. Based on the model of Wijnen, Renes & Storm (2004) and Kor & Wijnen (2002), the phases are as follows:

1. **Initiation phase** - The beginning of the project, in which the idea for the project is explored and elaborated and in which the feasibility of the project is examined. Also, decisions are made regarding who is to carry out the project, which stakeholders will be involved and whether the project has an adequate base of support among those who are involved.
2. **Definition phase** - In this phase, the requirements associated with the project are clearly specified. This also entails the identification of the expectations of all involved stakeholders.
3. **Design phase** - One or multiple designs are to be developed in this phase. The project supervisors have the responsibility of deciding on the definitive design that is to be executed by the project developers.
4. **Development phase** - In this phase, everything that is needed to properly implement the project design will be prepared.
5. **Implementation phase** - This phase involves the actual construction of the project. At the end of this phase, the result is evaluated according to the design and the list of requirements that was created in the definition phase.
6. **Follow-up phase** - This phase is very important but often neglected. It entails the arrangement of everything that is necessary to bring the project to a successful completion.
7. **Monitor & evaluation phase** - The last phase involves the management regarding the construction, the maintenance of the construction itself and the reflection on the project and process.

The roles that a stakeholder can have within the different phases of the project are data source, inform, consult, involve, collaborate, and empower. Note that the roles of a stakeholder can differ in each phase (see Table 5.3). When a stakeholder is not involved in the project yet, they also do not have a particular role. If a stakeholder is engaged as a data source, then they are only providing data if this is requested by another stakeholder within the project. A stakeholder with an inform role is a stakeholder that has knowledge of the findings of the project in order to create interest among the particular stakeholder. Whereas a stakeholder with a consulting role actually anticipates in the issues, gives suggestions regarding the issues and enhances the credibility of the project. One step further is a stakeholder with an involvement role, which means that the stakeholder has to give his/her approval on certain issues. This role also entails affirming the importance, appropriateness and utility of the project as well as attracting attention to findings and establishing credibility. The collaboration role goes even further as the stakeholder is considered as an important stakeholder because of its interest, interpersonal style, availability, influential position and/or connections, and sense of ownership of the project and therefore has the ability to take decisions regarding the project. Lastly, the empower role which in principle means that the stakeholder, who has this role, is responsible for the project. This stakeholder is responsible for the decision-making and the decisions will then be facilitated and implemented.

Table 5.3 | Stakeholder Participation Planning Matrix

	Do not engage	Engage as data source	Inform	Consult	Involve	Collaborate	Empower
Phase 1 Initiation	Project developers Tourists	Environmental interest groups Government Local authorities Marine Department Researchers	Royal family	Environmental interest groups Fishermen Hotels & resorts Inhabitants Local businesses Other NGOs Project investors	Landowners	Local authorities	Government Marine Department
Phase 2 Definition	Tourists	Environmental interest groups Government Local authorities Marine Department Researchers		Environmental interest groups Fishermen Hotels & resorts Inhabitants Local businesses Other NGOs Project investors	Landowners Royal family	Local authorities Project developers	Government Marine Department
Phase 3 Design	Tourists	Government Local authorities Marine Department Researchers	Fishermen Hotels & resorts Inhabitants Local businesses	Environmental interest groups Other NGOs	Landowners Royal family	Local authorities Project investors	Government Marine Department Project developers
Phase 4 Development	Environmental interest groups Royal family	Government Local authorities Marine Department Other NGOs Researchers	Fishermen Hotels & resorts Inhabitants Local businesses Tourists	Landowners	Project investors	Local authorities	Government Marine Department Project developers
Phase 5 Implementation	Environmental interest groups Royal family	Government Local authorities Marine Department Other NGOs Researchers	Fishermen Hotels & resorts Inhabitants Landowners Local businesses Tourists		Project investors	Local authorities	Government Marine Department Project developers
Phase 6 Follow-up	Environmental interest groups Other NGOs Tourists	Government Local authorities Marine Department Researchers	Fishermen Hotels & resorts Inhabitants Landowners Local businesses Royal family	Project investors		Local authorities	Government Marine Department Project developers
Phase 7 Monitor & Evaluation	Environmental interest groups Other NGOs	Government Local authorities Marine Department Researchers	Fishermen Inhabitants Landowners Tourists	Hotels & resorts Local businesses Royal family	Project investors		Government Local authorities Marine Department Project developers

6. System Engineering

This chapter provides a systematic overview of the problem and its context, in order to combine the previously separately made analyses in a comprehensive and cohesive model. In the previous chapters, both the stakeholders and the coastal area have been analysed extensively. However, the link between the technical and the managerial part is still missing. In order to ensure a more comprehensive and integral recommended solution, it is important to integrate these both parts. A way to link these two parts is Wasson's (2006) method of system engineering. According to Wasson, system engineering can be defined as 'the multidisciplinary application of analytical, mathematical, and scientific principles to formulating, selecting, and developing a solution that has acceptable risk, satisfies the user's operational need(s), and minimizes development and life cycle costs while balancing stakeholder interests'. The following chapter will describe how system engineering can be applied to our project when considering the prevention of coastal erosion as a system. First, the involved stakeholders will be discussed and their system roles will be determined. Then, the mission and objectives of the project will be discussed followed by an overview of the project as a system. The overview of the project as a system is made based on the analyses that have been carried out and the interviews (see Appendix I) that have been conducted.

6.1. Stakeholders and their system roles

In chapter 5, an extensive stakeholder analysis has been carried out regarding the involved stakeholders. As every stakeholder has different objectives and agendas that may contribute to the overall longevity and performance of the system, it is important to have an overview of them and their roles within the system. Table 6.1 lists all the stakeholders who have been identified in chapter 5 and for every stakeholder a role has been assigned based on the outcomes of the stakeholder analyses and the role definitions given by Wasson (see Appendix D.1).

As most human-made systems are directed toward contributing to and achieving the "owner" organization's roles, missions, and objectives, the system owner has to be defined first. In this project, the Thai Marine Department is defined as the system owner and the government can also be seen as owner, because the Marine Department is part of the government. However, the Marine Department has to apply for budget at the government. Therefore, the government is also considered as the system shareholder. The project investors, if involved in the project, can also seen as the system shareholder. The budget that will be allocated to the project may not be sufficient; therefore project investors might be necessary. Note that, if no project investors are found and the budget is still insufficient, then the project has to be altered or cancelled. As the local authorities are responsible for the area, they can also be seen as system shareholder but mainly in the operational phase.

The system users, who derive direct benefits from the system and may physically operate the system or provide input to the system, are mainly the people living and working in or near Cha-am and Hua Hin. Also tourists, including both day visitors and tourists with Cha-am or Hua Hin as their destination, are considered as system users as they are the main users of the beaches.

The system supporters/critics are mainly stakeholders that are involved in the system in terms of knowledge and expertise. Both researchers and environmental interest groups (NGOs) can be of great use in providing their knowledge and expertise. The other NGOs, who mainly consist of professors from universities, can also be supporters/critics as they have a lot of knowledge. However, NGOs are mostly seen as system critics. Generally, they only emphasize the shortcomings of the solutions, but do not provide alternative solutions. The Royal Family supports the prevention of coastal erosion as well, however they mainly provide the system with boundaries as their main interests are the preservation of cultural heritage and the preservation of aesthetically pleasing beaches.

The last role is the role of system developer, who is responsible for developing a verified system solution based on operational capabilities and performance, which are bounded and specified in a System Performance Specification. This role is still to be determined, as the Thai Marine Department first needs to decide to actually execute the recommended solution.

Table 6.1 | Stakeholders and their system roles

	Stakeholders	System Role	Adversary (-) / Advocate (+)
EIG	Environmental Interest Groups	System Critic	-
FM	Fishermen	System User	+
GO	Government	System Shareholder & Owner	+
HR	Hotels & Resorts	System User	+
IH	Inhabitants	System User	-/+
LO	Landowners	System User	-/+
LA	Local Authorities	System Shareholder	+
LB	Local Businesses	System User	+
MD	Marine Department	System Owner	+
ON	Other NGOs	System Critic	-
PD	Project Developers	System Developer	+
PI	Project Investors	System Shareholder	+
RE	Researchers	System Support/Critic	-/+
RF	Royal Family	System Boundary Indicator	+
TO	Tourists	System User	-/+

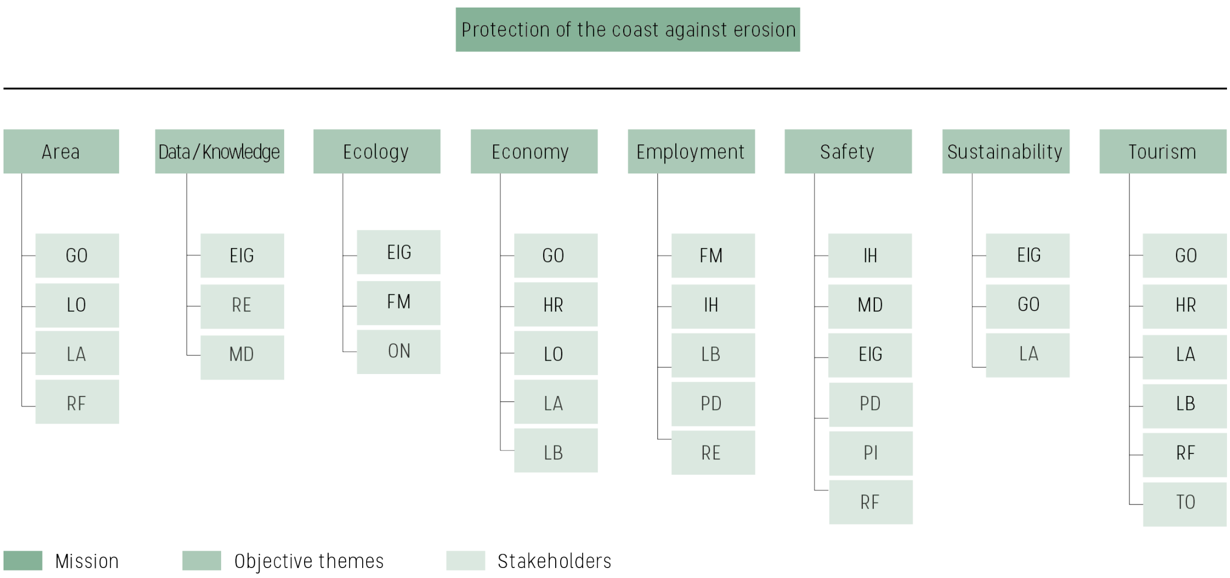


Figure 6.1 | Mission and objective tree including stakeholders (own ill.)

6.2. Mission and objectives

As already mentioned, most human-made systems are directed toward contributing to and achieving the "owner" organization's roles, missions, and objectives. The mission of the Thai Marine Department and the government is protecting the coast against erosion and their main objectives are (see Appendix C.2):

- Providing safety for the local people and the hinterland
- No disturbance to both the economical and tourism growth
- Preventing deterioration of the area
- Preserving cultural heritage
- Preserving the ecology
- Ensuring sustainable development & water management

All the involved stakeholders have their own interests, objectives, problem perceptions, etc. Therefore, an analysis has been carried out regarding these entities in order to determine groups that share the same objectives. This analysis has resulted in the overview as illustrated in Figure 6.1. From this figure it can be derived that safety, economy, employment and tourism are important objectives as it involves most of the critical stakeholders. The first objective of safety is perceived by the stakeholders as an important objective, however, in this case this is not an issue. The coastal erosion will not directly affect the safety of the inhabitants or the hinterland. The three latter subjects are interrelated, as tourism creates employment possibilities and contributes to a better economy. So, the focus of the recommended solution should be on these objectives However, the solution space should focus on all the mentioned areas in order to provide a solution that takes into account all the stakeholders involved.

6.3. Systematic approach

In order to provide a suitable solution, a framework that supports and enables the integrated elements of the system to provide the system's capabilities and perform missions should be established. This framework consists of two key components, being the System of Interest (SOI) and the Operating Environment (OE). The SOI and OE can be decomposed into respectively mission and support systems and higher order systems and physical environment domain.

Wasson (2006) defines the SOI as "a system consisting of a mission system and its support system(s) assigned to perform a specific organizational mission and accomplish performance based objective(s) within a specified time frame". In this case, the SOI is a coastal erosion prevention system, as protecting the coast against erosion is the mission of this system. The specific kind of measure will be determined by taking into account all the different objectives of the stakeholders and the operating environment of the SOI and can either be a soft measure or a hard measure or even a combination of the two.

Moreover, the Operating Environment is defined as "the representation of the totality of natural and human-made entities that a system must be prepared to cope with during missions and throughout its lifetime" (Wasson, 2006). In chapter 4, an extensive coastal analysis has been carried out and from this analysis multiple aspects can be derived that have to been taken into account while determining possible solutions. These aspects include mainly physical environment aspects. Together with the stakeholders and their objectives from the stakeholder analysis, Figure 6.2 has been formed. This figure illustrates all the involved aspects and relations of the SOI and its operating environment. Moreover, the figure can be used in developing possible solutions for the prevention of coastal erosion, while taking into account all the different aspects and stakeholder's objectives.

Additionally, it has to be taken into account that the project environment may differ from the system environment. For example, the project environment may also contain interfaces with the canals, energy supply system, residential system of Cha-am and Hua Hin, recreational system (beaches and waterborne activities), etc. When the recommended solution will eventually be executed, these interfaces also need proper management. Furthermore, Figure 6.2 can be used to link the capabilities of the SOI with the stakeholders. This is also to be done in a later stage of the project, as knowledge on all the subsystems are needed.

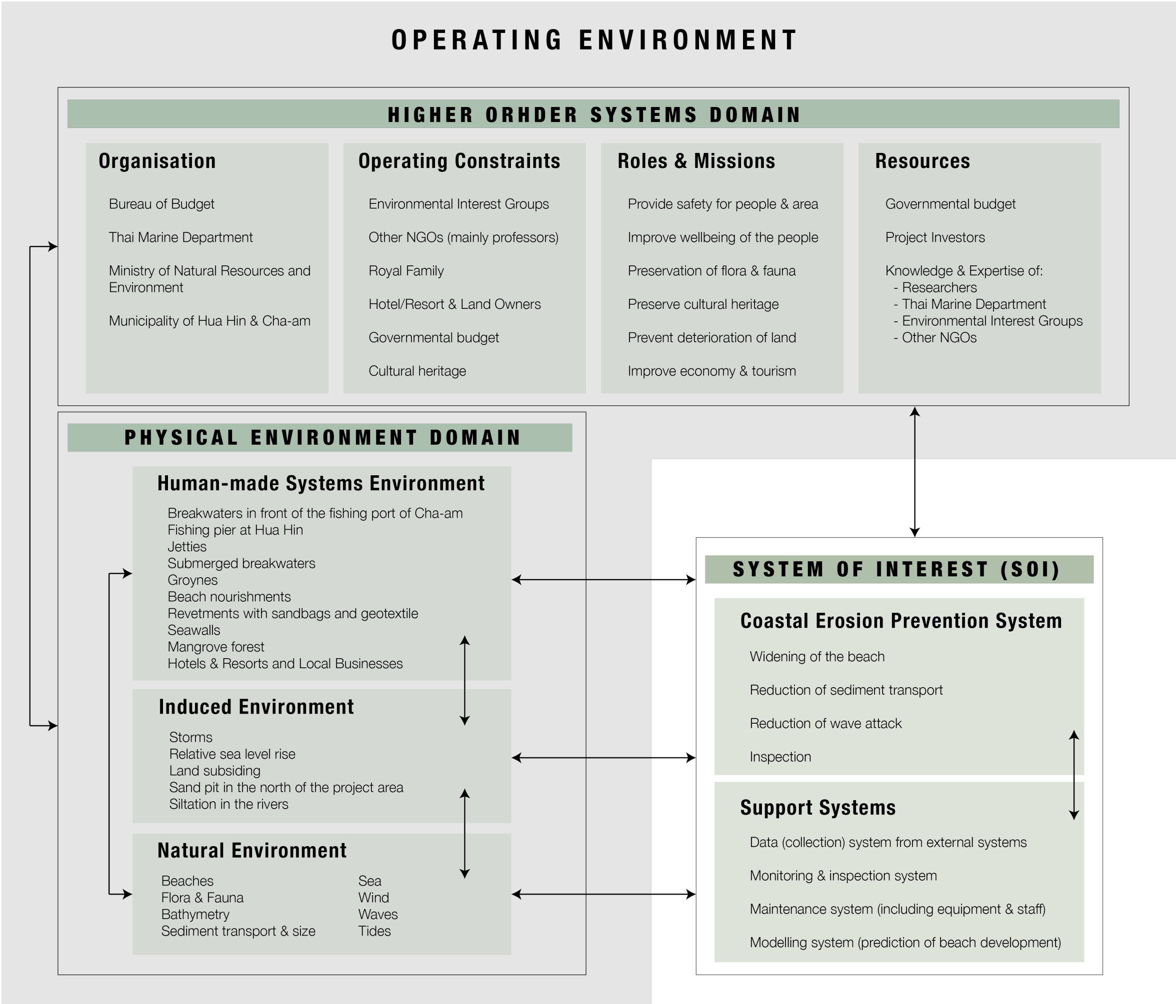


Figure 6.2 | System's architecture (own ill.)

PART III
Design Phase I

7. Nourishment

This chapter considers the first problem, namely large nourishment losses. As stated in chapter 2, nourishments were performed unsuccessfully. This chapter thus provides an advice on how to perform nourishments at the coast of Cha-am/Hua Hin. Only beach nourishments will be discussed since the main interest of the Marine Department is widening the beach for tourism. Different kinds of nourishment methods are discussed in Appendix E.

7.1. Introduction

Following Figure 7.1 it is first necessary to determine the causes and interests which is done in respectively chapter 4 and 5. The problem definition is partly based on these chapters but presented in chapter 2[7]. The decision-making is done in chapter 10 but the decision whether to perform nourishments or to use hard structures stands apart from this section. Paragraph 7.2 describes the design of nourishments and paragraph 7.3 will shortly elaborate on construction, monitoring and evaluation.

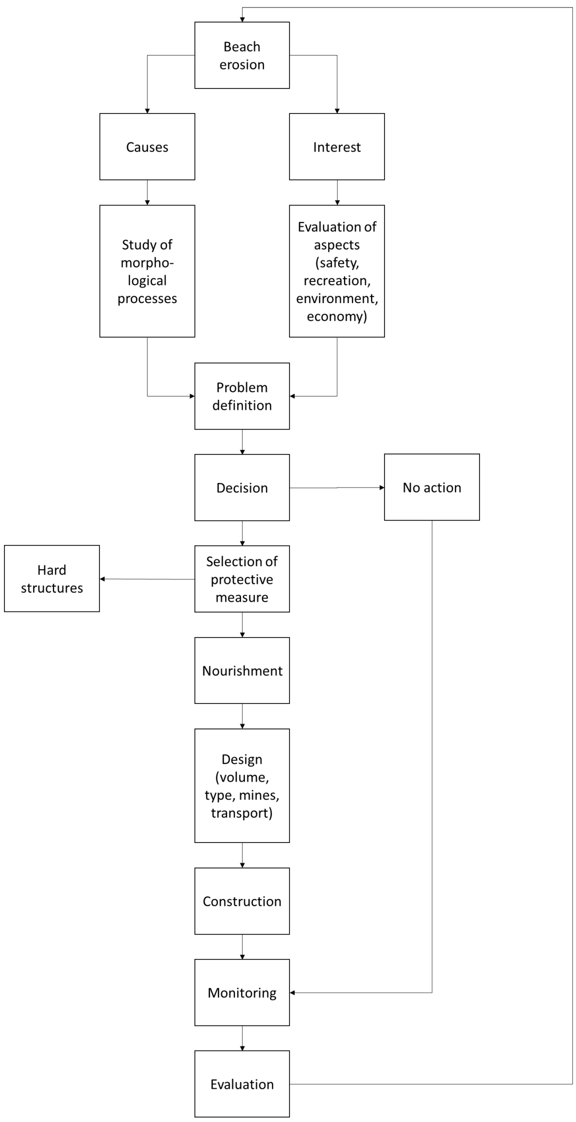


Figure 7.1 | Roadmap of making a nourishment scheme (based on Pilarczyk et. al, 1986)

[7] These chapters have a strong inter dependence. With an initial problem the analyses can be started but as the analyses progresses the problem definition often needs to be adjusted.

7.2.Design

This paragraph elaborates on the design of beach nourishments at the coastal section of Cha-am/Hua Hin. It also contains advices on the design based on previous nourishments.

Volume

The following formula can be used to calculate the necessary nourishment volume (Verhagen, 1992):

$$Volume\ [m^3/m] = (Erosion\ rate\ [m^3/m/year] + Expected\ losses\ [m^3/m/year]) \times Lifetime\ [years]$$

The erosion rate can be calculated using: $Erosion\ rate\ [m^3/m/year] = R(h+d)$ (Farris & List, 2007; Bosboom & Stive, 2015), in which R is the recession in m/year, h is the depth of the active profile (m) (e.g. the depth up to which the waves will influence the profile) and d is the dune height (m).
The expected losses are as a first approximation 40% (Verhagen, 1992) of which, according to Bosboom and Stive (2015), 10-20% consists of loss of fines. The lifetime is usually taken as 5-10 years (Bosboom & Stive, 2015).

When it is desired to widen the beach for recreational purposes the formula can also be used. The recession (R) in meters per year can then be replaced with the desired additional width of the beach in meters and the lifetime can be left out of this calculation. Of course there will still be erosion, so this should be taken into account by adding 'necessary volume for erosion' up by the 'necessary volume for creating a wider beach'.

It should be stressed that when the nourished sand seems to disappear quickly after the nourishment this does not mean that the nourishment failed. Sand naturally redistributes to adapt to a new equilibrium profile. It might thus seem that the nourishment failed but this is certainly not true. This can also be seen from the formula where the active profile height is explicitly taken into account. For a beach nourishment it is the goal to have a certain amount of extra metres of beach width after the reshaping of the profile. A nourishment should thus be initially be made much wider to account for the reshaping.

The current nourishment volume is placed over a section of a few hundreds of meters. Waves will probably refract towards this small section causing an increase in wave attack which will eventually result in a smoothening of this section and a redistribution of the sediment onto the entire coastal section. It is thus advised to nourish over the entire section (see also the example).

Example:

As an example the necessary volume for a lifetime of five years is calculated for the northern side of the project, section 1a and the northern part of section 1b. According to the Department of Natural Resources (2013) the erosion rate at the northern side of the jetty is 1.33 m/year. The active profile is assumed to reach a depth of 6.75m (see Appendix F), the dune height is assumed to be 2m (based on observations). Using a conservative approach we assume the losses to be 40%. The lifetime used for the calculation is 5 years. This results in the following:

$$Erosion\ rate\ [m^3/m/year] = 1.33 * (6.75 + 2) = 11.6\ m^3/m/year$$

$$Volume\ [m^3/m] = (11.6 + 0.40 * 11.6) * 5 = 81\ m^3/m$$

The section has an approximate length of 11km, and thus the necessary volume for a lifetime of 5 years is: $81 * 11{,}000 = 891{,}000 m^3$.

Sediment

The sediment is currently mined on the land since sea based equipment is not available and suitable marine based sources are not known. The sand is mined approximately 64 kilometres away from the project area and transported with trucks.

As explained in Appendix E, it is important that the mined sand has approximately the same grading as the original beach sand, especially the amount of fine sediment should be as low as possible. It is also possible to use coarser sediment than the original sediment but then a steeper profile is expected. Project data showed that the grading of the mined sand and the original beach sediment is approximately the same. However, own investigation showed that the mined sand has a relatively high amount of fine sediment (see Appendix B.2). We thus recommend to investigate other possible mining areas because a high amount of fines is undesirable. One mining area is a river, when mining sand in a river one has to realise that this sand is taken out of the system. The sand cannot reach the river mouth and mining in rivers can thus cause erosion problems near the river mouth area. Care has to be taken to ensure that this sand mining activities do not lead to serious erosion elsewhere.

Taking into account that currently sand from a river is used for the nourishment and that one cubic meter of sand currently costs approximately €13, we recommend to start investigation in possible sea mining areas. Mining with sea based equipment might be cheaper per cubic meter if a suitable mining area exists within several tens of kilometres. A depth of approximately 15 to 30 meters is probably suitable for this area (W. Jacobs, personal communication, 10-10-2016) but the cross shore transport of the waves should be taken into account. An offshore mining area does not cause erosion problems elsewhere (if situated at a suitable distance from the coast). When mining with sea based equipment is used, it is also an option to nourish the foreshore (see Appendix E). This option will not be discussed now since firstly a suitable area should be located.

Geotextile revetments
Currently sandbags made from geotextile and at other locations a stone revetment are used as a last line of defence. These have been built close to the hotels and are covered with sand. In front of the revetment a nourishment is performed. However, a few months after performing the nourishment the sandbags are already exposed. The used geotextile is not resistant to UV radiation and thus the sandbags tend to fail relatively quickly after being exposed. Another disadvantage is the impermeability of the sandbags. The sandbags are not able to absorb wave energy and can therefore accelerate erosion. The main advantage is the easy construction (Scottish Natural Heritage, n.d.). Considering the high price of construction of the revetment we recommend to not use this solution but to use the money for a wider beach nourishment.

a. **b.**

Figure 7.2 | Constuction of geotextile revetments (source Marine Department, 2016)

Profile
The beach profile is an important aspect of beach nourishments. The profile after the nourishment will be formed by the hydrodynamic forcing. This forcing remains the same, so if the same sediment size is used, the profile will be more or less the same as before. Storms are a very efficient way to redistribute the nourished sand over the profile. It is therefore possible that with a few storms a large part of the nourished sand on the beach has disappeared and is redistributed over the entire profile. Due to this redistribution the nourishment can be seen as a failure by the public. When the purpose of the nourishment is to create a wide recreational beach, this redistribution can be a problem (Verhagen, 1992). According to Van Rijn (2010), the slope of the nourishment determines the initial losses. He states that the initial slope of the nourishment should be 1 to 20 or flatter. Steeper slopes result in more initial losses on the beach.

To create a wide recreational beach it is advised to use a flat slope to reduce the initial losses. The constructed slope should be close to the slope that is expected to form after a few storms. It is also advised to dump the sand as high as possible on the beach.

7.3. Construction, monitoring and evaluation

This paragraph shortly elaborates on the construction, monitoring and evaluation.

Construction
Certain hotel owners do not want nourishment in front of their hotel. The execution of the nourishment takes a considerable time and when being executed the beach in front of the hotel is not accessible for tourists who are staying in the hotel. The owners also believe that nourishment do not improve the situation. This believe is probably caused by the fact that former nourishments disappeared fast because of the reshaping of the profile. Therefore, as stated in paragraph 3, more sand has to be deposited so that the lifetime is longer. This should be combined with informing the stakeholders about the fact that reshaping will occur. If certain stakeholders decide they do not want nourishment in front of their hotel this is not a big problem. As long as the overall length of the project is sufficiently long to not have extreme edge losses the nourished sand north and south of this area will redistribute to the area.

Monitoring and evaluation
An important part of a nourishment plan is the monitoring and evaluation of the project. In order to be able to make a plan for a coastal section data has to be available. When it is known how successful a nourishment was, it is possible to improve the next nourishment. This way a more cost effective construction can be used, which saves money. In order to be able to evaluate the nourishment, the nourishment has to be monitored. For a good evaluation it holds that the more data is gathered, the better, but this is budget wise not always possible. Profile measurements before and just after completion are essential. In order to monitor the development of the coast, more measurements are necessary, for example one measurement per year. Using the evaluation of the nourishment, a long-term plan can be made and the next nourishments can be improved. This way one can plan when budget is necessary to execute a new nourishment. A model, as for example UNIBEST-CL+, can also be used to predict the effects of the nourishment. However, the model is also dependent on measured data for calibration. Therefore it is strongly recommended to monitor the effects of the nourishment after construction.

PART IV Design Phase II

8. Coastal model

It was tried to set up a coastal model of the project area. Unfortunately, the model did not represent reality correctly. The aim of the model was to distinguish critical erosion areas in order to be able to set up a nourishment plan and to test the different scenarios. This is not possible with the current model. In this chapter it is discussed what the main results were of the model, which adjustment were tried in order to improve the results, possible reasons why these results were achieved, and finally what it means for the project. More information about the model can be found in Appendix F.

8.1. The results

It was not possible to calibrate the model to the calibration period (1954 to 1975). The transport became constant on a long stretch of the coast (Figure 8. 1). This results in neither erosion nor accretion, while in the calibration period several erosion and accretion areas were distinguished. The correlation with the calibration data was 0.03, which means there is almost no dependence at all between the results of the model and the calibration data. Therefore the model is not representable for the project area and it can not be used for the project.

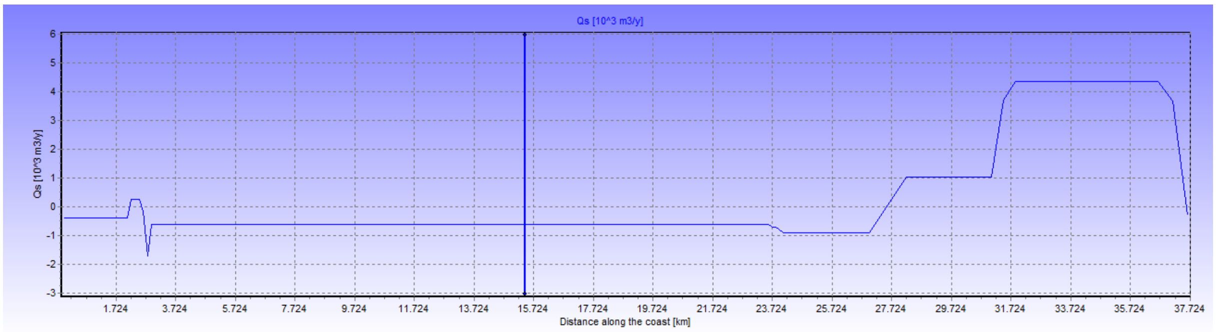


Figure 8. 1| The QS-graph in 1975

8.2. Improving the model

An effort has been made to improve the model. Due to time restraint only the wave conditions were looked at, because this is the most important input (B. Huisman, personal communication, 15 December, 2016). Several methods and sources have been used to determine the wave conditions. The two main sources were BMT ARGOSS (2016) and buoy data (J. Laksanalamai, personal communication, October, 2016). Both sources had their disadvantages (Table 8. 1), and neither of them resulted in a representative model.

Table 8. 1| Disadvantages of the two datasets

Dataset BMT ARGOSS (2016)	Dataset buoy
Also wave conditions from more southern locations of the Gulf of Thailand.	No wave direction (only wind direction)
No extreme events taken into account.	Short data set (2 years)
Uncertainty about the location and the corresponding depth of the wave conditions.	Holes in data set
Large directional bins.	No wave period
Not possible to link wind direction with wave direction.	

First the BMT ARGOSS dataset (2016) was used, because this dataset explicitly contains the wave direction. The wave conditions were run without transforming the waves in SWAN (Simulating WAves Nearshore). This did not provide the desired results and therefore SWAN was used to transform the waves to the nearshore (to ±7m depth). It was computationally very demanding to run all wave conditions, therefore it was decided to use averaged conditions. Monthly conditions were used initially, after which the wave conditions were averaged per directional bin. Small directional bins could be used. Unfortunately, this also did not result in a good model and therefore it was decided to use the buoy data as a source.

SWAN was also used to transform the wave conditions that were retrieved from the buoy data. To speed up the process, Matlab is used to write the files and to run SWAN. The dataset consisted of 3 hourly measurements for two years. Among others the wave height, wind directions, wind speed, current direction and current velocity were measured. There were however quite a few gaps in the dataset and the wave direction was not measured. The wave direction was assumed to be the same as the wind direction to use this dataset. Wave periods of the same order as the periods from the BMT ARGOSS (2016) dataset were assumed. The results from this dataset are used in this chapter and in Appendix F.

8.3.Possible reasons

Three possible reasons why the model is not representative are faulty wave conditions, sinks and/or sources that were not modelled, and limitations of UNIBEST-CL+. The inadequate wave conditions are the result of poor sources. The BMT ARGOSS (2016) data had the major disadvantage that also a large part from the southern part of the Gulf of Thailand was also taken into account and that the bathymetry necessary for SWAN was not available for such a large area. The buoy data had several disadvantages. The dataset was relatively small (2 years, every three hours, but with gaps in the dataset) and not all necessary information was available, i.e. the wave direction and the wave period. These disadvantages could have resulted in wave conditions that do not represent reality correctly.

The transport is constant along a large part of the coast (Table 8. 1). Therefore no erosion or accretion occurs. However, the calibration data shows several erosion and accretion spots. Local sinks or sources could alter the transport in such a way that erosion or accretion is present. Because the wave conditions were thought to be more important, no effort was made to look deeper into this possible problem.

It is also possible that UNIBEST-CL+ is not detailed enough to simulate the coastline. It is possible that 2D or 3D processes have a large effect on this coast. It is also a possibility that the bathymetry of this coastal area is too complex to be modelled with UNIBEST-CL+. This was the case around the headland near Hua Hin, where in the nearshore the bathymetry was too complex. This could have been solved if more detailed bathymetry was available. This was however not the case. A more detailed model (like Delft-3D) could be used to try to model the coastline correctly.

8.4.Consequences for the project

The purpose of the model was to be able to set up a nourishment plan and to test the different scenarios. No specific numbers can be given now for the nourishment plan, however it is still possible to give an advice about it. Nourishments do never really fail, but to design a proper nourishment some data should be available. This does not necessarily have to be model data, measurements can also be used to design nourishments and give more certain results.

It is not possible to determine the effects of the three scenarios. The 'do nothing' and the 'remove existing structures' scenarios can also be assessed by knowledge about the system and the governing processes and engineering experience. The design of the structures can be done by using design rules and the effects can also be assessed by using knowledge about the system, the governing processes and engineering experience. These assessments will mainly be qualitative instead of quantitative. To get quantitative results it is also possible to use a more detailed model as Delft-3D.

9. Scenarios

Based on the analysis of the previous part, three scenarios have been established in this chapter. The first scenario is the 'do nothing' scenario to provide a base case to compare the rest of the solutions with, the second scenario is the scenario in which four (combinations of) solutions are constructed, and the third scenario is a scenario in which all existing structures are removed, an alternative provided by the client. The alternatives that are elaborated in the second scenario are the remaining alternatives after both a technical and economic feasibility analysis have been performed and a SWOT analysis, which identifies the strengths, weaknesses, opportunities and threats of each solution, has been carried out. These assessments and results can be found in respectively Appendix G.1, Appendix G.2 and Appendix G.3.

9.1. Scenario 1. 'Do nothing'

The first scenario that has been determined is the 'Do Nothing' scenario. This entails the current situation without adding any new measures and can thus be used as a reference scenario as it can be compared to the other scenarios in order to verify their effectiveness.

9.2. Scenario 2. Construction of (a combination of) solutions

The second scenario that has been determined is the 'Construction of (a combination of) solutions' scenario, in which the resulting alternatives from the SWOT analysis (see Appendix G.3) are constructed in the existing situation. The following section describes the alternatives that are considered and are arranged from hard to soft measures.

The remaining alternatives will be assessed in the Multi Criteria Analysis:

- T-groynes, which are very similar to offshore breakwaters and groynes combined. A T-groyne is basically a groyne with an offshore breakwater at its tip. Nourishments also have to be performed.
- Groynes, which also has to be combined with nourishments. This will be cheaper than T-groynes; it is however expected to be less effective at stopping sediment transport.
- Beach nourishment, directly leads to a broader beach. It is a soft solution and thus more natural than constructing hard structures. More sand is put into the system so at other locations the erosion can also be alleviated, instead of the lee erosion, which occurs with hard structures.
- Coarse nourishment, which entails nourishing with coarser sand than the sand that is currently in the system, which is expected to have a longer lifetime than normal beach nourishment.

9.3. Scenario 3. Remove existing structures

The third scenario results from the views of the NGOs. Some NGOs have stated that, in their opinion, total removal of the structures that have been constructed would be the best solution. Therefore, this scenario has also been determined.

10. Stakeholder engagement plans

The stakeholder engagement plans for each remaining alternative, that has been determined in the previous chapter, can be found in this chapter. The plans are made based on all the analyses, but especially the stakeholder analyses. This chapter provides a plan for each solution to engage the stakeholders in such a way to minimize their resistance against the solution and maximize their co-operation. In chapter 5, the stakeholder analysis was concluded with a participation-planning matrix, in which the level of participation of each stakeholder was determined. In this chapter, this result will be used to develop a stakeholder engagement plan per remaining alternative. These stakeholder engagement plans will be assessed later on in the assessment of the scenarios.

10.1. T-groynes

Figure 10.1a illustrates the stakeholder engagement plan for the alternative of T-groynes. As can be concluded from the stakeholder analysis, both the EIGs and the other NGOs have a negative attitude towards the construction of T-groynes, meaning they are opposing to the alternative. Therefore, their power should be increased in order for them to engage to the alternative. By increasing their power, their interest may be more taken into account, which may then lead to a more positive attitude towards the alternative. The same holds for the researchers, as they seem to have a neutral attitude. By increasing their power, they can share their knowledge regarding T-groynes and may persuade the opposing stakeholders into engaging to the alternative. Moreover, the tourists seem to be really positive and thus supportive of the alternative. However, it is really important that the tourists' attitude stays positive, as they are one of the most important stakeholders as the project area is a tourist destination. So, the tourists should still be taken into account carefully.

10.2. Groynes

Figure 10.1b illustrates the stakeholder engagement plan for the alternative of groynes. As can be seen, the stakeholder engagement plan is quite equal to the plan for T-groynes. However, as groynes are already applied more often in the surrounding areas, more knowledge and expertise is available. This results in the fact that the researchers do not need to be engaged more with regard to this alternative. Also, the environmental interest groups are less opposing to the groynes than to the T-groynes, as the negative environmental impact is less. However, they still need to be engaged in order to move from a negative attitude towards a neutral or even positive attitude. This can be done by increasing their power, which is the same strategy as for the T-groynes. For the other NGOs the strategy for groynes is equal to the strategy for T-groynes as they are opposing to both alternatives equally. The tourists, however, ask for more attention in this case. Seeing as the project area is a tourist destination, it is of great importance that the tourists are attracted to the alternative. Therefore, the attitude of the tourists should be as high as possible towards the alternative. This can for example be done by providing extra facilities at and around the beach.

10.3. Beach nourishment

Figure 10.1c illustrates the stakeholder engagement plan for the alternative of beach nourishment. From the stakeholder analysis it became clear that this is the alternative that is supported by most of the stakeholders. However, in order for the alternative to succeed, it is of great importance to engage the following 2 groups of stakeholders. First, project investors and the environmental interest groups. As beach nourishments are quite expensive and need to be carried out every couple of years, it will probably be too expensive. A solution to this problem may be private investments. These investments can be for example made by other stakeholders who have major interest in the project, being hotels and resorts or other business owners in the area. In order to engage project investors into the project, it is important to increase the project investor's interest. For example, if hotel owners invest in beach nourishment, they have the opportunity to expand their services at and around the beach. Second, the environmental interest groups as adding an extra layer of sand may have a negative impact on the ecology.

10.4. Coarse nourishment

Figure 10.1d illustrates the stakeholder engagement plan for the alternative of coarse nourishment. As this alternative is quite equal to the alternative of beach nourishment, the opposing and supporting stakeholders are also quite equal. The main difference between normal beach nourishment and coarse nourishment is the grain size of the sand. The two groups of stakeholders that may be opposing are the tourists and the environmental interest groups. The tourists because their stated preference turned out to be fine sand, which is mainly because this is what they are used to. Because of the opposition of the tourists, the hotel and resort owners are also opposing to the solution, as this will have a negative impact on their business. Also, this kind of nourishment results in a steeper profile which means that the tourists can go less far into the sea. The environmental interest groups might be opposing to this alternative because of the fact that the coarser material may have a negative impact on the ecology and may eventually have even more environmental consequences.

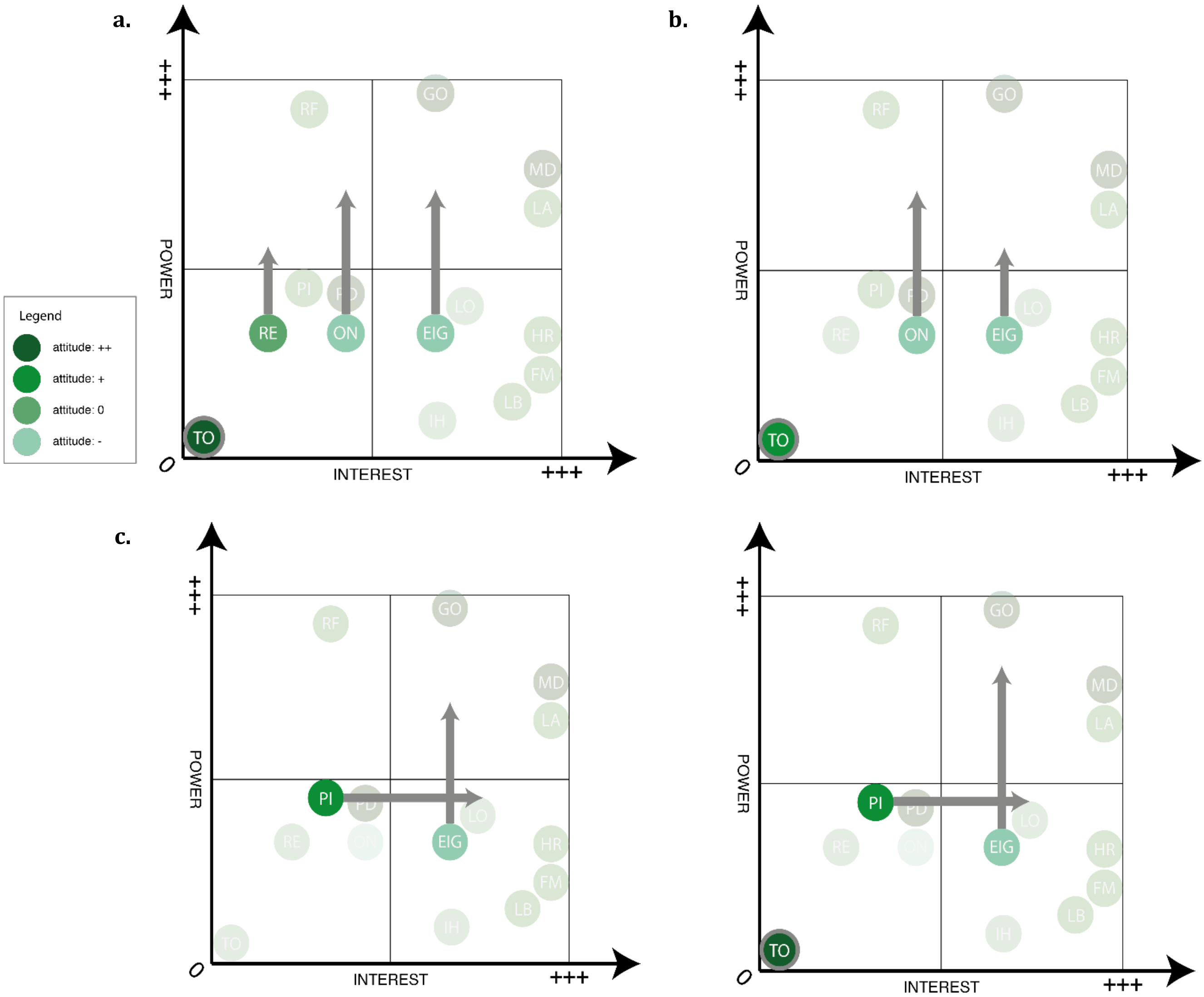


Figure 10.1 | Stakeholder engagement plans (a) T-groynes, (b) groynes, (c) beach nourishment, and (d) coarse nourishment

PART VI
Assessment Phase

11. Assessment of the alternatives

After the various analyses, the established scenarios and solutions, and the stakeholder management plans, the assessment can be made to determine the best suitable solution for the problem. The assessment consists of two parts: the risk management plan and the multi-criteria analysis (MCA).

11.1. Risk management

Before the multi-criteria analysis can be executed, the risks of the alternatives need to be evaluated. As certain risks can have a major impact on the solution's suitability for the problem and the decision-making of the client. This chapter includes an introduction about risk management and a summary of the process with the conclusions for the project. The whole setup and execution of the risk management can be found in Appendix H.1.

General information

To ensure a successful design, construction, operation and maintenance of a solution, risks need to be taken into account. A risk is the probability of an undesired event multiplied by the consequences (Jonkman, Steenbergen, Morales-Nápoles, Vrouwenvelder & Vrijling, 2016) and has an effect on the project's mission or at least on one of the project's objectives (PMI, 2008). Risks can have numerous causes and numerous impacts. These impacts can either be wanted or unwanted. Project Risk Management is often conducted to assure certainty by increasing the probability and impact of these wanted events (opportunities) and decreasing the probability and impact of the unwanted events (threats) in a project. Project Risk Management includes the processes of conducting risk management planning, identifying risks, analysing the risks, response planning and monitoring & controlling. Carefully planning and conducting these processes thus enhances the probability of project success.

Project Risk Management is especially useful with unknown risks, since they cannot be managed proactively. Risk management can then be used to create a contingency plan to deal with those uncertainties in the most optimal way. There are three types of uncertainties Vrancken (2014):

- stochastic uncertainty, where there is data available. Example: the weather
- known unknowns, where there is no data available. Example: human error
- unknown unknowns, also known as a black swan, where the occurrence is a complete surprise. Example: the Fukushima nuclear disaster

Other risks such as known risks and risks already occurred can also be included in the assessment.

Positive risks are also taken into consideration, since they also have an impact on project objectives (PMI, 2008). Developing strategies to deal with those risks will increase the likelihoods of them occurring and enhance their beneficial effects on the project.

According to PMI (2008) the risk management processes consist of the following steps:

1. **Plan risk management** - defining how to conduct risk management activities for a project.
2. **Identify the risks** - determining which risks affect the project and documenting their characteristics.
3. **Perform qualitative risk analysis** - prioritising the identified risks by assessing and combining their probability, occurrence and impact.
4. **Perform quantitative risk analysis** - numerically analysing the effects of the identified risks
5. **Plan risk responses** - developing options and actions to enhance opportunities and reduce threats
6. **Monitor and control risks** - implementing risk response plans, tracking identified risks, monitoring residual risks, identifying new risks and evaluating risk process effectiveness throughout the project.

Risk Management Plan for Sustainable Shores

Since the deliverable of this project is an advice for the Marine Department with recommendations for the coastal erosion problem, the risk management plan only included the initiation and the first risk assessment as can be seen in Figure 11.1, without the quantitative risk analysis. This figure shows the

ATOM method, which offers an approach for Active Threat and Opportunity Management (Simon & Hillson, 2007). The initiation and first risk assessment of the ATOM method includes the steps 1, 2, 3, and 5 of the previously mentioned PMI risk management processes. The quantitative risk analysis is left out, since there is not enough knowledge and expertise to map the risks into actual costs yet. Furthermore, since this risk assessment is in the preliminary phase, and thus not completely and comprehensively executed, the steps need to be further worked out if the project progresses and the recommendations are taken into consideration. The complete follow through of the steps for this project can be found in Appendix H.1..

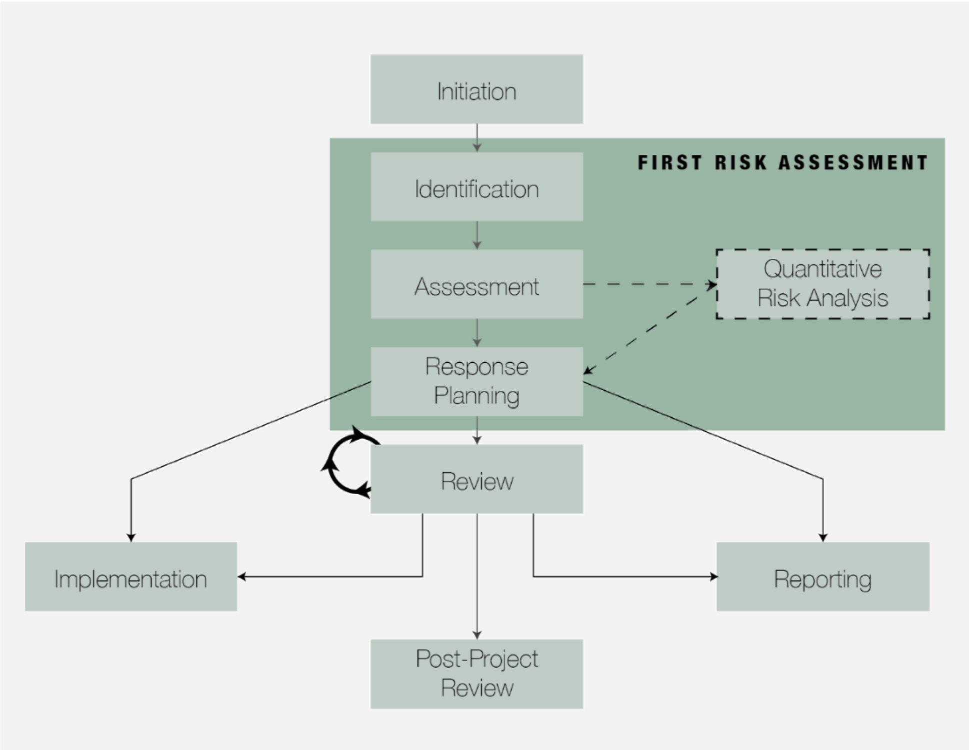


Figure 11.1 | Overview of the ATOM method (Simon & Hillson, 2007)

Risk register evaluation

As can be seen in the risk registers of the scenarios in Appendix H.1, the scenario with T-groynes and the scenario with groynes have the most risks. The reason for these risks is that the structures are established in the water, more prone to water damage, while the other scenarios are only nourishments of the beaches. Nevertheless, the alternative coarse nourishments have the highest risk severities, since the resources are scarce and the material is not preferred amongst the users of the beach, especially the tourists. At last, the scenario beach nourishment has the lowest amount of risks and the lowest risk severities since this option is the easiest to implement and is the most similar to the natural situation.

Since the risks of the regular beach nourishments solution are of the least amount, of the lowest severities and easily dealt with, this alternative will have a high risk acceptability by the stakeholders. Though the scenario coarse nourishments also has few risks, these risks have high severities and are challenging to deal with. The T-groynes and groynes will be the middle ground despite their higher amount of risks. Their risks are not as severe as those from the coarse nourishment and are less complicated to deal with. Most of these risks responses include extra effort and time in the design phase of the alternative.

The results and conclusions of the risk registers are used for the assessment of each scenario in the multi-criteria analysis in the next chapter. Since the general risk register is equal for all the scenarios, it was not taken into account with the assessment. Nonetheless, the general risk register is included in this chapter to give an indication of the risks involved with the alternatives.

11.2. Multi Criteria Analysis (MCA)

The final part of the research, before the conclusions and the discussion, is the multi-criteria analysis, which is an evaluation method used to assess the four discussed solutions. This chapter includes an introduction about the multi-criteria analysis and a summary of the process with the conclusions for the project. The whole setup and execution of the multi-criteria analysis can be found in Appendix H.2.

General information

The multi-criteria analysis is a method to compare different alternatives according to a variety of criteria to finally establish preferences amongst those alternatives (European Commission, 2007). Instead of assessing only on the monetary values (e.g. cost benefit analysis), the evaluation is done based on ratings, scores and weighted averages, expressing the importance of one criterion in respect to the other. In this manner, the analysis is used to assess alternatives on their monetised impacts as well their non-monetised impacts and is thus applicable if not all criteria can be valued into money in an acceptable way. However, it should be noted that the MCA is not a substitute for a monetary evaluation method, but can rather be used as a complement.

One of the biggest advantages of MCA methods is that they can integrate a diversity of criteria and can be used in all sectors and for various types of decisions. Another great advantage of MCA methods is that they are open, explicit and thus traceable (Department for Communities and Local Government, 2009). Various components of the MCA such as the objectives and criteria have an apparent setup and are open for analysis, discussion and change should they be inappropriate or unclear. Furthermore, since the scores and weights are accomplished openly according to established techniques, they can be cross-referenced to further support the method's transparency. A significant disadvantage of the MCA however is that it is based on the judgement of the decision making team, since the team decides on all the components (objectives, weights, etc.). This makes the analysis subjective to a certain extent.

Results MCA execution in Sustainable Shores

This paragraph includes a summary of the setup and execution of the MCA. The complete setup of the analysis as well as the execution can be found in Appendix H.2. The methodology used in this research for setting up the analysis consists of the following steps:

1. **Establish the context of the assessment: What are the aims of the MCA?** The aim of the research is to provide an advice plan with recommendations for the coastal erosion problem. Part of the process to achieve this plan is to assess the possible resulting in the most preferable solution. Because of the nature of the assessment and the nature of the MCA, this MCA assessment method is the most suitable for this project.
2. **Determine the objectives: What is to be achieved?** The MCA was expected to provide the team with a hierarchy of the four solutions based on their scores for each criterion. The scores should be supported by the arguments for each given score value.
3. **Identify the alternatives: What is to be assessed?** The alternatives were already defined in the scenarios chapter and include T-groynes, groynes, beach nourishment and coarse nourishment.
4. **Identify the criteria: What are the measures of performance?** The criteria were established using a value tree, which is used to link objectives to assessment criteria by creating an objectives hierarchy. Mission areas are linked to objectives, which in turn are linked to performance measures. This will ensure a clear reasoning behind each criterion.
5. **Define performance levels: What is the importance of each measure to the decision?** A relative weight matrix is used to determine the relative importance of the different criteria on which the alternatives are be assessed. The final results are weightings for the various criteria to show their importance compared to other criteria.
6. **Evaluate the MCA setup and correct: Are the objectives properly represented?** The MCA and its setup were evaluated by constant review of the team members.

Once the MCA was set up, each solution was assessed with the established criteria, weights and ratings, and earned certain scores. The scores were then multiplied by the weights of the criteria to attain the outcomes for each criterion. The total value for the solution assessment can then be found by summing up all the outcomes for each criterion. All the argumentations for each scoring can also be found in the appendix. Table 11.1shows the scores for all the solutions combined with their total values.

As can be seen in this table, the beach nourishment solution has the highest score, while the T-groynes scenario has the lowest score, resulting in the following ranking:

1. Beach nourishment
2. Groynes
3. Coarse nourishments
4. T-groynes

Table 11.1 | Results MCA

MISSION AREA	WEIGHT	OBJECTIVE	SCORE			
			T-groynes	Groynes	Beach Nourishment	Coarse Nourishments
Sustainability	8.5 %	Impact	1	4	3	2
	1.7 %	Integrality	1	2	5	1
	5.9 %	Resources	4	4	3	2
	3.4 %	Durability	5	5	2	4
Solution	5.1 %	Verification	4	4	5	4
	15.3 %	Validation	3	4	5	4
	5.9 %	Effectiveness	5	4	3	4
	0.8 %	Efficiency	5	5	4	5
Project management	16.5 %	Financial	3	4	1	1
	0.8 %	Planning	3	4	5	3
Stakeholder management	9.3 %	Stakeholder acceptability	2	4	4	3
	3.4 %	Stakeholder engagement	2	3	4	3
Risk management	16.5 %	Risk severity	1	2	5	4
	6.8 %	Risk acceptability	3	3	5	4
	100 %	OUTCOME	2.444	3.038	3.755	3.035

PART VI Conclusive Phase

12. Advice plan

12.1. Beach nourishment

The first mission was to write an advice on how to perform nourishments. This was discussed in chapter 7 and Appendix E. An overview of the general design process is given in Figure 12.1. Several choices have to be made during this process. The design of the nourishment starts with determining the purpose and type of the nourishment. An important step is determining the required volume that needs to be nourished. This can be determined using the lifetime and the erosion rate. Losses are expected to occur, these are estimated to be 40%.

$$Volume\ [m^3/m] = (Erosion\ rate\ [m^3/m/year] + Expected\ losses\ [m^3/m/year]) \times Lifetime\ [years]$$

Nourishments need to be seen as a success by the public. Large initial cross shore ‘losses’ are therefore undesirable. To reduce these ‘losses’ the layout of the nourishments should approach the natural profile. It is also not advised to make use of a (geotextile) revetment underneath the nourishment.

After the design has been made, the source of the material has to be determined. This can be either on land or underwater. Then the construction method needs to be selected. After the nourishment is performed, it also needs to be monitored and eventually evaluated. We advise to also allocate budget to the monitoring and evaluation of the nourishment. In this way experience can be gained which can be used in future projects. Using experience, nourishments can be performed more effective and efficient.

12.2. Erosion problem

Mission 2 dealt with the erosion problems. This mission was dealt with in Part IV. This resulted in a design of the solution, a stakeholder management plan and a risk management plan. The MCA yielded a regular beach nourishment as the best solution for the erosion problems.

12.3. Design of the solution

A regular nourishment is the best solution for the erosion problem. In chapter 7 an example of a calculation of the necessary nourish volume was given.

Example:

As an example the necessary volume for a lifetime of five years is calculated for the northern side of the project, section 1a and the northern part of section 1b. According to the Department of Natural Resources (2013) the erosion rate at the northern side of the jetty is 1.33 m/year. The active profile is assumed to reach a depth of 6.75m (see Appendix F), the dune height is assumed to be 2m (based on observations). Using a conservative approach we assume the losses to be 40%. The lifetime used for the calculation is 5 years. This results in the following:

$$Erosion\ rate\ [m^3/m/year] = 1.33 * (6.75 + 2) = 11.6\ m^3/m/year$$

$$Volume\ [m^3/m] = (11.6 + 0.40 * 11.6) * 5 = 81\ m^3/m$$

The section has an approximate length of 11km, and thus the necessary volume for a lifetime of 5 years is: $81 * 11{,}000 = 891{,}000 m^3$.

A marine based source is not available yet, so a land based source needs to be used. If a marine based source becomes available which is also financially attractive this might be a good opportunity. Because a land based source is used, land based equipment should be used by performing the nourishment. No use will be made of a revetment underneath the nourishment. After performing the nourishment it is recommended to monitor the nourishment frequently (at least once a year) to see what the nourishment is doing and how the sand is distributed. After a few years the nourishment need to be evaluated using the data of the monitoring. In this way experience in performing nourishments can be gained and future nourishments can be performed more efficiently.

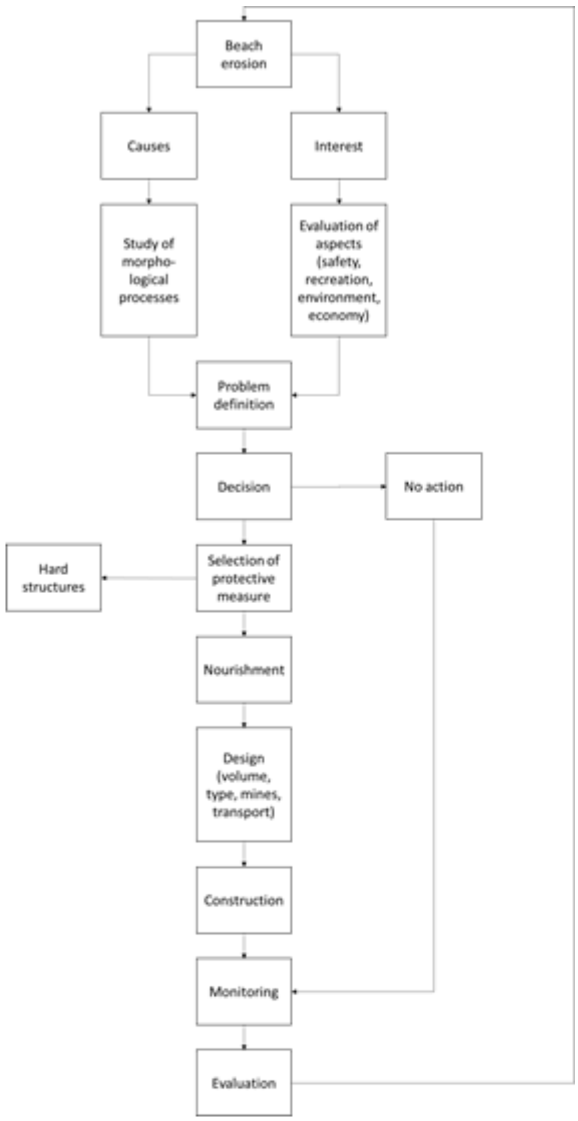


Figure 12.1 | Roadmap of making a nourishment scheme (based on Pilarczyk et. al, 1986)

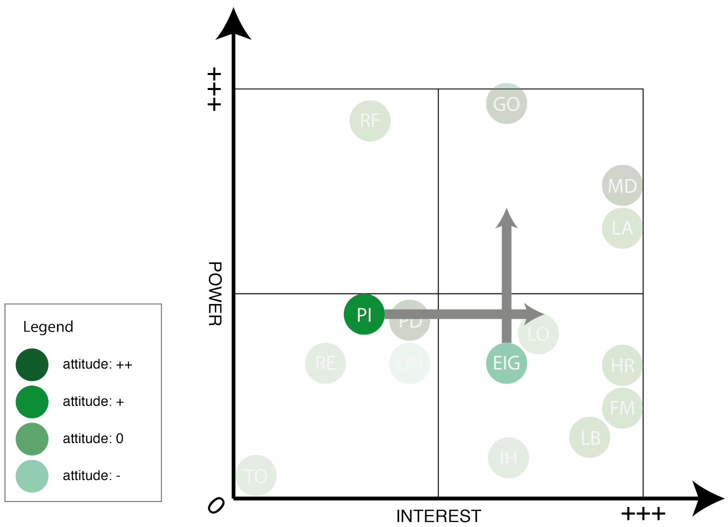


Figure 12.2 | Stakeholder engagement plan for beach nourishment (own ill.)

12.4. Stakeholder management

Figure 12.2 illustrates the stakeholder engagement plan for the alternative of beach nourishment. In order for the alternative to succeed, it is of great importance to engage the following two groups of stakeholders. First, project investors and the environmental interest groups. As beach nourishments are quite expensive and need to be carried out every couple of years, it might be too expensive for the Marine Department alone to handle or the Marine Department might prefer to invest the capital somewhere else. A solution to this problem may be private investments. These investments can be for example done by other stakeholders who have major interests in the project, being hotels and resorts or other business owners in the area. In order to engage project investors into the project, it is important to increase the project investor's interest and their awareness hereof. For example, if hotel owners invest in beach nourishment, they have the opportunity to expand their services at and around the beach. Second, the environmental interest groups as adding an extra layer of sand may have a negative impact on the ecology.

It is recommended for the Marine Department to continue the analysis and adjust the stakeholder engagement plan should there be new findings. The first step in the analysis could be interviewing more stakeholders to determine their complaints and interests. Furthermore, events can be organised for stakeholders to attend. This is especially useful to involve stakeholders who were previously not identified and to convey the possible project investors. However, stakeholders might not feel compelled to attend the event, thus its importance should be clearly conveyed. Additional meetings with the project investors can be made to convince them of the importance of the project and the need for their cooperation.

12.5. Risk management

According to the team's initial risk assessment, beach nourishment has three risks unique to the solutions, which can be found in Appendix H (see Table H.9). These risks can mostly be prevented or mitigated by properly preparing the design for construction, which includes additional research in certain aspects, additional inspections and involving experts in the needed fields.

Furthermore, beach nourishment has many other risks that might occur with any chosen solution, but are associated with the area and the problem. These risks can be found in Appendix H It is of great importance to assess these risks and determine their risk responses. The risk management should also be further executed to be able to determine all risks related to the project and to establish risk responses for each risk. Establishing a risk management plan for the project will ensure a proper response plan with structured ways to deal with the risks, should they occur. Furthermore, the plan can also be used during the design phase to minimize the risk probabilities and impacts. This will prevent additional unwanted effects to the surroundings and the beaches themselves and unnecessary costs.

14. Discussion & Further research

An evaluation of the conducted research is necessary to identify the shortcomings and maintain objective. This chapter will discuss the research's weaknesses and the areas that need to be improved. Furthermore, it will give recommendations on further research.

Problem definition

The site investigation showed that the states of the hard structures in the area were doubtful. This was however for the most part out of the scope of the project. A small part has been written about the structures and a few of the mistakes, which were made in designing them. This is however not an exhaustive description of the problems present in the current structures. If no further research is initiated into these problems, the mistakes in the designs leading to these problems might be repeated in the future. It is therefore highly recommended to investigate more clearly the problems with the structures and how these can be resolved for future structures.

According to J. Laksanalamai (personal communication, 28-09-2016) we found out that an important motivator for choosing certain structures was whether or not there was a requirement to perform an EIA. The procedure for the EIA is apparently too complex and time consuming and because it is only necessary for certain types of structures it eliminates these structures from the list of options. This is very problematic, because this means that often good solutions are not selected as an option because of this and lesser solutions are selected. It is recommended to look into ways to make the procedure of the EIA less time consuming and to make it required for all possible solutions. This eliminates an unwanted bias to certain solutions.

Coastal analysis

Most data as presented in the coastal analyses is derived from scientific reports, public and peer reviewed papers and can thus be considered as reliable. However because sediment data was scarce we took our own measurements. The analysis of this measurements is unfortunately done with poor equipment and therefore not very reliable. To first order we have an idea of the grain size distribution but we recommend to improve the results by using better equipment (e.g. better sieves). However, it should be noted that it will not have a very big effect on the results from a model as UNIBEST.

During our site visit we did not have the time to visit Hua Hin. We considered Cha-am to be more important since the initial project area is near Cha-am. We therefore might have missed some things. We did however use Google Earth and photos taken by the Marine Department to get an impression of the area.

Stakeholder analysis

The stakeholder analysis is done based on the conducted interviews by the team and the expertise of the team. Though scientific sources are used for the analysis, it might still be considered biased as there were very few conducted interviews. Furthermore, the stakeholder analysis is also made based on the team's expertise. Since the team consists of students with limited stakeholder management experience outside the academic world, our expertise might be biased and insufficient. Should the solution thus be further investigated, more stakeholders should be interviewed and more research should be done to determine all the involved stakeholders and to determine the best possible engagement plans. At last, experts on stakeholder management should be involved in the project to give their judgment on the analysis or perhaps conduct the whole analysis.

Beach nourishment

The nourishments performed the last years did not have the expected lifetime. This can be solved by a better design. A better design can be made with better information about the erosion rate and the profiles. Therefore it is advised to do more measurements of the profiles. Based on a large set of these measurements an accurate erosion rate can be determined and the geometry of the nourishment can be made. These measurements can also be used to monitor the nourishment (more measurements are advised for monitoring). Based on this monitoring the nourishments can be evaluated and experience is gained. This can be used to improve the design of new nourishments.

The nourished material is also important. It is important to use sediment with the proper characteristics. It is therefore important to look for more mines/sources that satisfy the requirements. It is also encouraged to continue the research on marine based sources. These sources could yield good material and moreover, they could also reduce the costs of the nourishment.

Coastal model

The model that was set up during this project did not represent the coastline correctly. One of the causes can be faulty input data (boundary conditions, profiles, sediment characteristics, wave conditions, tidal conditions). The most important input for UNIBEST are wave conditions, which were simulated using SWAN. The output of SWAN can be improved by improving the input for SWAN. The most important input in SWAN are wave data and bathymetry. By improving this input SWAN will simulate better wave conditions, which may lead to a better model. It is therefore recommended to critically look at all the data sets used as input for the model. If improvements can be made, this should be done. Most effort should be made to improve the wave data, because this will have the most effect.

It is also possible that the model did not represent the coastline correctly due to the limitations of UNIBEST. UNIBEST does not take all important processes into account. It is possible that cross shore processes have an unnegligible effect. The influence of cross shore processes could be assessed using numerical models (e.g. the UNIBEST-TC module). Also currents and 3D-effects (e.g. stratification) were not taken into account. The influence of these effects should be assessed. If these effects are deemed to be significant it should be considered using a more detailed model like Delft-3D. It is therefore recommended to assess the influence of cross shore processes, currents and 3D-effects to determine if a more detailed model is desirable.

The SWAN model is set up as a very simple file in which the recommended settings were used. When more research is conducted the parameters, assumptions and formulas as used in the SWAN model can be adapted to better represent the actual situation. The SWAN model can then also be calibrated by requesting output data at the Hua Hin and Phetchaburi buoy locations and comparing this with the buoy data.

Risk management

The risk management of this project is a first draft of the initial risk assessment and does not include a quantitative risk analysis. The assessment is thus very limited in its steps and re-evaluations. Furthermore, the assessment is done based on the team's expertise, which is limited and thus does not include judgements of risk management experts. The established risk management might thus be inaccurate in certain aspects or might become inaccurate should the project progress. Further execution of the risk management is does necessary to develop the initial risk management plan and to provide a complete overview of the risks involved and a risk response plan to deal with those risks.

However, a comprehensive risk analysis is only possible if the alternatives are more concrete. Since this research only includes concepts of the alternatives, an in depth risk management is more difficult to establish as certain aspects are not yet determined. The risk management assessment should thus continuously be carried out alongside the progression of the alternatives and finally the chosen solution.

Multi-criteria analysis

The multi-criteria analysis is setup and executed based on literature and the team members' expertise. Other stakeholders and thus also the client were not involved in the establishment of the criteria and in the determination of the weightings for each criterion. Therefore, the recommendations are made solely on the judgment of the team. Since the members' expertise on the whole project and the MCA might be limited in certain areas, the results might thus be subjective. Should the client wish to use this research, it is then advised to check the criteria in the analysis to determine their agreement. The client is then also advised to include experts to evaluate the criteria and their weightings. Furthermore, experts should also be involved to evaluate the scoring for the solutions on the criteria, since they might have better knowledge and expertise on the implementation, characteristics and behaviour of the solutions.

15. Literature

American Society for Testing and Materials (1998). *Standard Test Method for Particle-Size Analysis of Soils.*

ASEAN (2009). Cha-am Hua Hin Statement on East Asia Summit (EAS) Disaster Management Cha-am Hua Hin, Thailand, 25 October 2009. Retrieved from http://asean.org/?static_post=cha-am-hua-hin-statement-on-east-asia-summit-eas-disaster-management-cha-am-hua-hin-thailand-25-october-2009

Asia Discovery. (2011). *History of Hua Hin*. Retrieved from: https://www.asia-discovery.com/Thailand/huahin/history.htm

Aungsakul, K., Jaroensutasinee, M., & Jaroensutasinee, K. (2007). Numerical Study of Principal Tidal Constituents in the Gulf of Thailand and the Andaman Sea. *Walailak J Sci & Tech, 4*(1), 95-109.

BMT ARGOSS (2016). Wind and wave data. Retrieved from http://waveclimate.com/

Bosboom, J. & Stive, M.J.F. (2015). *Coastal dynamics I: Lecture notes CIE4305*. Delft, the Netherlands: Delft Academic Press.

BP (2016). *Statistical Review of World Energy June 2016*. Retrieved from https://www.bp.com/content/dam/bp/pdf/energy-economics/statistical-review-2016/bp-statistical-review-of-world-energy-2016-full-report.pdf

Bryson, J.M. (2011). *Strategic Planning for Public and Nonprofit Organizations: A Guide to Strengthening and Sustaining Organizational Achievement.* New York: John Wiley & Sons.

Bryson, J.M., Patton, M.Q. & Bowman, R.A. (2011). Working with evaluation stakeholders: A rationale, step-wise approach and toolkit. *Evaluation and Program Planning, 34*, 1-12.

Cha-Am Homes. (2005). *Beach Town Cha-Am*. Retrieved from: http://chaamhomes.com/beachtownchaam.php

Climatological Group, Meteorological Development Bureau, Meteorological Department. (2015). *The Climate of Thailand.* Retrieved from *http://www.tmd.go.th/en/archive/thailand_climate.pdf*

Deltares (2011). *UNIBEST-CL+ manual: Manual for version 7.1 of shoreline model UNIBEST-CL+*.

Department for Communities and Local Government (2009). *Multi-criteria analysis: a manual*. Wetherby: Communities and Local Government Publications

Department of Marine and Coastal Resources (2013). *Study, Survey, Monitoring and Design for Preventing Coastal Erosion at Sirindhorn International Environmental Park*. (In Thai)

Discovery Thailand. (2004). *Phetchaburi in Central Thailand.* Retrieved from: http://www.discoverythailand.com/Phetchaburi.asp.

Dunn, S., Friedman, R., & Baish, S. (2000). Coastal Erosion: Evaluating the Risk. *Environment Science and Policy for Sustainable Development, 42*(7), 36-45. doi: 10.1080/00139150009605749

Ecoca. (2002). *Tropical Climate*. Retrieved from: http://www.ecoca.ro/meteo/tutorial/climate/older/tropical_climate.html

European Commission (2007). *Multi-Criteria Analysis*. Retrieved from http://forlearn.jrc.ec.europa.eu/guide/4_methodology/meth_multi-criteria-analysis.htm

Facts and Details (2014). *Air and water pollution and environmental issues in Thailand*. Retrieved from: http://factsanddetails.com/southeast-asia/Thailand/sub5_8h/entry-3326.html#

Farris, A.S. & List, J.H. (2007). Shoreline Change as a Proxy for Subaerial Beach Volume Change. *Journal of Coastal Research, 23*(3), 740-748.

Grid Infrastructure Communication Toolkit (2016). *Information on Project Developers.* Retrieved from: https://webgate.ec.europa.eu/multisite/gridcommunicationstoolkit/en/content/information-project-developers

Hierarchy Structure (2013). *Thailand Political Hierarchy*. Retrieved from https://www.hierarchystructure.com/thailand-political-hierarchy/https://webgate.ec.europa.eu/multisite/gridcommunicationstoolkit/en/content/information-project-developers

Hillson, D. & Simon, P. (2007). *Practical Project Risk Management: The ATOM Methodology*. Vienna: Management Concepts Inc.

Hofstede, G. (2010a). *National Culture: Dimensions of National Culture*. Retrieved from: https://geert-hofstede.com/national-culture.html

Hofstede, G. (2010b). *What about Thailand?* Retrieved from: https://geert-hofstede.com/thailand.htmlhttps://geert-hofstede.com/national-culture.html

Hofstede, G., Hofstede, G.J. & Minkov, M. (2010) *Cultures and Organizations: Software of the Mind*. New York: MC Graw Hill

Hua Hin. (2015). *History of Hua Hin*. Retrieved from: http://www.huahin-huahin.com/history.htm

Index Mundi. (2016). *Thailand Demographics Profile 2016*. Retrieved from: http://www.indexmundi.com/thailand/demographics_profile.htmlhttp://www.huahin-huahin.com/history.htm

Jonkman, S.N., Steenbergen, R.D.J.M., Morales-Nápoles, O., Vrouwenvelder, A.C.W.M., Vrijling, J.K. (2016). *Probabilistic Design: Risk and Reliability Analysis in Civil Engineering*. Delft: Delft University of Technology.

Kor, R. & Wijnen, G. (2002). *50 checklisten voor project- en programmamanagement*. Deventer: Kluwer.

Maps of World (2016), Thailand Geography. Retrieved from http://www.mapsofworld.com/thailand/geography/

National Geographic (2016), Thailand Facts. Retrieved from http://travel.nationalgeographic.com/travel/countries/thailand-facts/

Negri, M.P., Sanflippo, R., Basso, D., & Rosso, A. (2015). Comparison of live and dead molluscan assemblages suggests recent human-driven decline in benthic diversity in Phetchaburi (NW Gulf of Thailand). *Continental Shelf Research, 111*(A), 9-30. http://dx.doi.org/10.1016/j.csr.2015.10.014

Nuttalaya, P. (1996). Coastal erosion in the Gulf of Thailand. *GeoJournal*, *38*(3), 283-300. doi: 10.1007/BF00204721

Olarn, K. & Yu, E., (2016). *Thailand closes diving sites over coral bleaching crisis*. Retrieved from http://edition.cnn.com/2016/05/27/travel/thailand-dive-sites-coral-bleaching/

Ongprasert, P. (2008). *Forest management in Thailand.* International Forestry Cooperation Office, Royal Forest Department, Ministry of Natural Resources and Environment. Retrieved from http://www.forest.go.th/foreign/images/stories/FOREST%20MANAGEMENT%20IN%20THAILAND.pdf

OSMEP. (2010). *The White Paper on Small and Medium Enterprises of Thailand in 2009 and Trends in 2010.* Retrieved from: http://www.sme.go.th/SiteCollectionDocuments/White%20Paper/2552/Eng_07.pdf

Pilarczyk, K.W., van Overeem, J., & Bakker, W.T. (1986). Design of Beach Nourishment Scheme. *Coastal Engineering Proceedings, 20*. doi: http://dx.doi.org/10.9753/icce.v20.%25p

Ping, X. (2011). *Environmental Problems and Greens Lifestyles in Thailand.* Assumption University, Thailand. Retrieved from https://www.nanzan-u.ac.jp/English/aseaccu/venue/pdf/2011_05.pdf

PMI (Project Management Institute), (2008). *A Guide to the Project Management Body of Knowledge (PMBOK Guide)*. 4th edition. Newton Square, PA: Project Management Institute, Inc.

Prevention Web (2015). *Thailand Disaster & Risk Profile - Basic Country Statistics and Indicators.* Retrieved from http://www.preventionweb.net/countries/tha/data/

Regional Centre of Expertise. (2008). *The Southwest Coastal Region of Phetchaburi and Prachap Kiri Khun Provinces*. Retrieved from: http://rcecha-am.sirindhornpark.or.th/geographical.html

Reizigersgids. (2012). *Cha Am*. Retrieved from: http://dereizigersgids.nl/thailand/cha-am

Ridder, H.A.J. de, Soons, F.A.M. & Voskamp, R. (2011). *Dictaat CT1062: Inleiding Integraal Ontwerpen.* Delft: Faculteit Civiele Techniek en Geowetenschappen.

Rijkswaterstaat. (2016). *De Zandmotor: succesvolle aanjager voor innovatief kustonderhoud.* Retrieved from: https://www.rijkswaterstaat.nl/over-ons/nieuws/nieuwsarchief/p2016/09/de-zandmotor-succesvolle-aanjager-voor-innovatief-kustonderhoud.aspx

Saengsupavanich, C., Chonwattana, S., & Naimsampao, T. (2009). Coastal erosion through integrated management: A case in Southern Thailand. Ocean & Coastal management, 52, 307-316.

Saramul, S. & Ezer, T. (2014). *Spatial variations of sea level along the coast of Thailand: Impacts of extreme land subsidence, earthquakes and the seasonal monsoon.* Global and Planetary Change, 122, 70-81.

Schiereck, G.J., updated by Verhagen, H.J., (2012). *Introduction to bed, bank and shore protection: Engineering the interface of soil and water.* Delft, the Netherlands: VSSD.

Scottish Natural Heritage (n.d.). *A guide to managing coastal erosion in beach/dune systems*. Retrieved from: http://www.snh.org.uk/publications/on-line/heritagemanagement/erosion/appendix_1.6.shtml

Simon, P., Hillson, D., (2007). *Practical Project Risk Management: The ATOM Methodology.* Leesburg, VA: Management Concepts, Inc.

Snidvongs, A., and P. Sojisuporn (1999), Numerical simulations of the net current in the Gulf of Thailand under different monsoon regimes, in Proceedings of the First Technical Seminar on Marine Fishery Resources Survey in the South China Sea, pp. 54 – 85, Samutprakan Press, Samutprakan, Thailand.

Sojisuporn, P., Sangmanee, C., & Wattayakorn, G. (2013). Recent estimate of sea-level rise in the Gulf of Thailand. *Maejo International Journal of Science and Technology, 7*(special issue), 106-113.

Soulsby, R.L., Hamm, L., Klopman, G., Myrhaug, D., Simons, R.R., & Thomas, G.P. (1993). Wave-Current Interaction within and outside the bottom boundary layer. *Coastal Engineering, 21*, 41-69.

Southeast Asia Technology Co.,Ltd. (2003). *Master Plan for Coastal Erosion Management from Phetchaburi River-Mouth, Phetchaburi Province to Pranburi River-Mouth, Prachuab Khiri Khan Province*.

Stive, M.J.F., de Schipper, M.A., Luijendijk, A.P., Aarninkhof, S.G.J., van Gelder-Maas, C., van Thiel de Vries, J.S.M., de Vries, S., Henriquez, M., Marx, S., & Ranasinghe, R. (2013). A New Alternative to Saving Our Beaches from Sea-Level Rise: The Sand Engine. *Journal of Coastal Research, 29*(5), 1001-1008. doi: http://dx.doi.org/10.2112/JCOASTRES-D-13-00070.1

Suwal, S. (2016). *Water in crisis - Thailand.* The Water Project Retrieved from https://thewaterproject.org/water-crisis/water-in-crisis-thailand

Szmytkiewics, M., Biegowski, J., Kaczmarek, L. M., Okrój, T., Ostrowski, R., Pruszak, Z., Różyńsky, G, & Skaja, M. (2000). Coastline changes nearby harbour structures: comparative analysis of one-line models versus field data. *Coastal Engineering*, *40*, 119-139. http://dx.doi.org/10.1016/S0378-3839(00)00008-9

Thai Law Forum (n.d.). *Thai Governmental Structure*. Retrieved from

http://www.thailawforum.com/articles/briggsgov.html

Thailand Legal (2016). Thai Judicial Court System. Retrieved from http://www.legal-thai.com/thai-judicial-court-system/

Thailand Sustainable Development. (2016a). *The Travel Business Is an Economic Mainstay*. Retrieved from: http://www.thailandsustainabledevelopment.com/topics/tourism/

Thailand Sustainable Development (2016b). *New waves of development bring prosperity, tourists and challenges*. Retrieved from http://www.thailandsustainabledevelopment.com/topics/oceans-and-seas/

Thailand Sustainable Development. (2016c). *Sustainable Development Requires Dialogue and Peace*. Retrieved from: http://www.thailandsustainabledevelopment.com/topics/conflict/

Thailand Sustainable Development. (2016d). *A Deep-rooted Menace to Thai society*. Retrieved from: http://www.thailandsustainabledevelopment.com/topics/corruption/http://www.thailandsustainabledevelopment.com/topics/conflict/

Thailand Sustainable Development. (2016e). *Cultural Achievements with Lasting Value*. Retrieved from: http://www.thailandsustainabledevelopment.com/topics/heritage/

Thailand Sustainable Development (2016f). *The power behind Thailand's past, present and future.* Retrieved from http://www.thailandsustainabledevelopment.com/topics/energy/

Thailand Sustainable Development (2016g). *Energy Consumption in Thailand*. Retrieved from http://www.thailandsustainabledevelopment.com/wpcontent/uploads/2015/11/energy_consumtion.pdf

Thailand Sustainable Development (2016h). *The biggest threat to flora and fauna is humankind.* Retrieved from http://www.thailandsustainabledevelopment.com/topics/biodiversity/

Thailand Sustainable Development (2016i). *Because cities consume a large amount of resources, they must be managed efficiently.* Retrieved from http://www.thailandsustainabledevelopment.com/topics/urbanization/

Thailand Sustainable Development (2016j). Few issues have such direct bearing on human health as these two. Retrieved from http://www.thailandsustainabledevelopment.com/topics/pollution-and-waste/

Thailand Sustainable Development (2016k). *Floods, droughts and the future of climate change*. Retrieved from http://www.thailandsustainabledevelopment.com/topics/disasters/

Thailand Sustainable Development. (2016l). *Reforming Education for the 21st Century*. Retrieved from: http://www.thailandsustainabledevelopment.com/topics/education/

Thailand Sustainable Development. (2016m). *Free coverage gives healthcare system further booster shot*. Retrieved from: http://www.thailandsustainabledevelopment.com/topics/health/

Thailand Sustainable Development. (2016n). *The Most Binding of Social Ties is Loosening with the Times*. Retrieved from: http://www.thailandsustainabledevelopment.com/topics/family/

Thailand Sustainable Development. (2016o). *While one has historically declined, the other rises*. Retrieved from: http://www.thailandsustainabledevelopment.com/topics/poverty-and-income-inequality/

Thailand Sustainable Development. (2016p). *An Ancient Institution Navigates the Modern World.* Retrieved from: http://www.thailandsustainabledevelopment.com/topics/monarchy/

Thailand Sustainable Development. (2016q). *The Spiritual and Ethical Roots of Sustainable Development*. Retrieved from: http://www.thailandsustainabledevelopment.com/topics/religion/

Thailand Travel. (2016). *Hua Hin & Cha'am*. Retrieved from: http://www.thailandtravel.nl/landinformatie--thailand-bestemmingen/hua-hin-chaamhttp://www.tmd.go.th/en/archive/thailand_climate.pdf

The British Geographer. (2016). *The Climate of Tropical Regions*. Retrieved from: http://thebritishgeographer.weebly.com/the-climate-of-tropical-regions.html

The Sirindhorn International Environmental Park. (2000). [Information board regarding the mangrove forest, September 26, 2016]. *Her Royal Highness Princess Maha Chakri Sirindhorn Mangrove Forest*. Thailand: Cha-Am.

The Sirindhorn International Environmental Park. (2010). *Energy and Environment Center*. Retrieved from: http://www.sirindhornpark.or.th/SIEPENG/

The Sirindhorn International Environmental Park (2016). *The Southwest coastal region of Phetchaburi and Prachuap Kiri Khun Provinces.* Retrieved from http://rcecha-am.sirindhornpark.or.th/geographical.html

The World Bank (2012). *Thailand Flood 2011 - OVERVIEW Rapid Assessment for Resilient Recovery and Reconstruction Planning*. Retrieved fromhttp://documents.worldbank.org/curated/en/677841468335414861/pdf/698220WP0v10P106011020120Box370022B.pdf

The World Bank (2014). *Terrestrial protected areas (% of total land area).* Retrieved from http://data.worldbank.org/indicator/ER.LND.PTLD.ZS

The World Bank (2015). *Urbanization in Thailand is dominated by the Bangkok urban area*. Retrieved fromhttps://www.worldbank.org/en/news/feature/2015/01/26/urbanization-in-thailand-is-dominated-by-the-bangkok-urban-area

The World Bank. (2016a). *Thailand: Overview*. Retrieved from: http://www.worldbank.org/en/country/thailand/overview

The World Bank. (2016b). *New country classifications by income level*. Retrieved from: http://blogs.worldbank.org/opendata/category/tags/newshttps://www.worldbank.org/en/news/feature/2015/01/26/urbanization-in-thailand-is-dominated-by-the-bangkok-urban-area

The World Bank. (2016c). *Thailand: Data*. Retrieved from: http://data.worldbank.org/country/thailand

The World Bank. (2016d). *Poverty & Equity: East Asia & Pacific*. Retrieved from: http://povertydata.worldbank.org/poverty/region/EAP

Tilmans, W.M.K., Klomp, W.H.G., & de Vroeg, J.H. (1993). Coastal erosion- The Kerteh case, Analysis of causative factors and mitigative measures using dedicated mathematical measures using dedicated mathematical modelling tools. Presented at the International Colloquium on Computer Applications in Coastal & Offshore Engineering.

Tourism Authority of Thailand. (2003). Hat Cha-Am: Beaches & Bay. Retrieved from: https://www.tourismthailand.org/Attraction/Hat-Cha-am--974

Tourism Hua Hin. (2016). *History Hua Hin*. Retrieved from: http://www.tourismhuahin.com/history-huahin.php

Trading Economics. (2016). *Thailand Corruption Rank*. Retrieved from: http://www.tradingeconomics.com/thailand/corruption-rank

TU Delft (n.d.). *Soil-water mixture and its phases.*

UNICEF. (2015). *Thailand*. Retrieved from: https://data.unicef.org/country/tha/

Van Rijn, L.C. (2004). *Analysis and modelling of shoreface nourishments* (Project identification Z3748.20). Retrieved from: repository.tudelft.nl/assets/uuid:8d3509b9-8b95-4b3b-a995.../Z3748_20.pdf

Van Rijn, L.C. (2010). *Coastal erosion control based on the concept of sediment cells* (Deliverable No. D 13a). Retrieved from: www.conscience-eu.net/documents/deliverable13a-controlling.pdf

Van Rijn, L.C. (2013). *Design of hard coastal structures against erosion.* Retrieved from: www.leovanrijn-sediment.com/papers/Coastalstructures2013.pdf

Verhagen, H.J. (1992). Method for artificial beach nourishment. Paper presented at the *International Conference on Coastal Engineering*. Retrieved from: http://repository.tudelft.nl/islandora/object/uuid:5d24ef34-1698-4860-9d78-8884269f79b2?collection=research

Vongvisessomjai, S. (2009a). *Tropical cyclone disasters in the Gulf of Thailand*. Songklanakarin J. Sci. Technol., 31 (2), 213-227.

Vongvisessomjai, S. (2009b). *Impacts of Typhoon Vae and Linda on wind waves in the Upper Gulf of Thailand and East Coast.* Southern Thailand Environment Management (STEM), J.Vol.1, No. 1.

Vrancken, J. (2014). Project Risk Management: Being smart in taking risks [pdf]. Retrieved from http://www.blackboard.tudelft.nl/

Walstra, D.J.R. (2000). *Unibest-TC Userguide.*

Wasson, C.S. (2006). *System Analysis, Design, and Development: Concepts, Principles, and Practices.* New Jersey: John Wiley & Sons, Inc.

Wijnen, G., Renes, W. and Storm, P. (2004). *Projectmatig werken.* Utrecht: Het Spectrum.

World Atlas (2016), Thailand Geography. Retrieved from http://www.worldatlas.com/webimage/countrys/asia/thailand/thland.htm

World Commission on Environment and Development (1987). *Our common future.* Oxford, NY: Oxford University Press.

World Culture Encyclopedia. (2016). *Culture of Thailand*. Retrieved from: http://www.everyculture.com/Sa-Th/Thailand.html

WWF (2013). *WWF-Thailand - Biodiversity, ecosystems, and sustainability.* Retrieved from http://d2ouvy59p0dg6k.cloudfront.net/downloads/wwf_thailand_english_final.pdf

Yates, J.J. (2012). Abundance on Trial: The Cultural Significance of “Sustainability”. The Hedgehog Review,14(2).

APPENDICES

A. Socio-economic analysis

A.1. Geographical and typographical characteristics

Figure A.1 | Thailand on the world map (own ill.)

Thailand's terrain in general contains 3 types of landscapes;

- A high level sandstone plain in the northeast, called the Khorat Plateau, supporting grasses and woodlands (National Geographic, 2016).
- Relatively high mountains in the north, which extend southward along the Burma border to the northern border of Malaysia in a narrow strip (World Atlas, 2016).
- A low level central plain where various rivers come together to become the Chao Phraya River (World Atlas, 2016).

Considering the climate pattern and meteorological conditions of Thailand, the country's 76 provinces can be categorised into 5 parts (Climatological Group, 2015): Northern, Northeastern, Central, Eastern and Southern parts (see Figure A.2.a). The topography of the country can be found in Figure A.2.b.

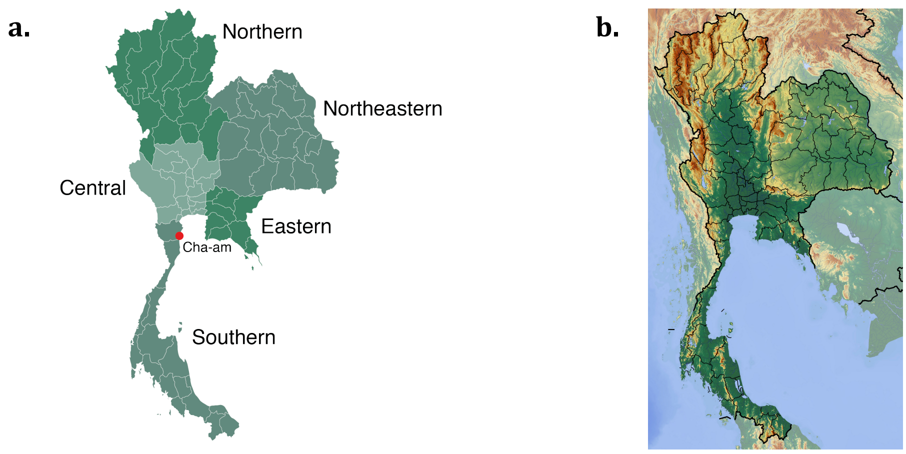


Figure A.2 | Geographical and typographical characteristics.
(a) Thailand subdivided into five parts (own ill.). (b) Typography of Thailand (Google Maps, 2016)

A.2. Climate

Figure A.3 illustrates the areas within the tropics all over the world. The tropical climate can be divided into three types, which are classified as tropical rainforest, tropical monsoon, and tropical wet and dry (The British Geographer, 2016).

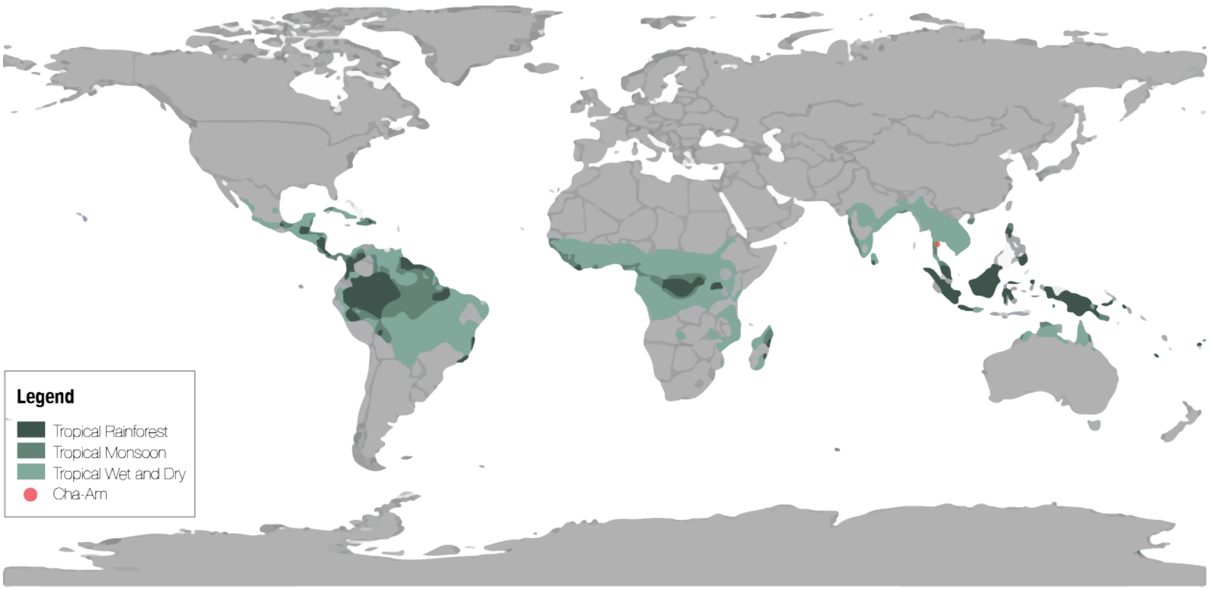


Figure A.3 | Map of the three types of tropical climate areas (own ill.)

Table A.1 | Seasonal temperatures (°C) in various parts of Thailand (Climatological Group, 2015)

Region	Winter			Summer			Rainy		
	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
North	17.5	23.4	31.1	21.8	28.1	36.1	23.8	27.3	32.4
Northeast	18.7	24.2	30.6	23.2	28.6	35.2	24.4	27.6	32.6
Central	21.2	26.2	32.3	24.6	29.7	36.2	24.8	28.2	33.4
East	22.3	26.7	32.0	25.2	29.1	34.1	25.2	28.3	32.3
South East Coast	22.8	26.3	30.4	24.1	28.2	33.0	24.4	27.8	32.7
South West Coast	23.2	27.0	32.0	24.0	28.4	34.1	24.3	27.5	31.6

Table A.2 | Seasonal rainfall (mm) in various parts of Thailand (Climatological Group, 2015)

Region	Winter	Summer	Rainy	Annual rainy days
North	100.4	187.3	943.2	122
Northeast	76.3	224.4	1103.8	116
Central	127.3	205.4	942.5	116
East	178.4	277.3	1433.2	130
South East Coast	827.9	229.0	680.0	145
South West Coast	464.6	411.3	1841.3	178

Table A.3 | Relative humidity (%) in various parts of Thailand (Climatological Group, 2015)

Region	Winter	Summer	Rainy	Annual
North	74	63	81	74
Northeast	69	66	80	73
Central	70	68	78	73
East	71	75	81	76
South East Coast	81	78	79	79
South West Coast	78	77	84	80

Tropical Cyclones

When Thailand is affected by tropical cyclones, they usually move from the Western North Pacific Ocean or the South China Sea. Within Thailand, they usually pass through the Northern and Northeastern parts in the early Southwest monsoon season and will move across the Southern Thailand from October to December. Depending on their wind speeds, tropical cyclones can be divided into the following:

- Tropical depression : maximum sustained winds < 63 km/h
- Tropical storm : 63 km/h < maximum sustained winds < 118 km/h
- Typhoon : maximum sustained winds > 118 km/h

Table A.4 | The Frequency of tropical cyclones moving through Thailand from 1951-2015 (Climatological Group, 2015)

Region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
North	-	-	-	-	5	2	10	17	25	11	1	-	71
Northeast	-	-	-	-	1	6	4	18	33	25	4	-	91
Central	-	-	-	-	2	1	1	-	7	9	2	-	22
East	-	-	-	-	1	1	1	-	3	13	2	-	21
South	-	-	-	1	1	-	-	-	3	15	24	9	53

A.3. History

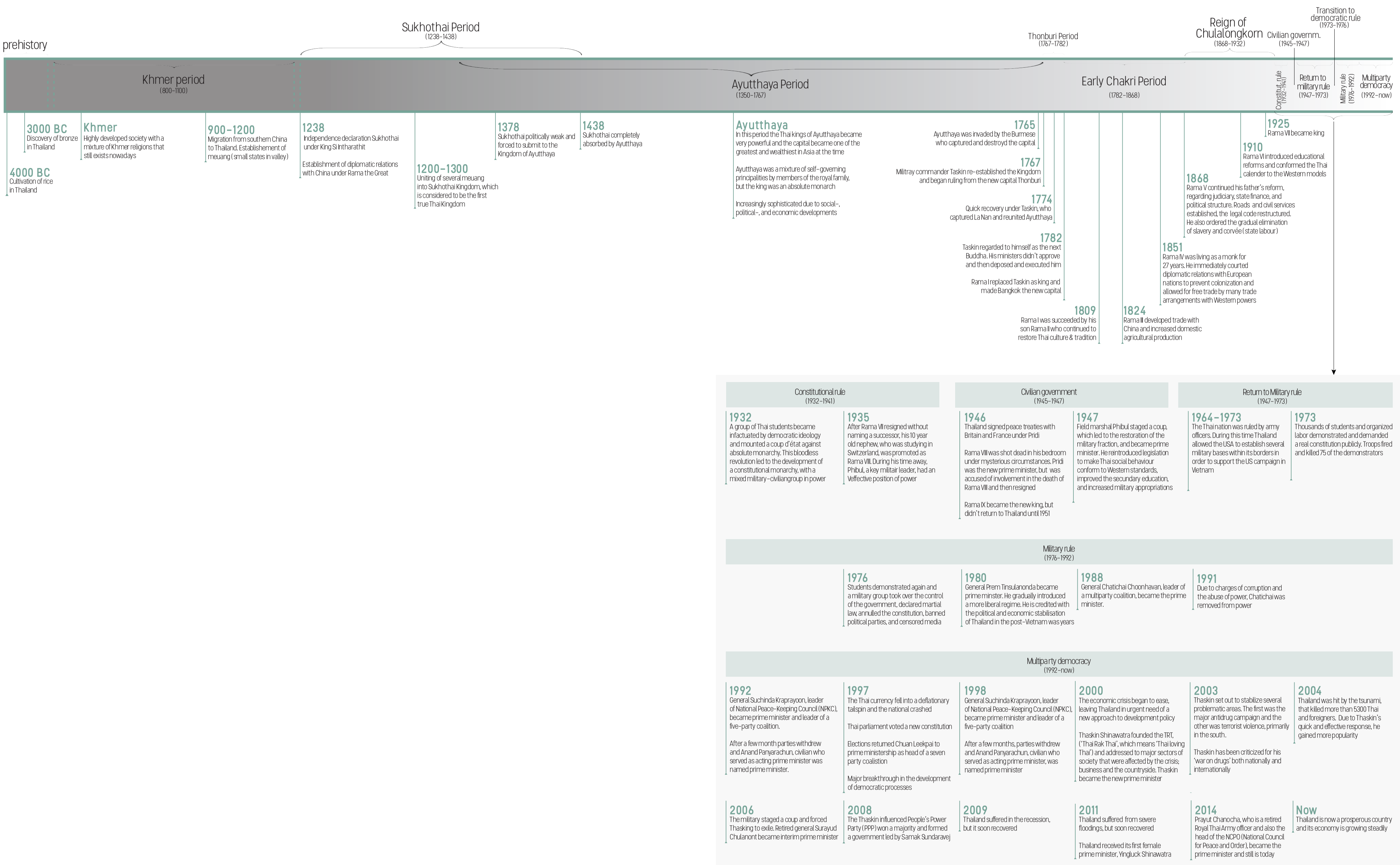


Figure A.4 | Timeline of the history of Thailand (own ill.)

A.4. Economy

Each year on July 1, the analytical classification of the world's economies based on estimates of Gross National Income (GNI) per capita for the previous years is revised. As of July 2016, table XXX applies, which is calculated using the World Bank Atlas Method. The updated GNI per capita estimates are also used as input to the World Bank's operational guidelines that determines lending eligibility (The World Bank, 2016b).

Table A.5 | Country classification by income level (The World Bank, 2016b)

Classification	Income GNI per capita
Low-income	$1,025 or lower
Lower-middle-income	$1,026 - $4,035
Upper-middle-income	$4,036 - $12,475
High-income	$12,476 or more

A.5. Environment

Energy

The energy sector in Thailand is managed by the Ministry of Energy of the Kingdom of Thailand. Its responsibility includes the granting of energy operating licenses and issuing energy pricing regulation. Included in the energy sector are the production, consumption, import and export of energy.

Table A.6 | Energy production and consumption in Thailand in 2015 (BP, 2016)

	Production	% of Thailand	% of world	Consumption	% of Thailand	% of world	Ratio production: consumption
Oil	17.2 mill. tonnes *477.000 barrels per day*	29.2%	0.4%	56.6 mill. tonnes *1.344.000 barrels per day*	45.3%	1,3%	1:3
Natural Gas	35.8 mill. tonnes oil equivalent *39,8 bill. cubic metres*	60.8%	1,1%	47.6 mill. tonnes oil equivalent *52.9 bill. cubic metres*	38.1%	1.5%	3:4
Coal	4.4 mill. tonnes oil equivalent	7.5%	0.1%	17.6 mill. tonnes oil equivalent	14.1%	0.5%	1:4
Nuclear Energy	-		-	-	-	-	
Hydro-electricity	-		-	0.9 mill. tonnes oil equivalent	0.7%	0.1%	
Renewable Energy	1.5 mill. tonnes oil equivalent	2.5%	2.0%	2.3 mill. tonnes oil equivalent	1.8%	0.6%	2:3
TOTAL	**58,9 mill. tonnes oil equivalent**	**100%**		**124,9. tonnes oil equivalent**	**100%**		**1:2**

As can be seen in Table A.6, Thailand roughly produces half of the energy it consumes, it produces roughly one-third of the oil consumption and three-fourth of the natural gas consumption. These two energy sources are most substantial in the consumption as well as the production, as 60% of the energy production is natural gas and the most used energy source is oil. The large production and consumption of natural gas is partially because of the strong opposition against coal-fired power plants and hydropower projects (Thailand Sustainable Development, 2016f). According to the Department of Alternative Energy Development and Efficiency (2015) and as can be seen in Table A.5, most of the energy consumption is due to the industrial and transportation sectors.

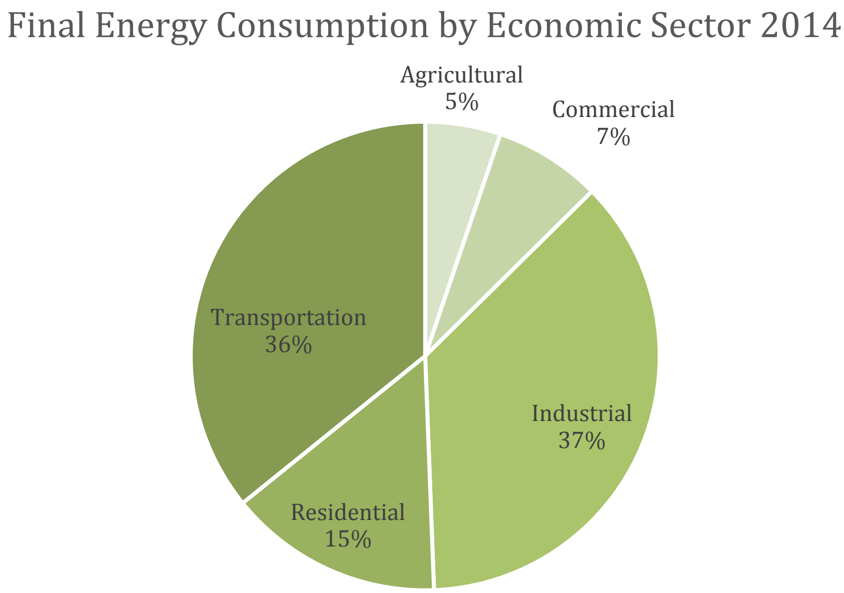


Figure A.5 | Final energy consumption by economic sector in 2014 (Thailand Sustainable Development, 2016g)

Soil

Thailand's landscape can be divided into several categories. The central plain is characterised by the rivers and has low-lying farmland and mudflats. The eastern coast and the southern provinces are filled with saline soil and alkaline soil, making them unsuited for crop cultivation. The northeast of Thailand has problems with its proneness to desertification and the salt deposits in the Korat Basin and the Sakhon Nakhon Basin. Both basins were seabeds in prehistoric times.

Water

As the country of Thailand continues to grow economically, so does the demand for water in the main economic sectors, such as industry and agriculture. The great demand has a significant effect on the water infrastructure and resources and has an impact on the quality of the water sources. Nevertheless, Thailand has a great abundance in available water resources due to its geographical position. Its average rainfall is 1700 millimetres per year, while the global average is 990 millimetres, thus supply is not a problem (Suwal, 2016). However, the storage and distribution management remain a challenge to the country, as its infrastructure has difficulties storing the water long-term during the monsoon season, resulting in the water flowing into the sea too quickly (The Sirindhorn International Environmental Park, 2016). Residents therefore have to resort to groundwater for supplementary water supply, even though the source is accompanied with rising energy costs and there is no clear policy on the extraction of groundwater, resulting in exploitation. Furthermore, the increasing population, urbanisation, agriculture and industry contribute to the degradation of the water quality. Pollution is a serious problem to the groundwater in Thailand, as one third of the surface water is considered of poor quality.

Forest

Forest management plays an important role in Thailand, as in 2010 37% of its land is covered by forests (Mongabay, 2010). However, the coverage is decreasing due to rapid population growth and economic development, as in 1960 the forest coverage was 53,33% (Ongprasert, 2008). Fortunately, the government is aware of the dangers of deforestation not only adding to global warming but also local problem, and thus affecting not only Thailand but also the rest of the world. It is thus desirable that the remaining forests are protected and that the deforested areas need to be replanted. Furthermore, it is necessary for the protection and conservation of the forests to inform and involve the local people in the process.

There are several protected forest areas in Thailand, namely the national parks, marine parks and the smaller forest parks. These parks are created to conserve and protect the natural scenic areas from economic and population growth. Even though these parks are under constant supervision of the Ministry of Natural Resources and Environment and local provincial administrations, they still face various challenges such as land encroachment, illegal logging, poaching and illegal swidden farming. Furthermore, controversies concerning the parks include allotment of private concessions, resulting in excessive bungalow developments for tourism. There are currently 105 national parks, 22 marine national parks and 69 parks. The total protected area is 18,8% of the country's total area (The World Bank, 2014).

Biodiversity
Since Thailand has various types of landscapes, it also has a wide variety of ecosystems. Situated between the Indochinese region in the north and the Sundaic region in the south, Thailand has a range of climates, a varied topography and long coastlines, providing a home to a rich variety of animals, trees and plants. Unfortunately, the biodiversity is threatened by numerous (illegal) activities, such as deforestation, poaching, overfishing, pollution and disturbances caused by infrastructure development (WWF, 2013).

However, the loss of biodiversity might be inevitable, as the country continues to grow at a significant rate and changes from a rural agrarian nation to an urban industrialized one. The more the population grows, the less the forests will be able to support the growth in providing the needed resources. Thus, forests had to make way for commercial crops, tourism and housing. The forest cover in Thailand shrank between 1961 and 2014 from 53 per cent to 31.5 per cent, leading to a serious decline in wildlife populations (Thailand Sustainable Development, 2016h). Fortunately, the decline has not gone unnoticed by the government and goals and campaigns have been set up to combat the loss in biodiversity.

Urbanisation
The urbanisation in Thailand is mainly located in the Bangkok urban area according to new World Bank data as the area grew from 1.900 square kilometres to 2.100 between 2000 and 2010, making the Bangkok urban area the fifth-largest urban area in East Asia in 2010 (The World Bank, 2015). However, the densest urban areas can be found in Hat Yai (5.900 people per square kilometre in 2010) and Chiang Mai (5.000 people per square kilometre), in Bangkok there are only roughly 4.700 people per square kilometre. Nevertheless, the Bangkok urban area accounted for nearly 80% of the total urban area in Thailand in 2010, of which more than 60% is located outside the boundaries of the Bangkok Metropolitan Administration.

Large cities consume large amounts of resources, requiring an efficient management of resources and waste. This is evident in the electricity and water consumption of Bangkok, since a third of the energy production in Thailand goes to its biggest city and the city consumes more water than the rest of the country combined. Furthermore, the carbon dioxide emission per person is more than 10 times that of a north easterner (Thailand Sustainable Development, 2016i). Bangkok is also dealing with a sanitation capacity problem, as the excess has to be dumped at a landfill in nearby provinces, creating protests from locals. At last, the growth of the cities results in growth of traffic, putting pressure on the existing infrastructure. The city has far too little road area to accommodate the nearly 10 million private automobiles, which mostly travel to and from the city's outer limits.

Pollution and waste
Pollution and waste are serious problems in Thailand, as many waters are foul and dirty, air quality is low in the big cities and plastic waste on the streets is prevalent in people's everyday lives. Pollution includes any pollution in the air, water and soil, while garbage is considered solid waste. As the population continues to grow, so does the consumption and thus the waste. Air pollution is mostly caused by vehicle emissions in the cities and emission from petrochemical plants, oil refineries and plastics and chemical factors in the countryside (Facts and Details, 2014). However, pollution from burning forests and other materials also form a hazard to the people, especially in the North (Thailand Sustainable Development, 2016c). Water pollution, on the other hand, is predominantly caused by untreated wastewater, garbage and industrial waste, released in the Thai waterways. The solid waste is not only an important cause for water pollution, but also the soil pollution, as the waste contaminates the land.

Pollution and waste have greatly affected the population's health, as well as the biodiversity, flora and fauna of Thailand (Ping, 2011). Thousands of people have been sickened by breathing polluted air and drinking polluted water, even disabilities in children can be traced back to pollution. Furthermore, the biodiversity, and flora and fauna numbers have been greatly diminished by waste and pollution. Though both environmental groups and the government have been trying to reduce the problems, progress is slow and the issues tend to remain.

Disasters
Disasters are not uncommon in Thailand and can cause great economic losses and losses of life, though most of them are not as severe as other disasters in countries such as the Philippines. The disasters can be divided into the categories natural disasters and manmade disasters. Natural disasters are often storm-, flood- and drought-related (Prevention Web, 2015), with the tsunami in 2004 and the floods in 2011 being the most memorable. The tsunami disaster involved a great part of Asia and Africa resulted in more than 5.000 confirmed deaths and more than 4.000 people missing in Thailand. The flooding of Thailand's Chao Phraya River in 2011 only directly affected Thailand, but resulted in a damage of 630.354 million baht and a loss of 795.191 million baht (The World Bank, 2012). The flood caused a chain reaction and affected the whole world by damaging the international companies in central Thailand. Floods are the main cause for economic issues in Thailand, as between 1989 and 2012 there were 227 floods (Thailand Sustainable Development, 2016k). Nonetheless, earthquakes have the highest mortality rate with a rate of 72,1% of the total deaths caused by disasters (Prevention Web, 2015). Furthermore, droughts are also a problem for Thailand, mainly in the northeast, causing the country millions of acres of farmland. Manmade disasters on the other hand were mostly plane crashes, fires and explosions in the last 50 years. The ASEAN Committee on Disaster Management (ACDM) is established by the Association of Southeast Asian Nations (ASEAN), as a cooperation amongst Asian countries to manage occurring disasters in ASEAN member countries. Its responsibility is to coordinate and implement regional activities (ASEAN, 2009). One of their priorities is to establish a framework, which will include the development of a regional agreement on disaster management and an emergency response, creating standard response mechanism to enhance quick responses and minimize the effects of disasters.

A.6. Society

Education
Education is considered to be very important among the Thai, however Thai education does not receive a high ranking in global education rankings. According to the 2014 report of the Institute for Management Development, Thailand's education performance ranks 54th out of 60 countries. Also, Times Higher Education University Rankings 2014 stated that Thailand only had one university (King Mongkut's University of Technology Thonburi) who made it into the world's top 400. This is not due to lack of financial resources, seeing as Thailand consistently allocates approximately 20 per cent of national budget to education, which is among the highest in the world. The importance of education is indicated by the amount of money that parents spent on supplementary education. On average, Thai students spend 1000 hours in these intensive, supervised study schools. However, some experts believe that these study schools are indicating a shortcoming in the education system, being the lack of child-centred learning which may lead to passive students who will experience trouble competing in a world where innovation and initiative matter most. As a response, Thailand has adopted student-centred learning since 2000. However, nowadays it is still a rarity in Thailand's schools (Thailand Sustainable Development, 2016l).

Table A.7 | Statistics on Thailand's education (UNICEF, 2015)

Subject	Percentage
Gross enrolment ratio in pre-primary education	100
Net attendance ratio in primary education (NAR)	96
Proportion of pupils starting grade 1 who reach grade 5	100
Proportion of out-of-school children of primary school age	4
Net attendance ratio in secondary education	79
Literacy rate 15-24 year-olds	98

Health
The average life expectancy in Thailand has risen from 31 years in 1930 to 74 years in 2015. This is mainly due to the vast improvement of the kingdom's healthcare system. The UN has laid down Millennium Development Goals in 2000 with a deadline set in 2015. However, Thailand had already achieved most of its health-related goals in 2004. For example, the elimination of malaria in almost all areas and providing 93% of the population access to proper sanitation and 96% to piped drinking water supply on premises or another improved water drinking source (UNICEF, 2015). From a historical point of view, this achievement does not come unexpectedly seeing as Thailand has a long history of traditional

medicine. Also, Thailand has recently been improving its facilities, sanitation, water treatment and professional know how (Thailand Sustainable Development, 2016m).

Family
Domestic units of Thai families often consist of an extended family, as Thai families are known to be a close-knit. Ideally, the nuclear family is the core of the domestic unit, but especially among poorer couples, residence with the parents of the wife, due to the matrilocal culture, is common. The presence of matrilocal culture in households also means that the female members of the household are responsible for the domestic chores (World Culture Encyclopedia, 2016). However, globalisation has exerted a tremendous influence over Thai families in recent year resulting in an increase in divorce rate. According to the Ministry of the Interior, the number of family members in a household has dropped from 5.2 in 1980 to 2.8 in 2012. Nowadays, more and more the delaying of both marriage and childbearing takes place, as many Thais pursue their careers. Nevertheless, the birth rate of 782000 children has remained consistent over the previous decade (Thailand Sustainable Development, 2016n).

Poverty and income inequality
According to The World Bank (2016d), Thailand has the lowest poverty headcount with only 1.2% of the population below the poverty line of $3.10 per day. Even though different measures regarding poverty show slightly different numbers, all agree on the fact that Thailand has drastically reduced poverty over the last few decades (Thailand Sustainable Development, 2016o). The poverty is primarily a rural phenomenon, with 88% of the country's 5.4 million poor living in rural areas in the year of 2012. Some regions and some ethnic groups greatly lag behind others and the benefits of the economic success are not shared equally. The inequality especially exists between Bangkok, Thailand's largest urban area, and the rest of the country. Figure A. illustrates to what extent poorer quintiles (20%) of a population have disproportionately smaller shares of total income or consumption compared to richer quintiles (The World Bank, 2016d).

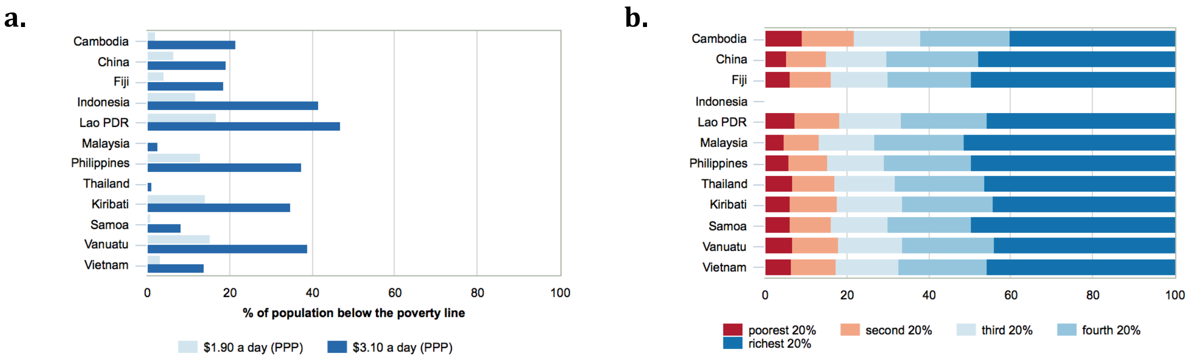


Figure A.6 | Country data (The World Bank, 2016d). (a) Latest poverty data. (b) Latest inequality data.

Monarchy
Thailand's monarchy is one of the most enduring of all monarchies. From the 13th century until 1932 Siamese kings ruled and from 1932 until today they have continued to reign. This span of over 750 years is remarkable for both its length and its on-going impact; few countries remain so extraordinarily dedicated to and defined by their royalty.

King Mongkut (Rama IV) is credited with beginning the modernisation process, which was taken over by his son King Chulalongkorn (Rama V) towards the end of the 19th century. King Chulalongkorn led a massive reformation and expansion of the government bureaucracy in which he centralized power in Bangkok and formed the foundations of the current nation-state. King Bhumibol Adulyadej (Rama IX), who recently passed away on October 13th, 2016, provided Thailand with fresh relevance during the constitutional era. He recognised the importance of the monarchy's symbolism to the country's identity and people and simultaneously transformed the monarchy into an agent of development (Thailand Sustainable Development, 2016p).

A.7. Culture

Religion
Long before national consciousness even existed, religion has helped form the values of Thai communities. Therefore, religion is an important part of Thai culture and is even incorporated in the Thai flag of red, white and blue. Red represents the nation, white represents Buddhism's purity, and blue represents the monarchy. Buddhism is the main religion in Thailand, but the compassion and tolerance that are exuded by Buddhism result in freedom of religion throughout Thailand. Other religions practiced in Thailand are the Islam, Christianity and Animism. In Sanskrit, Buddha means "awakened", by which awakened is meant as reality as it is, so no delusions of ego, anger and lust which are mental constructs but the ephemeral nature of feelings and the inescapable life cycle of all sentient beings: birth, old age, suffering and death. In Thailand Buddhism can be divided in two components, namely practiced by monks, who follow myriad rules, and practiced by laypeople, who are not required to follow as many rules. Monks hope to attain a greater sense of enlightenment and ethical behaviour by immersing themselves in the teaching of the Buddha. They often function as advisors in their communities while spreading the wisdom of the Lord Buddha. For laypeople, Buddhism is an integral part of their daily life. One of the most important aspects throughout the Buddha's teaching is the natural world. This can be seen by the fact that nature is often used as a metaphor. Moreover, nature is also used to emphasise the interdependence of all life to produce a body of teachings, ethics, and practices that encouraged mindfulness, which remains at the roots of ethical behaviour in Thailand (Thailand Sustainable Development, 2016q).

Cross Cultural Differences

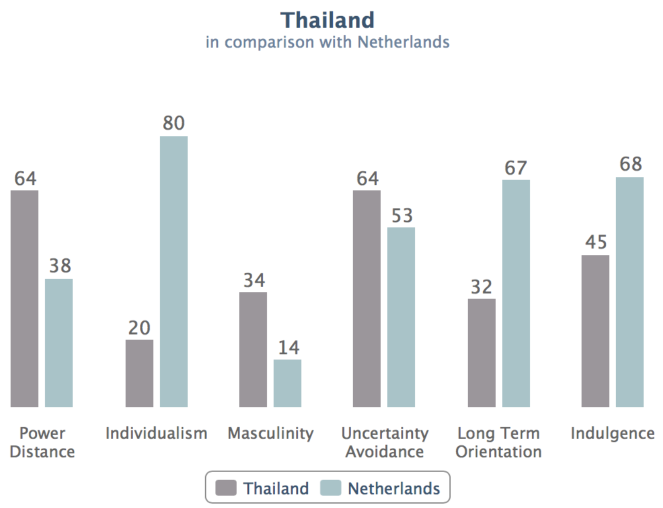


Figure A.7 | Cross cultural differences of Thailand vs. The Netherlands

Power Distance - This dimension expresses the attitude of the culture towards the inequalities amongst us. Power Distance is defined as the extent to which the less powerful members of institutions and organisations within a country expect and accept that power is distributed unequally.

Thailand scores 64 on PDI index, slightly lower than the average Asian countries (71). It is a society in which inequalities are accepted; a strict chain of command and protocol are observed. Each rank has its privileges and employees show loyalty, respect and deference for their superiors in return for protection and guidance. This may lead to paternalistic management. Thus, the attitude towards managers are more formal, the information flow is hierarchical and controlled (Hofstede, 2010b).

Individualism - The fundamental issue addressed by this dimension is the degree of interdependence a society maintains among its members. In Individualist societies people are supposed to look after themselves and their direct family only. In Collectivist societies people belong to 'in groups' that take care of them in exchange for loyalty.

With a score of 20 Thailand is a highly collectivist country. This is manifest in a close long-term commitment to the member 'group' (a family, extended family, or extended relationships). Loyalty to the in-group in a collectivist culture is paramount, and overrides most other societal rules and regulations. The society fosters strong relationships where everyone takes responsibility for fellow members of their group. In order to preserve the in-group, Thai are not confrontational and in their communication a “Yes” may not mean an acceptance or agreement. An offence leads to loss of face and Thai are very sensitive not to feel shamed in front of their group. Personal relationship is key to conducting business and it takes time to build such relations thus patience is necessary as well as not openly discuss business on first occasions (Hofstede, 2010b).

Masculinity - A high score on this dimension indicates that the society is masculine and will be driven by competition, achievement and success, with success being defined by the winner/best in field – a value system that starts in school and continues throughout organisational life. A low score on the dimension means that the society is feminine and the dominant values in society are caring for others and quality of life. A Feminine society is one where quality of life is the sign of success and standing out from the crowd is not admirable.

Thailand scores 34 on this dimension and is thus considered a Feminine society. Thailand has the lowest Masculinity ranking among the average Asian countries of 53 and the World average of 50. This lower level is indicative of a society with little assertiveness and competitiveness. This situation also reinforces more traditional male and female roles within the population (Hofstede, 2010b).

Uncertainty Avoidance - The dimension Uncertainty Avoidance has to do with the way that a society deals with the fact that the future can never be known. This ambiguity brings with it anxiety and different cultures have learnt to deal with this anxiety in different ways. The extent to which the members of a culture feel threatened by ambiguous or unknown situations and have created beliefs and institutions that try to avoid these is reflected in the score on Uncertainty Avoidance.

Thailand scores an intermediate 64 on this dimension, but it slightly indicates a preference for avoiding uncertainty. In order to minimize or reduce this level of uncertainty, strict rules, laws, policies, and regulations are adopted and implemented. The ultimate goal of this population is to control everything in order to eliminate or avoid the unexpected. As a result of this high Uncertainty Avoidance characteristic, the society does not readily accept change and is very risk adverse. Change has to be seen for the greater good of the in-group (Hofstede, 2010b).

Long Term Orientation - This dimension describes how every society has to maintain some links with its own past while dealing with the challenges of the present and future, and societies prioritise these two existential goals differently. Normative societies, which score low on this dimension, for example, prefer to maintain time-honoured traditions and norms while viewing societal change with suspicion. Those with a culture that scores high, on the other hand, take a more pragmatic approach: they encourage thrift and efforts in modern education as a way to prepare for the future.

Thailand's low score of 32 indicates that Thai culture is more normative than pragmatic. People in such societies have a strong concern with establishing the absolute Truth; they are normative in their thinking. They exhibit great respect for traditions, a relatively small propensity to save for the future, and a focus on achieving quick results (Hofstede, 2010b).

Indulgence - One challenge that confronts humanity, now and in the past, is the degree to which small children are socialized. Without socialization we do not become “human”. This dimension is defined as the extent to which people try to control their desires and impulses, based on the way they were raised. Relatively weak control is called “Indulgence” and relatively strong control is called “Restraint”. Cultures can, therefore, be described as Indulgent or Restrained.

With an intermediate score of 45, a preference on this dimension cannot be determined for Thailand (Hofstede, 2010b).

B. Coastal analysis

B.1. Hydrodynamic processes

To fully understand the effectivity of the solutions as proposed in this report it is, without doubt, important to get an idea of the underlying processes. This appendix is therefore drawn up to give a short overview of the most important hydrodynamic processes. The information here is mostly based on Bosboom and Stive (2015), when other sources are used it is mentioned. It should be emphasized that the sediment on the beach in the project area is sand. When it would be a muddy beach the hydrodynamic processes as explained would not apply. Instead other processes would be important.

B.1.1. Sediment transport

Sediment can only be transported if the moving forces exceed the stabilising forces. Sediment starts to move if a critical value for the velocity (or shear stress) is exceeded. This is the so-called threshold of motion. This critical velocity is caused by the hydrodynamic forcing (waves and currents). Once the sediment is brought into motion several transport modes can occur: bed load transport and suspended load transport.

Initiation of motion

The forces acting on a grain are the drag force, the lift force and gravity (Figure B.1a) The drag force can be divided into the effect of skin friction and pressure differences between the up- and downstream side of the grain. The lift force is caused by vertical pressure differences and flow separation. These two forces are the driving forces, gravity is the resisting force.

The driving forces (drag and lift) are proportional to the density of the water times the velocity squared times the grain diameter squared. The resisting force is proportional to the difference between the density of the sediment and the density of the water times the gravitational acceleration constant time the grain diameter to the power 3.

$$\rho_w u_c^2 d^2 \propto (\rho_s - \rho_w) g d^3$$

The grains start to move if the driving forces exceed the resisting force. The velocity (or shear stress) when this happens is called the critical velocity (or critical shear stress, τ_c). When the shear stress is used the proportionality can be used to determine the so-called Shields parameter.

$$\psi_C = \frac{load}{strength} = \frac{\tau_C d^2}{(\rho_s - \rho_w) g d^3} = \frac{\tau_C}{(\rho_s - \rho_w) g d}$$

Shields conducted experiments that resulted in the Shields curve (Figure B.1b). This curve shows when grains start to move. It is however not clearly defined what initiation of motion means. Therefore several lines can be drawn. In Figure B.1c three lines are drawn. The lowest (1) stand for occasional movement at some locations, the middle line is the line defined by Shields and stands for continuous motion at all locations and the highest line (7) stands for general transport of grains (Schiereck & Verhagen, 2012).

The Shields curve is however only valid for uniform flow on a flat bottom. Short waves cause the flow to be non-uniform, and therefore Shields is not valid. The main principles remain the same: the driving forces need to exceed the resisting forces. The effect of the combination of unidirectional and oscillatory flow on the initiation of motion is still largely unknown. Sleath (1978), as cited in Schiereck and Verhagen (2012) used several investigations to determine a Shields type of graph but with the effect of waves included (Figure B.1d). The results are different because the different development of the boundary layer in oscillatory flow.

When the bed has a slope the critical velocity can become larger or smaller. For a downward sloping bed the critical velocity will be smaller and for an upward sloping bed the critical velocity will be larger.

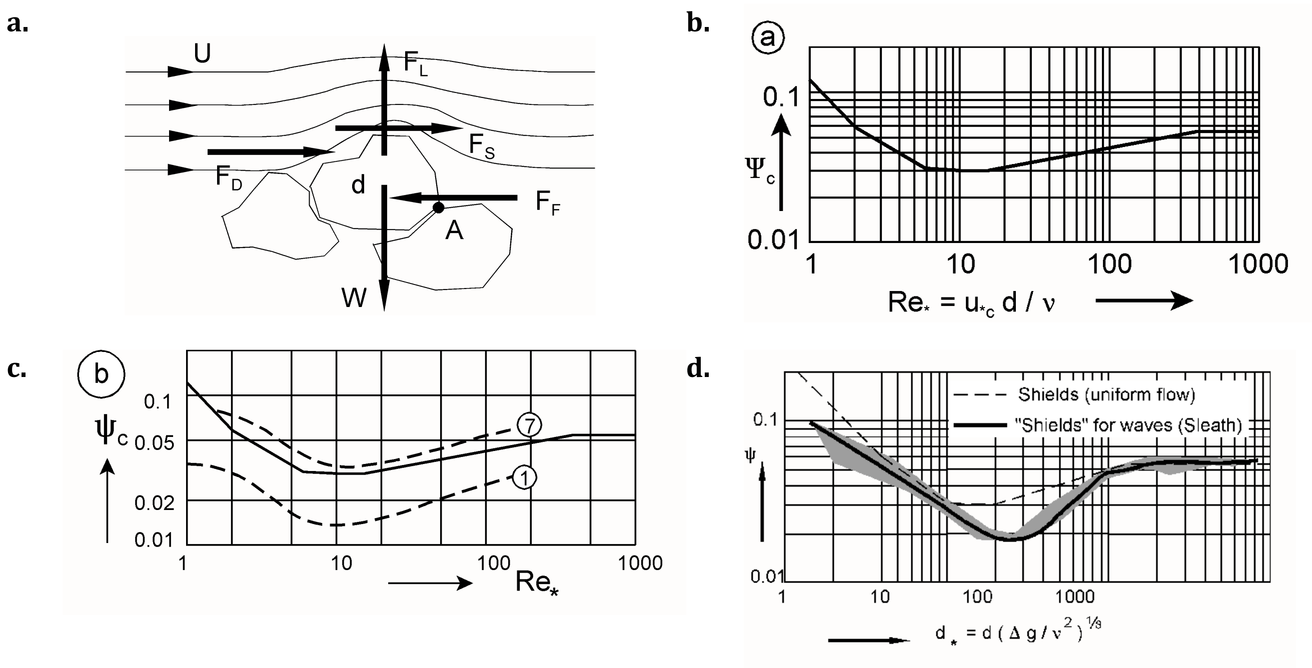


Figure B.1 | Sediment transport. (a) Forces on a grain. (b) Shields curve. (c) Shields curve for different thresholds of motion. (d) "Shields curve" for waves by Sleath. (Schiereck & Verhagen, 2012).

Transport modes

Once the sediment is brought into motion it can be transported as bedload or as suspended load. At higher shear stresses the material can also transported through so called sheet-flow. A third category is wash load, but this category is not taken into account. Wash load is not found in the bed and only settles in still water. Therefore it does not contribute to bed level changes and is not taken into account. The mass balance of sediment transport reads:

- **Bedload transport** – Transported sediment can be classified as bedload transport if the grains remain in frequent contact with the bed. The particles either roll or slide over the bed or they make small jumps, so called saltations. When the length of the jumps remains smaller than a few times the grain diameter this type of motion can be classified as bedload transport. With longer jumps it would be classified as suspended transport.
- **Sheet-flow transport** – This is also considered as bedload transport because grain-grain interactions play an important role. Sheet-flow occurs at high shear stresses. Instead of rolling and jumping in one layer the particles start moving in several layers. The thickness of the moving particles is in the order of centimetres.
- **Suspended load transport** – Particles that do not have contact with the bed are called suspended particles. These particles are supported by turbulent diffusive forces. These turbulent forces prevent the particles from settling according to their fall velocity. Bed ripples are a major factor to bring sediment in suspension. The organized pattern of vortices behind ripples is capable of bringing large amounts of sediment into suspension.

B.1.2. Erosion and accretion

To get an idea of the cause of erosion or accretion one has to consider a coastal cell. Which can be defined a predefined part of the coast with the same properties. Predominantly due to either longshore or cross shore transport sand enters the cell and sand leaves the cell. If there is an imbalance in sand entering and sand leaving the cell there will be either erosion or accretion. The case in which an equal amount of sand enters the system as leaves is called the dynamic equilibrium. A static equilibrium is the case when there is no sediment transport which is only hypothetical. Sand entering the coastal cell can be due to cross shore or longshore but also due to nourishments, runoff, river deposition, etc. Runoff is believed to have a minor effect in the project area, nourishments are explained in Appendix E. Therefore this paragraphs focuses on river deposits, longshore and cross shore transport.

River deposits
The main source for beach sediment originates from rivers. The flow velocity in the river mouth decreases which causes the sediment to settle, the sediment is then moved alongshore by the relevant hydrodynamic processes. In this report little attention is paid to rivers since there are no rivers in the project area. It is however the sediment from all the larger and smaller streams that balance the net transport. Dams and other obstructions have however been built which results in an imbalance in the transport and thus in erosion. Sand mining from river beds is therefore also not preferable since it can cause erosion. Sediment mining upstream of dams is however a good idea since the sediment is trapped there and when mined brought back into the system.

Cross shore transport
Cross shore transport mainly happens due to the presence of waves, although slope instability and local currents can have effect. In the case of sediment transport caused by waves, wave stir up sediment, which is both, moved onshore as offshore. The bulk transport is generally quite high whereas the net transport is quite low. Generally the cross-shore profile is in a dynamic equilibrium where differences exist in seasonal profiles.

Waves cause a flow that will look like Figure B.2 if there is no breaking. The waves will enter the shore and since the water cannot build up on the beach it will flow back as a return current. The small velocity near the bottom is called the Longuet-Higgins streaming and is caused by vorticity effects, it is not always present.

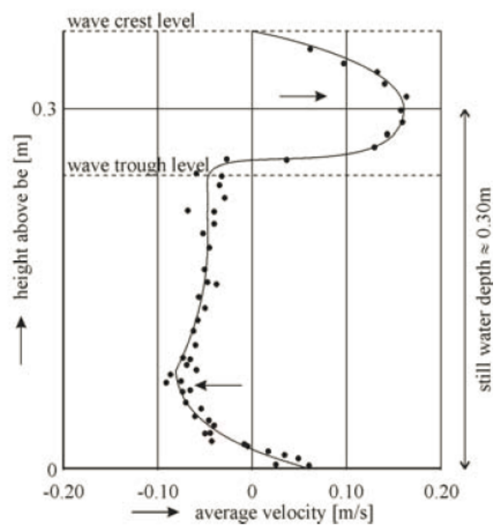


Figure B.2 | Nearshore velocity profile in the case of no breaking

The transformation due to shoaling can be seen in Figure B.3. Higher velocities are present under the crest in which the velocity is onshore directed, and lower velocities under the trough in which the velocities are offshore directed. So net transport is then onshore.

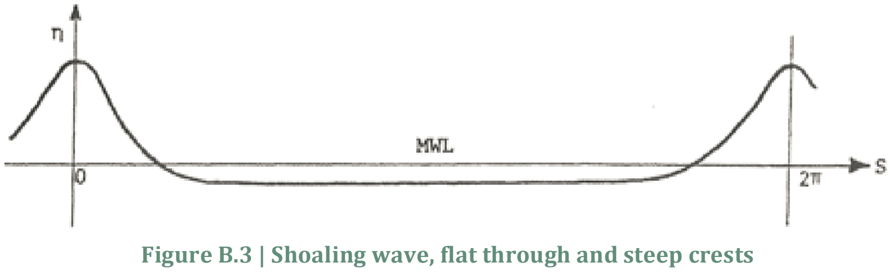


Figure B.3 | Shoaling wave, flat through and steep crests

Sea level rise will also cause losses in cross shore direction. The shoreline will then retreat, the sediment will be used to adapt to a new equilibrium profile.

Longshore transport
The transfer of momentum from waves, which approach the shore under an angle, to the mean flow generates a longshore current. This longshore current transports the sediment that is stirred up by the breaking waves. A wind that is parallel to the coastline also generates a longshore current. The influence of the wind is usually less important because the highest velocities of this current are at the surface and are much lower near the bed where the highest sediment concentrations occur. The tides also cause currents, which could have an impact on the longshore transport, usually the effect of the tides is not very large because the effect is largely symmetrical. Most sediment stirring occurs just seaward of the breaker bar, because wave-breaking predominantly takes place here. Most of the longshore transport will occur a bit shoreward from this location.

Erosion and accretion only occur when there are gradients in the littoral transport rates, when the transport decreases accretion occurs and when it increases erosion occurs. These changes in transport rates occur due to differing wave action and wave incidence. Changes in wave action and wave incidence are due to refraction, shoaling and diffraction.

Refraction is the process of waves changing direction due to the bathymetry, the waves turn as the part of the wave that is in deeper water moves faster than the part of the wave that is in shallower water. This changes the wave incidence and thus changes the direction in which these waves support littoral transport, leading to convergence and divergence of wave energy. This leads to transport gradients along the coastline and thus to erosion and accretion. Because refraction converges energy on areas of the coastline that stick out farther seaward, it increases erosion there and shorelines have the tendency to go to a straight equilibrium coastline.

Divergence is the process in which waves redistribute their energy over a larger area as a part of the wave is blocked into entering a certain area, after which the part of the wave that does enter spreads out into the area. This spreads and lowers waves over a larger area and also changes its incidence.

Obstacles offshore, like small islands or offshore breakwaters create shadow effects in their leeside. Wave action behind those obstacles is significantly reduced, which decreases the transport capacity and divergence leads waves from both sides to the centre of the leeside amassing sediment behind these obstacles.

Shore normal obstacles block the longshore sediment transport, by being a physical boundary to the current in the littoral transport zone. The length of the obstacle seawards determines the severity of the reduction in transport.

Spits are formed where the coastline is interrupted, for example by a river or a bay, when there is longshore transport present. Sediment settles down here because the transport capacity at these areas reduces to almost zero, which leads to the formation of a tongue, which grows over time.

B.2. Particle size analysis

This appendix contains the particle size analysis. The first paragraph contains a description of the sampling we performed during our site visit. The second paragraph contains the analysis method, and the third paragraph contains the results. The fourth paragraph contains an analysis of previous research on sediment diameters in the area. The fifth paragraph contains a short comparison and the values, which we will use for UNIBEST.

B.2.1. Sampling

Figure B.4 and Table B.1 show the locations of measurements. The criteria on which we based our sample locations are based on visual inspection of the coast. We observed different sections that were separated due to structures (hotels, breakwaters and jetties) or small creeks. We furthermore took extra samples when it seemed appropriate (see Table B.1) One sample at location A has been taken because the sediment seemed quite homogeneous in this area (in front of the city). It also is one uninterrupted beach stretch. Locations B and C are at an area with many hotels. More samples were taken because of the presence of nourishment sand and because of the interruption of the beach by the hotels. Five samples were taken in front of the Mrigadayavan palace. This is because we noticed many different sediment types. Two samples were taken south of the southern jetty (E and F). This is an area that is interrupted by this jetty. G is a nourishment sample, which is taken to compare our data with the data delivered from the current project. The sample in the mangrove area (sample D) is taken to compare this sediment to the sediment offshore of the palace.

Figure B.4 | Location of samples (Google Earth, 2016)

Table B.1 | Numbering, location and analysis method of samples. HM means hydrometer analysis, 'w' means wet sieving, samples without code are sieved when oven dried.

Code	Details	Analysis method
A	Beach sample	Sieving
B1	Beach sample	Sieving
B2	Nourishment sand on sandbags	Sieving
C1 (w)	Beach sample close to the sea	Sieving
C2	Beach sample close to the restaurants	Sieving
D (HM)	Mangrove area	Hydrometer
E1 (HM)	About 170 meter seawards from most seaward part of palace	Hydrometer and wet sieve
E2 (w)	About 100 meter seawards from most seaward part of palace	Sieve and wet sieve
$E3_{I}$ (w)	Beach sample upper layer	Sieving
$E3_{II}$	Beach sample under layer (about 20 centimetre under upper layer)	Sieving
E4	Beach sample close to most seaward part of palace	Sieve and wet sieve
F	Beach sample	Sieving
G	Nourishment sample	Sieving

B.2.2. Lab analysis method

On the samples taken at the beach a particle size analysis was performed. The goal was to determine the sediment sizes (D_{10}, D_{30}, D_{50}, D_{60}, D_{90}) and the gradation of the sediment (the coefficient of uniformity: $\frac{D_{60}}{D_{10}}$, and the coefficient of curvature: $\frac{D_{30}^2}{D_{60} \times D_{10}}$). This can be shown graphically with a sieve curve. Three methods have been used to determine the particle sizes: sieving, wet sieving and the hydrometer test.

All samples were first dried in an oven to make sure the samples were dry. This was not successful, because a few samples were still a bit wet. These samples (C1, E2 and $E3_I$) were sieved wet. Samples E1 and D were tested with the hydrometer test. Sample E4 was sieved dry and wet. The scale used to weigh the samples was not very accurate. This means the uncertainty in the results is high. We assume that the results still give a good view on the gradation and the median grain size. The analysis was performed according to ASTM standard D422-63 (American Society for Testing and Materials [ASTM], 1998). The results from this analysis will be compared with the analysis from previous reports (SEATEC and the Department of Marine and Coastal Resources).

For the sieving test 7 sieves were used (Table B.2). Each sieve and each oven dried sample was weighed. Then the sieve tower was put in the sieving machine and left there for several minutes. After some time the sieving was stopped and each sieve plus the retained soil was measured. These weights were used to determine the sieve curve.

Table B.2 | Sieve numbers used

Sieve number	Diameter (mm)
#4	4.75
#8	2.36
#16	1.18
#30	0.60
#50	0.30
#100	0.15
#200	0.075

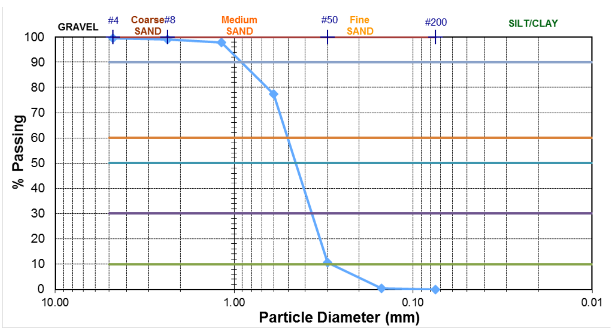
The soils that were not completely dry after being in the oven were sieved wet. The sieves used for this were sieves #30, #50, #100 and #200. The sample was put on the first sieve and water was poured over the sample. The soil that was retained in a sieve was dried in an oven again and weighed after. With these weights the sieve curves were determined.

The samples E1 and D were very fine and thus a hydrometer test was deemed necessary. This did however not yield satisfactory results and thus the samples were not taken into account.

B.2.3. Results

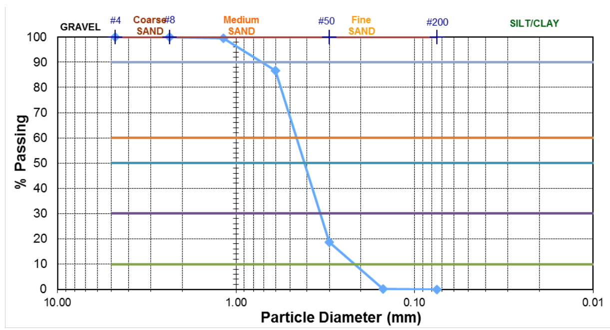
The results of the three tests are the sieve curves (Figure B.5) and the main sediment characteristics (Table B.3).

a.



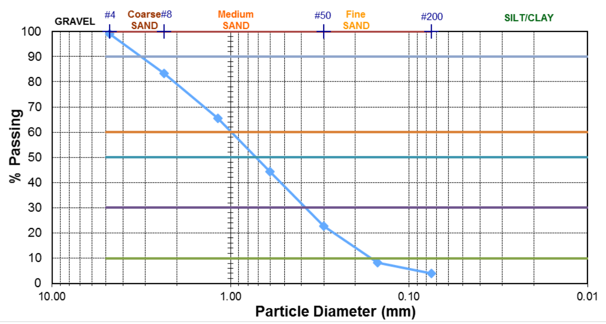
Sample A

b.



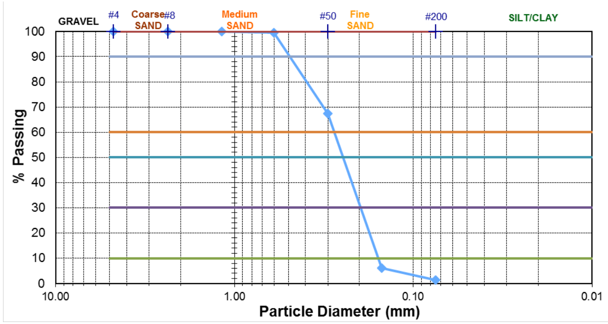
Sample B1

c.



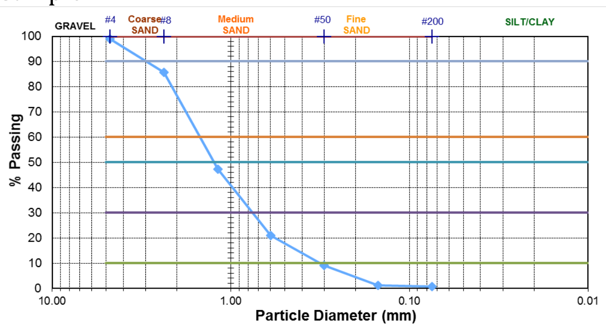
Sample B2

d.



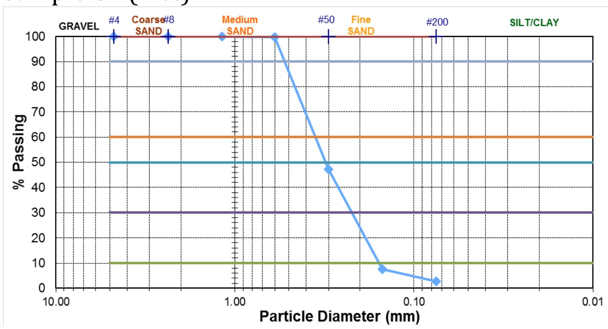
Sample C1 (wet)

e.



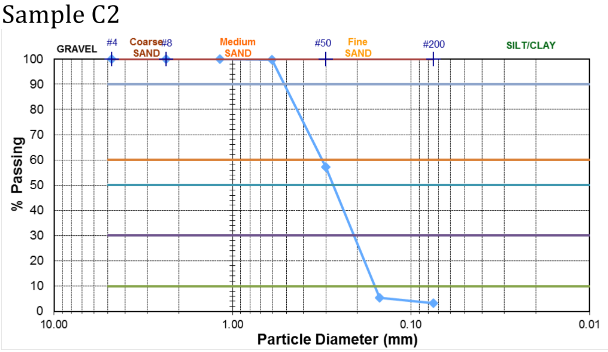
Sample C2

f.



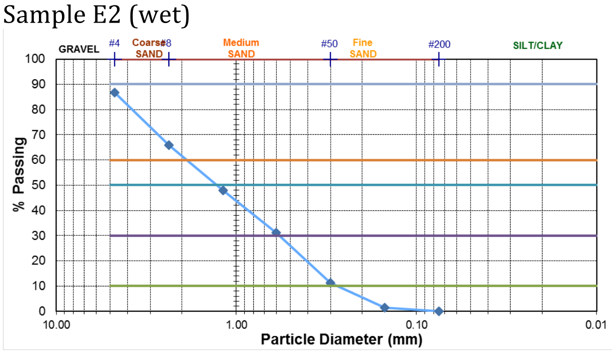
Sample E2 (wet)

g.



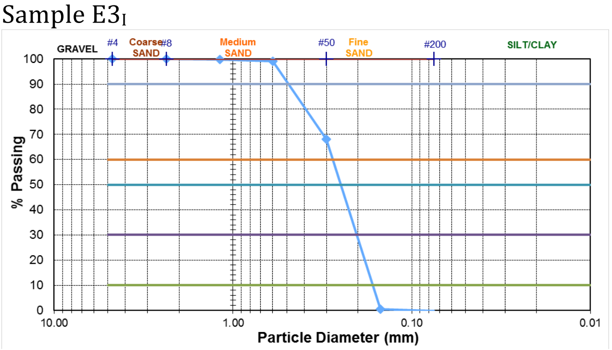
Sample E3$_{I}$

h.



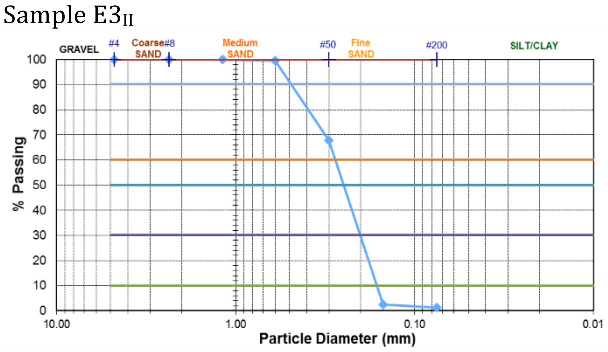
Sample E3$_{II}$

i.



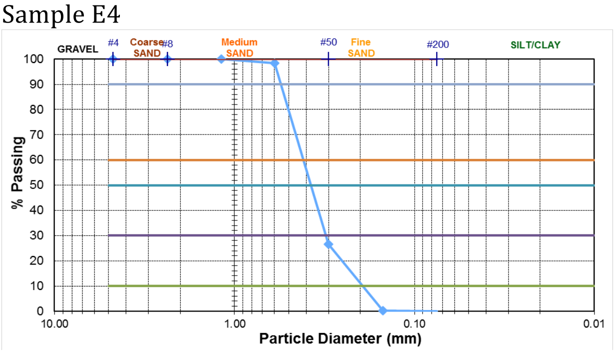
Sample E4

j.



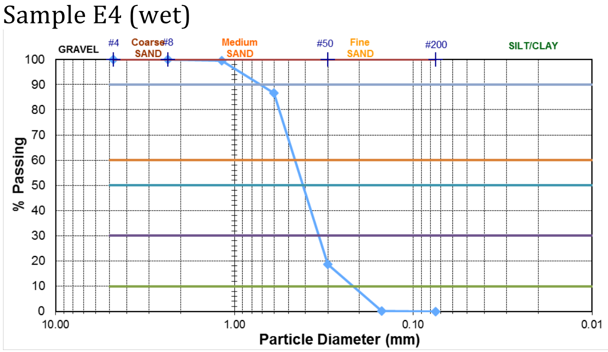
Sample E4 (wet)

k.



Sample F

l.



Sample G

Figure B.5 | Sieve curves of the soil samples

Table B.3 | Sediment characteristics determined from the particle size analysis. HM means that the parameters are determined using a hydrometer test. 'w' means that the parameters are determined using a wet sieving test. When no sign is present it means that parameters are determined sieving an oven dried sample.

Sample	D_{10} (mm)	D_{30} (mm)	D_{50} (mm)	D_{60} (mm)	D_{90} (mm)	C_u	C_c
A	0.28	0.36	0.43	0.50	0.82	1.79	0.93
B1	0.25	0.35	0.42	0.43	0.65	1.72	1.14
B2	0.16	0.39	0.72	0.99	3.22	6.19	0.96
C1 (w)	0.16	0.20	0.25	0.27	0.46	1.69	0.93
C2	0.33	0.81	1.20	1.50	2.76	4.55	1.33
E2 (w)	0.17	0.23	0.30	0.36	0.60	2.12	0.86
$E3_I$ (w)	0.17	0.22	0.27	0.32	0.50	1.88	0.89
$E3_{II}$	0.27	0.54	1.31	1.93		7.15	0.56
E4	0.16	0.20	0.26	0.28	0.43	1.75	0.89
E4 (w)	0.17	0.21	0.25	0.28	0.46	1.65	0.93
F	0.21	0.32	0.36	0.42	0.51	2.00	1.16
G	0.34	0.46	0.63	0.73	1.18	2.15	0.85

From the sieve curves and the coefficients of uniformity three samples stand out: B2, C2 and $E3_I$. These samples are well-graded, while the other samples are poorly-graded. Also the particle sizes are larger for these samples. The differences between these two groups are large, which means this is probably not caused by the inaccuracy of the scale. Sample B2 was taken on top of the sandbags from the nourishment of phase 3. Sample $E3_{II}$ was taken from upper layer of the palace beach. We believe that these samples are the sand used for the nourishments. This means they use a very wide gradation and sand that is very different from the native material. The sand mines used for the nourishment have a D_{50} of 0.624mm and 1.279mm, which compares well to our sieving tests.

B.2.4. Particle size from previous reports

The main goal of our samples was to cross check the information from the report of SEATEC and the report of the Department of Marine and Coastal Resources. First the data of both reports will be shown, and then all data will be compared with each other.

The SEATEC report only had the D_{50} of the sediment for 11 locations along the coast, but not all locations are in our project area. For every location that is also in our project area the D_{50} was 0.25mm (SEATEC, 2003).

The Department of Marine and Coastal Resources has the D_5, D_{16}, D_{50}, D_{84} and the D_{95} for eight different locations and for the 2 sand mines used to obtain the nourishment sand (Table B.4 and Figure B.6 for locations).

Table B.4 | Sediment diameters for 8 locations (1-8) and the two sand mines (N1, N2) (Department of Marine and Coastal Resources, 2013)

Number	**D_5 (mm)**	**D_{16} (mm)**	**D_{50} (mm)**	**D_{84} (mm)**	**D_{95} (mm)**
BH-1	0.036	0.048	0.182	1.904	3.564
BH-2	0.045	0.076	0.319	2.586	4.665
BH-3	0.050	0.104	0.630	3.807	7.262
BH-4	0.045	0.075	0.307	2.353	4.635
BH-5	0.047	0.083	0.335	2.859	4.677
BH-6	0.046	0.080	0.336	2.828	5.145
BH-7	0.046	0.080	0.339	3.049	5.074
BH-8	0.046	0.080	0.329	2.789	5.145
N1	0.167	0.288	1.279	3.898	6.715
N2	0.120	0.209	0.624	2.473	5.398

Figure B.6 | Locations of samples south of southern jetty (Google Earth, 2016)

B.2.5. Particle size as used in further calculations

The particle size is determined using the all three data sources (e.g. own measurements, SEATEC and the Department of Marine and Coastal Resources). Every defined section (see chapter 4) gets a corresponding particle size. The final particle size is mainly based on SEATEC (2003) and own measurements since the Department of Marine and Coastal Resources only has data from a small distinct area. Since we are not sure of both sources we used an average when possible.

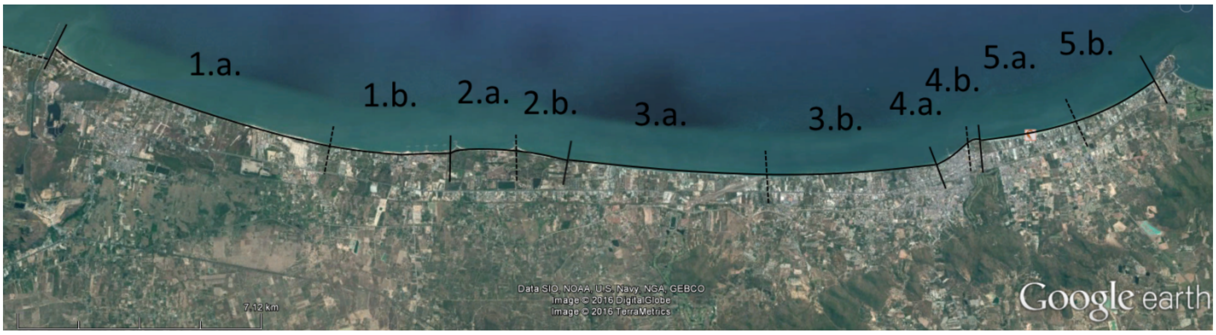


Figure B.7 | Different sections (Google Earth, 2016)

Table B.5 | Particle sizes as used in the model

Section	$D_{10,\,model}$ (μm)	$D_{50,\,model}$ (μm)	$D_{90,\,model}$ (μm)	D_{SS} (μm)
1a	280	430	820	334
1b	205	340	560	272
2a	168	270	500	226.8
2b	210	360	510	288
3a	153	250	426	217.5
3b	153	250	426	217.5
4a	153	250	426	217.5
4b	153	250	426	217.5
5a	153	250	426	217.5
5b	153	250	426	217.5

B.3. Analysis of current structures

The site visit and the meetings gave us an invaluable impression of the design of the structures and their current state. The lifetime of a structures has in the past been wrongly combined with wave design conditions. This appendix will first elaborate on the lifetime of structures and will then specifically treat the jetties and the revetments.

B.3.1. Lifetime

The Poisson equation provides a semi-probabilistic approach to determine the relation between the lifespan of a structure and the frequency of occurrence of the design wave conditions:

$$P = 1 - e^{-fT}$$

Where:
P is the probability of occurrence of one or more events during T;
T is the lifetime of the structure;
f is the average frequency of occurrence per year

The jetty for example was supposed to be constructed with a lifetime of 25 years in mind. The design wave conditions are however chosen as 1/25 years wave condition. P is then the probability of failure, this means that the probability of failure of the structure is:

$$P = 1 - e^{-\frac{1}{25}*25} = 0.63$$

There is thus a 63% chance that the structure will fail in its expected life time. If the structure is intended to last for 25 years a more normal value for P would be a 5% or 10% failure probability; this would result in wave conditions with an average occurrence per year of:

$$0.05 = 1 - e^{-f*25}$$
$$f = \frac{1}{1122} year$$

For 10% this will be significantly lower again. So it depends on the level of certainty the Marine Department wants in its constructions. But currently structures are not constructed with a lifespan of 25 years while they are expected to last that long. Therefore we advise to critically look at the design method and parameters to check if correct values, calculated with the Poisson equation, are used.

B.3.2. Jetties

The jetties that were constructed in 2005 displayed signs of some severe damage. At the revetment at the seaside stones were washed away and the concrete sheet pile wall at the inner side was deformed (Figure B.8a,b,c). Behind the sheet pile wall there was erosion of the soil, which appears to have slipped through the damaged sheet pile wall. Lack of maintenance was also apparent, and the steel reinforcement has corroded and damaged the concrete. Some steel reinforcement seems to have been left sticking out of the concrete during construction, which has amplified the corrosion process.

B.3.3. Revetments

The revetments, which have been built behind the newly nourished beaches, part of phase 3 and 4, also appear to have some shortcomings. Two things were most notable; no bed protection has been constructed in front of the revetments, see Figure B.8, this will lead to undermining of the revetment resulting in its collapse if no maintenance is performed. Secondly the geotextile sandbags, are not UV resistant this leads to rapid degradation of the sandbags when they are exposed (actually in use). The revetments are designed to be a red flag for the Marine Department to start new nourishments at that location and to provide them with the necessary time to do so. This is an interesting concept, but because of the high costs involved in building these revetments, 100.000 Baht/m (2800 USD/m) for the geotextile sandbags and 60.000 baht/m (1700 USD/m) for the rock revetment, and their short lifetime, it might be better to use that money instead for extra nourishment.

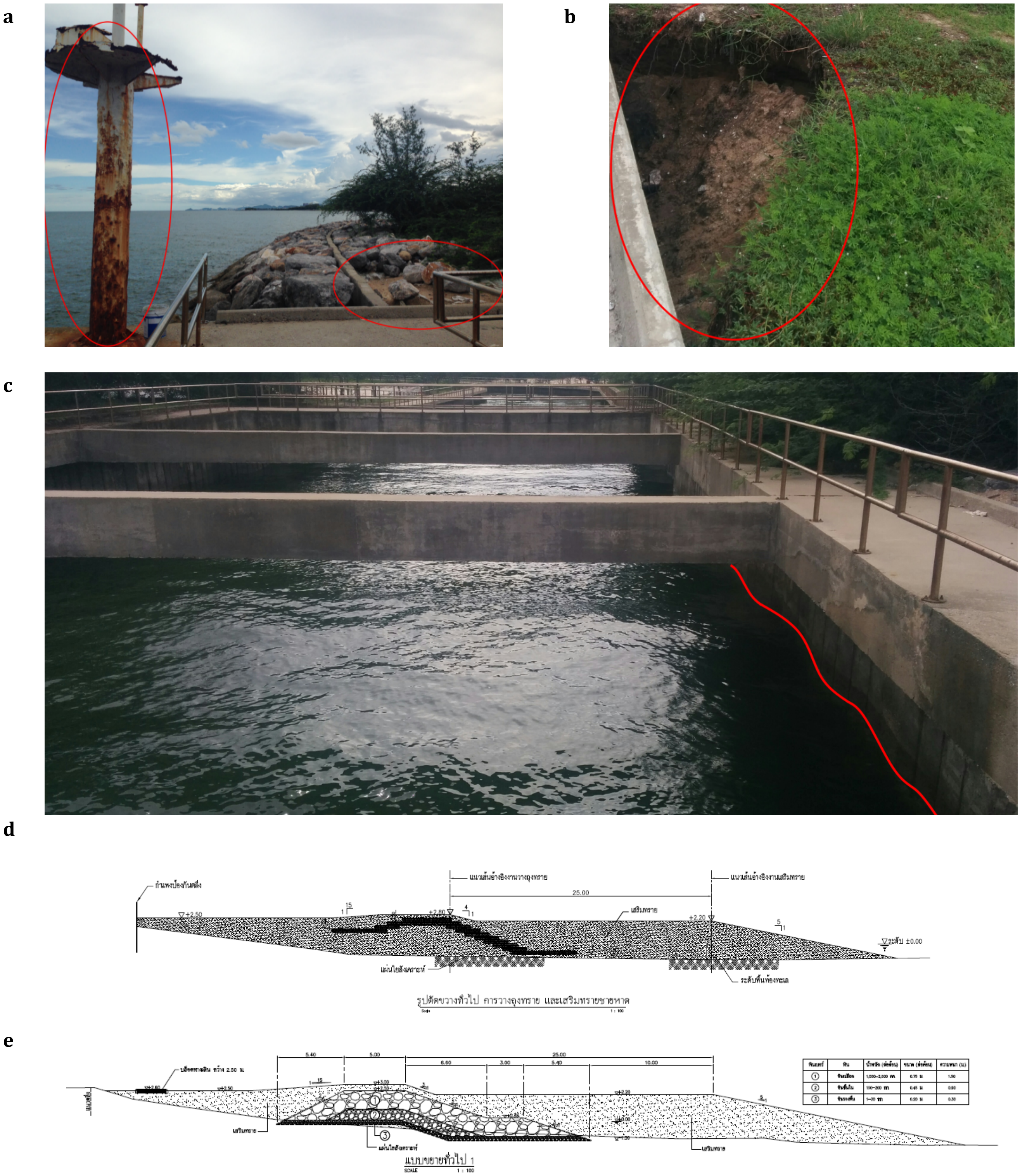


Figure B.8 | Photos jetty at palace site (a) Visible lack of maintenance and washed away stones indicating that the stone size is too small. (b) Sediment washed away behind concrete sheet piles of the jetty, indicating that filter has failed. (c) Deformed concrete sheet pile wall at inner side of the jetty d. Sandbag revetment e. Stone revetment; both in combination with a nourishment

C. Stakeholder analysis

C.1. Stakeholder description

This appendix will give a short description of the involved stakeholders regarding who they are, what they do, and what they are responsible of. The information for the descriptions is gathered through the interviews (see appendix I) and meetings.

Environmental Interest Groups (part of NGOs) - As the Environmental Interest Groups have a lot of knowledge regarding their field of interest, they can be of great help regarding the environmental analysis of the area. Another reason to take the Environmental Interest Groups into account is that they might be a powerful opposing party when it comes to environmental issues.

Fishermen - The fishermen are important stakeholders from a historical point of view. Cha-am used to be a fishing village and fishery is still one of the main occupancies and thus a source of income next to tourism. Fishermen prefer a solution in which the beaches won't block their boats' docks. Actually, they prefer the offshore breakwaters as the ones that have been built in front of the Mrigadayavan Palace, because this solution has multiple advantages for them. For example, they can use the breakwater to shelter their boats from different wind/storm directions.

Government - The central government consists of ministries, bureaus and departments, of which only a few have a connection with the coastal erosion problem in Cha-am and Hua Hin. This includes the instances responsible for the water management and the instances responsible for the budget allocation. Communication between the different instances will determine the amount of support that the defence against coastal erosion will receive from instances other than water management.

Hotels & Resorts - Many resorts and hotels are situated along the coastline from Hua Hin to Cha-am. Even though the beaches are right in front of the hotels/resorts, they are not owned by them. However, the hotels/resorts do provide access to the beaches (Wuttichai, personal communication, October 11, 2016). Overall, the owners of the hotels and resorts prefer beach nourishments as the solution for the coastal erosion, since it will not affect their businesses negatively

Inhabitants - The inhabitants, in this project, are the local communities living near the beaches of Cha-am and Hua Hin. The local people are actually one of the stakeholders that often initiate the projects by addressing the issue , since they are in need of the solutions. After addressing the problem, locals do not have much to say with regard to the solution. This is due to the fact that the concerned beaches are right in front of hotels and resorts and the local inhabitants are thus supposedly not directly affected by the erosion (Wuttichai, personal communication, October 11, 2016). However, they still have the opportunities to protest against the proposed solutions. Also, according to Dr. Mana (personal communication, September 22, 2016), the local communities tend to support every solution that is proposed, as they do not have the required knowledge on preventing or solving coastal erosion and just want it to be solved.

Landowners - Though the beaches do not have any landowners except for the government, landowners are still stakeholders in this project. The land behind the beaches do have owners and are affected by the measures taken on the beaches, either by temporary use of their land during the construction phase or by changes in their views and surroundings. Furthermore, the measures might be of considerable size, directly affecting their land.

Local authorities - Local authorities include an array of different instances, such as municipalities, the provincial government, the district government and any administrative organisations. Since the beaches are in the territory of the local authorities, they are responsible for the management and maintenance of them. However, since the project is on a more national scale and requires a budget and approval of the national government, instead of the local authorities, the Marine Department will be responsible for the project.

Local Businesses - The local businesses mostly consist of bar, restaurant and shop owners. Also, a few water sports rentals can be found along the beaches. The local businesses strongly depend on tourism, as this is their main source of income. With the beaches eroding, the tourism decreases which leads to less income. As no regulations exist on one's boundaries, every business only takes care of its own section. Therefore, the businesses have to work together in order to solve the problem

Marine Department - In this case, the Thai Marine Department oversees the work that prevents coastal erosion, by means of both hard and soft structures such as jetties, offshore breakwaters, beach nourishments and bypassing (J. Laksanalamai, personal communication, October 21, 2016). The Marine Department also has the ability to incorporate project requests into the long term plan for the upcoming 5 to 10 years, which is sent to the Bureau of Budget, who then decide upon the allocation of the budget (J. Laksanalamai, personal communication, October 11, 2016).

Other NGOs - Other NGOs than the Environmental Interest Groups, mostly consist of professors from universities. However, the professors are more active in Southern Thailand, in the Songkhla Province. The professors are one of the actors that prefer the soft measures, because they think that nature will heal itself and should not be interrupted. They are strongly against the constructed jetties, but are only opposing and not proposing any other solution. Overall, NGOs are not very powerful, but they use media to spread their ideas and they unveil inappropriate actions that occur (Wuttichai, personal communication, October 11, 2016).

Project Developers - Project developers are involved in the project for the planning, construction and operation of the measures (Grid Infrastructure Communication Toolkit, 2016). They are usually contractors, have initially no great decision-making power and are selected by the instances responsible for the project. Their task is to successfully implement and develop the design of the project in order for the measures to properly perform their functions. At last, they might be responsible for the maintenance to ensure the realisation of the desired lifetime of the structures.

Project Investors - The presence of investors in the project depends on the possibilities for new businesses and the intentions of the investors. Should the investment have a considerable rate of return for the investor, the project is more likely to attract financial backers. Furthermore, if the project is of great environmental value or of great ethical value, it is also more likely to attract backers. Nevertheless, the investors will not be the main financial source, since the project will mostly be supported by the government.

Royal Family - The Royal Family can be seen as a stakeholder in this project area, as royal palaces can be found in both Hua Hin and Cha-am. For example, the Klai Kangwon Palace in Hua Hin is still used by the royal family till this day. Also, the Mrigadayavan Palace, which is situated in Cha-am and is now a tourist attraction. Moreover, Princess Maha Chakri Sirindhorn has played an important role in this area, as she initiated the mangrove plantation called the Sirindhorn's Mangrove Forest in 1994 (The Sirindhorn International Environmental Park, 2000).

Tourists - As Hua Hin and Cha-am beach are known as tourist destinations, the tourists are important stakeholders. There are two different kinds of tourists, the Western tourists who prefer beautiful sandy beaches and the Thai, mostly from Bangkok, who want to escape the big city for the weekend and prefer swimming pools rather than beaches.

C.2. Stakeholder identification

Table C.1 | Identification of stakeholders' interests, problem perceptions, goal definitions and responsibilities

	Stakeholder	Interest *What do they want to get out of the project?*	Problem perception *What is the problem for them?*	Goal definition *What would they like to achieve?*	Responsibilities
EIG	Environmental Interest Groups (NGOs)	Preserve flora and fauna Improve quality of animals' habitats Promote use of sustainable materials/services/processes Provide the project with their knowledge	The seawater's quality is affected by water pollution The coast and seawater are facing pollution by garbage Overfishing and illegal fishing practices Tourism and coastal erosion have an ecological impact	Solve the pollution problems Prevent projects from affecting flora and fauna Restore and improve flora and fauna Create awareness of the environment	Advise and inform on environmental issues and their impact
FM	Fishermen	Enough spots to dock their boats Provide shelter for the boats from the storms/winds Preserve/improve the ecology to ensure enough fish Access to the beach by boat	The storms are destroying their ships and docking areas The coastal erosion decreases their working space	Catch more of the right kind of fish to make more profit Favourable locations for catching fish and docking boats	Keep the beaches clean and proper Report deficiencies
GO	Government	Ensure economical growth Ensure tourism growth Prevent deterioration of the area Preserve cultural heritage Sustainable development Sustainable water management	The erosion is a threat for the safety of the people The erosion is a threat to the cultural heritage The erosion leads to a decrease in tourism Siltation of the canals which are connected to the sea	Improve the wellbeing of the people Improve the economy Preserve nature Preserve cultural heritage	Budget allocation Regulations Set boundaries
HR	Hotels & Resorts	Clean and beautiful beaches Enough beach for the tourists Clean and clear water Possibilities for activities on the beach and water	There is no/little beach to attract tourists from abroad The beaches are not clean and not beautiful enough Scattered rocks of broken breakwater Wastewater near the hotels repulse the tourists	Attract more tourists to maximize profits	Maintain beaches in front of their properties Report deficiencies
IH	Inhabitants	Maintain a habitable home and surroundings Increase of employment possibilities	The beach erosion is forming a threat to their houses	Improve living quality	Keep the beaches proper and clean Report deficiencies
LO	Landowners	Preserve as much of their land as possible Prevent deterioration of their land	The erosion is affecting the surface area	Maximize profits Improve quality of their land	Grant access to their property if needed
LA	Local Authorities	Ensure economical growth Ensure tourism growth Prevent deterioration of the area Preserve cultural heritage Sustainable development Sustainable water management	The eroding beaches are affecting tourism The eroding beaches are frightening local inhabitants The eroding beaches are affecting the quality of the area The eroding beaches are a threat to the cultural heritage	Create possibilities to accommodate growth Improve the economy Sustainable development Sustainable water management	Monitor the system Create awareness / sense of responsibility amongst locals regarding the cleanliness of the beaches
LB	Local Businesses	Keep their business going Attract more customers	The erosion problem is endangering their business area The problematic beaches are repelling their customers	Maximize profits Expand business	Maintain the beaches in front of their properties Report deficiencies
MD	Marine Department	Provide service for the wellbeing of the people	The erosion is a threat for the safety of the people	Improve the wellbeing of the people	Development of the system Operation of the system Inspection and maintenance of the system
ON	Other NGOs	Ensure soft measures Preserve flora and fauna	The hard structures are damaging nature The natural healing process of the beaches is interrupted by the hard structures	Self-sufficient and natural (looking) beaches	Give advice regarding the measures
PD	Project Developers	Obtain the work Low construction costs Successful completion	Other stakeholders might oppose the project Obstructions might increase the costs and the time	Maximize profits Keep the client happy Increase company image	Development and execution of the system
PI	Project Investors	Investing in desirable/necessary projects for the users	No available investment possibilities	Maximize profits	
RE	Researchers	Put knowledge and expertise into practice Gain new knowledge and expertise	Lack of knowledge on coastal erosion solutions	Determine the causes, effects and courses of issues Contribute to the scientific research	Share knowledge and expertise
RF	Royal Family	Keep the people happy Keep the beaches aesthetically pleasing Preserve their royal properties	The hard structures are not aesthetically pleasing The erosion is endangering the Mrigadayavan Palace The erosion is affecting the beauty of the beaches The erosion is threatening the mangroves	Preserve the beaches Have aesthetically pleasing beaches Maintain face	Set boundaries for the development of the system
TO	Tourists	Enough facilities on the beaches and in the area Enough beaches for recreation Clean and beautiful beaches Clean and clear water Not too many people on the beach Aesthetically pleasing views	There is too little beach The beaches are not clean and beautiful enough The water is not clean and clear enough There are not enough services on the beaches	Visit beautiful and clean beaches Have enough places for recreation and relaxation Have enough options for activities	Keep the beaches proper and clean

C.3. Typology explanation

This appendix will give an overview of the eight different positions that stakeholders can have regarding their power, interest and attitude. Also, a short description will be given on each position according to the theory of Hillson and Simon (2007).

Saviour - Powerful, with a high interest level and a positive attitude toward the project. It is important to pay attention to these stakeholders; harness their support and do whatever is necessary to keep it.

Friend - Low power, but high interest and positive attitude, these stakeholders can be used as confidants or sounding boards. Maintain their support in case they gain additional power within the organization.

Sleeping Giant - Powerful stakeholders who support the project but displaying low levels of interest: they need to be awakened to raise their commitment to the project and maximize their positive input.

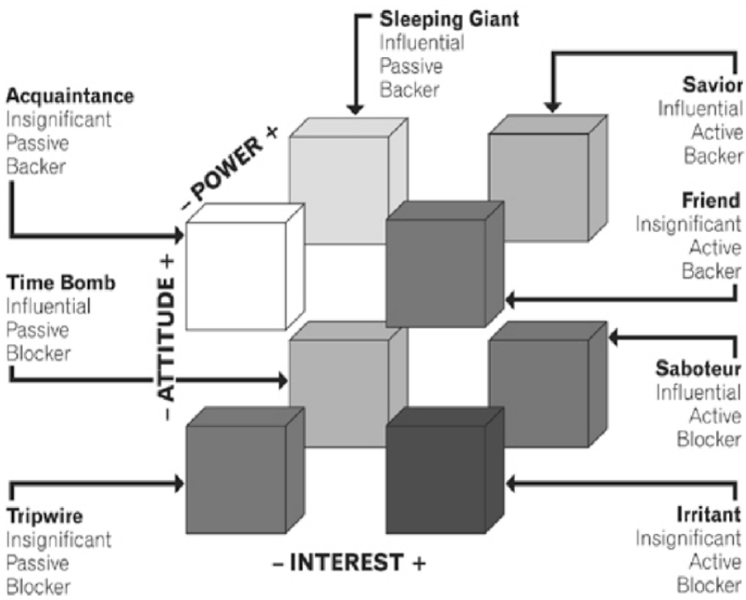
Acquaintance - Low-power, low-interest backers who should be kept informed, but need not be a top priority unless their levels of power or interest increase.

Saboteur - Powerful, with a high interest level in the project, but display a negative attitude; they must be actively engaged to prevent them causing significant disruption to the project. The aim is to make their attitude toward the project more supportive and to use their influence to benefit the project.

Irritant - Very interested in the project but do not support it, though they have little power to influence things. Their negative attitude must be contained and countered where possible.

Time Bomb - Powerful but with low interest levels and a negative attitude towards the project; these stakeholders must be understood so they can be "defused before the bomb goes off". Efforts should be made to improve their attitude and engage active input.

Trip Wire - Low-power, low-interest, negative-attitude stakeholders who are likely to hinder the project; their interaction with the project should be minimized as much as possible.



D. System engineering

D.1. System stakeholder role definition

According to Wasson (2006), the system stakeholder roles can be defined as follows:

System adversary – A hostile individual, organization, or enterprise whose interest, ideology, goals, and objectives are counter to another system's missions, goals, and/or objectives or exhibits behavioural patterns and actions that appear to be threatening.

System advocate – An individual, organization, or enterprise that champions the system's cause, mission, or reason for existence. System advocates may derive tangible or intangible benefits from their support of the system, or they may simply believe the system contributes to some higher level cause that they support.

System architect – An individual, organization, or enterprise that visualizes, conceptualizes, and formulates the system, system concepts, missions, goals, and objectives. Since SE is viewed as multidiscipline, the system architect role manifests itself via hardware architects, software architects, instructional architects, etc.

System critic – An individual, organization, or enterprise with competitive, adversarial, or hostile motivations to publicize the shortcomings of a system to fulfil its assigned missions, goals, and objectives in a cost effective, value-added manner and/or believes the system is a threat to some other system for which the system critic serves as a system advocate.

System developer – An individual, organization, or enterprise responsible for developing a verified system solution based on operational capabilities and performance bounded and specified in a System Performance Specification (SPS).

System owner – An individual, organization, or enterprise that is legally and administratively responsible and accountable for the system, its development, operation, products, by-products, and outcomes and disposal.

System shareholder – An individual, organization, or enterprise that "owns", either directly or indirectly, all or equity shares in the system and its development, operation, products, and by-products.

System support – An individual, organization, or enterprise responsible for supporting the system, its capabilities, and/or performance at a sustainment level that ensures successful achievement of the system's mission and objectives. System support includes activities such as maintenance, training, data, technical manuals, resources, and management.

System user(s) – An individual, organization, or enterprise that derives direct benefits from a system and/or its products, services, or by-products. Users may physically operate a system or provide inputs - data, materials, raw materials, pre-processed materials, etc. - to the system and await the results of value-added processing in the form of products, services, or information. Users may directly or indirectly include the System Advocate, System Owner, or other Users.

D.2. Hierarchical level of abstraction analysis

Figure D.1 visualizes the analysis of the hierarchical level of abstraction. From the stakeholder analysis, all the stakeholder objectives have been derived. Thereafter, the stakeholder objectives have been grouped according to their common aspects. Those common aspects are referred to as the objective themes. All the objective themes together contribute to the mission of the system, being the protection of the coast against erosion.

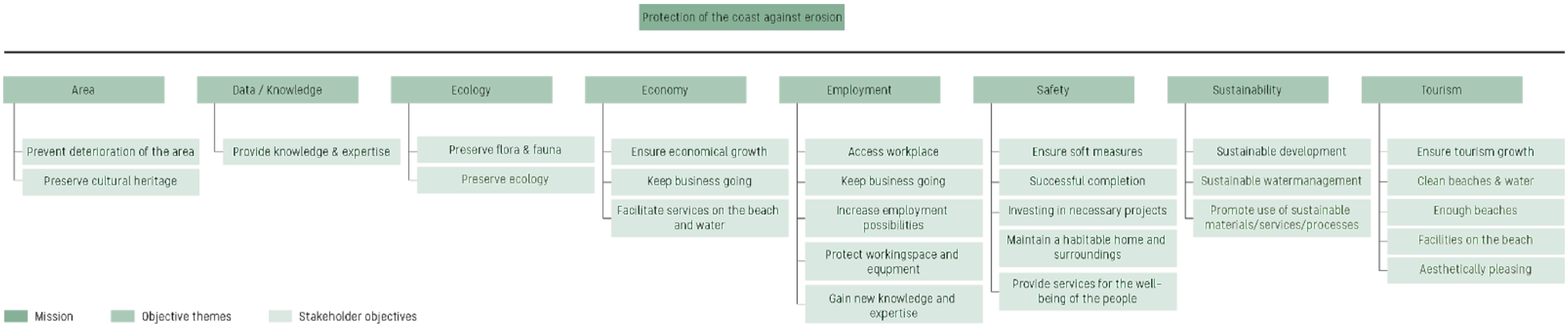


Figure D.1 | Hierarchical level of abstraction (own ill.)

E. Information on nourishments

Sand nourishments are an attractive measure to counter coastal erosion. With these so-called soft solutions the coast is left in a more natural way compared to hard structures such as groynes and breakwaters. Additional advantages are that the recreational value of the coast is preserved and that when results are different as expected one can easily adapt the design (Bosboom & Stive, 2015). All nourishments add a certain volume of sand to the coastal profile, but the main purpose of the nourishments can be quite different. There are three main purposes of a nourishment (Verhagen, 1992):

- Combatting coastal erosion (chronic erosion).
- Preventing flooding (safety).
- Maintaining a wide recreational beach.

Nourishments do not solve the erosion in the long run, they have to be repeated after a few years. This is because the erosion rate of the coast is not altered, so erosion will still occur. It is important that a sand mine is located nearby. This sand mine should contain ample material (Bosboom & Stive, 2015).

To come up with a proper problem definition to solve the problem one needs to know certain aspects. Firstly, one has to be familiar with the causes of the beach erosion. It is difficult to solve a problem when the cause remains unknown. A study on the morphological processes is thus necessary. Secondly, one has to know which interests are at stake. These interest determine among others also the purpose of the nourishment. Aspects that should be looked at are (flood) safety, recreation, environment and economy (Pilarczyk, van Overeem, & Bakker, 1986).

Different options

There are several options to choose from when designing a nourishment. Each option has its advantages and disadvantages. For each situation a choice has to be made which option is most appropriate.

Beach nourishment

The nourished material is directly placed on beach when constructing a beach nourishment. This means that the coastline is shifted seaward. The main location of this type of nourishment is high on the beach and typical volumes range from 30 to 150 m^3/m (Van Rijn, 2010). The nourishment can be placed with both floating and land based equipment. The use of pipelines is also possible. The main advantage of a beach nourishment is the direct widening of the beach. When a wide recreational beach is desired, this type of nourishment is most attractive.

It is also possible to combine the beach nourishment with a revetment of sandbags. The main function of the sandbags is to form a last line against erosion. The sandbags are not allowed to be exposed. Due to UV radiation from the sun the material deteriorates which increases the chance of failure. Another disadvantage is the impermeability of the sandbags. The sandbags are not able to absorb wave energy and can therefore accelerate erosion. The main advantage is the easy construction (Scottish Natural Heritage, n.d.).

It is also possible to place a stone revetment underneath the nourishment. This has the same functions as the sand bags. The advantage of a stone revetment is that when exposed the structure is not in direct danger of failure. The disadvantage is that the construction is more difficult than the option with sandbags.

Shoreface nourishment

The location of the shoreface nourishment is the seaward side of the surf zone. This results in a relatively simple execution, because the depth is large enough for hopper dredgers. The effect of shoreface nourishments on beach widening is low. However, the main effect is the contribution to the sediment balance of the active surf zone. Shoreface nourishments both add volume to the system and filter large waves. They work basically as submerged offshore breakwaters (Van Rijn, 2010). There are two types of shoreface nourishments that can be distinguished:

- **Stable reef berms** only function as a wave filter. Due to this berm large waves break and a sheltered area is created. The volume remains mainly on the berm and the placement site is between 10 to 15 meters deep.

- **Active feeder berms** are executed in shallower water (<8 meters deep). Active feeder berms also act as a wave filter, dissipating wave energy from larger waves, and as a sediment source for the surf zone.
-

The shoreface nourishments are believed to have longshore and cross-shore effects. The longshore effects are a decrease of longshore transport, updrift sedimentation and downdrift erosion. Cross-shore effects are an increase of the onshore sediment transport and a reduction of the offshore sediment transport (Van Rijn, 2004).

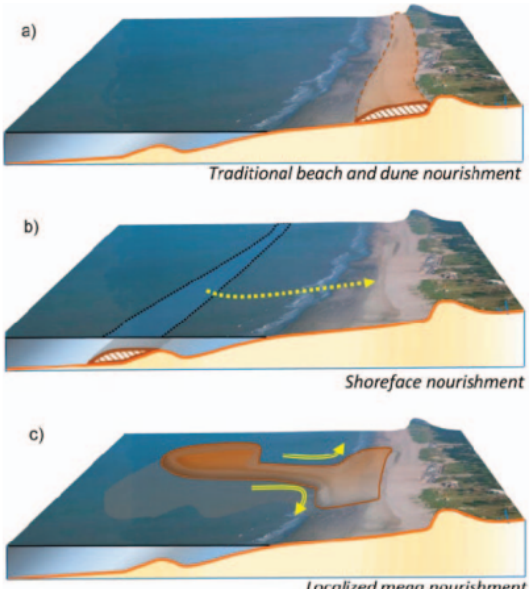


Figure E.1 | Different types of nourishments
(a) Traditional beach and dune nourishment. (b)shoreface nourishment; (c)Mega nourishment (Stive et. al, 2013)

Mega nourishment
A mega nourishment is a relatively new option, and is like a normal nourishment, but many times larger. Instead of a lifetime of 5 years, a mega nourishment has a longer lifetime of for example 20 years. Stive et. al (2013) expect mega nourishments to be more efficient and economical over the whole lifetime when compared to the more traditional designs. This is because the construction costs only occur once instead of multiple times. Another advantage is that the nourishment can be beneficial for the ecology and recreation. The main disadvantage is that the construction costs are not spread out over time. This means that the mega nourishment needs a relatively high investment.

Figure E.2 | The Dutch mega nourishment called the "Sand Engine" (21.5Mm^3 sand) just after construction

Design

For a nourishment to be successful, a proper design has to be made. If not enough sand is nourished, the nourished material can disappear quickly, which is of course undesirable. Also the layout of the design can influence the success of the nourishment.

Volume

To determine the necessary volume one needs to know the loss of sand in m^3/year per coastal section. This can be obtained through coastal profile measurements, but also through computer models like GENESIS and UNIBEST. Measurements are preferred because there is less uncertainty. To be able to have an accurate value for the loss of sand at least 10 years of measurements are advised (Verhagen, 1992).
The total volume can be calculated with:

$$Volume\ [m^3] = (Erosion\ rate\ [m^3/year] + Expected\ losses\ [m^3/year]) \times Lifetime\ [years]$$

The expected losses are estimated to be 40% of the yearly erosion rate. The losses consist of several parts: cross shore loss of sediment (the sediment leaves the control volume) and because the beach is further into the sea the wave attack is heavier. Losses in longshore direction are not accounted for, because these losses always occur due to the limited length of the nourishment. Losses of fine sand are usually 10 to 20 per cent of the nourished volume (Bosboom & Stive, 2015). When more experience is gained, the expected losses can be determined more accurately (Verhagen, 1992). The lifetime of a nourishment is usually 5 to 10 years (Bosboom & Stive, 2015).

Layout

For beach nourishments two options are available: an elongated beach fill or a stockpile (Figure E.3). For an elongated beach fill Van Rijn (2010) advises to place the fill as much landward of the high tide line as possible. The layer should be 2 to 3m thick and the bank should be 20 to 30m wide (if required). To reduce loss of material the length of the nourishment should be at least 3km. Stockpiling is dumping the sand on concentrated places in a triangular-shaped pattern. The main advantage is the lower construction cost.

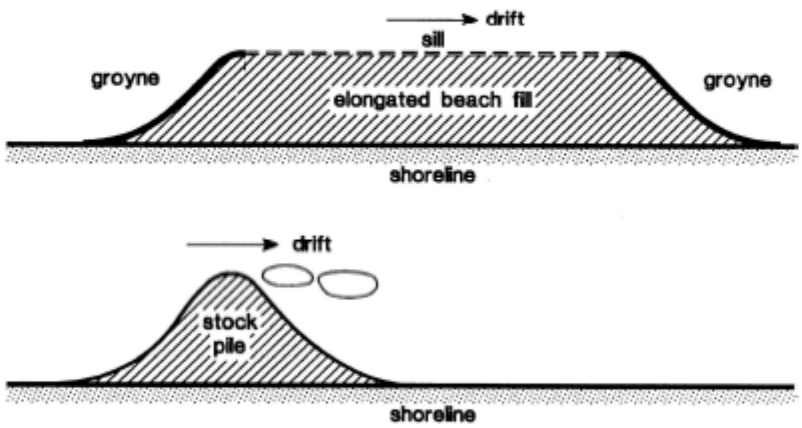


Figure E.3 | Options for beach nourishment (Van Rijn, 2010)

Shoreface nourishments are constructed in shallow water that ranges from 5 to 10m. The volume ranges from 300 to 500 m^3/m and the length scale is 2 to 5km. For shoreface nourishments more sand is needed than for beach nourishments. Only 20 to 30% of the nourished volume makes it to the beach in 5 years (Van Rijn, 2010).

The beach profile

The beach profile is an important aspect of beach nourishments. The profile after the nourishment will be formed by the hydrodynamic forcing. This forcing remains the same, so if the same sediment size is used, the profile will be more or less the same as before. Storms are a very efficient way to redistribute the nourished sand over the profile. It is therefore possible that with a few storms the nourished sand on the beach has completely disappeared and is redistributed over the entire profile. Due to this redistribution the nourishment can be seen as a failure by the public. When the purpose of the nourishment is to create a wide recreational beach, this redistribution can be a problem (Verhagen, 1992).

The slope of the nourishment determines the initial losses, according to Van Rijn (2010). He states that the initial slope of the nourishment should be 1 to 20 or flatter. Steeper slopes result in more initial losses on the beach, as can be concluded from laboratory tests (Figure E.4 and Figure E.5).

To create a wide recreational beach it is advised to use a flat slope to reduce the initial losses. The constructed slope should be close to the slope that is expected to form after a few storms. It is also advised to dump the sand as high as possible on the beach.

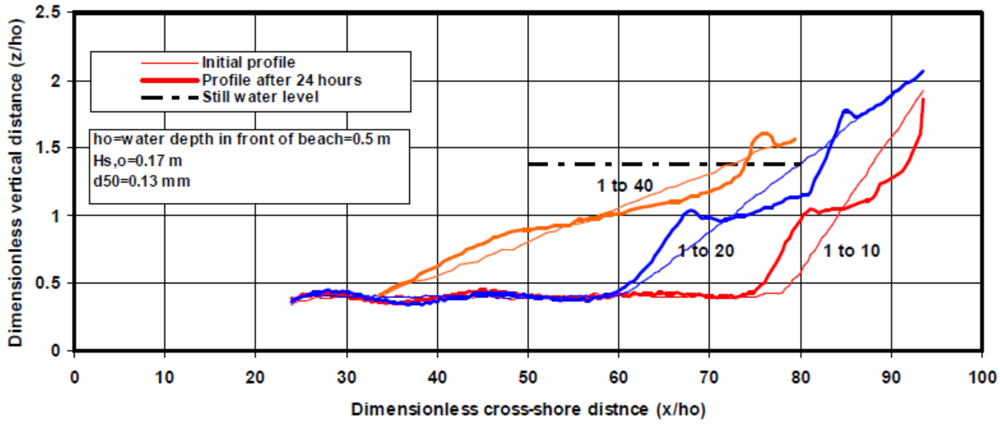


Figure E.4 | Beach profile development for initial slopes between 1 to 10 and 1 to 40 (laboratory tests) (Van Rijn, 2010)

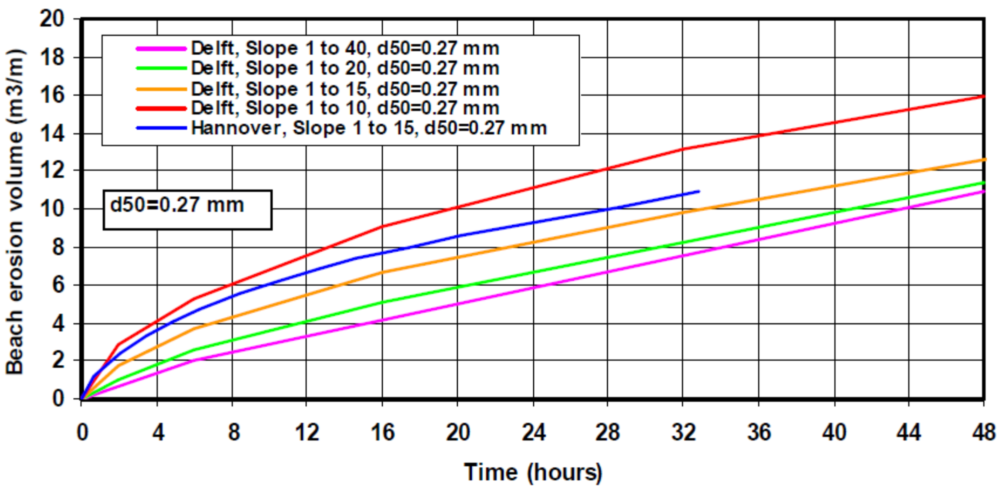


Figure E.5 | Beach erosion volumes for plane sloping beaches in nature with daily waves of about 1m at toe of beach (Van Rijn, 2010)

The location of the shoreface nourishment is on the seaward edge of the surf zone. The nourishment should be constructed as a bar or submerged offshore breakwater. The length of the nourishment should at least be 10 times the local wave height. The width of the crest should be between 0.5 to 1 times the local wave length, which means it is between 5 and 10 times the water depth. The slope of the sides should be between 1:30 and 1:50 and the end slopes should be gentle. This results in a slope of around 1:100. This is to reduce wave focusing due to refraction. Care should be taken to execute the nourishment far from possible sinks as navigation channels (Van Rijn, 2004).

Common design mistakes
There are some common design errors that can be prevented. These errors however do not result in a bad investment. The nourished sand can still fulfil its function. This is one of the main reasons nourishments is such an attractive solution.

1. The erosion rate used for the design is incorrect. When there is more erosion than expected, the lifetime of the nourishment is shorter than designed for. This can be solved by nourishing more sand during the next nourishment.
2. The losses are larger than accounted for. The result is the same, the lifetime is shorter. One can use the experience from this nourishment to improve the next one.

Nourish material
A very important aspect of the design is the used material. There are certain, important requirements for the material that have to be satisfied. This can influence the choice of sand mine, which can be on the land or in the sea.

Requirements
The main concerns around the nourished material are about the grain size, the grading and the fine content. When the sand mine is in the sea, fines are brought into the sea water via the overflow system of the dredge. Fines can have a negative effect on the local ecology and can disrupt the equilibrium. In the breaker zone all fines can be expected to be washed out. This means that the water is relatively clear, which is important for the local marine environment. Therefore it is important that the material contains little to no fines. A normal percentage of silt is 2%. When the fine content is too high, it is possible that measures need to be taken to wash out the fines (Bosboom & Stive, 2015). A second aspect covers the economical side. As a part of the sediment, fines are transported towards the project area. The fines thus take a certain volume of the trucks but do not contribute in the coastal protection. They are lost during construction or washed out by waves and blown away by the wind. The sand that is nourished will be exposed to the same hydrodynamic forcing as the native sand. When it is undesirable that coastal features and the beach slope change, it is necessary that the nourished material has the same properties as the native sand. This means that the grain size and the grading should be more or less the same. In this case the sediment transport will not change. It is however also possible to use coarser material to reduce losses. When coarser sand is used the sediment transport will decrease and thus the lifetime of the nourishment will be increased. Using a larger grain size changes coastal features and the slope of the beach. It is inadvisable to use smaller grain sizes, because the transport rate will increase and the lifetime will decrease (Bosboom & Stive, 2015).

Sand mines
The nourished material will be taken from sand mines that satisfy the requirements (0). These mines can be located on the land, but it is also possible to mine sand from the sea. The most important aspect in deciding what mine to choose is the sand quality. Other important aspects are availability of material, availability of equipment and costs. Land based mines may be located in rivers, but it is also possible to use dry sand deposits. In case of a river bed source the transport can be done via ship and truck. Material from dry sand deposits can be transported via truck, and if necessary also through ships. Mining from rivers can however also result in coastal erosion since the beach sediment originates from river deposits. The effects of river mining should therefore be investigated before making a decision. The sources in the sea can either be estuaries or the seabed. This sand has to be dredged by ships. It is very important that the sand mine is located far enough offshore. Otherwise the sand mine can increase erosion rates at nearby shores.

Construction method
Nourishments can be constructed using floating equipment and land based equipment. A combination of the two is also possible. Several aspects are important when making a choice on which equipment to use. These aspects include the chosen design, the available equipment, the costs, the location of the sand mine, the local infrastructure and the available space.

Transport
The transport of the material can be done with land based equipment, but also with ships. The location of the sand mine is leading in the decision what equipment to use. The local infrastructure can also be a determining factor. The land-based equipment consists of dump trucks that can be loaded at the sand mine (when located on land) or at port (when the sand mine is under water). The trucks will drive

towards the construction site where they can dump the material. Hopper dredgers can dredge the material directly from the mine and sail to the construction site.

Construction
It is possible to use only land based equipment, only floating equipment or a combination of these two.
The land based equipment that can be used during the constructing are among others:

- Dump trucks
- Wheel loaders
- Track loaders
- Backhoe crane
- Front shovel
- Bulldozer
-

Dump trucks are used to transport the material towards the construction site. The other equipment can be used to redistribute the material over the beach. It is dependent on the local infrastructure, the local conditions, the available space and the available equipment on what equipment to use. Combinations are possible and sometimes even necessary. For beach nourishments land based equipment is necessary.
The floating equipment that can be used during the constructing are among other:

- Pipelines
- Shallow draft dredgers (doors in the bottom)
- Shallow draft dredgers (rainbowing) (see Figure E.6)

Floating equipment can be used for both shoreface and beach nourishments. Pipelines can be used when the dredgers cannot reach the beach. It depends on the type of nourishment and available equipment what to use.

Figure E.6 | Nourishment through rainbowing

Monitoring and evaluation
An important part of a nourishment plan is the monitoring and evaluation of the project. To be able to make a plan for a coastal section data has to be available. When it is known how successful a nourishment was, it is possible to improve the next nourishment. In this way a more cost effective construction can be used, which saves money. To be able to evaluate the nourishment the nourishment has to be monitored. For a good evaluation more data is better, but this is budget ways not always possible. Profile measurements before, and just after completion are essential. To follow the development of the coast more measurements are necessary, for example one measurement per year. Dry and wet measurements are essential. Using the evaluation of the nourishment a long term plan can be made and the next nourishments can be improved. In this way one can plan when budget is necessary to execute a new nourishment.

Conclusion
Figure E.7 shows a roadmap on how to design a nourishment scheme. Notice that this scheme is an on-going process, because the erosion problem itself will not be solved by the nourishment. This scheme is a long term plan. The most important decision to take are:

- What is the purpose of the nourishment?

- What nourishment type will be used?
- How much sand needs to be nourished?
- What sand mine will be used, and is this located on land or under water?
- How will the nourishment be constructed?
- How often will the coast be monitored and evaluated?

It is important to notice that the design process is an iteration process itself. The chosen nourishment type has influence on for example the construction method used, but the available equipment also has influence on the possibilities to construct these nourishment types. And the availability of sand mines also has influence on which type can be executed and which equipment can be used. The design itself should therefore be made with care. Nourishments can also be combined with hard structures as groynes and offshore breakwaters. This is however not covered in this document.

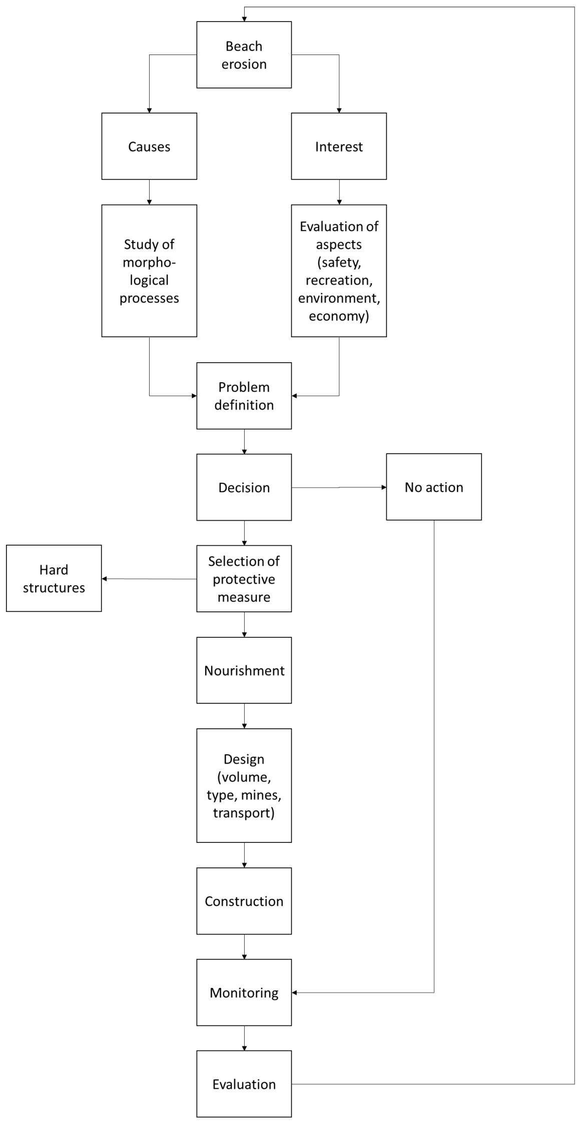


Figure E.7 | Roadmap of making a nourishment scheme (based on Pilarczyk et. al, 1986)

F. Coastal model

In this appendix all additional information about the coastal model is presented. In this project the model UNIBEST-CL+ is used (version 7.1.12). First general information about UNIBEST is given after which the model set up is discussed. This appendix ends with a comparison between UNIBEST and GENESIS.

F.1. General information

The UNIBEST-CL+ (UNIform Beach Sediment Transport) model is developed by Deltares (former Delft Hydraulics) and is used to simulate shoreline changes. The model consists of two modules and can be extended with two additional modules. The modules are the LT-module for the computation of longshore transport, the CL-module for the computation of the coastline change and the additional modules are the TC-module for cross shore transport and the DE-module for the computation of dune erosion. The LT- and CL-module will be discussed in detail, while the TC- and DE-module are only discussed briefly. First the general processes and assumptions of UNIBEST are discussed, after which the modules will be discussed. The shortcomings and some tips are also given.

This document is meant to give an introduction to UNIBEST and how to use it. When the reader wants to use the model, he/she is advised to read the manual as well. The information in this document is retrieved from this manual and our own experience. Information can also be found on the Deltares website: https://www.deltares.nl/en/software/unibest-cl/#8.

F.1.1. General processes and assumptions

Processes

The longshore sediment transport is computed and schematised with the LT-module separately for a number of cross-shore profiles along a coast. These schematised transports are then used in the CL-module to perform coastline evolution simulations in which effects of structures such as groynes, offshore breakwaters and revetments can be incorporated (although transports will have to be computed and schematised within the LT module). The following paragraphs are directly copied from the UNIBEST manual (2011), because it describes accurately the functionalities of the models.

Longshore transport module

"The LT-module is designed to compute tide and wave induced longshore currents and resulting sediment transport for a specific cross-shore beach profile assuming that the beach is uniform in alongshore direction. The surfzone dynamics are derived from a built-in random wave propagation and decay model, which transforms offshore wave data to the coast taking the principal processes of linear refraction and non-linear dissipation by wave breaking and bottom friction into account. The longshore sediment transports and cross-shore distribution are evaluated according to various transport formulas, which enables a sensitivity analysis for local conditions. The computational procedure may take any pre-defined wave climate and tidal regime into account in order to enable an assessment of gross and yearly longshore transports, seasonal variation and even storm events."

Coastline module

"The CL-module is designed to simulate coastline changes due to longshore sediment transport gradients of an alongshore nearly uniform coast, on the basis of the single line theory. Various initial and boundary conditions may be introduced as to represent a variety of coastal situations. Along the modelled coastline sediment sources and sinks may be defined at any location, to cater for river sediment yield, subsidence, offshore sediment losses, beach mining, etc.. Furthermore, it is capable of modelling the morphological impacts of various coastal engineering measures, such as headlands, permeable and non-permeable groynes, coastal revetments and seawalls, breakwaters, harbour moles, river mouth training works, artificial sand by-pass systems and beach nourishments. The effect of wave shielding (diffraction, directional wave spreading) behind coastal structures can also be incorporated in the model. The model can be used for the conceptual design (location, dimensions and spacing) of coastal structures and the impact assessment on adjacent coastal stretches."

Assumptions

The basic assumption of UNIBEST is that a beach of arbitrary cross shore profile with straight, parallel depth contours is considered, which is attacked by a random wave field, homogenous alongshore and obliquely incident, and by a tidal current, homogeneous alongshore in its current strength. In this situation the sediment transport due to an alongshore flow induced by the waves and the tide is considered.

UNIBEST uses single line theory. For the single line theory the coastal profile is schematized according to Figure F.1. The x-axis is chosen along the original coastline. The shore-normal y-axis is chosen in a direction parallel to the original coastline pointing in offshore direction to create a right-hand coordinate system Figure F.1a.

The profile characterizing the beach to be studied is assumed to move horizontally over its entire active profile height as a result of erosion or accretion (Figure F.1b). The beach slope therefore does not change. Beyond the active profile height the bottom does not move. The shoreward limit of the profile changes is located at the top of the active profile. This is the most fundamental assumption of the single line theory. Important implications of this assumption are that only longshore sediment transports can be taken into account and that the beach profile is always in equilibrium. This theory is also used in GENESIS.

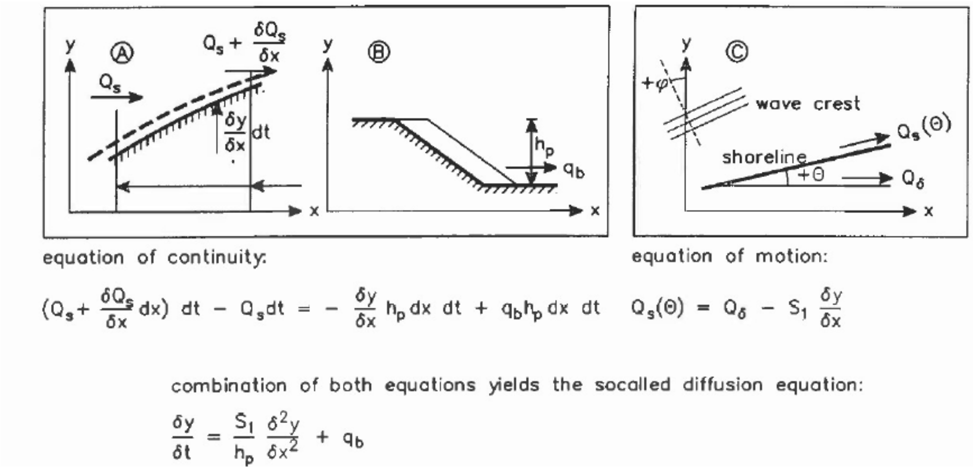


Figure F.1 | Schematisation of single line theory (Deltares, 2011)

F.1.2. LT-module

Like stated before, the LT-module calculates the longshore transport. This module needs most input. The cross-sections need to be defined, as well as the transport and wave parameters and most importantly, the hydrodynamic forcing (waves and tides).

Coastal profiles

Coastal orientation and active profile height

The coastal orientation and active profile height can be specified at the LTR run tab. The coastal orientation needs to be specified relative to the shore normal (Figure F.2).

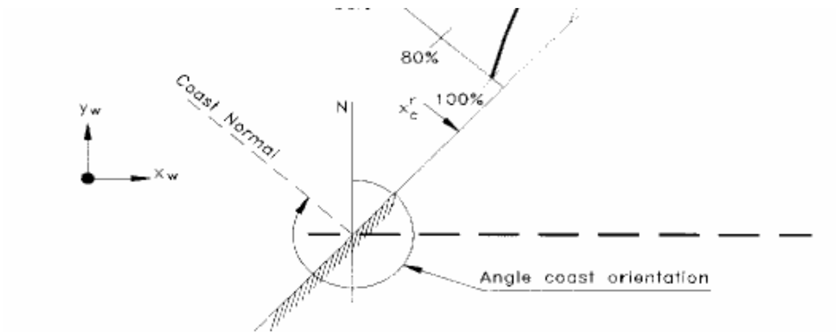


Figure F.2 | Definition of the angle of coastal orientation (Deltares, 2011)

The active profile height is as a rule of thumb 2-3 times the 1/1 year significant wave height. The profile height also depends on the time that is simulated. If the time frame is years to decades, more of the profile is expected to be active because higher waves are more likely to occur during this period.

Profiles
The profiles can be plugged in through tables. Care should be taken that the landward and seaward side are correctly defined. The depth is relative to a reference level which also can be specified and should reach high enough on the beach. Other parameters that should be specified are the reference x-point, the x-point dynamic boundary and the x-point truncation transport.

The reference x-point is the location where the water level meets the profile. The x-point dynamic boundary is the location up to where the longshore transport is computed. The dynamic part of the profile rotates the same way as the coastline. The x-point truncation transport stands for the location up to where the longshore transport is accounted for in the total longshore transport. In general this has the same value as the dynamic boundary.

Transport parameters
There are several transport formulae that can be used, including one for gravel beaches. Van Rijn (2004) gives the best uncalibrated results and was therefore chosen for this project. Other formulae are however also possible. Every formulae requests several input parameters

Table F.1 | The different transport formulae with their input parameters (Deltares, 2011)

Formula:								Symbol	Parameters	Remarks
Bijker (1967, 1971)	Van Rijn (1992)	Van Rijn (1993)	Van Rijn (2004)	Soulsby/ Van Rijn	Kamphuis (2000)	CERC (1984)	Van der Meer-Pilarczyk (1992)			
			X					D_{10}	10th percentile grain diameter [μm]	
X	X	X	X	X	X			D_{50}	median grain diameter [μm]	
X	X	X	X	X				D_{90}	90th percentile grain diameter [μm]	
							X	D_{n50}	median stone diameter [m]	
X	X							Ws	Sediment fall velocity [m/s]	depends on sediment
		X	X					Dss	Grain diameter of suspended sediment [μm]	threshold of suspension
X	X	X	X	X	X		X	ρ_s	Sediment density [kg/m3]	default : 2650 kg/m3
X	X	X	X	X	X	X	X	ρ_w	Seawater density [kg/m3]	default : 1025 kg/m3
X	X	X	X	X	X			por	Porosity [-]	default : 0.4
X								cr_{dp}	Criterion deep water Hsig/h	default : 0.07
X								b_{dp}	Coefficient b deep water	default : 2
X								cr_{sh}	Criterion shallow water Hsig/h	default : 0.6
X								b_{sh}	Coefficient b shallow water	default : 5
X								k_{bot}	Bottom roughness	depends on bedform
	X	X	X	X				$k_{s,cur}$	Current related bottom roughness [m]	depends on bedform
	X	X	X					$k_{s,wave}$	Wave related bottom roughness [m]	depends on bedform
							X	z_0	Roughness lengths [m]	-
	X			X				υ_{mol}	Kinematic viscosity [10^{-6} m^2/s]	depends on temperature
	X			X			X	cal	Correction / Calibration / Multiplication factor	calibration factor
	X							z_{rel}	Relative bottom transport layer thickness [-]	default : 0.03 m
		X	X					T	Temperature [°C]	default : 15 °C
		X	X					s	Salinity [ppm]	default : 30 ppm
		X	X					fac_{CS}	Current related suspended transport factor [-]	calibration factor
		X	X					fac_{CB}	Current related bedload transport factor [-]	calibration factor
		X	X					fac_{WS}	Wave related suspended transport factor [-]	calibration factor
		X	X					fac_{WB}	Wave related bedload transport factor [-]	calibration factor
						X		A	parameter A [-]	depends on bedform
					X	X		γ	breaker coefficient gamma [-]	wave breaking parameter
							X	θ	Shields number [-]	

Van Rijn (2004)
The reader is advised to read the report of Van Rijn itself (*Description of TRANSPOR2004 and Implementation in Delft3D-ONLINE,* 2004). The wave and current related bottom roughness does not to be provided (this is shown incorrectly in Table F.1).

The several sediment diameters can be measured and the suspended sediment diameter is usually between 0.6-1.0 times the median grain diameter (D_{50}). For sediment sizes smaller than 0.15mm the D_{SS} is 1.0 times the D_{50} and for sizes larger than 0.30mm the D_{SS} is 0.8 times the D_{50}. For intermediate values a gradual scale can be used. The temperature and salinity[8] can also be measured. With these two parameters the density of the seawater can be calculated:

$$\rho = 1000 + 1.455CL - 0.0065(Te - 4 + 0.4CL)^2$$
$$CL = \frac{Sa - 0.03}{1.805}$$

Where:
ρ is the density in kg/m³.
CL is the chlorinity of the seawater.
Sa is the salinity of the seawater in psu or ppt.
Te is the temperature of the seawater in °C.

In this report the value of the salinity is 33psu and the temperature is 30°C (Snidvongs, & Sojisuporn, 1999). This results in a density of 1019kg/m³. The density of the sediment and the porosity can be determined using tests as well. In this report regular values of sand are used (2650kg/m³ and 0.4 respectively; TU Delft, n.d.).

Wave parameters
The wave parameters that need to be specified are two breaker parameters and a coefficient for bottom friction and a coefficient for bottom roughness. All these parameters can be calibrated. The first breaker parameter (γ) corresponds to wave steepness and a first calculation can be made (Table F.2).

Table F.2 | Wave breaker parameter

H_{RMS}/λ	0	0.01	0.02	0.03	0.04
γ	0.5	0.63	0.73	0.81	0.85

The second wave breaker parameter (α) corresponds to the dissipation of wave energy through rollers. The coefficient for bottom roughness (k_b) depends on the bedform.

Wave and tide scenarios
The input of the hydrodynamic forcing consists of wave scenarios and tidal scenarios. All wave conditions are combined with all tidal conditions. The product of wave conditions and tidal conditions should be lower than 1000. Otherwise too many conditions need to be computed. It is also possible to create local wave scenarios to account for offshore breakwater. These local scenarios are created with for example SWAN (Simulating WAves Nearshore).

Wave scenarios
For the wave scenarios a few aspects need to be specified: the duration of the scenario, the normalisation value, the wave current interaction model, if there is a dynamic boundary and if there are wind driven currents.

The duration depends on the wave conditions and the normalisation value is usually 365 days (the number of days in one year). There are several possibilities for the wave current interaction model:
- Fredøe (1984)
- Myrhaug and Slaattelid (1990)
- Huyn-Thanh and Temperville (1991)
- Grant and Madsen (1979)
- Davies, Soulsby and King (1988)
- Bijker (1967, 1971)

[8] NOTE: Table F.1 and UNIBEST states it should be in ppm, this should be psu or ppt

- Chrostoffersen and Jonsson (1985)
- O'Connor and Yoo (1988)

Soulsby et al. (1993) researched these wave current interaction models. They concluded that all models give similar results.

It is possible to select a dynamic boundary. When this is selected, the equilibrium orientation of the beach profile is based on the representative wave angle at a certain cumulative transport position. The cross-shore distribution of the sediment transport I taken into account in the derivation of the equilibrium orientation.
Wind driven currents can also be activated. When this is selected more data has to be provided in the *wave conditions* window: wind speed, wind direction and wind drag force.

For the wave currents the wind induced set up (H0 in meters), the significant wave height (Hsig in meters), the peak period (Tp in seconds), the direction (Dir in °N) and the duration of the condition (in days) need to be specified.

The wind set up can be determined using numerical models, the other parameters can be determined with measurements.

Tide scenarios
For the tidal conditions the water level elevation with respect to MSL (DH in meters), the current velocity (V_{getij} in meters per second), a reference depth and the percentage of occurrence need to be specified. A simple example is given in Figure F.3. It is advised to use representative tidal conditions. All parameters can be measured. It is also possible to compute the current velocity:

$$V_{gety} = C\sqrt{d_{ref}\frac{dh_0}{dy}}$$

Where:
C is the Chèzy friction coefficient in $m^{1/2}/s$ defined as: $C = 18\log\left(\frac{12d}{k_0}\right)$;
$\frac{dh_0}{dy}$ is the tidal surface slope alongshore, implicitly defined by the tidal current velocity;
d_{ref} is the reference depth in m.

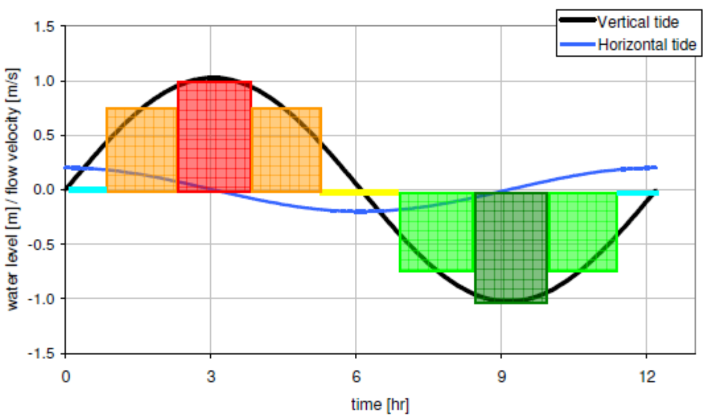


Figure F.3 | Tidal conditions

Local wave scenarios
UNIBEST is unable to directly take account of offshore breakwaters. They can be taken into account using local wave scenarios. These local wave scenarios simulate the wave conditions behind the breakwater. This scenario can be created using for example SWAN. These local wave scenario can be added through the *Tools* tab.

Output

When all the input parameters have been determined and plugged into the model, the model can be run. The model computes the longshore sediment transport that will be used in the CL-module.

F.1.3. CL-module

The CL-module simulates the coastline change due to the transport processes. In this module the coastline is build and the structures build on the coast need to be schematised. It is also possible to implement sources and sinks.

Model dimensions & GIS-layers
When starting with the CL-module first the model dimensions need to be specified. This is specified with stating the minimum and maximum X and Y coordinates. It is advised to use a coordinate system that corresponds to data (for example the UTM coordinate system which is used in the current report), but it is not necessary. After this specification, a layer can be added, for instance an image. The location of the image is determined by the locations. It is necessary to make sure that the image is not rotated and that the top part is in northward direction. If a random coordinate system is used, the image can be located with geo-referencing.

Definition of the coastline
Next the basic model needs to be specified (Figure F.4). Two lines are created, the reference line and the support line. The reference line is created with the Xw and Yw coordinates. This line follows the general contours of the coast. The support line is created with the Y1-points. This is the distance between the reference line and the support line (Figure F.5). This line will be used as the coastline in the model. Y2 values can be specified when there is a step in the profile (e.g. at a groyne).

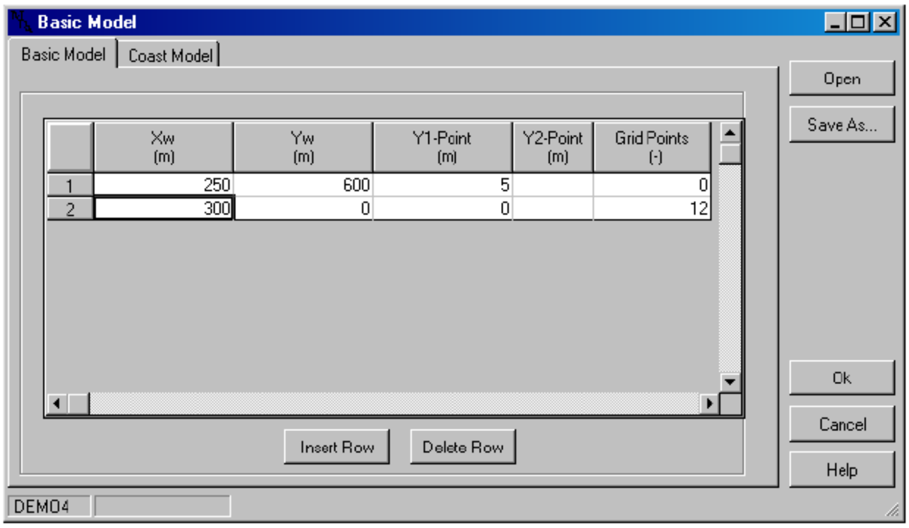


Figure F.4: Table to create the basic model

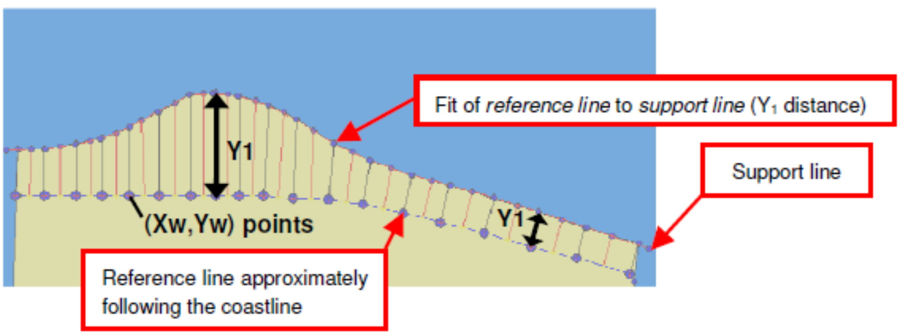


Figure F.5: The reference and support line of the basic model

Global climate
The output of the LT-module are a couple of wave rays. In the CL-module these files can be coupled to certain locations. This results in the global climate that contains a relation between the coast angle and sediment transport. It is possible to change the global climate per period. New periods can be added via the *Edit* menu. Per period different files (for example boundary conditions and structures) can be used.

Boundary conditions
There are four different types of boundary conditions:

- The coastline position y remains constant.
- The coastal angle remains constant (this implies that the transport at the boundary is kept constant).
- The transport Q_S is a user-defined constant value.
- The transport Q_S is a user-defined function of time.

Structures and sources and sinks
It is possible to specify structures as groynes, revetments and offshore breakwaters in UNIBEST. It is also possible to create internal boundaries and sources and sinks.

Groynes
Groynes can be drawn in the *Model visualisation area* by selecting two points. The type of groyne needs to be selected. It is possible to specify on which side of the groyne local wave climates need to be used (no local rays is also a possibility). These local wave climates can be computed with SWAN or using theoretical formulations. Also the blocking percentage of the groyne needs to be specified.

Revetments
Revetments need to be specified seaward of the reference line. Revetments keep the coastline at the same position, while sediment transport can still bypass the location. The coastline in front of the revetment can accrete or erode until it meets the revetment.

Offshore breakwaters
Offshore breakwaters can be specified in UNIBEST, but no effects are taken into account. To take the offshore breakwater into account a local wave climate needs to be specified as described in the paragraph about the LT-module.

Internal boundaries
In some cases obstructions can be present which block the sediment transport. In such a case an internal boundary can be used that can be added in a similar way as the structures.

Sources and sinks
It is possible to add sediment sources and sinks. This can be a one-time point source/sink or a time dependent function on one point.

Computation
Now the CL-module can be run. The output consists of a changing graph of erosion and Q_S. Also tables are available with the erosion rate in m/year at a certain point in time, the erosion rate over the whole simulation period and the Q_S at a certain point in time. Excel files can be obtained from these tables. Also a *PRN-file* is created which consists of:

- A header with considered time step and year.
- Information at the coastline points, like:
    - X, Y coordinates.
    - Distance in cross-shore direction of shoreline from reference line (Y).
    - Coastline change in cross-shore direction since t=0 (Y-Y0).
    - Rate and total volume of local source and sink terms (source).
    - Total volume of sediment stored in a cell due to accretion or erosion (stored).
- Information at the sediment transport points (in-between the coastline points), like:
    - X location along coast of transport point (X=0 is left boundary).
    - Coast angle (alpha).

- Transport rate through each cell (transport).
- Total cumulative transport through each cell (vol. passed).

F.1.4. Other modules

The other modules of the UNIBEST-CL+ model are the TC-module and DE-module. These will be discussed only briefly since these were not used during the project.

TC-module
UNIBEST-TC is a model for Time dependent Cross-shore transport. It can be implemented in the UNIBEST-CL module manually. This creates a quasi-3D-like coastal model. If it is expected that a lot of cross shore transport takes place, it is advised to also use the TC-module.
UNIBEST-TC can be applied on:

- Dynamics of cross-shore profiles.
- Cross-shore development due to seasonal variations of the incident wave field.
- Bar generation.
- To check the stability of beach nourishments and foreshore nourishments.
- To estimate the impact of sand extraction on the cross-shore bottom profile development.

UNIBEST-TC can not be applied to explicitly study the morphodynamic behaviour of the shallow surf zone (depth less than 0.5-1m) and swash zone (Walstra, 2000).

DE-module
UNIBEST-DE is a model for Dune Erosion during storm surges. There are no dunes along the project area, so this module is not necessary.

F.2. Model set-up

Now the model set up is discussed. The wave conditions that were used in the model were simulated using SWAN (Simulating WAves Nearshore). First the SWAN model is discussed after which the UNIBEST model is discussed. This contains the set-up of the LT- and CL-module and the calibration of the model.

F.2.1. SWAN

The input for SWAN consists of wave parameters and bathymetry. Three different sets of wave data have been used. All are listed. The bathymetry used for SWAN first had to be rewritten in a different form. It is explained how this was done.

Wave parameters

BMT ARGOSS (2016)

Two sets of data have been used from BMT ARGOSS (2016) as an input for SWAN (Table F.3 and Table F.4). In chapter 8 more information about the use of these sets is given.

Table F.3 | Wave data (Waveclimate, 2016)

Dir (°)	H_s (m)	T_p (s)	Days	Dir (°)	H_s (m)	T_p (s)	Days
0 (N)	0.25	2.5	0.365	180 (S)	0.25	2.5	4.015
		3.5	0.365			3.5	16.06
	0.75	2.5	0.73			4.5	1.825
		3.5	2.92			5.5	3.65
		4.5	0.365			6.5	0.365
	1.25	3.5	0.73		0.75	2.5	0.73
		4.5	1.095			3.5	4.745
	1.75	4.5	0.365			4.5	0.73
		5.5	0.365	225 (SW)	0.25	2.5	16.06
45 (NE)	0.25	2.5	1.825			3.5	25.55
		3.5	4.745			4.5	2.555
	0.75	2.5	1.46			5.5	0.73
		3.5	12.775		0.75	2.5	2.92
		4.5	5.11			3.5	28.835
		5.5	0.365			4.5	15.33
	1.25	3.5	1.825			5.5	2.555
		4.5	7.3		1.25	3.5	0.73
		5.5	1.46			4.5	6.57
	1.75	4.5	1.095			5.5	2.92
		5.5	1.825		1.75	5.5	1.095
	2.25	5.5	0.365	270 (W)	0.25	2.5	5.475
90 (E)	0.25	2.5	1.46			3.5	5.11
		3.5	10.95		0.75	2.5	2.19
		4.5	2.555			3.5	12.41
		5.5	1.095			4.5	1.825
	0.75	2.5	0.73		1.25	3.5	1.095
		3.5	6.205			4.5	2.92
		4.5	6.935		1.75	4.5	0.365
		5.5	2.92			5.5	0.365
		6.5	0.73	315 (NW)	0.25	2.5	0.365
	1.25	3.5	0.365			3.5	0.365
		4.5	2.19				
		5.5	1.46				
		6.5	0.365				
	1.75	5.5	0.365				
135 (SE)	0.25	2.5	2.555				
		3.5	41.975				
		4.5	19.71				
		5.5	8.395				
		6.5	0.73				
	0.75	2.5	1.095				
		3.5	12.045				
		4.5	8.76				
		5.5	10.585				
		6.5	1.095				

Table F.4 | Monthly averaged wave conditions (Waveclimate, 2016)

Month	Wind direction (degree)	Wind speed (m/s)	Wave direction (degree)	Significant wave height (m)
January	82.5770	4.1075	105.2277	0.5805
February	172.5511	3.936	130.8351	0.53575
March	181.8052	3.866	140.0694	0.4965
April	191.5176	3.7345	154.4072	0.3825
May	232.6904	4.2775	204.8517	0.449
June	247.4821	4.998	225.3422	0.57975
July	251.3411	5.2755	226.5199	0.644
August	254.0706	5.384	229.2171	0.67175
September	257.7741	4.484	220.8094	0.515
October	9.5119	3.69	122.5544	0.43025
November	33.1437	5.051	73.7553	0.71675
December	30.9613	5.4255	67.4714	0.78375

Table F.5 | Buoy data 13

Direction (degrees)	Average H_{sig} in bin (m)	Wind speed (m/s)	Duration (%)	T (s)	Direction (degrees)	Average H_{sig} in bin (m)	Wind speed (m/s)	Duration (%)	T (s)
0.0	0.3	3.5	2.5	3.5	80.0	0.4	2.4	0.9	3.5
0.0	0.7	5.5	2.3	3.5	80.0	0.8	2.8	0.1	3.5
0.0	1.2	8.0	1.0	3.8	100.0	0.3	2.9	1.1	3.5
0.0	1.7	8.6	0.3	4.0	100.0	0.9	0.9	0.1	3.5
20.0	0.3	3.4	2.3	3.5	100.0	2.0	6.1	0.1	4.0
20.0	0.8	5.5	1.7	3.5	120.0	0.3	3.5	2.0	3.5
20.0	1.1	8.4	0.5	3.8	120.0	0.7	1.9	0.2	3.5
20.0	1.6	9.1	0.1	4.0	140.0	0.3	3.7	3.0	3.5
40.0	0.3	3.5	1.5	3.5	140.0	0.7	5.2	0.7	3.5
40.0	0.8	6.1	1.0	3.5	160.0	0.4	4.7	6.7	3.5
40.0	1.2	6.3	0.3	3.8	160.0	0.7	5.7	2.4	3.5
40.0	2.0	7.5	0.1	4.0	160.0	1.2	4.2	0.1	3.8
60.0	0.3	3.3	1.3	3.5	180.0	0.4	4.3	7.0	3.5
60.0	0.8	5.5	0.2	3.5	180.0	0.7	5.6	7.2	3.5
60.0	1.3	8.2	0.1	3.8	180.0	1.1	5.3	0.3	3.8
60.0	1.7	6.1	0.1	4.0					

Bathymetry

MATLAB was used to transform the data set to the proper form. The following script was used to transform the measured depths to certain grid points. This resulted in a grid with a lot of zeros, because there were only few and irregularly placed measurements.

```
clear,clc
%Bathymetry file construction SWAN

%Data van gebied
load 'ALL_POINT_ORGINAL_D_PROMPT.csv'
a=ALL_POINT_ORGINAL_D_PROMPT;
b=a(:,2)<1406250 & a(:,2)>1402750;

nn=length(a);
for n=1:nn
  if b(n)==1
    c(n,:)=a(n,:);
  end
```

```
end
c;
d=([nonzeros(c(:,1)),nonzeros(c(:,2)),nonzeros(c(:,3)),nonzeros(c(:,4))]);

%Restructuring
e=sortrows(d,2);
clear n
clear f

%x coordinaten
BP=1402750;
EP=1406250;
GS=20;
nnn=length(e);
%y coordinaten
YS=min(min(e(:,3)))
GSY=4;
YE=max(max(e(:,3)))

ygridlength=length(YS:GSY:YE);
xgridlength=(length(BP:GS:EP));

AA=zeros(xgridlength,ygridlength);

for SS=BP:GS:EP
   p=(SS-BP)./GS+1;
   for YY=YS:GSY:YE
      r=(YY-YS)./GSY+1;
      for n=1:nnn
         if e(n,2)>SS & e(n,2)<SS+GS & e(n,3)>YY & e(n,3)<YY+GSY
            AA(p,r)=e(n,4);
         elseif AA(p,r)~=0
            AA(p,r)=AA(p,r);
         else
            AA(p,r)=0;
         end
      end
   end
end
AA;
save ('AA','AA')
```

To remove the zeros from the grid, the data was interpolated between the points where measurement data was available. First it was looked if the grid size could be enlarged, but because the measured data was so irregularly placed this did not lead to an improved grid and even to a loss of data. The data was interpolated over the y direction and over the x direction and the final bathymetry file was the average of them both.

```
clear,clc
%manual interpolation
load AA

x=length(AA);
y=length(AA(1,:));
yp=y;
dlmwrite('depths.csv',AA,'delimiter',',')

%estimate depth at final Y coordinate
```

```
for nx=1:x
   if AA(nx,yp)~=0
      BB(nx)=AA(nx,yp);
   end
end
BB( :, ~any(BB,1) ) = [];
for nx=1:x
   AA(nx,yp)=BB(1);
end
AA;

%interpolate over y
for xx=1:x
   for yy=2:y
      nn=y-yy;
      if AA(xx,yy-1)~=0 & AA(xx,yy)==0
         for n=1:nn
            if AA(xx,yy+n)~=0 & AA(xx,yy)==0
              AA(xx,yy)=((AA(xx,yy+n)-AA(xx,yy-1))./(n+1))+AA(xx,yy-1);
            end
         end
      end
   end
end
AA;
CC=AA(1,:);
DD=AA(x-1,:);
AA(x,:)=DD;
Bed=AA;
dlmwrite('bedyinterpol.csv',Bed,'delimiter',',')

%interpolate over x
clear AA
load AA
AA(1,:)=CC;
AA(x,:)=DD;
AA;
for yy=1:y
   for xx=2:x
      nn=x-xx;
      if AA(xx-1,yy)~=0 & AA(xx,yy)==0
         for n=1:nn
            if AA(xx+n,yy)~=0 & AA(xx,yy)==0
              AA(xx,yy)=((AA(xx+n,yy)-AA(xx-1,yy))./(n+1))+AA(xx-1,yy);
            end
         end
      end
   end
end
AA;
dlmwrite('bedxinterpol.csv',AA,'delimiter',',')
%figures
BP=1402750;
EP=1406250;
GS=20;
YS=605050;
GSY=4;
YE=605663;
y=(YS:GSY:YE);
```

```
x=(BP:GS:EP);

figure(1),clf
surf(y,x,Bed)
colormap(jet)

figure(2),clf
surf(y,x,AA)
colormap(jet)

%combine x and y interpolation
Double_interpolation=(AA+Bed)./2;
dlmwrite('bedxandyinterpol.csv',Double_interpolation,'delimiter',',')

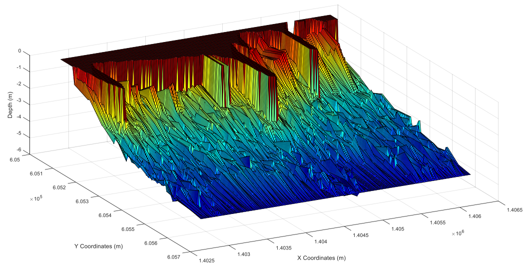
%figures
figure(3),clf(3)
surf(y,x,Double_interpolation)
colormap(jet)

figure(3),clf(3)
surf(y,x,Double_interpolation)
colormap(jet)
```

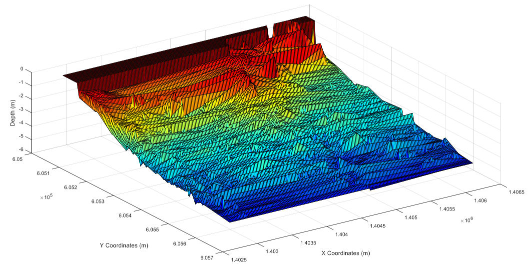
Results

The resulting bathymetry file has also been used to produce figures of the seabed as a means of clarification.

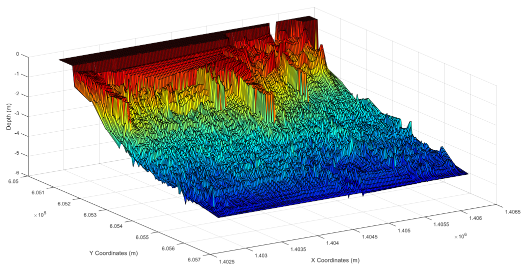
a.



b.



c.



d.

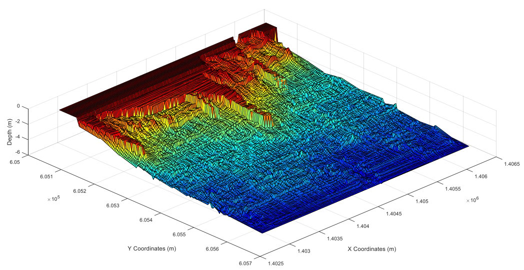


Figure F.6 | Resulting bathymetry. (a) Bathymetry after interpolation over the y-coordinates. (b) Bathymetry after interpolation over the x-coordinates. (c) and (d) Final bathymetry after accounting for both interpolations.

Discussion of the results
The results were checked by looking at the figures created in MATLAB. After the y and x interpolation the results were not extremely satisfying, but after averaging both the results were much better. Most of the strange peaks were taken out. These peaks were formed because interpolation over only one direction could not account for certain gaps in the received data, this lead to invalid results. Using both interpolations smoothed most of these locations out, there are however still some apparent omissions. These mostly occur at locations where groynes, offshore breakwaters and the jetties are present. It is expected that this will not be a problem in SWAN, as these structures will be constructed in SWAN on top of the bottom and thus will be able to remove most faults at these locations.

SWAN file
The SWAN file has been made with the UTM coordinates as reference. The obstacles were identified using the maps as provided by the Marine Department.

```
$> Generated by Swan Professional version 1.2.1.5.
$> 20161110 0448
PROJECT '' '1'
SET  NAUTICAL
MODE TWODIMENSIONAL
CGRID 604042 1375212 0 48160 77280 500 800 SEC 0 180 36 0.05 1.2
INPGRID BOTTOM 604042 1375212 0 602 966 80 80
READINP BOTTOM -1 'Gulf_section.txt' 3 0
WIND .... ...
BOUNDPAR1 SHAPESPEC JONSWAP PEAK
BOUNDPAR2 SIDE .. CONSTANT PAR ... ... ... ....
BOUNDPAR2 SIDE .. CONSTANT PAR ... ... ... ....
GEN3 KOMen
NUM NUM ACCUR npnts=101 STAT 50
FRICtion JON 0.038
OBSTACLE TRANSM 0.0 LINE  607702 1417317 &
  608785 1416809
OBSTACLE TRANSM 0.0 LINE  607660 1417129 &
  608750 1416612
OBSTACLE TRANSM 0.0 LINE  607149.3 1383874.7 &
  606123.4 1384330.6
POINTS 'SWANPRO2'
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  607035.3 1387750.1 &
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PER PDIR
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F.2.2. UNIBEST-CL+

Longshore transport module
Ten sections have been defined. For each section the different input parameters can be differentiated. Each section requires a cross shore profile, transport parameters, wave parameters and a wave scenario consisting of tidal conditions and wave conditions. Per section a coastal orientation needs to be defined as well as an active profile height. This is two or three times the 1/1 year significant wave height (UNIBEST manual). If a longer time period is simulated, the active profile height is larger. Therefore, three times the 1/1 year significant wave height was taken, which resulted in an active profile height of 6.75m.

For the profiles the profile itself needs to be defined. This is defined with combining cross shore distances with depths. The profiles should begin where the wave conditions are determined. For this model the profiles start at a depth of seven meters. The profiles also need to extend landwards.

For the transport parameters a sediment transport formula needs to be chosen. There are several options. In the used model Van Rijn (2004) was used, because this gives the best uncalibrated results (B. Huisman, personal communication, October 19, 2016). The parameters that are necessary for this formula are the D_{10}, D_{50}, D_{90}, D_{SS}, the density of the sediment, the density of the seawater, the porosity, the temperature, the salinity and four calibration parameters.

For the wave parameters two breaking parameters (γ and α) need to be defined. Also a value for the bottom friction (f_W) and bottom roughness (k_b) need to be given. γ can vary between 0.4 and 0.9. α can vary between 0.8 and 1.2. f_W can vary between 0 and 0.2 and k_b can vary between 0.01 and 0.5. The representative wave conditions were determined using SWAN.

No tidal conditions were taken into account. This is physically not entirely correct. No representative data for the tidal conditions were found. Therefore it was not possible to define good tidal conditions. An advantage of leaving out tidal conditions is a large decrease in computation time. It is expected not to have a large effect, because the tidal current is around 0 when averaged over time.

To be able to account for offshore breakwaters and the sheltering effect of groynes, breakwaters and jetties local wave climates need to be defined. They require the same type of input as the normal locations. The main difference is the wave climate retrieved from SWAN. It is also likely the profiles need to be shortened, because the structures are in shallower water.

Coastline module
In the coastline module the coastline change is simulated. In this module the grid is specified as well as the location of the transport rays, the boundary conditions, and several structures, sources and sinks. Several periods can be defined. Per period all these parameters can be changed. In total 10 periods have been defined (Table F.6). The time step can also be defined, in the model this is taken as 500 seconds.

Table F.6 | The periods defined in the CL-module and the files used to schematise the structures and sources in the model

Period	Year from	Year to	Groynes	Sources and sinks	Offshore breakwaters
1	1954	1968	Groyne_0	Source_0	OffshBw_0
2	1968	1975	Groyne_1	Source_0	OffshBw_0
3	1975	1994	Groyne_1	Source_0	OffshBw_0
4	1994	2005	Groyne_1	Source_0	OffshBw_0
5	2005	2007	Groyne_2	Source_0	OffshBw_1
6	2007	2008	Groyne_3	Source_0	OffshBw_2
7	2008	2014	Groyne_3	Source_0	OffshBw_2
8	2014	2015	Groyne_3	Source_1	OffshBw_2
9	2015	2016	Groyne_3	Source_2	OffshBw_2
10	2016	2017	Groyne_3	Source_3	OffshBw_2

Table F.7 | The contents of the files used to schematise the structures

Filename	Corresponding structures and sources
Groyne_0	No structures.
Groyne_1	Breakwater at Cha-am and fish pier at Hua Hin.
Groyne_2	Groynes and Jetty at the Mrigadayavan Palace are added.
Groyne_3	Groyne behind the emerged breakwaters north of the Mrigadayavan Palace are added.
Source_0	No sources.
Source_1	Phase 2 nourishment.
Source_2	Phase 3 nourishment.
Source_3	Phase 4 nourishment.
OffshBw_0	No offshore breakwaters.
OffshBw_1	Submerged offshore breakwaters at the Mrigadayavan Palace.
OffshBw_2	Emerged offshore breakwater north of the Mrigadayavan Palace are added.

The coastline is modelled with a reference line and a support line. The reference line is determined with reference points. Through these points a polynomial line is fitted, this line should follow the main orientation of the coast. The support line, which acts as the coastline, is defined through distances with respect to the reference points. Between the reference points the number of grid points can be defined. The number of grid points have been determined with respect to accuracy. More grid points can make the model unstable, but less grid points also results in less results.

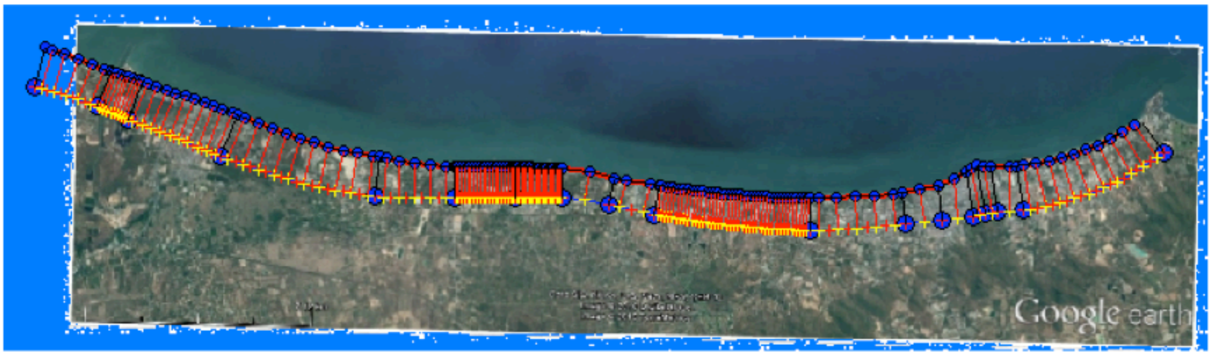

Figure F.7 | The used grid in the CL-module

For every location transport rays are created as output from the LT-module. It is important the rays are projected perpendicular on the coast. The transport rays were defined in the middle of the locations.
There are two boundaries in the model, north and south. Both conditions will be calibrated.

In total thirteen groynes have been defined. The breakwater at Cha-am (1968) has a 100% blocking percentage and a local wave climate. The fish pier at Hua Hin (1968) has a blocking percentage of 0.01% and no local wave climate. The jetties at the palace (2005) have a blocking percentage of 100%, the groynes (2005) have a blocking percentage that will be calibrated. The groyne behind the emerged breakwaters (2007) has a blocking percentage that will be calibrated as well. All these groynes (Figure F.8) have also local wave climates (mainly due to the breakwaters).

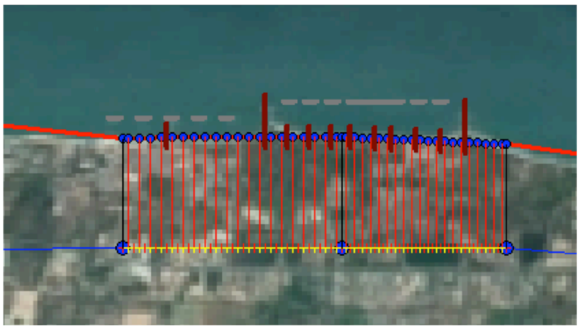

Figure F.8 | Schematisation of the groynes and breakwaters near the Mrigadayavan Palace

Several offshore breakwaters were used in the model. Five submerged breakwaters in front of the palace (2005) and five emerged breakwaters north of that (2007). Per breakwater a local wave ray was used. The dimensions of the breakwaters can be found in chapter 4.

Sources and sinks can be defined along the coastline. In this model 3 sources have been defined to account for the nourishments in the phases two, three and four of the current project (2014, 2015 and 2016).

Calibration: 1954-1975

After the initial model set-up the model has to be calibrated to make sure the model represents the coastline change correctly. First the method of calibration will be discussed after which the results will be presented. The calibration period is 1954-1975, which corresponds to period 1 and 2 in the model (Table F.6).

Method

During the calibration parameters are changed to check which value gives the best representation of the coastline. In this paragraph the general method and the changed parameters are discussed, as well as the data on which the model is calibrated. Lastly, also the tests used to determine the goodness of fit are presented.

The model is calibrated using the Q_s-graph from the output of the CL-module. The Q_s-graph shows the sediment transport in 1000 m^3/year. The calibration data shows where erosion and accretion occurs. Erosion and accretion depend on the gradient of the Q_S-curve. Using the calibration data, a rough sketch of the desirable Q_S-graph can be made. Using this graph, one can determine the desired sediment transports at the different locations. By changing the parameters in the LT-module, the desired transports can be achieved.

The parameters in the LT-module that can be changed are the wave parameters and the transport parameters in the sediment transport formula. It was discovered that the transport parameters had no effect, so these were set on 1 and not changed anymore. The wave parameters were used to achieve the right magnitude of sediment transport.

The breaking parameter γ varies between 0.4 and 0.9. The breaking parameter α varies between 0.8 and 1.2. The bottom friction coefficient f_w varies between 0 and 0.2. The bottom roughness coefficient k_b varies between 0.01 and 0.5. By changing these parameters one can often achieve the desired transport magnitude. There are however bounds to how much the transport can be changed due to the hydrodynamic forcing and the coastal orientation.

The data on which the model is calibrated is retrieved from the SEATEC report (2003)(Figure F.9). The SEATEC report (2003) analysed aerial photographs from 1954 and 1975. They identified several erosion and accretion areas. A point was given on the coastline with a mean accretion/erosion rate. Also the total length of the area was given. This data was related to the grid points of the CL-model.

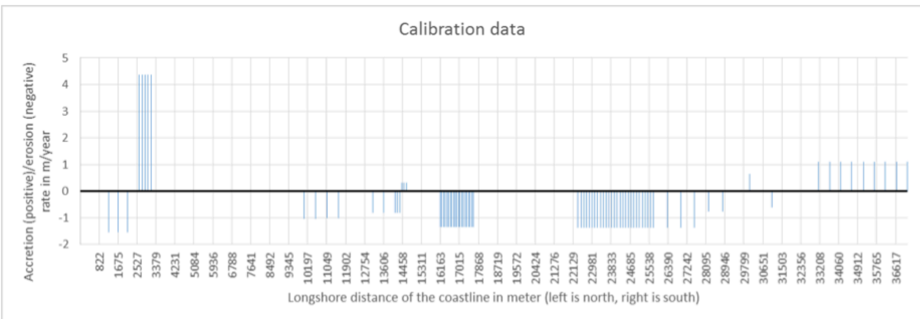

Figure F.9 | Calibration data (SEATEC, 2003)

As can be seen in Figure F.9 the calibration data is rough and long stretches of the coast have 0 erosion/accretion which can be difficult to model. Therefore we assume that this means that it is possible that there is either little accretion or little erosion (smaller than 0.3 meter/year).

The measure to determine the goodness of fit that is used is the correlation between the model results and the data from the SEATEC report (2003). The correlation is given by:

$$\rho_{X,Y} = \frac{cov(X,Y)}{\sigma_X \sigma_Y}$$

Where the covariance is given by:

$$cov(X,Y) = \frac{1}{n}\sum_{i=1}^{n}(x_i - E(X))(y_i - E(Y))$$

The standard deviation by:

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - E(x))^2}$$

And the expected value by:

$$E(x) = \frac{1}{n}\sum_{i=1}^{n} x_i$$

The correlation score is between -1 and 1. Where 1 stands for complete positive dependence (when X is high, Y is high as well), 0 stands for no dependence and -1 stands for complete negative dependence (when X is high, Y is low and vice versa). A value as close as possible to 1 is aimed at.

The correlation does not say something about the magnitude of the transport and thus the magnitude of the error. Therefore also the mean absolute error was determined. The error should be as close to zero as possible.

$$MAE = \frac{1}{n}\sum_{i=1}^{n} ABS(x_i - X_i)$$

The length of the grid cells is not constant. Therefore each grid point is weighted with respect to the length it represents. The mean absolute error, the mean squared error and the correlation, and the judgment of the modeller were used to determine what value performed best.

Results

The calibration resulted in a correlation score of 0.03 and a mean absolute error of 0.84. The values of the parameters that were used can be viewed in Table F.8. The Q_S-graph in 1975 is shown in Figure F.10. The correlation score is too low and therefore means that the model is inadequate. This results are discussed in chapter 8.

Table F.8 | Wave parameters per location

Location	γ	α	f_w	k_b (m)
Location 1a	0.4	0.8	0.06	0.01
Location 1b	0.4	1.2	0.2	0.5
Location 2a	0.9	1.2	0	0.143
Location 2b	0.5	0.8	0	0.0248
Location 3a	0.4	0.8	0.2	0.5
Location 3b	0.9	0.8	0	0.01
Location 4a	0.9	1.2	0	0.033
Location 4b	0.9	1.2	0	0.038
Location 5a	0.9	1.1	0	0.103
Location 5b	0.9	1.2	0	0.03

Table F.9 | The used boundary conditions

BC north	Coastal angle constant
BC south	Coastal angle constant

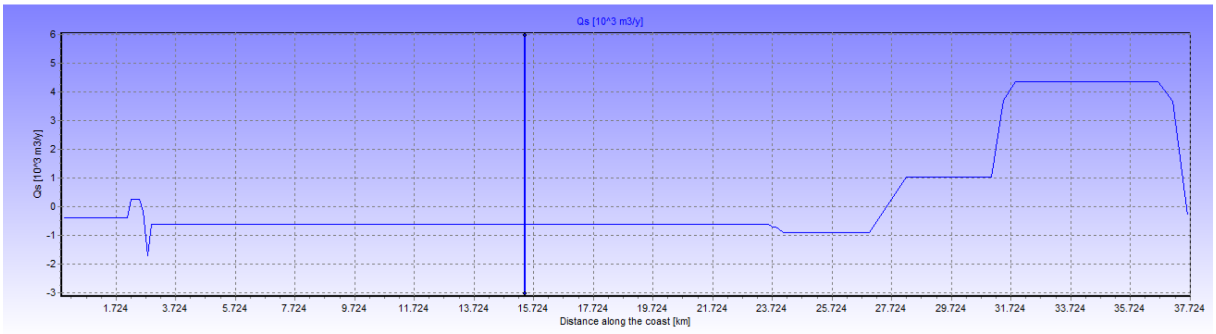

Figure F.10 | Q_S-graph in 1975

F.3. Comparing GENESIS and UNIBEST

There are several programs available to model shoreline change. These models range from 1D to full 3D. It depends on the amount of resources (time, computational power and money) and the requested level of detail what kind of model is used. In this project the model UNIBEST is used. In Thailand there is however a lot of experience with GENESIS. Therefore a comparison between these two models is given here.
Szmytkiewicz, Biegowski, Kaczmarek, Okrój, Ostrowski, Pruszak, Różyńsky & Skaja (2000) did a research in which they compared several programs for a test case in Poland (near the Hel peninsula). Both GENESIS and UNIBEST had satisfactory results, but other aspects in modelling were found to be important as well. Among others, the degrees of freedom for the modeller, the option for the engineer to use his engineering intuition and his knowledge of the local coast and the underlying physical processes. These degrees of freedom are important to have to get to the right results, they should however not be too large to prevent the model from interfering with the scientific basis. Another important aspect is the computation time and effort. When taking into account all these aspects Szmytkiewicz et al. (2000) concluded that UNIBEST was the better choice. This is because UNIBEST 'offers a bit more reasonable compromise between accuracy of physical description and the user's engineering intuition'.

F.3.1. GENESIS

GENESIS (GENEralized model for SImulating Shoreline change) is a model developed by the Department of the Army (Vicksburg, MS, USA) and the Department of Water Resources Engineering (Lund, Sweden) to simulate long-term shoreline change. The usual spatial scale is 1 to 100km long and the usual time range is 1 to 100 months. This is however not a strict limit, so it could also be used for longer coastlines and longer time periods.

GENESIS uses so called wave energy windows, areas that are open to incident waves. These areas are separated from each other by hard structures. Wave transformation computations are used to calculate the breaking wave parameters that are used in the next stages of the process.

The sediment transport equation that is used is an empirical CERC-type equation. This equation consists of two parts: the first term is of the same type as the standard CERC formula, and the second term is used to determine the contribution from the longshore gradient in breaking wave height. Sand can be transported past a structure by bypassing and transmission. The single-line theory of Pelnard-Considère is used as a basis to calculate the shoreline change.

GENESIS is less flexible in the calibration, because only a few parameters can be modified. These include two calibration coefficients, and characteristics of the structures as their permeability, their length and the water depth at their tips. The limited amount of parameters that can also be modified can be seen as an advantage, because less data is necessary to run the model. One of the major disadvantages of GENESIS is that it is not updated anymore.

F.3.2. UNIBEST

UNIBEST is a model that is developed at Delft Hydraulics (now part of Deltares) and consists of several packages. For this project the longshore transport package (UNIBEST-LT) and the coastline evolution package (UNIBEST-CL) were used. The LT-module needs only one cross-shore profile that characterizes the whole coast line, but it is possible to have more. This means that it is not necessary to have very detailed bathymetry. It is possible to use 8 different theoretical equations to calculate the longshore sediment transport. Several angles of wave incidence are used to determine the transport rate. It is possible to alter the longshore transport by so called user tables. These tables enable the user to model processes that are not incorporated in the basic model. The UNIBEST-CL module uses these transport rates to determine the evolution of the coastline. UNIBEST like GENESIS uses the single-line theory.

Because it is possible to modify transport rates with the so called user tables it is possible to get a well calibrated model. These user tables increase the flexibility of UNIBEST. This is also a disadvantage, because when UNIBEST is not used properly, the results can be incorrect to even physically impossible.

F.3.3. Main differences

Szmytkiewics et al. (2000) summarized the main differences between the two programs (Table F.10).

Bathymetry
The first main difference is the necessity of data of the 2D bathymetry. UNIBEST only needs one representative profile (but more can be added). GENESIS does not need detailed data for the simplified run, but for the full run this is necessary. This means that more bathymetry data is needed for GENESIS. Both models do not take the variability of the seabed properties into account.

Waves
Both models use the significant wave height as the wave input parameter. Wave chronology is important for GENESIS, while UNIBEST does not take this into account. The wave transformation is done with the Battjes-Janssen model in UNIBEST. GENESIS uses the "mild slope" equation in the full run. The Battjes-Janssen model computes the surf zone dynamics. This is done by a random wave propagation and decay model. Deep water wave data is transformed while taking wave energy changes due to bottom refraction, shoals and dissipation by bottom friction and wave breaking into account.

GENESIS takes diffraction around structures into account, while UNIBEST does not. This can be solved by using SWAN (Simulating WAves Nearshore) to adapt the wave rays. GENESIS does not take the longshore current into account. UNIBEST uses a Longuet-Higgins type of longshore current.

Sediment transport
GENESIS uses an empirical CERC-type formula. The CERC-formula can only be used for long and straight beaches, otherwise it is not valid. UNIBEST has 8 possibilities: Bijker (1967, 1971), Van Rijn (1992), Van Rijn (1993), Van Rijn (2004), Soulsby/Van Rijn, Kamphuis (2000), CERC and Van der Meer-Pilarczyk. These formulas make UNIBEST more flexible and a better choice can be made to accurately describe the sediment transport.

Human interventions
Beach nourishments, groins, jetties, seawalls and revetments are taken into account by both models. Offshore breakwaters are not directly taken into account by UNIBEST. It is however possible to use SWAN to adapt the wave rays to take the breakwaters into account. GENESIS takes these offshore breakwaters directly into account.

Table F.10 | Features from GENESIS and UNIBEST (Szmytkiewics et al., 2000)

Feature	GENESIS	UNIBEST
2-D Bathymetry	Necessary in full run; not used in simplified run	Required only for determination of representative profile
Variability of seabed properties	Not taken into account	Not taken into account
Wave input parameters	Significant	Significant
Wave chronology	Taken into account	Not taken into account
Wave transformation	"mild slope" equation – type in full run; linear refraction/shoaling in simplified run	Battjes-Janssen
Diffraction around structures	Taken into account	Not directly taken into account
Longshore current	Not modelled	Longuet-Higgins type
Longshore sediment transport	CERC-type formula	Bijker, Van Rijn (1992, 1993, 2004), Soulsby/Van Rijn, Kamphuis, CERC, Van der Meer-Pilarczyk
Beach nourishment	Taken into account	Taken into account
Groins, jetties	Taken into account	Taken into account
Offshore breakwaters	Taken into account	Not directly taken into account
Seawalls, revetments	Taken into account	Taken into account

G. Scenarios

G.1. Eliminated solutions

In this appendix the solutions that have been eliminated based on their technical and economic feasibility are discussed for completeness of the alternatives. These solutions have also been used as possible solutions in the interviews.

Mangroves/Saltmarsh
It has been considered to protect with nature as this can provides a durable solution to the problem. There were however a lot of problems with this idea for the project site. The beach needs to be accessible for fishermen and tourists. The beach is too steep for mangroves and saltmarshes so either large nourishment has to be executed or the coastline has to be moved farther inward. The first would be very expensive and the second is simply impossible because of the large amount of houses and buildings close to the shoreline.

Beach park
Constructing a new shoreline a little off the coast with coast angles, which would lead to zero longshore transport was considered as an option. It would be very attractive for tourism and could provide a durable solution. Such a thing has been constructed successfully in Denmark. At this location it is however difficult to realise because the wave angles differ significantly over the year, thus it would not lead to zero transport under all conditions. Also the costs would be very high, as it is a very big nourishment.

Hotels and facilities as breakwaters
An idea to integrate tourism and shore protection was to build hotels and other facilities offshore which would serve as offshore breakwaters, behind which would be a beach and smooth water. This could maybe be a partial solution, but far too expensive to apply everywhere along the project site. Therefore we have incorporated this idea in a possible opportunity for offshore breakwaters.

Boulevard
Constructing a seawall along the coastline with a boulevard behind it would be one way of solving the erosion problem. The seawall would however have to be supported strongly and would be very expensive. Furthermore the area is very important for tourism, for which a beach is wanted. Because of these issues this solution has been discarded.

Gradual reclamation
Gradual land reclamation has also been considered. This idea was inspired by efforts by Dutch communities in the Waddenzee area, which have reclaimed land at low water by building new dikes in that timeframe. This is however not very well possible here since the slope of the beach is much steeper, which would cause the dikes which would have to be build to become very high and the seabed will not become dry at low water over significant lengths into sea.

G.2. Description of remaining solutions

This appendix will describe the remaining feasible solutions regarding both soft and hard measures.

Soft measures

The main reason for the Marine Department to initiate this research was the alarmingly high erosion rate of the current projects. The Marine Department specifically asked for calculations on beach nourishments for the research, which is a soft measure. The reason for the Marine Department to ask for these calculations on soft measures can be found in the fact that the NGOs are putting a lot of pressure on the Marine Department to make use of soft measures in new projects. When performing sand nourishment, a certain volume of sand is added to the existing coastal profile. The result of this measure is that the coastline will be moved seaward. However, this has no effect on the erosion rate. Usually, the nourished sand is of the same size and grading as the native sand and can be obtained from either sand mines onshore or offshore. The on-going investigation into offshore sand deposits might provide the project with more abundant and cheaper sand than is currently offered by the land based sand deposit.

Four different types of nourishments can be carried out, namely beach nourishment, shoreface nourishment, a sand engine, and coarse nourishment. Currently, beach nourishments are being executed because of the tourism desire to have wide beaches. However, the relative lower costs of shoreface nourishment, makes shoreface nourishment a viable alternative. Beach nourishments can be constructed by either floating equipment (e.g. rainbowing) or land based equipment (e.g. trucks). The shoreface nourishment can only be constructed by floating equipment and the mega nourishment can also only viably be constructed using floating equipment. Mega nourishment can basically be described as a very large nourishment in which the natural longshore transport capacity redistributes the sand along the coast. This solution involves very high initial costs, however the costs in later years will be almost zero for a longer time span. More information on nourishments can be found in Appendix E. Another possible solution is to nourish with a more coarse material. In this case, the sediment will be picked up less quickly compared to a more refined material, which will lead to more stable nourished beaches. Also, the new beach profile could be a lot steeper, due to the larger angle of friction of the material, meaning less material is needed. The sediment can range from coarse sand to small gravel, though gravel might not be desirable at the project location. For example, fishermen need to drag their boats on land and gravel will contribute to more resistance than coarse sand. Also, the desires of the tourists need to be determined, as the project area is a tourist destination as well. The construction method for this kind of nourishment is the same as for the sand nourishments

Hard measures

In the current situation hard measures have been applied and the constructed groynes and offshore breakwaters have been successful so far. It is possible to extend these structures along the whole coastline of the project area, as this area is a virtually closed system and no major effects would occur in other areas. The successfully completed projects also have an additional benefit for the local population; the offshore breakwaters provide fishermen with a sheltering and docking area for their boats. The submerged offshore breakwaters in front of the Mrigadayavan palace have also been successful and might offer a good solution to other areas along the coast where the aesthetics of the beach are also very important. The purpose of groynes is to (partially) stop the longshore sediment transport, whereas the purpose of (submerged) offshore breakwaters is to dissipate wave energy, which results in less sediment transport. Both hard structures consist of a core, a filter layer (a geotextile or small rocks) and an armour layer (large rocks). Also, it might be necessary to construct bed and/or toe protection when erosion around the breakwater would occur. Both land based and floating equipment can be used, though floating equipment is usually a more logical choice for the offshore breakwaters. The length over offshore distance is a very important ratio for an offshore breakwater. The ratio for the current offshore breakwaters is approximately 0.65. A larger ratio will lead to the formation of tombolos and a smaller ratio will lead to less accretion. However, a smaller ratio is not advised, because the current salient formation is already quite small. Another important ratio is the gap length over the offshore distance. In the current structure this is approximately 0.7, which should lead to no gap erosion at all. Furthermore, the submerged offshore breakwaters should not have a crest height lower than 0.5m below MSL to be effective (van Rijn, 2013).

G.3. SWOT analysis

In this appendix, the SWOT analysis can be found with an explanation regarding the strengths, weaknesses, opportunities, and threats of the (combined) solutions.

A note for the SWOT analysis: The Marine Department indicated that performing an environmental impact analysis is a difficult process in Thailand and is therefore an important consideration for which structures to build. The fact that not all measures require an environmental impact assessment (EIA), i.e. nourishments, has not been incorporated as a plus for that specific construction. It is strongly recommended to perform these assessments for every construction that is to be built along the coast. Performing nourishment can also have a significant environmental impact; especially when it is not investigated beforehand and mitigating measures are not taken.

Groynes and offshore breakwaters

The solution of groynes and offshore breakwaters is designed to maximally hold the sediment in place in order to reduce the need for nourishments. Nourishments will also be executed as part of this plan; this should be done whenever groynes and offshore breakwaters are constructed (Van Rijn, 2010).

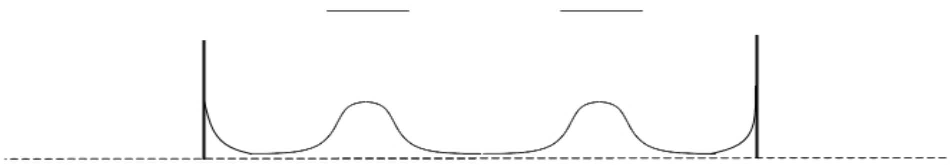

Figure G.1 | Coastline change due to the construction of groynes and offshore breakwaters. Dotted lines: initial shoreline; black curved lines: new shoreline; black straight

Strengths

The combination of groynes and offshore breakwaters is designed to maximally hold the sediment in place in order to reduce the need for nourishments. Nourishment will also be executed as part of this plan; according to Van Rijn (2013) this should be done whenever groynes and offshore breakwaters are constructed. Also, this combination of hard structures has already been executed in the project area and by most of the stakeholders perceived as successful.

Weaknesses

Downstream of locations where these hard structures are built erosion is expected, because the transported sediment of the stretch of coast on which this is constructed will become much less. Moreover, offshore breakwaters are more expensive than other hard solutions, mainly because floating equipment has to be used for construction or unwieldy measures have to be taken to reach the offshore breakwaters with land based equipment. Also, the realisation of such a confined beach area hinders waterborne activities for tourists. Furthermore, the coastline variability (the accretion at one point and erosion at another, within the construction site) can lead to coastline retreat where this is not acceptable. Lastly, multiple stakeholders are opposing hard structures for different reasons. Main reasons are the aesthetics of the measures, which are perceived as an important aspect by the Royal Family (especially taken into account the Klai Kangwon Palace in Hua Hin) and tourists, and the preference of soft structures by NGOs and the Marine Department.

Opportunities

The beach can easily be maintained wider after the construction of the hard structures; this will be good for tourism. Also the coastline variability leads to a longer coastline for tourists to use. Another aspect that might be possible is to let investors build on the offshore breakwaters, for example condos or hotels, this would be expensive but the idea is that the investor pays for it and then also for the breakwater reducing construction and maintenance costs for the Marine Department. Also, the offshore breakwaters may serve as a shelter/docking spot for fishermen, similarly to the fishing pier in Cha-am.

Threats
Around groynes rip currents can be generated, this is dangerous for swimmers and thus harmful for tourism. The reduced water flow due to the structures can lead to water quality problems, which would be extremely harmful to tourism. Also tourists can perceive the hard structures as ugly. Moreover, offshore breakwaters can have some to severe gap erosion; it has to be constructed with the right gap length over the offshore distance ratio to prevent this.

Table G.1 | SWOT groynes and offshore breakwaters

Strengths	**Weaknesses**
Strongly reduces longshore transport	Coastline variability
Perceived as successful	Downstream erosion
	Expensive
	Limited space for water activities
	Not supported by the royal family
	Opposition from NGOs
	Blocks sea view
Opportunities	**Threats**
Broader beaches	Generation of rip currents
Construction opportunities on the breakwaters	Tourists perceive it as ugly
Longer coastline for tourists	Water quality problems
Serve as a shelter/docking spot for fishermen	Gap erosion

T-groynes
T-groynes are very similar to offshore breakwaters and groynes combined. A T-groyne is basically a groyne with an offshore breakwater at its tip. Nourishments also have to be performed. Because of this similarity, only the differences in strengths, weaknesses, opportunities and threats will be discussed.

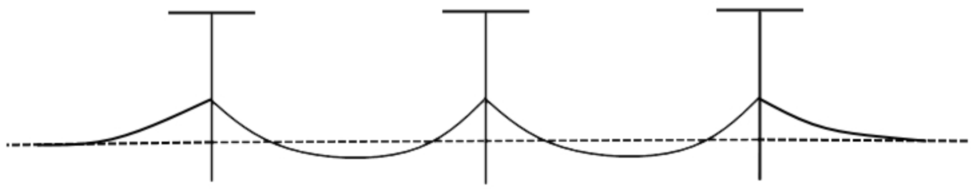

Figure G.2 | Coastline change due to the construction of T-groynes. Dotted line: initial shoreline; black curved line: new shoreline; black straight lines: structures.

Strengths
The biggest difference between T-groynes and a combination of groynes and offshore breakwaters is that the construction of T-groynes is cheaper.

Weaknesses
The weaknesses are all the same as with the combination of groynes and offshore breakwaters, expect for the fact that the T-groynes are less expensive.

Opportunities
The opportunities are the same as with the combination of groynes and offshore breakwaters. In addition, the T-groynes can provide access to the fishing boats that dock their boats at the tip of the groynes.

Threats
The threats are almost the same as with the combination of groynes and offshore breakwaters, however the water quality problems can be more severe in case of T-groynes, due to even more reduction in water circulation. In addition, the wave reflection on the groyne tip can undermine the groyne, resulting in additional measures that have to be taken to prevent this.

Table G.2 | SWOT T-groynes

Strengths	Weaknesses
Strongly reduces longshore transport Cheaper than groynes and offshore breakwaters Perceived as successful	Coastline variability Downstream erosion Limited space for water activities Not supported by the royal family Opposition from NGOs Blocks sea view
Opportunities	**Threats**
Broader beaches Construction opportunities on the T-groynes Serve as a shelter/docking spot for fishermen Provide access to fishing boats	Generation of rip currents Tourists perceive it as ugly More severe water quality problems Gap erosion Wave reflection at groynes tips

Groynes

Constructing groynes only is also an option; this also has to be combined with nourishments. This will be cheaper than the first and second solution; it is however expected to be less effective at stopping sediment transport. Many of the drawbacks, opportunities and threats have already been discussed for the other solutions. Therefore only the differences will be discussed.

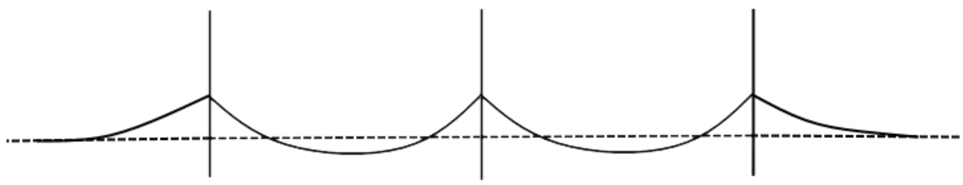

Figure G.3 | Coastline change due to the construction of groynes. Dotted line: initial shoreline; black curved lines: new shoreline; black straight lines: structures.

Strengths

In contrast to both the combination of groynes and offshore breakwaters and T-groynes, the groynes do not block the sea view, as they are only constructed perpendicular to the beaches. This is also the reason that this solution is supported by the Royal Family. As the Klai Kangwon Palace in Hua Hin is also situated in our project area, the interest of the Royal Family are important at that specific location, as they are setting the boundaries at that location.

Weaknesses

The weaknesses are similar to both solutions, except for the two aspects that have been mentioned above, being blocking sea view and opposition of the Royal Family.

Opportunities

The opportunities differ a bit, seeing as groynes only do not provide any possibility to construct on it. Also, only the tip of a groyne can serve as a shelter/docking spot for fishermen. Seeing as a single groynes is perpendicular to the beach, no sheltering or docking is possible. However, the fact that the groynes are perpendicular to the beach does provide more space for waterborne activities and might improve tourism.

Threats

The only threats that might occur are generation of rip currents and the fact that tourists may perceive the groynes as ugly.

Table G.3 | SWOT groynes

Strengths	Weaknesses
Strongly reduces longshore transport Perceived as successful Broad sea view Supported by the royal family	Coastline variability Downstream erosion Limited space for water activities Not preferred by the Marine Department Opposition from NGOs

Opportunities	Threats
Broader beaches	Generation of rip currents
Space for water activities (tourism)	Tourists perceive it as ugly

Beach nourishments
Applying direct beach nourishment, as is currently done, directly leads to a broader beach. It is a soft solution and thus more natural than constructing hard structures. More sand is put into the system so at other locations the erosion can also be alleviated, instead of the lee erosion, which occurs with hard structures.

Strengths
Applying direct beach nourishment, as is currently done, directly leads to broader beaches. It is a soft solution and thus more natural than constructing hard structures. More sand is put into the system so at other locations the erosion can also be alleviated, instead of the lee erosion, which occurs with hard structures. It is also much more flexible than hard solutions. When it does not work satisfactory anymore, new nourishment can be easily performed again, whereas hard structures cannot be easily modified after construction. Moreover, all stakeholders stated to prefer soft measures, meaning that stakeholders such as NGOs will not oppose to the solution.

Weaknesses
The longshore and cross shore transport are not reduced, when there is a large erosion rate a lot of sand has to be nourished. Also a large initial cross-shore redistribution can be expected, up to 40% of the nourished sand will be redistributed reducing the beach width again. It is also more expensive per cubic meter than shoreface nourishments, thus it is a less effective way of bringing sand into the system. The lifetime of nourishments is generally much shorter than the lifetime of hard structures; this depends on the design, but is often in the range of 5 years. The fact that beach nourishments need a lot of maintenance, causes more hindrance for tourists, however this might be executed during low tourist season.

Opportunities
The broader beaches give opportunities to improve tourism and because no structures are built there is ample of room for waterborne activities and other facilities while keeping natural appearance. Moreover, beach nourishment can be carried out by getting sand from land and may be also from offshore in the future, seeing as investigation into offshore sand deposits is in progress.

Threats
The possibility for offshore sandpits does bring some threats. For example, it is highly likely that international companies need to be involved, as Thailand does not own their own dredgers. By involving international companies, the construction will become much more expensive. Another important threat is that the amount of sediment from land based and offshore sources is very limited; this can however due to the aforementioned investigation into offshore sand deposits. Another threat is that the beaches might become too crowded as the broad beaches and activities attract more tourists.

Table G.4 | SWOT beach nourishment

Strengths	Weaknesses
Natural (looking)	Longshore and cross shore transport not reduced
Broader beaches	A large initial cross shore redistribution
More sand into the system	More expensive than shoreface nourishment
More flexible than hard structures	Limited lifetime
Preferred by all stakeholders	Hindrance for tourists
No opposition from NGOs	Negative impact on ecology
No lee side erosion	
Opportunities	**Threats**
Broader beaches	Limited sediment supply
Space for water activities (tourism)	Overcrowded beaches
Investigation into offshore sand deposits (in progress)	Possibly international company involvement (expensive)
More facilities on the beach	

Shore face and beach nourishments
Shoreface nourishment alone has been disregarded as an option, since only a small amount of sediment makes it to the beach. However, a combination of both shoreface and beach nourishments is also possible.

Strengths
Combining shoreface and beach nourishments can make the beach nourishment more effective by reducing the amount of cross-shore redistribution. Because this solution reduces the cross-shore redistribution of the beach nourishment, which is more expensive per cubic meter of sand, this could be a viable option. The shoreface nourishment also reduces longshore transport, because it acts as a shoal reducing the wave attack.

Weaknesses
Drawbacks are that the cross-shore transport is not reduced and most importantly a lot more sediment will have to be nourished. The weaknesses of limited lifetime and hindrance for tourists remain in this solution. Also, adding an extra layer of sand may have a negative impact on the ecology.

Opportunities
The opportunities stay the same as without shoreface nourishments. However, if nearby offshore sand deposits are found, then shoreface becomes much more attractive.

Threats
The threats are the same as with beach nourishments only. However, the chance of having to involve an international company is much bigger with shoreface nourishment as this is can only be done with floating equipment/dredgers.

Table G.5 | SWOT shoreface and beach nourishment

Strengths	**Weaknesses**
More natural looking and flexible Broader beaches Smaller cross shore losses of the beach nourishment Shoreface nourished part is cheaper Reduces longshore transport Preferred by all stakeholders No opposition from NGOs Sand transport towards the beach	Cross shore transport not reduced More sediment has to be nourished Returning hindrance for tourists Negative impact on ecology
Opportunities	**Threats**
Broader beaches Space for water activities (tourism) Investigation into offshore sand deposits (in progress) More facilities on the beach	Limited sediment supply Overcrowded beaches Possibly international company involvement (expensive)

Mega nourishment
Another nourishment option is to perform mega nourishment. A large amount of sediment is placed at one location, forming a large artificial salient, which is allowed to erode and the eroded sediment is then distributed along the coast stopping erosion elsewhere.

Strengths
An advantage of a mega nourishment is that performing one big nourishment is more economical than performing several smaller ones due to the mobilisation costs only having to be paid once. The lifespan depends on the amount of nourished sand, but the lifespan of this solution can be around 20 years (Rijkswaterstaat, 2016) Moreover, this solution is preferred by hotels/resorts and local businesses, due to the fact that this may provide them with expansion of their services (Rijkswaterstaat, 2016).

Weaknesses
However, there are high initial costs compared to normal nourishments. An important weakness is that an international company has to be involved leading to relatively high costs, this is because of the need for

advanced dredging equipment and expertise on how to successfully design a mega nourishment. Also, adding an extra layer of sand may have a negative impact on the ecology.

Opportunities
The opportunities are also broader beaches and space for waterborne activities regarding tourism, just as the previous two solutions. In addition, ecological value could be added from the artificial island, if designed right it could become a habitat for species. Moreover, this solution may become iconic to the area, as this is a high tech solution. Also on the mega nourishment there will be a lot of space for temporary touristic activities.

Threats
The threat of limited sediment supply also exists in this solution. Moreover, a NPV (Net Present Value) analysis could have a negative result compared to normal nourishment, also depending on the discount rate due to the large initial investment.

Table G.6 | SWOT mega nourishment

Strengths	**Weaknesses**
More natural looking than a hard solution	Longshore and cross shore transport not reduced
Broader beaches	Large initial cross shore losses, might be perceived as a failure
More sand into the system, downstream accretion	Large initial investment
More economical over lifespan than separate nourishments	International company involvement
	Negative impact on ecology
Preferred by hotels/resorts and local businesses	
Opportunities	**Threats**
Broader beaches	Limited sediment supply
Space for water activities (tourism)	NPV analysis might conclude it is expensive due to large initial investment
Ecology improvement/expansion	
May become iconic for the area	
Temporary space for tourist activities	

Coarse nourishment
This entails nourishing with coarser sand than the sand that is currently in the system.

Strengths
Nourishing with coarser sand than the sand, which is currently in the system can reduce the transport rates and thus make a nourishment last longer and make it more economical. The natural cross-shore profile of this larger sediment will be steeper and thus less cross-shore distribution has to take place. This will result in less sediment that has to be nourished.

Weaknesses
Drawback is that this new steeper coastline will mean than tourists can go less far offshore before it gets too deep. It is also an unnatural addition to this coastal system and the ecology. Also, tourists do not prefer this solution as they mostly prefer fine sand. Also, adding an extra layer of sand may have a negative impact on the ecology.

Opportunities
Apart from the existence of broader beaches and waterborne activities, another opportunity is that this solution can be combined with groynes. Groynes are more cost effective for larger grain sizes because they can be made shorter. This would make a combination cheaper.

Threats
The sediment supply will probably be even more limited and nourished sediment might be expensive. Nourishing with larger grain sizes could have large environmental consequences and this would first have to be thoroughly researched. The steeper profile will also lead to more severe wave action near the shore, with possible negative influences on the sediment transport there and tourism. When the new sediment is gravel this could lead to a lot of other issues with the beach use, for example for a decrease in tourists, as they prefer fine sand beaches.

Table G.7 | SWOT coarse nourishment

Strengths	**Weaknesses**
Natural looking Broader beaches Less cross shore and longshore transport Steeper cross shore profile, thus less sediment	Unnatural for the ecology Steeper profile, tourists can go less far offshore Not preferred by tourists
Opportunities	**Threats**
Broader beaches Space for water activities (tourism) Groynes are more effective for coarser sediment	Even more limited sediment supply Environmental consequences Increased wave action due to steeper profile Decrease of tourists

Results SWOT analysis

The following alternatives have been discarded on the basis of the SWOT analysis:

- Shoreface and beach nourishment: In the future this might be a good alternative, but currently there are still solutions, which will be more cost effective. Because a lot of sand could be nourished cheaply the shoreface nourishment would be a good solution, however because an international company would have to be involved (there is a need for a large dredger) it becomes far less attractive. These companies have to be paid in dollars which would be relatively expensive for the Marine Department and instead of indirectly investing money in the local economy through the construction companies, money is lost to foreign countries. Currently an investigation into offshore sand deposits is underway, if large deposits were to be found shoreface nourishment would become much more viable. Especially if in the future Thai construction companies would be able to invest in own dredging equipment due to sustained growth of the Thai economy.
- Mega nourishment: For the execution of a mega nourishment an international company will have to be involved, to deliver the necessary expertise and large dredgers. Since the mega nourishment already requires a very big initial expense, the involvement of international companies makes it even more expensive. With continuing economic growth the execution of such projects will become relatively less expensive for the government, therefore it is thought that Net Present Value wise it would be better not to make such a big investment now, which could also be spread out over the years.
- Groynes and offshore breakwaters: This solution is very similar to T-groynes, but T-groynes will be far cheaper to construct especially in Thailand where floating equipment is relatively expensive. Due to the costs, we will continue with the T-groynes solution and not with the groynes and offshore breakwaters solution. T-groynes could also have an additional opportunity as currently a structure very similar to a T-groyne is being used by fishermen as a docking space. Additional research would be needed into the water quality for the T-groynes but this would have been necessary for the groynes and offshore breakwaters solution.

H. Assessment of alternatives

H.1. Riskmanagement

Parts of the risk management setup (initiation), which are included in this research project are:

- **Methodology** – Defining the approaches, tools and data sources that will be used to perform the risk management
- **Risk Categories** – Providing a structure to ensure a comprehensive process of systematically identifying the risks, such as a risk breakdown structure
- **Risk Probability and Impact** – Determining the scales of risk probability and risk impact
- **Risk Prioritisation** – Prioritising risks using a probability and impact matrix

These parts are elaborated in the following paragraphs.

Risk Management Setup - Methodology

As mentioned before, the following PMI risk management processes are used in this project to define a risk management plan:

1. **Plan risk management** – define how to conduct risk management activities for a project.
2. **Identify the risks** – determine which risks affect the project and document their characteristics.
3. **Perform qualitative risk analysis** – prioritise the identified risks by assessing and combining their probability, occurrence and impact.
4. **Plan risk responses** – develop options and actions to enhance opportunities and reduce threats

To be able to perform the steps of the risk management processes, the following inputs are used:

- Risk Management setup (set up in this chapter)
- Stakeholder analyses (to be found in chapter 5)
- Team members' expertise

The output of the assessment were comprehensive risk registers for each solution with risks specific to those solutions and a general risk register with risks occurring in each solution. Each risk will be elaborated in the register with the responses and the assessments. At last, conclusions were made for each solution with its included risk assessment.

Risk Management Setup - Risk categories

A risk breakdown structure (RBS) is used to determine the risk areas relevant to the project and to provide a structure to systematically identify the category of the risk. This will add to the effectiveness and quality of the risks identification process as it can be used as a constant reminder of the many sources from which risks may arise and the certain level of detail to which the risks can be identified (PMI, 2008). As can be seen in Figure, the risks of the project are divided into 4 categories, being technical, project management, external and internal. These are the four categories in which all the risks can be classified to. All the technical risks, related to the design and physical aspects can be divided in the technical category, while all the risks related to planning, budgeting and other management aspects can be categorized in the project management category. The internal category is for other risks in the project, which cannot be categorized under the technical nor the project management categories. Finally, all the extrinsic risks are listed under external.

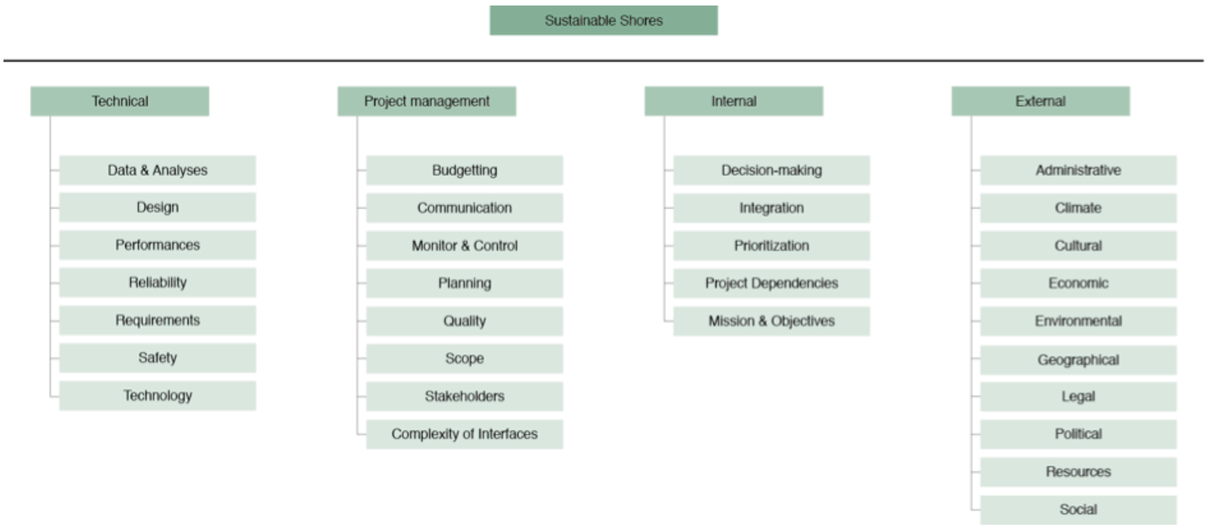

Figure H.1 | Risk Breakdown Structure of the Sustainable Shores project (own ill.)

Risk Management Setup - Risk probability and impact

Before the risk register can be established, the scales of risk probability and impact need to be defined to provide a consistent base for assessment. Risk probability is the likelihood that the risk will actually materialise, while risk impact is the effect the materialisation of the risk will have on various aspects of the project and the context. The impact definition can be done for negative as well as positive impacts. Both the risk probability and the risk impact can be expressed as qualitative and quantitative values. The definition of risk probability can be found in Table H.1. The scale consists of five levels to ensure a sufficient level of detail for the first risk assessment of the project.

Table H.1 | Definition of risk probability scale

Level	Description	Likelihood of occurrence
5 0.90	Expected	There is a certainty that the situation will occur at least once during the lifecycle of the solution.
4 0.70	High	Event has a high probability of occurring during the solution's lifecycle.
3 0.50	Moderate	The event is likely to occur sometime in the lifetime of the project.
2 0.30	Low	Situation is unlikely to occur, though the possibility exists that it might occur once in the lifecycle.
1 0.10	Unlikely	Event has such a low probability that it is not anticipated to occur during the whole lifetime of the solution.

The definitions of the risk impact scales for negative event and positive events can respectively be found in Table H.2 and Table H.3. The scales of the risk impact also consist of 5 levels to ensure a sufficient level of detail for the first risk assessment. However, there are four project objectives included in the tables, namely sustainability, quality, cost and time. These aspects are of high value to the project team as well as the client, thus risks impacts on these should be taken into consideration to determine each risk impact level. It should be noted however that the cost and time estimations made for this risk assessment are of little value, since there was not sufficient research to make proper estimations.

Table H.2 | Definition of risk impact scale for negative events

Level	Description	Sustainability	Quality	Cost	Time
5 0.80	Very high	Alternative is not sustainable	Alternative is effectively useless	>40% cost increase	>20% time increase
4 0.40	High	Sustainability reduction is unacceptable to the client	Quality reduction is unacceptable	20-40% cost increase	10-20% time increase
3 0.20	Moderate	Sustainability reduction requires client's approval	Quality reduction requires client's approval	10-20% cost increase	5-10% time increase
2 0.10	Low	Only very demanding features are affected	Only very demanding features are affected	<10% cost increase	<5% time increase
1 0.05	Very low	Sustainability reduction is barely noticeable	Quality degradation is barely noticeable	Insignificant cost increase	Insignificant time increase

Table H.3 | Definition of risk impact scale for positive events

Level	Description	Sustainability	Quality	Cost	Time
5 0.80	Very high	Alternative is exceptionally sustainable	Alternative is of excellent quality	>40% cost decrease	>20% time decrease
4 0.40	High	Sustainability improvement is very noticeable to the client	Quality improvement is very noticeable to the client	20-40% cost decrease	10-20% time decrease
3 0.20	Moderate	Sustainability improvement needs to be reported to the client	Quality improvement needs to be reported to the client	10-20% cost decrease	5-10% time decrease
2 0.10	Low	Only certain features are affected	Only certain features are affected	<10% cost decrease	<5% time decrease
1 0.05	Very low	Sustainability improvement is barely noticeable	Quality improvement is barely noticeable	Insignificant cost decrease	Insignificant time decrease

Risk Management Setup - Risk prioritisation

Combining the probability and the impact scales resulted in the probability and impact matrix as can be seen in Table H.4. This matrix is used to prioritise risks according to their potential implications for having an effect on the project's objectives. Thus each risk was rated on its occurrence probability and its impact on an objective, indicating whether the risks are of low, moderate of high priority based on their score. The risks scores are calculated by multiplying the probability with the impact. Prioritising the risks with the probability and impact matrix determined the need for risk responses and the appropriate type of risk responses. For example, threats with a high priority might require an immediate response, while threats with a low priority might only need to be monitored. Nevertheless, the difference between high probability x low impact and low probability x high impact should be marked.

Table H.4 | Probability and impact matrix (PMI, 2008)

Probability	Threats					Opportunities				
0.90	0.05	0.09	0.18	0.36	0.72	0.72	0.36	0.18	0.09	0.05
0.70	0.04	0.07	0.14	0.28	0.56	0.56	0.28	0.14	0.07	0.04
0.50	0.03	0.05	0.10	0.20	0.40	0.40	0.20	0.10	0.05	0.03
0.30	0.02	0.03	0.06	0.12	0.24	0.24	0.12	0.06	0.03	0.02
0.10	0.01	0.01	0.02	0.04	0.08	0.08	0.04	0.02	0.01	0.01
Impact	0.05	0.10	0.20	0.40	0.80	0.80	0.40	0.20	0.10	0.05

Once the risks have been identified and assessed, the risks will be prioritized. Top risks will be included in the updated risk register with risk responses and post-response assessments. Low priority risks will be

Risk Register

The risk register is the output of the steps 2 to 5 of the risk management processes, respectively the identification of the risks, the qualitative and quantitative analyses and the planning of the risk responses. The set-up of the risk register was done in step 2, the identification of the risks, and was constantly updated during each of the following steps. However, there will not be a final update in step 5, the planning of the risk responses, as the register and thus the risks will continuously be monitored and controlled. Furthermore, since the project concerns the evaluation of four scenarios, five risk registers have been made: one for each scenario with risks specific to that scenario and a general one with risks appearing in each scenario. After the pre-response assessment of the general risk register, the top five risks are determined in order to develop risk responses for each of these risks.

The risk register set up for the risk assessment of the Sustainable Shores project consists of five sections:

- **Risk identification** – This section will include the categorisation of the risk, with its ID and the phase of occurrence. Since the register will contain a significant amount of risks, the identification will ensure certain amount of order and structure. The identified project phases are
    1. Initiation phase – The very beginning of the project, in which the idea for the project and its feasibility is explored and elaborated. Decisions regarding responsibilities and involved stakeholders are also made in this stage.
    2. Definition phase – The requirements of the project are clearly specified in this phase, including the expectations of the stakeholders.
    3. Design phase – The development of one or multiple designs, to then be evolved into a definitive design with the decisions made by the project supervisors.
    4. Development phase – This phase is for the preparation before the implementation.
    5. Implementation phase – The actual construction of the project.
    6. Follow-up phase – The phase entails the arrangement of everything that is necessary to bring the project to a successful completion.
    7. Monitor & evaluation phase – Involves the operation, maintenance and management of the construction. The reflection on the project and process is also included.
- **Risk description** – The risk description will contain the risk itself with an elaboration on its cause and consequences on the project as well as its environment. Various aspects will be taken into account for the causes and consequences such as the costs and planning. The risk description is formed using the proper formulation of risk according to Vrancken (2014):
  "<An uncertain event> may happen, caused by <a cause>, which can lead to <effect on project promises>"
- **Pre-response assessment** – In this section the risk will be assessed if it should occur without any applied responses, including its probability, impact and score (see Table H.4). The score of the assessment determines the priority level of the risk. Furthermore, the assessment also contains the type of the risk, describing whether it's positive or negative.

- **Risk response** – The risk response includes various mitigation strategies for the risk, which can be of the type avoidance (stop it from happening), transference (shifting the responsibility to a third party), mitigation (make the risk less of a problem) and acceptance (do nothing about it) for negative risks (Vrancken, 2014). For positive risks the risk responses can be of the type exploitation (make sure it happens), sharing (maximise benefit by sharing), enhancement (increase the probability) and acceptance (do nothing about it).
- **Post-response assessment** – The final section of the risk register is the assessment of the various risk responses, based on the probability, impact, post-risk action and secondary risk. The probability and impact assess the risks once the responses are applied. The post-risk action is the activity after the execution of the risk response to ensure further control and monitor of the risk, while the secondary risk is the direct risk created by the risk response.

Table H.5 | General risk register without risk responses and post-response assessments

#	Risk identification			Risk description			Pre-response assessment			
	ID	*Category*	*Phase*	*Risk event*	*Cause*	*Consequences*	*Type*	*Prob.*	*Impact*	*Score*
1	GR-001	- budgeting	- initiation	**Marine Department does not get the budget allocation from the government**	- Application is insufficient - Application submitted after due date - Government has other priorities - Government has insufficient budget - Government turns down the application	- Project cancellation - Project delay - Project scope changes	–	4	5	0.56 high
2	GR-002	- stakeholders	- initiation - definition - design	**Royal Family disagrees with the solution**	- Poor communication with RF - Design does not fit their desires - Scope changes	- Project cancellation - Project delay - Loss of face	–	2	4	0.12 medium
3	GR-003	- data & analysis	- initiation - definition - design	**Lack of data**	- Improper data storage - Lack of expertise and knowledge - Lack of (proper) measuring equipment	- Unforeseen damages to the structures - Collapse of the structures - More maintenance needed	–	3	2-4	0.10-0.20 medium-high
4	GR-004	- data & analysis	- initiation - definition - design	**Incorrect data**	- Improper data storage - Lack of expertise and knowledge - Lack of (proper) measuring equipment	- Unforeseen damage to the structures - Collapse of the structures - More maintenance needed	–	3	2-4	0.10-0.20 medium-high
5	GR-005	- decision-making	- initiation - definition - design - development - implementation	**Cancellation of the project**	- Other priorities - Insufficient budget - Insufficient resources - High opposition of the stakeholders - Improper design - (Fatal) accidents - Illegal practices - Permits cannot be acquired	- Beach erosion continues to be a problem - Loss of budget - Loss of face - Dissatisfaction stakeholders - Decrease in government's and Marine Department's reputation	–	1	5	0.08 medium
6	GR-006	- requirements - communication	- definition	**Requirements are unclear**	- Client's needs and wants are vague - Lack of expertise and knowledge - Lack of proper communication	- Incorrect design - Project delay - Dissatisfaction client - Scope changes	–	3	3-4	0.10-0.20 medium-high
7	GR-007	- legal - administrative - political	- definition - design - development - implementation - follow-up	**Changes in legislation**	- International legislation changes - National legislation changes	- Cancellation of the project - Project delay - Scope change	–	1	4	0.04 low
8	GR-008	- design	- design	**Overdimension of design**	- Faulty calculations - Lack of knowledge - Poor data - Sense of uncertainty - Unclear requirements	- Unnecessary costs - Unnecessary long construction phases - Overuse of resources	–	1	4	0.04 low
9	GR-009	- design	- design	**Incorrect design**	- Insufficient data - Incorrect calculations - Incorrect methodology - Lack of knowledge and expertise - Unclear requirements	- Collapse of the structures - More maintenance needed - Unnecessary costs - Unnecessary long construction phases - Overuse of resources	–	3	5	0.40 high
10	GR-010	- data & analyses	- design	**Uncertainty in soil foundation**	- Lack of data - Faulty data	- Damages to structures - Collapse of structures - Project delay - Damage to the surroundings	–	2	5	0.24 high
11	GR-011	- scope	- design - development - implementation	**Scope changes**	- Client's priorities change - Newly found information - Protests from stakeholders - Unclear requirements	- Project cancellation - Project delay - Dissatisfaction stakeholders - Satisfaction stakeholders	–/+	2-3	1-5	0.02-0.56 low-high
12	GR-012	- resources	- design - development - implementation	**Unavailability of resources**	- Inadequate education - Geological location of the project - Other projects have priority - Preoccupation of labour - Tight budget/ planning	- Cancellation of the project - Project delay - Scope changes	–	2	4	0.12 medium
13	GR-013	- planning	- design - development - implementation - follow-up	**Sub-deadlines are not met**	- Insufficient amount of resources available - Unworkable weather conditions - Lack of knowledge and expertise - Inadequate project planning - Miscommunication between parties	- Project delay - Final deadline will not be met - Project cancellation	–	3	3-4	0.10-0.20 medium-high
14	GR-014	- planning	- design - development - implementation	**Final deadline is not met**	- Insufficient amount of resources available - Unworkable weather conditions - Lack of knowledge and expertise	- Project delay	–	3	3-4	0.03-0.12 low-medium

			- follow-up		- Inadequate project planning - Miscommunication between parties					
15	GR-015	- legal - administrative	- development	**Permits cannot be acquired**	- Inadequate planning - Lack of knowledge - Insufficient application	- Project cancellation - Project delay	–	2	4	0.12 medium
16	GR-016	- resources	- development	**Lack of competent contractor to execute the project**	- Lack of education in Thailand - Lack of knowledge and expertise - High expectations of the client	- Project cancellation - Project delay	–	1	4	0.04 low
17	GR-017	- data & analyses	- development - implementation	**Unexpected contamination of the soil and water**	- Soil/water inspections were inaccurate - Unforeseen/ unidentified pollution	- Delay of the project - Changes to the scope - Damage to the environment - Project cancellation	–	1	2	0.01 low
18	GR-018	- stakeholders	- development - implementation - follow-up - monitor & evaluation	**Stakeholders refuse to cooperate**	- Opposing views - Stakeholders feel neglected - Stakeholder are negatively affected - Stakeholders' interests were insufficiently incorporated	- Project delay - Cancellation project - Adjustment of scope	–	2	3	0.06 medium
19	GR-019	- stakeholders	- development - implementation - follow-up - monitor & evaluation	**High opposition against the alternative**	- Opposing views - Stakeholders feel neglected - Stakeholder are negatively affected - Stakeholders' interests were insufficiently incorporated	- Decrease in government's and Marine Department's reputation - Demonstrations - Damages to the structures - Project cancellation - Project delay - Adjustment of scope	–	1	3	0.02 low
20	GR-020	- quality - reliability	- implementation - follow-up	**Improper construction**	- Insufficient data - Lack of expertise - Poor knowledge - Inadequate resources - Faulty design	- Decrease of structures' lifespan - Increase of needed maintenance - Collapse of structures - Damage to structures - Less effective structures - Beach erosion is more than expected	–	2	2-4	0.3-0.12 low-medium
21	GR-021	- budgeting - estimating	- implementation - follow-up	**Insufficient funds for construction completion**	- Cost estimates were inaccurate - Unforeseen circumstances - Project has no priority	- Project cancellation - Project delay - Project scope changes	–	2	4	0.12 medium
22	GR-022	- safety	- implementation - follow-up - monitor & evaluation	**(Fatal) accidents**	- Unclear safety measures - Disobeying of safety measures - Inadequate construction site organization - Unsatisfactory safety incorporation in the design	- Project cancellation - Project delay - Fines - Compensation costs	–	2	1-3	0.01-0.02 low
23	GR-023	- environmental	- implementation - follow-up - monitor & evaluation	**Damage to surroundings**	- Poor construction methodology - Inadequate design - Collapse of structures - Damaged structures	- Dissatisfied stakeholders - Additional repair costs - Failure of system	–	2	4	0.12 medium
24	GR-024	- quality - reliability - design - safety	- implementation - follow-up - monitor & evaluation	**Collapse of solution**	- Incorrect design - Poor construction - Force majeure	- Damage to the government's and Marine Department's reputations - Erosion problem continues to exist - Damage to the surroundings	–	1	5	0.08 medium
25	GR-025	- budgeting - estimating	- monitor & evaluation	**Insufficient funds for proper maintenance**	- Cost estimates were inaccurate - Unforeseen circumstances - Project has no priority	- Beach erosion is more than expected - Decrease of structures' lifespan - Collapse of structures - Damage to structures - Less effective structures	–	2	3	0.06 medium
26	GR-026	- monitor & control	- monitor & evaluation	**Improper monitoring**	- Faulty/lack of equipment - Untrained staff - Inadequate planning - Poor work allocation	- Unsatisfactory maintenance - Unforeseen damage	–	3	3	0.10 medium
27	GR-027	- monitor & control	- monitor & evaluation	**Maintenance is more demanding than expected**	- Incorrect calculations - Incorrect design	- Shorter lifespan than anticipated	–	3	3	0.10 medium
28	GR-028	- monitor & control	- monitor & evaluation	**Lack of (proper) maintenance**	- Insufficient amount of budget - High opposition from the stakeholders - Insufficient trained labor - Poor work allocation	- Shorter lifespan - Collapse of structures - Early necessary replacement of elements	–	3	4	0.20 high
29	GR-029	- communication	- monitor & evaluation	**Improper use of the solution (e.g. fishers dock their boats)**	- Interests stakeholders are not properly taken into account - Lack of information - Poor communication	- Damages to the structures - Shortened lifespan - Increase of needed maintenance	–	4	2	0.07 medium
30	GR-030	- culture - social	- monitor & evaluation	**Damage caused by third party (e.g. stolen sand)**	- Poor monitoring - Disobeying of rules - Unclear rules	- Shortened lifespan - Additional maintenance costs	–	3	3	0.10 medium

31	GR-031	- environmental	- monitor & evaluation	**Positive environmental impact**	- Sustainable project execution (planning, designing, construction and operation) - Consultation from the NGOs and environmental interest groups.	- Increase in government's and Marine Department's reputation - Stakeholders' satisfaction	+	2	2	0.03 low
32	GR-032	- environmental	- monitor & evaluation	**Negative environmental impact**	- Incorrect design - Insufficient analyses - Negligence - Conscious decision - Unsustainable project execution (planning, designing, construction and operation) - Lack of consultation from the NGOs and environmental interest groups.	- Disappearance of species - Fishermen are negative affected - NGO's and EIG's dissatisfaction - Decrease in government's and Marine Department's reputation	–	2	4	0.12 medium
33	GR-033	- performances	- monitor & evaluation	**Beach erosion increases**	- Poor design and execution - Insufficient expertise and knowledge - Inadequate project management - Wave conditions change	- Tourism decreases - Local economy decreases - Safety decrease	–	3	5	0.40 high
34	GE-034	- performances	- monitor & evaluation	**Beach erosion decreases**	- Proper design and execution - Sufficient expertise and knowledge - Adequate project management	- Tourism increases - Local economy increases - Safety increase	+	3	5	0.40 high
35	GR-035	- quality	- monitor & evaluation	**Constructed solution might be of insufficient quality**	- Design was faulty - Contractor overestimated his capabilities - Lack of knowledge and expertise - Insufficient resources	- Structure's lifespan is shorter than anticipated - More maintenance is needed - Damage to the surroundings	–	2	3	0.06 medium
36	GR-036	- performances	- monitor & evaluation	**Solution's performance is unacceptable**	- Incorrect design - Poor communication - Lack of expertise - Insufficient knowledge	- Solution is not fulfilling its purpose - Problem is only partially solved or not solved at all - Dissatisfaction of stakeholders	–	1	4	0.04 low
37	GR-037	- design - integration	- monitor & evaluation	**Shifting of the problem to a different location**	- Poor integral design - Insufficient data - Lack of knowledge	- Damage to environment - Protests from stakeholders	–	4	3	0.14 medium
38	GR-038	- cultural	- all phases	**Corruption**	- Political instability - Poor law enforcement - Culture	- Illegal activities - Unsound interests gratified - Changes in stakeholders' opinions	–	1	3	0.03 low
39	GR-039	- political	- all phases	**Coup d'état**	- Force majeure	- Cancellation of the project - Project delay - Scope change - Change in legislation - No budget allocation	–	1	3	0.03 low
40	GR-040	- economic	- all phases	**Economical crisis**	- Force majeure	- Project cancellation - Project delay - No budget allocation - Insufficient funds - Unavailability of resources	–	1	4	0.04 low
41	GR-041	- political	- all phases	**War**	- Force majeure	- Project cancellation - Project delay - Destruction of structures - No budget allocation	–	1	4	0.04 low
42	GR-042	- climate - geographical	- all phases	**Occurrence of severe storms**	- Force majeure	- Damage to the structures - Collapse of the structures - Project cancellation - Project delay - No budget allocation	–	2	5	0.09 medium
43	GR-043	- geographical	- all phases	**Occurrence of an earthquake**	- Force majeure	- Damage to the structures - Collapse of the structures - Project cancellation - Project delay - No budget allocation	–	1	5	0.08 medium
44	GR-044	- geographical	- all phases	**Occurrence of a tsunami**	- Force majeure	- Damage to the structures - Collapse of the structures - Project cancellation - Project delay - No budget allocation	–	1	5	0.08 medium

Table H.6 | General risk register with priority risks

#	Risk identification			Risk description			Pre-response assessment				Risk response	Post-response assessment			
	ID	*Category*	*Phase*	*Risk event*	*Cause*	*Consequences*	*Type*	*Prob.*	*Impact*	*Score*		*Prob.*	*Impact*	*Post-risk action*	*Secondary risk*
1	GR-001	- budgeting	- initiation	**Marine Department does not get the budget allocation from the government**	- Application is insufficient - Application submitted after due date - Government has other priorities - Government has insufficient budget - Government turns down the application	- Project cancellation - Project delay - Project scope changes	–	4	5	0..56 high	- The risk can be avoided by ascertaining the requirements of the government and accommodating those in the application. - The risk can be avoided by setting up a final deadline before the submission date. - The risk can be mitigated by gathering other sponsors for the project.	2	3	- Cleary show the sponsors their interest in the project - Check the application after the extra final deadline	- Project delay - Extra final deadline is not met - Sponsors cannot be found
2	GR-009	- design	- design	**Incorrect design**	- Insufficient data - Incorrect calculations - Incorrect methodology - Lack of knowledge and expertise - Unclear requirements	- Collapse of the structures - More maintenance needed - Unnecessary costs - Unnecessary long construction phases - Overuse of resources	–	3	5	0.40 high	- The risk can be avoided by including a third party to check the design. - The risk can be avoided by investing more time and effort in the analyses. - The risk can be avoided by clear communication strategies between the parties. - The risk can be transferred by contracting a third part for the design.	1	4	- Frequently check the design on changes - Keep clear communication with the stakeholders	- Extended design phase - Additional third party costs - Insufficient budget - Third party is inadequate
3	GR-033	- performances	- monitor & evaluation	**Beach erosion increases**	- Poor design and execution - Insufficient expertise and knowledge - Inadequate project management - Faulty or lack of data	- Tourism decreases - Local economy decreases - Safety decrease	–	3	5	0.40 high	- The risk can be avoided by double checking the design before implementation. - The risk can be avoided by transferring the risk to a third party for the design. - The risk can be avoided by thoroughly analysing the available data. - The risk can be mitigated by endorsing other economy drivers. - The risk can be mitigated by keeping the people away from the beaches.	1	4	- Frequently check on the situation - Communicate with the third party on the consequences	- Additional third party costs - Project delay because of extra activities - Economy decreases - Tourism decreases
4	GE-034	- performances	- monitor & evaluation	**Beach erosion decreases**	- Proper design and execution - Sufficient expertise and knowledge - Adequate project management	- Tourism increases - Local economy increases - Safety increase	+	3	5	0.40 high	- The risk can be enhanced by including experts in the design phase.	4	5	- Monitor the experts	- Experts are inadequate - Additional third party costs
5	GR-010	- data & analyses	- design	**Uncertainty in soil foundation**	- Lack of data - Faulty data	- Damages to structures - Collapse of structures - Project delay - Damage to the surroundings	–	2	5	0.24 high	- The risk can be avoided by executing extra soils tests.	1	5	- Monitor the tests and their results	- Test results are inadequate - Project delay - Poor soil
6	GR-028	- monitor & control	- monitor & evaluation	**Lack of (proper) maintenance**	- Insufficient amount of budget - High opposition from the stakeholders - Insufficient trained labour - Poor work allocation - Unforeseen circumstances	- Shorter lifespan - Collapse of structures - Early necessary replacement of elements	–	3	4	0.20 high	- The risk can be avoided by including sponsors for the maintenance. - The risk can be avoided by communicating with the stakeholders the necessity of the solution and its maintenance. - The risk can be avoided by including an expert to educate work labour.	2	2	- Cleary show the sponsors their interest in the project - Keep clear communication with the stakeholders. - Keep updating the work labour	- Sponsors cannot be found - Stakeholders cannot be convinced - Expert is inadequate
7	GR-011	- scope	- design - development - implementation	**Scope changes**	- Client's priorities change - Newly found information - Protests from stakeholders - Unclear requirements	- Project cancellation - Project delay - Dissatisfaction stakeholders - Satisfaction stakeholders	–	2-3	1-5	0.02-0.56 low-high	- The risk can be avoided by clear communication strategies in the development phase with all the stakeholders.	2	1-5	- Keep checking on the various stakeholders	- Stakeholders do not cooperate
8	GR-003	- data & analysis	- initiation - definition - design	**Lack of data**	- Improper data storage - Lack of expertise and knowledge - Lack of (proper) measuring equipment	- Unforeseen damages to the structures - Collapse of the structures - More maintenance needed	–	3	2-4	0.10-0.20 medium-high	- The risk can be mitigated by performing additional tests (by a third party) to acquire more data. - The risk can be mitigated by creating a proper data storage.	2	2-4	- Monitor the tests and their results - Educate employees on the data storage - Maintain the storage	- Test results are inadequate - Proper data storage setup and maintaining proves unsuccessful
9	GR-004	- data & analysis	- initiation - definition - design	**Incorrect data**	- Improper data storage - Lack of expertise and knowledge - Lack of (proper) measuring equipment	- Unforeseen damage to the structures - Collapse of the structures - More maintenance needed	–	3	2-4	0.10-0.20 medium-high	- The risk can be mitigated by including a third party to check the data. - The risk can be mitigated by performing additional tests (by a third party) to acquire more data. - The risk can be mitigated by creating a proper data storage.	1	2-4	- Monitor the third party - Monitor the tests and their results - Educate employees on the data storage - Maintain the storage	- Third party is inadequate - Test results are inadequate - Proper data storage setup and maintaining proves unsuccessful
10	GR-013	- planning	- design - development - implementation - follow-up	**Sub-deadlines are not met**	- Insufficient amount of resources available - Unworkable weather conditions - Lack of knowledge and expertise - Inadequate project planning - Miscommunication between parties	- Project delay - Final deadline will not be met - Project cancellation	–	3	3-4	0.10-0.20 medium-high	- The risk can be avoided by creating incentives for the contractor to meet his deadlines. - The risk can be mitigated by creating time buffers. - The risk can be mitigated by clear communication strategies between parties.	2	3	- Proper documentation of the incentives - Monitor the contractor - Keep up communication	- Incentives do not work - Time buffers are not enough - Project delay - Contractor does not cooperate properly

Table H.7 | Risk register for T-groynes

#	Risk identification			Risk description			Pre-response assessment				Risk response	Post-response assessment			
	ID	*Category*	*Phase*	*Risk event*	*Cause*	*Consequences*	*Type*	*Prob.*	*Impact*	*Score*		*Prob.*	*Impact*	*Post-risk action*	*Secondary risk*
1	TG-001	- performances	- monitor & evaluation	**Severe down drift erosion**	- Incorrect design - Poor wave data	- One side of the groyne has a shortage of sand, while the other has a surplus - Dissatisfaction of stakeholders - Decrease in tourism	–	2	3	0.06 medium	- The risks can be avoided/mitigated by optimizing the design during the design phase with extensive analyses. - The risk can be accepted, as the original erosion problem has a higher priority.	1	2	- Monitor the wave action and update the data - Clear communication with the stakeholders	- Additional design phase costs and time - Continued/increased dissatisfaction of stakeholders
2	TG-002	- performances	- monitor & evaluation	**Heavy erosion in between the groynes**	- Poor wave data - Incorrect design - Lack of expertise and knowledge	- The beaches form a U-shape - Dissatisfaction of the stakeholders - Decrease in tourism - More maintenance needed	–	2	3	0.06 medium	- The risks can be avoided/mitigated by optimizing the design during the design phase with extensive analyses. - The risk can be mitigated by maintaining an evenly spread out beach. - The risk can be accepted, as the original erosion problem has a higher priority.	1	2	- Monitor the wave action and update the data - Clear communication with the stakeholders	- Additional design phase costs and time - Extra maintenance - Continued/increased dissatisfaction of stakeholders
3	TG-003	- reliability	- monitor & evaluation	**Wave reflections at the groyne tips lead to scour**	- Incorrect design - Poor wave data - Lack of expertise and knowledge	- Damages to the structures - Shortened lifespan	–	2	3	0.06 medium	- The risk can be avoided by using more durable materials at the groyne tips. - The risks can be mitigated by optimizing the design during the design phase with extensive analyses.	1	1	- Monitor the wave action and update the data	- Additional material costs - Additional design phase costs and time
4	TG-004	- safety	- monitor & evaluation	**Dangerous rip currents**	- Poor wave data - Incorrect design - Lack of expertise and knowledge	- Danger to swimmers - Danger to fishers	–	1	2	0.01 low	- The risks can be mitigated by optimizing the design during the design phase with extensive analyses. - The risk can be mitigated by prohibiting swimmers. - The risk can be mitigated by creating awareness amongst the beach users. - The risk can be mitigated by informing and educating the fishermen	1	1	- Monitor the beach users - Put up signs on the beaches	- Additional design phase costs and time - The signs and warnings might be ignored - (Fatal) accidents
5	TG-005	- economic	- monitor & evaluation	**Tourism is negatively affected**	- Tourists prefer aesthetically pleasing beaches - Facilities are negatively affected	- Project cancellation - Project scope changes - Local economy declines - Dissatisfaction of stakeholders	–	3	4	0.20 high	- The risk can be mitigated by creating new facilities to attract tourists. - The risk can be mitigated by providing other job opportunities for workers in the tourism industry. - The risk can be accepted, as the original erosion problem has a higher priority.	2	3	- Promote the area for the tourists - Communicate with affected stakeholders on other possibilities	- Additional design phase costs and time - Additional job creation costs - Continued/increased dissatisfaction of stakeholders
6	TG-006	- environmental	- monitor & evaluation	**Limited water flow near the beaches and in between the T-groynes**	- Poor wave data - Incorrect design - Lack of expertise and knowledge	- Water quality between T-groynes is affected - Flora and fauna is affected - Danger to swimmers - Fishermen are affected - Dissatisfaction of stakeholders - NGO's and EIG's dissatisfaction - Decrease in tourism	–	2	4	0.12 medium	- The risks can be mitigated by optimizing the design during the design phase with extensive analyses. - The risks can be mitigated by warning the beach users - The risk can be accepted, as the original erosion problem has a higher priority.	1	3	- Monitor the wave action and update the data - Put up signs on the beaches - Clear communication with the stakeholders	- Additional design phase costs and time - Signs and warnings might be ignored - (Fatal) accidents - Continued/increased dissatisfaction of stakeholders

Table H.8 | Risk register for groynes

#	Risk identification			Risk description			Pre-response assessment				Risk response	Post-response assessment			
	ID	*Category*	*Phase*	*Risk event*	*Cause*	*Consequences*	*Type*	*Prob.*	*Impact*	*Score*		*Prob.*	*Impact*	*Post-risk action*	*Secondary risk*
1	GN-001	- performances	- monitor & evaluation	**Severe down drift erosion**	- Incorrect design - Poor wave data	- One side of the groyne has a shortage of sand, while the other has a surplus - Dissatisfaction of stakeholders - Decrease in tourism	–	2	3	0.06 medium	- The risks can be avoided/mitigated by optimizing the design during the design phase with extensive analyses. - The risk can be accepted, as the original erosion problem has a higher priority.	1	2	- Monitor the wave action and update the data - Clear communication with the stakeholders	- Additional design phase costs and time - Continued/increased dissatisfaction of stakeholders
2	GN-002	- performances	- monitor & evaluation	**Heavy erosion in between the groynes**	- Poor wave data - Incorrect design - Lack of expertise and knowledge	- The beaches form a U-shape - Dissatisfaction of the stakeholders - Decrease in tourism - More maintenance needed	–	2	3	0.06 medium	- The risks can be avoided/mitigated by optimizing the design during the design phase with extensive analyses. - The risk can be mitigated by maintaining an evenly spread out beach. - The risk can be accepted, as the original erosion problem has a higher priority.	1	2	- Monitor the wave action and update the data - Clear communication with the stakeholders	- Additional design phase costs and time - Extra maintenance - Continued/increased dissatisfaction of stakeholders
3	GN-003	- reliability	- monitor & evaluation	**Wave reflections at the groyne tips lead to scour**	- Incorrect design - Poor wave data - Lack of expertise and knowledge	- Damages to the structures - Shortened lifespan	–	1	2	0.01 low	- The risk can be avoided by using more durable materials at the groyne tips. - The risks can be mitigated by optimizing the design during the design phase with extensive analyses.	1	1	- Monitor the wave action and update the data	- Additional material costs - Additional design phase costs and time
4	GN-004	- safety	- monitor & evaluation	**Dangerous rip currents**	- Poor wave data - Incorrect design - Lack of expertise and knowledge	- Danger to swimmers - Danger to fishers	–	1	2	0.01 low	- The risks can be mitigated by optimizing the design during the design phase with extensive analyses. - The risk can be mitigated by prohibiting swimmers. - The risk can be mitigated by creating awareness amongst the beach users. - The risk can be mitigated by informing and educating the fishermen	1	1	- Monitor the beach users - Put up signs on the beaches	- Additional design phase costs and time - The signs and warnings might be ignored - (Fatal) accidents
5	GN-005	- economic	- monitor & evaluation	**Tourism is negatively affected**	- Tourists prefer aesthetically pleasing beaches - Facilities are negatively affected	- Project cancellation - Project scope changes - Local economy declines - Dissatisfaction of stakeholders	–	3	4	0.20 high	- The risk can be mitigated by creating new facilities to attract tourists. - The risk can be mitigated by providing other job opportunities for workers in the tourism industry. - The risk can be accepted, as the original erosion problem has a higher priority.	2	3	- Promote the area for the tourists - Communicate with affected stakeholders on other possibilities	- Additional design phase costs and time - Additional job creation costs - Continued/increased dissatisfaction of stakeholders
6	GN-006	- environmental	- monitor & evaluation	**Limited water flow near the beaches and in between the T-groynes**	- Poor wave data - Incorrect design - Lack of expertise and knowledge	- Water quality between T-groynes is affected - Flora and fauna is affected - Danger to swimmers - Fishermen are affected - Dissatisfaction of stakeholders - NGO's and EIG's dissatisfaction - Decrease in tourism	–	1	3	0.02 low	- The risks can be mitigated by optimizing the design during the design phase with extensive analyses. - The risks can be mitigated by warning the beach users - The risk can be accepted, as the original erosion problem has a higher priority.	1	2	- Monitor the wave action and update the data - Put up signs on the beaches - Clear communication with the stakeholders	- Additional design phase costs and time - Signs and warnings might be ignored - (Fatal) accidents - Continued/increased dissatisfaction of stakeholders

Table H.9 | Risk register for beach nourishment

#	Risk identification			Risk description			Pre-response assessment				Risk response	Post-response assessment			
	ID	*Category*	*Phase*	*Risk event*	*Cause*	*Consequences*	*Type*	*Prob.*	*Impact*	*Score*		*Prob.*	*Impact*	*Post-risk action*	*Secondary risk*
1	BM-001	- Environmental	- Implementation - Follow-up - Monitor & evaluation	**Crabs' habitat are negatively impacted**	- Incorrect design - Insufficient analyses - Negligence - Conscious decision	- NGO's and EIG's dissatisfaction - Crabs are eradicated - Eradication of the crabs affect the ecosystem	–	4	2	0.07 medium	- The risk can be avoided/mitigated by assessing in the design phase the most optimal construction method, material and design. - The risk can be accepted, as the erosion problem has a higher priority.	1-4	1-2	- Test the adjustments - Monitor the crabs and their habitat	- Additional design phase costs and time - NGO's and EIG's dissatisfaction
2	BM-002	- Performances	- Monitor & evaluation	**Beach erosion is more than expected**	- Faulty data - Incorrect design - Insufficient analyses - Sand theft	- More nourishments necessary than expected - Tourism is affected	–	3	3	0.10 medium	- The risk can be avoided/mitigated by involving a third party to check the design and data. - The risk can be avoided/mitigated by increasing the time and effort needed for the design phase to perform more research. - The risk can be avoided/mitigated by increasing the fine for theft, controlling the area more frequently and awarding the people who warned of the theft. - The risk can be transferred by insuring against theft	1-2	1-2	- Continuously update the data - Adjust the new nourishment planning when necessary - Be accessible for the discoverers to alert - Keep a separate budget for awarding - Additional costs and monitoring for insurance	- Project delay - Additional design phase costs and time - Competition between the spotters
3	BM-003	- Resources - Geographical	- Implementation	**Sand is not available**	- Geological location - Depletion of available resources	- Project cancellation - Project delay - Project scope changes - Continued narrowing of the beaches - Maintenance not possible	–	1	5	0.08 medium	- The risk can be mitigated by importing sand from other regions/countries. - The risk can be mitigated by reducing the physical scope if there is not enough coarse sand.	1	3	- Communicate with providers to ensure continued supply - Search for other possible materials - Monitor erosion after scope changes	- Additional import costs - Project delay to incorporate import time - Beach erosion continues as scope is smaller

Table H.10 | Risk register for coarse nourishment

#	Risk identification			Risk description			Pre-response assessment				Risk response	Post-response assessment			
	ID	*Category*	*Phase*	*Risk event*	*Cause*	*Consequences*	*Type*	*Prob.*	*Impact*	*Score*		*Prob.*	*Impact*	*Post-risk action*	*Secondary risk*
1	CM-001	- Performances	- Monitor & evaluation	**Steeper profile**	- Incorrect data - Insufficient analyses - Negligence - Conscious decision	- More wave action than expected - More erosion than expected - Danger to swimmers - Danger to fishermen	–	3	2	0.05 low	- The risk can be mitigated by prohibiting swimmers. - The risk can be mitigated by creating awareness amongst the users - The risk can be avoided/mitigated by extra coarse nourishments - The risk can be mitigated by informing and educating the fishermen	2	1	- Put up signs on the beaches - Monitor the beach users - Monitor erosion after extra nourishments	- Signs and warnings might be ignored - Erosion continues - Steeper profile still exists - Fatal accidents
2	CM-002	- Resources - Geographical	- Design - Implementation - Monitor & evaluation	**Coarse sand is unavailable**	- Geological location - Depletion of available resources	- Project cancellation - Project delay - Project scope changes - Continued narrowing of the beaches - Maintenance not possible	–	4	5	0.56 high	- The risk can be avoided/mitigated by importing the sand from other regions/countries - The risk can be avoided/mitigated by reducing the physical scope if there is not enough coarse sand.	1	3	- Communicate with providers to ensure continued supply - Search for other possible materials - Monitor erosion after scope changes	- Additional import costs - Project delay to incorporate import time - Beach erosion continues as scope is smaller
3	CM-003	- Economic - Stakeholders	- Monitor & evaluation	**Tourism is negatively affected**	- Tourists prefer softer beaches - Facilities are negatively affected	- Project cancellation - Project scope changes - Local economy declines - Dissatisfaction of stakeholders	–	3	4	0.20 high	- The risk can be mitigated by creating new facilities to attract tourists. - The risk can be accepted, as the threat to the hinterland is more important. - The risk can be mitigated by providing other job opportunities for workers in the tourism industry.	2	3	- Promote the area for the tourists - Communicate with affected stakeholders on other possibilities	- Additional design phase costs and time - Additional job creation costs - Continued/increased dissatisfaction of stakeholders
4	CM-004	- Stakeholders	- Implementation - Follow-up - Monitor & evaluation	**Stakeholders experience problems with the coarser grain size**	- Insufficient analysis - Negligence - Conscious decision	- Local economy declines - Dissatisfaction stakeholders - Project delay	–	3	3	0.10 medium	- The risk can be mitigated by incorporating design solutions for the stakeholders. - The risk can be accepted, as the threat to the hinterland is more important.	2	2	- Extensive communication with the stakeholders - Testing the design solutions	- Additional design phase costs and time - Continued/increased dissatisfaction of stakeholders

H.2. Multi Criteria Analysis (MCA)

H.2.1. MCA setup methodology

The methodology used in this research for setting up the analysis consists of the following steps:

1. **Establish the context of the assessment: What are the aims of the MCA?** As is prevalent in the problem definition chapter, the aim of the research is to provide an advice plan with recommendations for the coastal erosion problem. Part of the process to achieve this plan is to assess the possible solutions mentioned in the chapter scenarios resulting in the most preferable solution. Since the solutions need to be judged on various and diverse criteria, one more important than the other, the MCA is the most suitable for the assessment. Furthermore, because of its nature, the MCA will show a clear and substantiated evaluation process, easy for all the involved parties to follow the course of argumentation.

2. **Determine the objectives: What is to be achieved?** The MCA was expected to provide the team with a hierarchy of the four solutions based on their scores for each criterion. The scores should be supported by the arguments for each given score value.

3. **Identify the alternatives: What is to be assessed?** The alternatives assessed in the MCA are established in the scenarios chapter and consist of the following four solutions:
    - T-groynes, which are basically groynes with an offshore breakwaters at their tips. Nourishments also have to be performed.
    - Groynes, also has to be combined with nourishments. This alternative will be cheaper than T-groynes; it is however expected to be less effective at stopping sediment transport.
    - Beach nourishment, directly leads to a broader beach. It is a soft solution and thus more natural than constructing hard structures. More sand is put into the system so at other locations the erosion can also be alleviated, instead of the lee erosion, which occurs with hard structures.
    - Coarse nourishment, which entails nourishing with coarser sand than the sand that is currently in the system.

4. **Identify the criteria: What are the measures of performance?** Establishing criteria for the assessment of the alternatives was done with value trees. Value trees are used to link objectives to assessment criteria by creating an objectives hierarchy. Mission areas are linked to objectives, which in turn are linked to performance measures. This will ensure a clear reasoning behind each criterion. As can be seen in the Sustainable Shores' value tree in Figure H.2, the project has five mission areas. These areas are discussed between the members of the team and show the most important aspects of the project and thus the areas on which the solutions should be assessed. Each of the mission area is then subdivided into objectives, to further establish the exact measures to be evaluated. The setup of the value tree resulted in fourteen criteria to be assessed for each solution. The five mission areas are:
    - *Sustainability* – As stated in the introduction chapter and is evident in the project's name, sustainability plays an important role in the project and in the team's vision. Environmental impacts, resource origins, project integrality as well as solution's durability all add to the mission area.
    - *Solution* – Aside from the various managerial aspects and sustainability, the solution itself is an important mission area. The objectives related to the solution are validation, verification, effectiveness and efficiency. These objectives all relate to the solution itself, its correctness, accuracy, reliability and relevancy.
    - *Project management* – Project management plays a crucial role in the electing of the most suitable solution, as technical suitability is not enough to make the solution suitable. Financial aspects and various lifecycle durations are important conditions that need to be taken into account.
    - *Stakeholder management* – In order for an implementation of a solution to be successful, the stakeholders need to be taken into account. As they can greatly oppose the project

and thwart various processes. They should be engaged in every relevant process and their acceptability should be a measure for solution suitability.

- *Risk management* – Each solution has its own risks, one more severe than the other, creating an effect of uncertainty on the solution. These risks may be accepted if they are within tolerances and in balance with the rewards that may be gained by taking the risks.

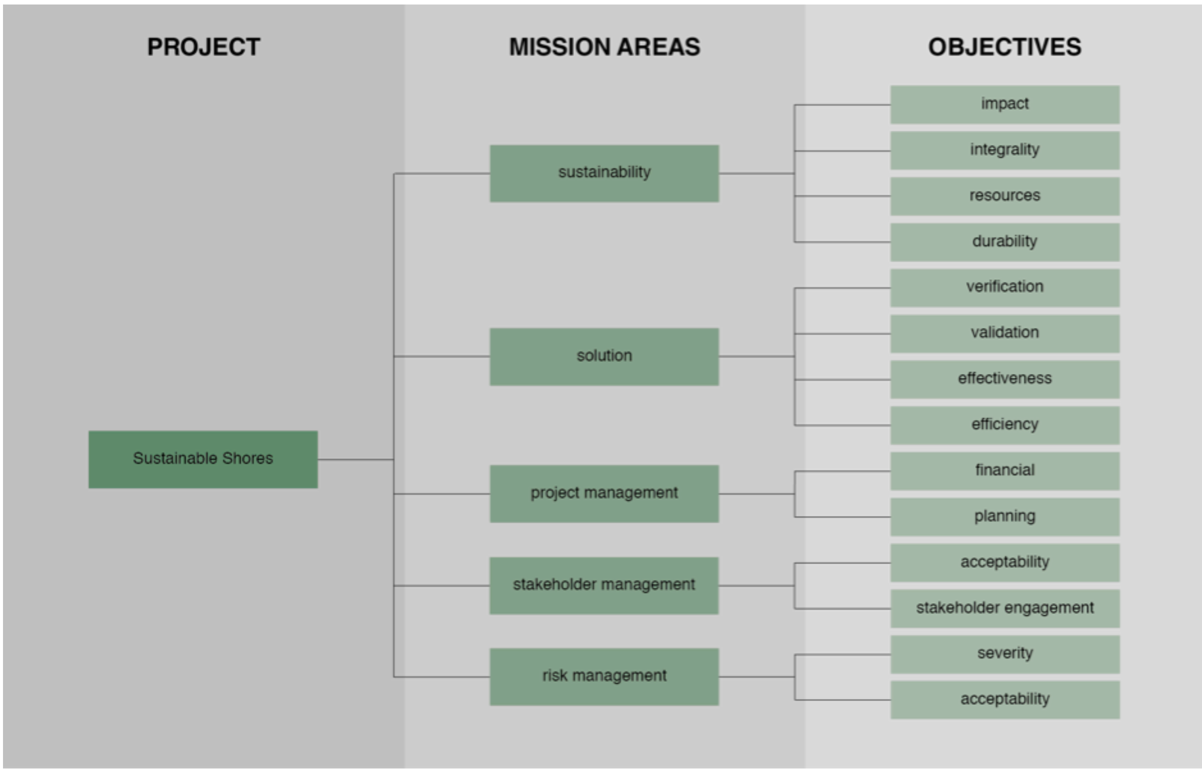

Figure H.2 | Value tree of Sustainable Shores (own ill.)

5. **Define performance levels: What is the importance of each measure to the decision?** In order to determine the relative importance of the different criteria on which the alternatives will be assessed, weighting criteria need to be implemented. This can be done by a pairwise comparison of each criterion relative to every other criterion. In the pairwise comparison, a matrix is used in which it is determined which criterion (the row criterion or the column criterion) is more important. If the row criterion is more important, a 1 will be placed in the common cell and if the column criterion is more important, a 0 will be placed in the common cell. If it cannot be determined which criterion is more important, then both common cells get a 1. The horizontal summation indicates the importance of the criteria. By adding scores for each criterion, a ranking of the various criteria is obtained, which is expressed in a quantitative weighting for each criterion (de Ridder, Soons & Voskamp, 2011). Table H.11 shows the relative weight matrix for the established criteria of the Sustainable Shores project, assessed by the team members of the project. The table has an additional column with a multiplier to incorporate the values of the client.

6. **Evaluate the MCA setup and correct: Are the objectives properly represented?** The MCA setup is evaluated and corrected multiple times during various meetings of the team members in order to ensure a reliable and a comprehensive setup. The value tree together with the various criteria was reviewed multiple times to include important and relevant criteria and exclude insignificant and redundant ones. Furthermore, the relative weight matrix was also corrected to further improve the client's wants. The final result of the MCA setup can be found in Table H.12 it includes a list with all the established criteria and their relative weights.

H.2.1. MCA execution

Once the multi-criteria analysis was set up and the alternatives were defined, the analysis itself was performed. Each solution was examined based on the criteria list and earned certain scores for each criterion. These scores were given based on comparisons between the different solutions and on the team members' expertise. To ensure a sufficient level of acknowledgement, the scale for the scores was 1 to 5, with 1 being the lowest score and 5 being the highest. The final outcome of the criterion for the solution is then calculated by multiplying the score with the weight of the criterion. The total value for the solution assessment can then be found by summing up all the outcomes for each criterion. The final outcomes and results of the score appointments with the clarifications for each score can found in Table H.13 for T-groynes, Table H.14 for groynes, Table H.15 for beach nourishment and Table H.16 for coarse nourishment.

Table H.11 | Relative weight matrix

	Impact	Integrality	Resources	Durability	Verification	Validation	Effectiveness	Efficiency	Financial	Planning	Stakeholder Acceptability	Stakeholder Engagement	Risk severity	Risk acceptability	TOTAL	Multiplier	OUTCOME	WEIGHT
Impact		1	1	0	1	0	1	1	0	1	1	1	1	1	10		10	8.5 %
Integrality	0		0	0	0	0	0	1	0	1	0	0	0	0	2		2	1.7 %
Resources	1	1		1	0	0	0	1	0	1	0	1	0	1	7		7	5.9 %
Durability	1	1	0		0	0	0	1	0	1	0	0	0	0	4		4	3.4 %
Verification	0	1	1	1		0	0	1	0	1	0	0	0	1	6		6	5.1 %
Validation	1	1	1	1	1		1	1	0	1	1	1	1	1	12	1.5	18	15.3 %
Effectiveness	0	1	1	1	1	0		1	0	1	0	1	0	0	7		7	5.9 %
Efficiency	0	0	0	0	0	0	0		0	1	0	0	0	0	1		1	0.8 %
Financial	1	1	1	1	1	1	1	1		1	1	1	1	1	13	1.5	19.5	16.5 %
Planning	0	0	0	0	0	0	0	1	0		0	0	0	0	1		1	0.8 %
Stakeholder acceptability	1	1	1	1	1	1	1	1	0	1		1	0	1	11		11	9.3%
Stakeholder engagement	0	1	0	1	1	0	0	1	0	0	0		0	0	4		4	3.4 %
Risk severity	1	1	1	1	1	1	1	1	1	1	1	1		1	13	1.5	19.5	16.5 %
Risk acceptability	1	1	0	1	1	0	1	1	0	1	0	1	0		8		8	6.8%
TOTAL															99		118	100%

NOTE: Based on the needs of the Marine Department, a multiplier is applied to the aspects that they perceive as most important. The multiplier ensures that the important aspects will not be outweighed by less important ones, when the scores are assigned.

Table H.12 | Criteria including weighting

MISSION AREA	ID	WEIGHT	OBJECTIVE	DESCRIPTION
Sustainability	SU-01	8.5 %	Impact	The impact concerns the effects of the alternative on the built environment as well as the flora and fauna, which can be positive or negative.
	SU-02	1.7 %	Integrality	The project should not only be focused on individual parts but also on the coastal system as a whole to prevent the problem from shifting to another area and to efficiently manage the whole coast.
	SU-03	5.9 %	Resources	Both the use of sustainable resources and the location of those resources contribute to overall sustainability of resources. The farther the origin of the resources to the project area, the less sustainable.
	SU-04	3.4 %	Durability	The longer the durability of the alternative, the less time, money and energy might need to be spend on an replacement and maintenance.
Solution	SO-01	5.1 %	Verification	The verification of the solution is determined by the correctness of the used data, the accuracy of the model, the reliability of the solution and the extent to which the solution meets the regulations, specifications and requirement.
	SO-02	15.3 %	Validation	The validation of the solution is determined by the extent to which the solution is relevant to the problem, satisfies the client's needs, and is in alignment with team's vision.
	SO-03	5.9 %	Effectiveness	The extent in which the alternative solves the problem determined in the problem definition defines its effectiveness.
	SO-04	0.8 %	Efficiency	The alternative's availability determines its efficiency, since downtime (planned or unplanned) leads to less protection and thus a lower efficiency rate.
Project management	PM-01	16.5 %	Financial	The general estimated costs of the solution and its economic value, in which the costs outweigh the economic value to a large extent.
	PM-02	0.8 %	Planning	The amount of time spent on the design and construction of the alternative. The shorter the execution, the higher the grading of the measure.
Stakeholder management	SM-01	9.3 %	Stakeholder acceptability	The extent to which stakeholders accept the solution, based on the extent to which their interests are taken into account.
	SM-02	3.4 %	Stakeholder engagement	Stakeholder engagement shows the depth of the engagement of the stakeholders into the project and the extent to which opposing stakeholders are persuaded to support the alternative.
Risk management	RM-01	16.5 %	Risk severity	The severity of the risks during the solution's life cycle.
	RM-02	6.8 %	Risk acceptability	The extent of acceptance of the risks and risk management by the key stakeholders shows the risk acceptability.
		100 %		

Table H.13 | MCA assessment for T-groynes

MISSION AREA	WEIGHT	OBJECTIVE	SCORE	EXPLANATION	OUTCOME
Sustainability	8.5 %	Impact	1	High negative impact on the water quality as well as on the environment. As T-groynes are hard structures, they are not natural, which might lead to even more negative environmental issues.	0.085
	1.7 %	Integrality	1	By constructing T-groynes, the sediment transport is largely stopped. This will lead to lee side erosion.	0.017
	5.9 %	Resources	4	Due to the long lifetime of the T-groyne and relatively small material use, T-groynes are considered to have relatively little impact on the available natural resources of Thailand.	0.236
	3.4 %	Durability	5	Based on their lifetime duration, T-groynes are highly sustainable when it comes to durability.	0.170
Solution	5.1 %	Verification	4	The verification for T-groynes is quite high. However, currents around the groynes and reflection on the groynes tips can have an effect on the outcome. Therefore, the verification score of T-groynes is slightly lower.	0.204
	15.3 %	Validation	3	The Marine Depart would like a solution to the erosion problem as well as an attractive beach to improve tourism. From a tourist's perspective T-groynes might be perceived as ugly and therefore not satisfy the client's needs. Also, if the water quality problems are severe, this will affect to tourism. However, the solution is relevant to the erosion problem and beach widening.	0.459
	5.9 %	Effectiveness	5	Based on the problem definition of the Marine Department, T-groynes are the most effective solution as they ensure both coastal erosion prevention and beach widening.	0.295
	0.8 %	Efficiency	5	As almost no maintenance is required during its lifetime, T-groynes are considered to be highly efficient.	0.040
Project management	16.5 %	Financial	3	When compared with the other alternatives T-groynes are neither expensive nor cheap. They are more expensive than groynes since they are in fact a groyne combined with a breakwater. Breakwaters are generally more expensive than groynes because they are more difficult to build. T-groynes are however less expensive than beach nourishment since the price of a cubic meter of rock is quite similar to the price of a cubic meter of sand. Considering the lifetime of both options and the amount of material needed T-groynes will be much cheaper than nourishment.	0.495
	0.8 %	Planning	3	Groynes have already been executed before and therefore previous experiences and knowledge can be used to speed up the design and execution process. However, T-groynes will need more investigation regarding water quality problems and also need a more detailed plan compared to beach nourishment.	0.024
Stakeholder management	9.3 %	Stakeholder acceptability	2	Due to the possible negative impact on water quality and their unnatural appearances, it is very likely that environmental interest groups will oppose to T-groynes, as well as the tourists. Also, NGOs are strongly against the construction of hard structures. However, all other stakeholders perceive this solution as successful based on previous projects.	0.186
	3.4 %	Stakeholder engagement	2	As NGOs strongly oppose to the construction of hard structures, it is very unlikely that they can be engaged to the solution. Environmental interest groups might be persuaded by applying additional measures regarding the water quality and tourists might be easily persuaded by providing additional services/facilities.	0.068
Risk management	16.5 %	Risk severity	1	There is a chance that the T-groynes will affect the quality of the water and that the sand will not behave according to the plans. These risks have a high impact, as they affect the satisfaction of the stakeholders and have an environmental impact.	0.165
	6.8 %	Risk acceptability	3	The involved risks unique to the solution can mostly be prevented with extra attention to the design phase, making the risks and its measures easily acceptable.	0,204
	100 %				**2.444**

Table H.14 | MCA assessment for groynes

MISSION AREA	WEIGHT	OBJECTIVE	SCORE	EXPLANATION	OUTCOME
Sustainability	8.5 %	Impact	4	Even though groynes are also hard structures, the measure itself does not cause significant environmental problems as only rocks are placed on a limited surface area.	0.340
	1.7 %	Integrality	2	Constructing groynes will also lead to lee side erosion, however this will be less severe compared to constructing T-groynes.	0.034
	5.9 %	Resources	4	Similar to T-groynes, groynes have a long lifetime and relatively small material use, groynes are considered to have relatively little impact on the available natural resources of Thailand.	0.236
	3.4 %	Durability	5	Based on their lifetime, groynes are also highly sustainable when it comes to durability.	0.170
Solution	5.1 %	Verification	4	The verification for groynes is quite high. Even though only currents around the groynes can have an effect on the outcome, the verification score of groynes is similar to the score of T-groynes.	0.204
	15.3 %	Validation	4	The construction of groynes might also be perceived as ugly by tourists and therefore not satisfy the client's needs. However, as this solution is blocking the sea view much less than the T-groynes, the perception of the tourists regarding the aesthetics will probably be more positive. Furthermore, the solution is relevant to the erosion problem and beach widening.	0.612
	5.9 %	Effectiveness	4	Groynes also ensure both coastal erosion prevention and beach widening, however the erosion prevention is less than for the T-groynes.	0.236
	0.8 %	Efficiency	5	Groynes also require minimal maintenance and are therefore also perceived as highly efficient.	0.040
Project management	16.5 %	Financial	4	The price per cubic meter of material is approximately the same as nourishment but groynes require less material and maintenance, since they generally have a significant larger lifetime. Groynes also require less material than T-groynes, as they do not have the breakwaters at the tip and are easier to construct. They are therefore to be considered as the least expensive solution.	0.66
	0.8 %	Planning	4	Groynes have also been executed before and therefore previous experiences and knowledge can be used to speed up the design and execution process. However, a more detailed plan has to be made compared to beach nourishment.	0.032
Stakeholder management	9.3 %	Stakeholder acceptability	4	Only the NGOs will probably oppose to this solution, as it also concerns a hard structure. Due to the open sea view it is probably less perceived as ugly by the tourists and also no water quality impact occurs in this solution.	0.372
	3.4 %	Stakeholder engagement	3	Similarly to the T-groynes, NGOs will be opposing to this solution as well as it concerns hard structures and thus very unlikely to be engaged to the solution. Other stakeholders are more easily engaged as they are less opposing to the solution.	0.102
Risk management	16.5 %	Risk severity	2	Unlike the T-groynes, the groynes a very low possibility to negatively affect the quality of the water. However, the other risks involved are mostly the same with the same probability and impact.	0,330
	6.8 %	Risk acceptability	3	Just like the risks of the T-groynes, the involved risks unique to the solution can mostly be prevented with extra attention to the design phase, making the risks and its measures easily acceptable.	0,204
	100 %				**3.038**

Table H.15 | MCA assessment for beach nourishments

MISSION AREA	WEIGHT	OBJECTIVE	SCORE	EXPLANATION	OUTCOME
Sustainability	8.5 %	Impact	3	Being a soft measure, beach nourishments are considered to have a low environmental impact. However, fauna can be adversely affected by nourishing a large layer of sand on the existing beach.	0.255
	1.7 %	Integrality	5	Nourishing the beach will provide the system with additional sand, this will probably alleviate problems elsewhere.	0.085
	5.9 %	Resources	3	As beach nourishments need to be executed every couple of years, the current limited supply might be a problem. This might change, due to ongoing seabed exploration. However, this would require dredging equipment, which would also radically change other aspects regarding this solution.	0.177
	3.4 %	Durability	2	As beach nourishments have a much shorter lifetime and thus need to be executed every couple of years, their durability is relatively low.	0.068
Solution	5.1 %	Verification	5	The uncertainties in the beach nourishment are the most accurate, because the side effects that are not taken into account are minimal. Therefore, the beach nourishments are the most reliable solution compared to the other solutions.	0.225
	15.3 %	Validation	5	By nourishing the beach, the client's needs are satisfied the most. Beach nourishments have no objections regarding tourism, as it ensures a wide and natural looking beach. Also, soft measures are preferred by both the NGOs and the Marine Department.	0.765
	5.9 %	Effectiveness	3	Beach nourishments are less effective than the other solutions, as the coastline will retreat from the new established coastline. So, the beach will gradually become less and less wide during its lifetime.	0.177
	0.8 %	Efficiency	4	Due to its shorter lifetime, beach nourishments are considered to be less efficient as they need to be executed every couple of years to maintain their width. However, this can be done during the low season, which causes minimal hindrance to the tourists and is therefore perceived slightly less efficient than the other solutions.	0.032
Project management	16.5 %	Financial	1	Since beach nourishment requires a lot of material (soil) and since the material price per cubic meter is approximately the same as the material price of groynes (rock) beach nourishment is considered relatively expensive.	0.165
	0.8 %	Planning	5	Because the worst-case scenario is that the lifetime is shorter than expected, beach nourishments can be executed relatively quickly. If the lifetime would too short, this could be addressed later without any further issues.	0.040
Stakeholder management	9.3 %	Stakeholder acceptability	4	As this solution concerns a soft structure that looks natural with low environmental impact, the solution will probably be accepted by all stakeholders except perhaps the environmental interest groups.	0.465
	3.4 %	Stakeholder engagement	4	Based on the fact that this solution has high stakeholder acceptability, it is very likely that the opposing stakeholders can be persuaded into engaging to the solution. Also project investors might need to be engaged, as this is a quite expensive solution.	0.136
Risk management	16.5 %	Risk severity	5	The solution has few risks which are unique to beach nourishments, since there are no hard structures in the water. Furthermore, these risks have little impact on the project.	0.825
	6.8 %	Risk acceptability	5	Beach nourishments has little risks and the risks involved can easily be dealt with, giving the solution a high risk acceptability	0.340
	100 %				**3.755**

Table H.16 | MCA assessment for coarse nourishments

MISSION AREA	WEIGHT	OBJECTIVE	SCORE	EXPLANATION	OUTCOME
Sustainability	8.5 %	Impact	2	Local fauna can be affected by larger grain diameter and resulting steeper profile of coarse nourishments. Also, the steeper profile might result in more wave action, which alters the fauna's habitat and might lead to loss of species at the beach site.	0.170
	1.7 %	Integrality	1	Coarse nourishment will reduce the longshore transport at the site also leading to lee side erosion. When using coarse nourishment at one location, special attention needs to be paid to the transition area as significant erosion could be expected there.	0.017
	5.9 %	Resources	2	In order to apply coarse nourishment, a more coarse sediment source needs to found first. Subsequently, a large amount of this material needs to be transported, which could prove to be an issue.	0.118
	3.4 %	Durability	4	As coarse nourishments should have a longer lifetime than beach nourishment, their durability is considered to be much higher.	0.136
Solution	5.1 %	Verification	4	Compared to the beach nourishments, the coarse nourishments are slightly less reliable as more wave action might be caused by this solution. Therefore, the verification for this solution is slightly lower.	0.204
	15.3 %	Validation	4	Coarse nourishment might be less satisfactory to the tourists, as they generally prefer fine sand over coarser grains. Therefore, the validation of coarse nourishment is slightly lower than beach nourishment. However, it is still perceived as a natural looking and a soft measure and therefore preferred by NGOs and the Marine Department.	0.612
	5.9 %	Effectiveness	4	Coarse nourishment is more effective than beach nourishment, as the newly established coastline will retreat less quickly.	0.236
	0.8 %	Efficiency	5	As coarse nourishment has a longer lifetime than beach nourishment and thus needs less maintenance, this solution is also perceived as highly efficient.	0.040
Project management	16.5 %	Financial	1	Since beach nourishment requires a lot of material (soil) and since the material price per cubic meter is approximately the same as the material price of groynes (rock) beach nourishment is considered relatively expensive. No distinction is made between coarse nourishment and normal nourishment since the price of the sand will be approximately the same. However, since there is no source in the near area, transportation costs will be more significant than those of normal nourishments.	0.165
	0.8 %	Planning	3	Coarse nourishments need to be planned carefully as it is virtually impossible to remove the sediment after nourishment. Also, more research has to be carried out regarding the effect of the steeper profile on wave action and environmental impact.	0.024
Stakeholder management	9.3 %	Stakeholder acceptability	3	Besides the environmental interest groups that might oppose based on the same aspects as with beach nourishments, the tourists might also be an opposing stakeholder, as they prefer fine sand over a more coarse material. Besides, the environmental interest groups might also be more opposing in this case as even more species might be lost.	0.279
	3.4 %	Stakeholder engagement	3	Similarly to the beach nourishments, this solution is quite likely to engage stakeholders. However, due to more environmental impact compared to the beach nourishment it might be slightly less easy to engage the environmental interest groups. Also, tourists are also likely to oppose to this solution and thus also need to be persuaded, which will however not be impossible to do. Also project investors need to be engaged, as this is a quite expensive solution.	0.102
Risk management	16.5 %	Risk severity	4	Though few risks as well, there are a few significant risks since coarser sand is not commonly used. Nevertheless, the impact of the risks is small compared to the hard structure solutions.	0.660
	6.8 %	Risk acceptability	4	Availability of material risk might be difficult to deal with and thus less acceptable to the stakeholders. Nevertheless, there are still fewer risks than those of the hard structure solutions and might therefore be more acceptable to the stakeholders.	0.272
	100 %				**3.035**

I. Interviews

In order to get a better insight into the project, we arranged ourselves a three-day site visit to the project location, Cha-Am. During the site visit we analysed the project area, take sand- and water samples, visit the on-going projects, and conduct interviews. This appendix will provide the interviews that have been conducted as well as some photographs of the interviewees.

Figure I.1 | Conducting interviews during site visit. (a) Tourist at Cher Resort, (b) restaurant owner, (c) local fisherman, (d) hobby fisherman, (e) local fisherman, (f) tourist at Platoo restaurant, and (g) resident manager at Novotel Hua Hin Cha-am Beach Resort & Spa (own ill.)

Category	: Hotel/Resort	1
Name resort	: Novotel Hua Hin Cha Am Beach Resort & Spa	
Function of interviewee	: Resident manager	

Do you experience any problems with the beach? If yes, what?
Yes, the beach is not clean because the wastewater from the villages in the area is dumped into the seawater. The wastewater is dumped into the canals and the canals flow into the sea next to our hotel. Also, there are many rocks in the sea in front of our hotel. The rock structure that used to be in front of this beach was destroyed during the storm and the rocks are still in the water. Moreover, we have a lot of jellyfish, so it is a big risk if you go swimming in the sea. Another problem that is experienced by the local people is that they think that the natural habitat and the sea are destroyed by the breakwaters. According to the community, sand comes into the canals, which causes fish, shellfish, etc. to die due to lack of oxygen.

Are you aware of the coastal erosion problem?
Yes.

How does the coastal erosion affect you/the hotel?
There are some guests that are complaining about that there is no proper beach, a real beach. But those complaints mainly come from the western guests. I don't think that it has an impact on the amount of guests, because we have also have many guests from Bangkok and the Philippines and they prefer the swimming pool over the sea.

Is there enough beach right now or is more beach necessary?
I would like it if there would be more beach, because that would mean more guests. Also I would like more beach because then we could provide beach activities such as water-skiing, canoeing, jet skiing, etc. A few kilometres north there is a lot more beach and there they have sailboat activities.

What are your expectations of the future of the resort and the beach?
I hope that the government will really look into the coastal erosion problem and see Cha-Am as an important tourist destination. Right now the beaches are really dirty and unattractive. Sometimes you can even smell the odor from the canal.

What is in your perception the cause of the coastal erosion problem?
I don't have any idea what could be the cause of the coastal erosion.

How should the erosion problem be solved according to you?
I think we should have a rock-structured barrier just like the other ones in the area at the south.

Who have tried to solve it? Was it successful in your opinion?
There used to be a barrier over here and there also used to be a little beach in front of our resort. This little beach was about a few meters, but it was a real beach. However, this was only temporarily solution. Also, the government tried to make artificial beaches with sand bags a few months ago. These sand bags were supposed to be covered by sand, but during the storms the sand disappeared and now the sandbags are exposed.

Have you tried to solve the problem yourself? Alone or in collaboration? Was it successful?
Not the erosion problem, but we are trying to solve the problem with the canal. Every month our staff is cleaning the canal and maintaining the opening of the canal so the water can go in and out. Also, we made an artificial beach ourselves. We built a sea wall and put some sand on it.

What do you think about the following alternative solutions? What do you think is the best solution?
I think the alternative of land reclamation during low tide is a bit weird. I really like the alternative of an artificial island in front of the beach, because this gives us the opportunity to provide our guests with activities. I dislike 8 because this is too artificial!

Category	: Hotel/Resort
Name resort	: Chaamaran
Function of interviewee	: Hotel owner

2

Do you experience any problems with the beach? If yes, what?
No

Are you aware of the coastal erosion problem?
No

How does the coastal erosion affect you/the hotel?
It doesn't affect me or the hotel too much. Guests do complain about the beach but not about the hotel itself. We don't experience any decrease in guests.

Is there enough beach right now or is more beach necessary?
There is enough beach, but it should be more clean and more beautiful. People should feel more responsible for the beach, especially the tourists. For example, they should clean up after themselves.

What are your expectations of the future of the resort and the beach?
I think it will be better in the future, because of the customer service. Also, if the beach will be cleaner then it will be better for the hotel and the guests.

What is in your perception the cause of the coastal erosion problem?
Too many people on the beach and the area cannot handle it.

How should the erosion problem be solved according to you?
That's difficult because there are too many problems (cleanness, etc.). People should have a sense of personal responsibility first. Everyone should work together to solve the problem.

Who have tried to solve it? Was it successful in your opinion?
I don't know.

Have you tried to solve the problem yourself? Alone or in collaboration? Was it successful?
No.

What do you think about the following alternative solutions? What do you think is the best solution?
See Table I.1.

Category	: Hotel/Resort	3
Name resort	: Banluansan	
Function of interviewee	: Hotel owner	

Do you experience any problems with the beach? If yes, what?
Yes, there is too much rubbish on the beach and too many sun loungers.

Are you aware of the coastal erosion problem?
Yes

How does the coastal erosion affect you/the hotel?
We experience a decrease in guests, but we do not decrease or increase the prices.

Is there enough beach right now or is more beach necessary?
There is enough right now, but it should not decrease any further.

What are your expectations of the future of the resort and the beach?
We would like a more beautiful and clean beach for our customers.

What is in your perception the cause of the coastal erosion problem?
We think that the erosion problem is caused by the rubbish. There is too much rubbish on the beaches.

How should the erosion problem be solved according to you?
People should not throw their rubbish on the beaches and feel more responsible for their own garbage.

Who have tried to solve it? Was it successful in your opinion?
Everyone can solve the problem because the beach is open to everyone.

Have you tried to solve the problem yourself? Alone or in collaboration? Was it successful?
No, because it needs to be done in collaboration. I cannot solve the problem by myself. The cleaning of the beach should be done together.

What do you think about the following alternative solutions? What do you think is the best solution?
-

Name resort : Blue Moon Cha-Am
Function of interviewee : Hotel owner
Place of interview : Cha-Am

4

Do you experience any problems with the beach? If yes, what?
Yes, the beach is the worse in the morning at low tide. At low tide there are a lot of stones so you cannot walk barefoot. Also, there are a lot of shells. I heard that this is because of the fishermen. They take all the shells with them when they are catching squid and crab with their big nets. There is also a lot of trash on the beach and in the sea, which is stuck on the breakwaters and the stones at the seawall.

Are you aware of the coastal erosion problem?
No

How does the coastal erosion affect you/the hotel?
I never thought about it up until now. This area is really touristic, it's only 2 hours from Bangkok. It would be a problem for me is the beaches are becoming smaller.

Is there enough beach right now or is more beach necessary?
The beaches should be wider.

What are your expectations of the future of the resort and the beach?
I would like it if the beaches were cleaner and more tidy on the beach and of course a bigger and wider beach.

What is in your perception the cause of the coastal erosion problem?
I think that it has a natural cause, maybe because of the waves? I actually don't have any knowledge on this area.

How should the erosion problem be solved according to you?
I have no idea. Can it be solved?

Who have tried to solve it? Was it successful in your opinion?
The government has tried to solve it with the barriers. I think the barriers are ugly and they are the cause of more trash. The government hasn't taken this area seriously. Pattaya, a city across the sea, is already really clean and beautiful. I want the government to take this area as seriously as that area.

Have you tried to solve the problem yourself? Alone or in collaboration? Was it successful?
No, because there is no association for local businesses in this area. I think there should be one. There is no paperwork at the beach stalls. No one knows which beach is whose, so no one feels responsible. So it is also hard for the government to manage the area.

What do you think about the following alternative solutions? What do you think is the best solution?
Bigger grain size on the beach and the island in front of the beach would be nice alternatives. The extra beach nourishment would be nice too, but I don't think that this is a long-term solution.

** **NOTE**: Half of this area is owned by the King, so that may be the reason for the people in this area to be more or extra loyal to the King.*

Category	: Tourist	5
Nationality	: Thai	
Place of interview	: Platoo restaurant @ Cha-Am	

How long are you staying here?
Only one day.

Why do you go to the beach?
To make some pictures.

Why did you choose this beach?
-

How often do you go to the beach here?
Monthly

What would make you go to this beach more often?
A clean and relaxing beach that is not too busy.

Do you experience any problems with the beach? If yes, what?
I can't really tell, because it is my first time here.

Are you aware of the coastal erosion problem?
No.

Do you care about the coastal erosion?
Yes.

What is in your perception the cause of the coastal erosion problem?
That's a difficult question. I think it is because of human behaviour.

How should the erosion problem be solved according to you?
We have to make people aware that it's going to be a big problem soon. Also, the government has to take charge.

What do you think about the following alternative solutions? What do you think is the best solution?
See Table I.1.

Category	: Tourist	6
Nationality	: Thai	
Place of interview	: Cher Resort @ Cha-Am	

How long are you staying here?
Two days

Why do you go to the beach?
For relaxation

Why did you choose this beach?
Because it is beautiful

How often do you go to the beach here?
Often

What would make you go to this beach more often?
If it was even more beautiful

Do you experience any problems with the beach? If yes, what?
Yes, there is a lot of trash on the beach

Are you aware of the coastal erosion problem?
Yes

Do you care about the coastal erosion?
Yes

What is in your perception the cause of the coastal erosion problem?
The sea and its waves

How should the erosion problem be solved according to you?
Perhaps build a dam or a seawall

What do you think about the following alternative solutions? What do you think is the best solution?
The mangroves look like the best solution to me, because it is functional and pretty.

Category : Tourist
Nationality : Thai
Place of interview : Cha-Am boulevard

7

How long are you staying here?
-

Why do you go to the beach?
I am travelling around, and this was on my list.

Why did you choose this beach?
Because it is clean

How often do you go to the beach here?
-

What would make you go to this beach more often?
More impressive beach

Do you experience any problems with the beach? If yes, what?
No

Are you aware of the coastal erosion problem?
No

Do you care about the coastal erosion?
Yes, because I fear the collapse of the coast

What is in your perception the cause of the coastal erosion problem?
I really do not know

How should the erosion problem be solved according to you?
I also do not know the answer to this question

What do you think about the following alternative solutions? What do you think is the best solution?
-

Category : Tourist
Nationality : Dutch
Place of interview : Cha-Am beach

8

How long are you staying here?
Just a few days

Why do you go to the beach?
To relax and enjoy the nice weather and scenery

Why did you choose this beach?
Just another stop on my tour through Thailand

How often do you go to the beach here?
This is my first time staying here and I've been here to the beach two times during my stay.

What would make you go to this beach more often?
I would like it if the beach was cleaner. There are a lot of shells, seaweed and other natural debris. Trash caused by humans can also be found everywhere. Plus I would like a wider beach, it will give better and more private places to choose to stay on the beach.

Do you experience any problems with the beach? If yes, what?
The biggest problem for me would be the debris and rubbish everywhere. Second biggest would be the small beaches. Then the water quality, as it is not as clear and clean as in the south.

Are you aware of the coastal erosion problem?
Yes

Do you care about the coastal erosion?
Of course!

What is in your perception the cause of the coastal erosion problem?
Probably the storms and waves caused by the wind. I don't really have the knowledge to explain the problem.

How should the erosion problem be solved according to you?
I don't think I have the expertise to know the solution.

What do you think about the following alternative solutions? What do you think is the best solution?

1. *Negative, since the beaches will continue to disappear.*
2. *Positive, the more beach the better.*
3. *Negative, if it will negatively affect the beaches.*
4. *Negative, the beaches should either stay or be improved.*
5. *Negative, I prefer fine sand.*
6. *Positive, since they will be in the water and not negatively affect the beaches.*
7. *Neutral, it depends on the water between the coast and the island and the facilities on the island. Won't the problem just be shifted from the coast to the island?*
8. *Neutral, not sure about the hotel, but a beautiful park would be nice.*
9. *Positive, if it is necessary. Perhaps some recreational purposes can be built on the groins? Some benches and greenery.*
10. *Negative, beaches are necessary for good tourism.*

Category	: Tourist
Nationality	: Dutch
Place of interview	: Platoo Restaurant

9

How long are you staying here?
I will only be here for a couple of days.

Why do you go to the beach?
Most of the time I go to the beach to sunbathe or just for a stroll along the shoreline.

Why did you choose this beach?
I chose this beach because we wanted to have some dinner and went to Platoo.

How often do you go to the beach here?
This is my very first time here.

What would make you go to this beach more often?
I think if the beach was a bit more attractive to tourists. Now you only have a few restaurants and a lot of hotels and resorts, but you don't see any sunbeds or activities at the beach even though this is a touristic area.

Do you experience any problems with the beach? If yes, what?
The beach is not that clean and at some points there is no beach at all at high tide.

Are you aware of the coastal erosion problem?
Yes I am.

Do you care about the coastal erosion?
Sure, it would be a shame if there wouldn't be any beaches along the coast anymore. I also think that it affects the natural habitat in the sea when the beaches disappear.

What is in your perception the cause of the coastal erosion problem?
I'm not really familiar with how coastal erosion works, but I think that it's just natural, so because of the wind and the waves that roll over at the coastline.

How should the erosion problem be solved according to you?
I think that there should be one integral solution for the whole coastline, if you look to the south side you'll see some structures that have already been built. However, they protect only a little part of the coast. I don't know how the government works, but I think that an integral plan would be a good start in solving the erosion problem.

What do you think about the following alternative solutions? What do you think is the best solution?

1. Negative. If you do nothing than all the beaches will disappear eventually.
2. Positive. If this works, than I think that this would be the best solution because this way it stays natural, or at least is seems like it's natural.
3. Negative. I don't really think that the view on mangroves is nice when you lay on the beach.
4. Negative. There should be a beach at the coast, not a swamp.
5. Neutral. I personally prefer fine sand, but if this stops the erosion then this is a good option.
6. Neutral. We have this at the Netherlands, but I don't know if this will also work here.
7. Positive. But only if the island is not too close to the coast.
8. Positive. But only if the hotel is not to immense, because it destroys the view.
9. Positive. This is already done at the south side and it seems like it works. I also like the view of the little fishing boats that are parked at the breakwater.
10. Negative. This area is a very touristic area in high season and I think that a touristic area needs a beach.

Category : Restaurant/Shop owner
Place of interview : Cha-Am

10

Do you live in Cha-Am?
Yes

Do you experience any problems with the beach? If yes, what?
Yes, the coastal erosion

Are you aware of the coastal erosion problem?
Yes

How does the coastal erosion affect your business?
Less customers

What is in your perception the cause of the coastal erosion problem?
No idea

How should the erosion problem be solved according to you?
The coast should be protected. Maybe build a dam/sea wall to protect it from the waves.

Who have tried to solve it? Was it successful?
-

Have you tried to solve the problem yourself? Alone or in collaboration? Was it successful?
He needs the government to care of the coast and solve the problem.

What do you think about the following alternative solutions? What do you think is the best solution? (show pictures)
2, 3, 5, 8, 9 are the best solutions.

Category : Restaurant/Shop owner
Place of interview : Cha-Am

11

Do you live in Cha-Am?
Yes

Do you experience any problems with the beach? If yes, what?
Yes, because the waves destroy the coast and the mangroves. They also destroy parts of the parking lot.

Are you aware of the coastal erosion problem?
Yes

How does the coastal erosion affect your business?
Yes, the amount of tourists decreases because there are not enough parking lots.

What is in your perception the cause of the coastal erosion problem?
I think that it is happening from the wave, the quality of the water and the increased level of water every year.

How should the erosion problem be solved according to you?
There should be rocks to protect the land.

Who have tried to solve it? Was it successful?
People who rent out sun loungers. They tried to bring rocks to expand the land but it is not enough.

Have you tried to solve the problem yourself? Alone or in collaboration? Was it successful?
Every section of the beach with the people working/living there has to look after the mangroves and the government must look after all the sections too.

What do you think about the following alternative solutions? What do you think is the best solution? (show pictures)
7, 9, 10 are good solutions I think.

Category : Restaurant/Shop owner
Place of interview : Cha-Am

12

Do you live in Cha-Am?
Yes

Do you experience any problems with the beach? If yes, what?
Yes, there is a lot of rubbish at the beach.

Are you aware of the coastal erosion problem?
-

How does the coastal erosion affect your business?
-

What is in your perception the cause of the coastal erosion problem?
-

How should the erosion problem be solved according to you?
-

Who have tried to solve it? Was it successful?
No one ever tried to solve the problem.

Have you tried to solve the problem yourself? Alone or in collaboration? Was it successful?
I can't do it all alone, because every section has its own owner. So everyone should work together.

What do you think about the following alternative solutions? What do you think is the best solution? (show pictures)
-

Category : Restaurant/Shop owner
Place of interview : Cha-Am

13

Do you live in Cha-Am?
Yes

Do you experience any problems with the beach? If yes, what?
Yes, because there is a lot of waste at the beach.

Are you aware of the coastal erosion problem?
Yes

How does the coastal erosion affect your business?
Less customers

What is in your perception the cause of the coastal erosion problem?
-

How should the erosion problem be solved according to you?
We need to build a protection line along the coast.

Who have tried to solve it? Was it successful?
There is no one who tries to fix it, and solve the problem.

Have you tried to solve the problem yourself? Alone or in collaboration? Was it successful?
No, we need to work together to solve the problem.

What do you think about the following alternative solutions? What do you think is the best solution? (show pictures)
Number 2 and 3 are the best solutions.

Category : Restaurant/Shop owner
Place of interview : Square behind the Mrigadayavan Palace

14

Do you live in Cha-Am? YES / NO
Yes

Do you experience any problems with the beach? If yes, what?
Yes, because the coastal erosion has been destroying the coast every year.

Are you aware of the coastal erosion problem? YES / NO
Yes

How does the coastal erosion affect your business?
Sometimes it affects my business, but not too much. My food stall is behind the Mrigadayavan Palace, which has many tourists even if it's not high season, so I always have the guests that visit the palace.

What is in your perception the cause of the coastal erosion problem?
I think that the change in ecology is the cause.

How should the erosion problem be solved according to you?
I think that a dam should be built or a wall to protect the coast.

Who have tried to solve it? Was it successful?
I have no idea who have tried to solve the problem, but there are people who made some constructions.

Have you tried to solve the problem yourself? Alone or in collaboration? Was it successful?
No, but I think that we have to work together to solve the problem.

What do you think about the following alternative solutions? What do you think is the best solution? (show pictures)
I think that number 2, 3 and 9 may be appropriate solutions.

Category : Restaurant/Shop owner
Place of interview : Cha-Am

15

Do you live in Cha-Am? YES / NO
Yes

Do you experience any problems with the beach? If yes, what?
Yes, there is a lot of rubbish on the beach and the coast is eroding.

Are you aware of the coastal erosion problem? YES / NO
Yes

How does the coastal erosion affect your business?
It does affect my business, it causes a decrease in customers.

What is in your perception the cause of the coastal erosion problem?
I don't know what could be the cause, I don't have the knowledge.

How should the erosion problem be solved according to you?
I don't know.

Who have tried to solve it? Was it successful?
It hasn't been solved yet.

Have you tried to solve the problem yourself? Alone or in collaboration? Was it successful?
No, but we should work together to solve it.

What do you think about the following alternative solutions? What do you think is the best solution? (show pictures)
All the alternatives, except for alternative 1, could be a good solution.

Category : Local inhabitant
Place of interview : Cha-Am

16

Do you live in Cha-Am? YES / NO
Yes

Do you experience any problems with the beach? If yes, what?
Yes, there is many rubbish on and around the beach. There are also many dogs walking around.

Are you aware of the coastal erosion problem? YES / NO
Yes

How does the coastal erosion affect your business?
Sometimes we experience a decrease in customers.

What is in your perception the cause of the coastal erosion problem?
I don't know.

How should the erosion problem be solved according to you?
I don't know, but it should be solved.

Who have tried to solve it? Was it successful?
I think that no one has tried to solve it yet.

Have you tried to solve the problem yourself? Alone or in collaboration? Was it successful?
No, I haven't.

What do you think about the following alternative solutions? What do you think is the best solution? (show pictures)
I think that the boulevard would be the best option.

Category : Local inhabitant
Place of interview : Cha-Am

17

Do you live in Cha-Am?
Yes

Do you experience any problems with the beach? If yes, what?
Erosion problem

Are you aware of the coastal erosion problem?
Yes

How does the coastal erosion affect your business?
No

What is in your perception the cause of the coastal erosion problem?
Natural causes

How should the erosion problem be solved according to you?
The government should help solve the problem

Who have tried to solve it? Was it successful?
The government should solve the problem and solve together with the people

Have you tried to solve the problem yourself? Alone or in collaboration? Was it successful?
I cannot do it by myself. It should be solved in collaboration.

What do you think about the following alternative solutions? What do you think is the best solution? (show pictures)
Number 2 is the best solution

Category : Local inhabitant
Place of interview : Cha-Am

18

Do you live in Cha-Am? YES / NO
Yes

Do you experience any problems with the beach? If yes, what?
Yes, erosion problem

Are you aware of the coastal erosion problem? YES / NO
Yes

How does the coastal erosion affect your business?
Yes

What is in your perception the cause of the coastal erosion problem?
Yes

How should the erosion problem be solved according to you?
No

Who have tried to solve it? Was it successful?
No, not successful. They have tried every year by themselves.

Have you tried to solve the problem yourself? Alone or in collaboration? Was it successful?
Everyone protects their own land.

What do you think about the following alternative solutions? What do you think is the best solution? (show pictures)
The road (boulevard) and the beach nourishments are the best.

Category : Local Inhabitant
Place of interview : ...n

19

Do you live in Cha-Am?
Yes

How often do you go to the beach here?
Almost every day

Do you experience any problems with the beach? If yes, what?
Yes, the erosion of the beach

Are you aware of the coastal erosion problem?
Yes

Do you think that the coastal erosion problem has an impact on you/your job?
Yes, because of the erosion might be a threat to my house. It might collapse or get under water.

What would make you go to this beach more often?
-

How should the erosion problem be solved according to you?
The government should be involved and take care of the councils of Cha-Am. So there are people responsible for the protection of the land from the water.

What do you think about the following alternative solutions? What do you think is the best solution?
The groins should be built.

Category	: Other locals	20
Occupancy	: Fishermen	
Place of interview	: Fishing dock near the offshore breakwaters	

Do you live in Cha-Am?
Yes.

How often do you go to the beach here?
Every day.

Do you experience any problems with the beach? If yes, what?
We used to experience a lot of storms that caused very high tides. But the princess made structures and now we experience less problems then before the structures.

Are you aware of the coastal erosion problem?
Yes.

Do you think that the coastal erosion problem has an impact on you/your job?
Yes, we used to work more south, about 1 km, near the trees and now we shifted to this place. But it's better now.

How should the erosion problem be solved according to you?
I think that there should be breakwaters everywhere along the coastline. We can also use the breakwater as a shelter. It protects our fisher boats from the wind.

What do you think about the following alternative solutions? What do you think is the best solution?
We cannot do nothing, because the water will destroy everything. I think the mangroves are the most beautiful solution, but the sea doesn't have the right soil for the mangroves to grow so it's not possible. I tried to grow the mangroves myself, but I failed because the lack of clay. The land reclamation at low tide is not possible, because the fishing boats need to get to the land safely, so their should be openings. This is the case in the alternative with the island in front of the beach. This is a beautiful solution and the boats can even come inside. The alternative with the hotel on top of the breakwater would be a good solution for the community. The alternative with the offshore breakwaters seems good to me, because it's working now. But the breakwaters should be closer to one another. Right now we also use the breakwaters as parking spot for our boats. The last alternative is good, but we don't have enough money to realize this. The government doesn't want this, it has already done at Prajubkireekan province.

Category : Other locals
Occupancy : Hobby fishermen
Place of interview : Beach near Mrigadayavan Palace

21

Do you live in Cha-Am?
Actually I'm from England but I'm planning on retiring here. I have a house in Hua Hin for 20 years now.

How often do you go to the beach here?
Infrequently

Do you experience any problems with the beach? If yes, what?
No, not at all. Except from the rubbish all over the beaches.

Are you aware of the coastal erosion problem?
Yes.

Do you think that the coastal erosion problem has an impact on you/your job?
I think this problem has an impact on the world in general.

What would make you go to this beach more often?
If they provide some services, like food and drinks or general facilities like restrooms.

How should the erosion problem be solved according to you?
I have a feeling that the impact of the sea could be reduced. If between the barriers, not all of them because they still need access and they still need movement, but on some of the barriers if there was wave generation it would reduce the impact of the waves on the beach and it would also provide a source of renewable energy. That's my personal thing, I think that would help.

What do you think about the following alternative solutions? What do you think is the best solution?
An erosion problem is addressing, so "Do nothing" is not an option, because it is important to have beaches. Tourism is quite important for Thailand and if the beaches vanish then the tourism will also vanish. The option of a bigger grain size would be a mistake. If you want to increase the tourism you'll need fine sand. I don't know if the island in front of the beach would be cost-effective, if it is then I think it would work. The offshore breakwaters with groins are a complex thing. The breakwaters change the whole thing, due to the wave impact. I think that the impact on the land should be researched. My wife already wrote a letter to the princess with the idea of implementing wave generators on the breakwaters. So maybe you can look into that alternative. The boulevard option is awful, well that's what I think personally.

Category	: Experts	22
Name	: Mrs. Duangrudee (University Lecturer)	
University	: KMUTT	

What is your relation with the Thai beaches?
They are the popular travelling spots in my country.

Do you experience any problems with the Thai beaches? If yes, what?
Yes, the erosion on the coastal zone in Bangkok, which is very close to my university. However, if this question is about only beaches, we also have the erosion problem in many beaches.

Are you aware of the coastal erosion problem in Thailand?
Yes

How does the coastal erosion affect you?
In Bangkok, there was the boundary landmark for the Bangkok area. However, the area on one side of Bangkok is now located in the Gulf of Thailand because of the erosion problem. I could say that it is not directly affected to me but the problem is in the larger scale, which can cause the problem in the community.

What is in your perception the cause of the coastal erosion problem?

- *Land use*
- *Type of soil or soil characteristics / Geomorphology*
- *Flow direction / Rain / Wind / Natural behaviors*
- *Human activities*

How should the erosion problem be solved according to you?
In my opinion, I prefer soft measures with no structure. I think that it would be better if human activities will not negatively affect the beach or coastal area. Moreover, using natural method for example mangroves, to protect coastal zone from erosion may help.

Were the attempts to solve the problem successful in your opinion?
In some places, they are successful but not completely success. It may take some more time to improve the method. Also, the community should be the main core parameter to solve this problem.

Have you tried anything to bring awareness to or to solve the problem yourself? Alone or in collaboration? Was it successful?
Since I have some students take erosion and sedimentation class of mine. I do ask them to study from the existing situation. Some of them visit the location and talk with community. I hope it may let people aware of this problem.

Do you think the amount of beach available is enough?
Yes, it is.

What are your expectations for the future of the beaches?
There should be some ideas that can solve the problem and can be integrated with some other soft measures. From those ideas, everyone should be happy with the solution. The beaches can be used as a touring spot and local community can accept the solution.

What do you think about the following alternative solutions? (see pictures) What is in your opinion the best alternative?
Number 2 and 3 might be the best solutions for me, as I mentioned the soft measures without structure. I still believe that using the hard structures may cause other continuous problems as usual.

Category : Experts
Name : Mr. Warat (University Lecturer)
University : T

23

What is your relation with the Thai beaches?
I am just a visitor.

Do you experience any problems with the Thai beaches? If yes, what?
Yes. Many beaches in the country, for example, Pattaya, Cha-Am, Hua-Hin, are being scoured.

Are you aware of the coastal erosion problem in Thailand?
Yes.

How does the coastal erosion affect you?
This affects in the sense that we are losing the lands that are residences of a lot of people and recreation areas that persuade million visitors from both inside and outside the country. This will surely affect the local and global economy, and thereafter, reflects back to myself.

What is in your perception the cause of the coastal erosion problem?

- *Global warming due to CO_2 emission results in the rising of sea level*
- *Poor seashore management as can be seen by examples showing that if there are break waters constructed on a location, the current may change to create scouring on the other locations where originally have no problem. The solution for this kind of problem seems not to be case by case, but rather should be done as a whole.*
- *Land subsidence by uses of ground water.*

How should the erosion problem be solved according to you?
Research for the whole seacoast that are affected together, not location by location. Different solving methods can be selected different locations along the affected seacoast, depending on the outcomes of the research.

Were the attempts to solve the problem successful in your opinion?
Locally yes. Globally no. We solved it for a location, at the same time, we create the problem to the other locations.

Have you tried anything to bring awareness to or to solve the problem yourself? Alone or in collaboration? Was it successful?
Yes. I believe that officials know what I mentioned. However we need collaboration from many groups of people, and this is a big problem. Additionally this will be a mega project and thus needs a lot of budget.

Do you think the amount of beach available is enough?
No. We could not think this way while the problem is running, otherwise there will no more beach someday.

What are your expectations for the future of the beaches?
Naturally looking and sustainable against any erosion.

What do you think about the following alternative solutions? (see pictures)
What is in your opinion the best alternative?
Globally, we need to research the seacoasts that are affected as a whole at once. Different solutions can be employed locally to achieve the best global outcome.

Category	: Experts	24
Name	: Jirat Laksanalamai (Civil Engineer)	
Department	: Marine Department, Ministry of Transport	

What is your relation with the Thai beaches?
The Marine Department of Thailand oversee the work against coastal erosion by means the construction of both hard structures and soft solution such as beach nourishment and sand bypassing.

Do you experience any problems with the Thai beaches? If yes, what?
Yes, many coastal areas in Thailand in general either the Gulf of Thailand or Andaman Sea experience erosion to some increasing degree in recent years. The erosion rates are varied depending on different factors, such as land use, morphology, man-made induced construction, etc.

Are you aware of the coastal erosion problem in Thailand?
Yes

How does the coastal erosion affect you?
From Public administration point of view, the Marine Department is responsible for providing good service for the well being of the people. Countering coastal erosion is one of our main responsibility to ensure that the local people, private sectors, and government office that situated along the coast are well protected and safety assurance from the sea threat and erosion problem. From personal point of view, the Thai coast holds significant value to the country identity and also important for tourist industry. All lands along the coast are therefore desired to be preserved as much as possible.

What is in your perception the cause of the coastal erosion problem?
The causes of erosion in general and in Thailand can be categorized in 2 causes; natural causes and man-made induced causes. The Natural causes are storm with more frequent return period due to climate change, and wave with stronger impact due to sea level rise. Manmade-induced causes are construction exceeding to the sea, and intervene with long shore sediment transport. This kind of impact usually cause erosion problem to greater degree than other general causes. The loss of sediment from the rivers due to the existence of many dams on the upper stream is significant to coastal erosion but usually neglected in the public discussion, probably due to a lack of scientific research on its effect.

How should the erosion problem be solved according to you?
Erosion problem should never be solved with typical design of certain structures on any beach with different characteristics. Nowadays, there are agencies who are actively involved in adopting certain typical design in shapes of seawall and revetment. By doing so, more erosion might be induced. The erosion problem should be solved with intensive studies taking into account essential relevant factors such as cause of erosion, land use, and environmental effect. The countermeasure should be done in a way that solves or mitigates problem without inducing other unexpected problem.

Were the attempts to solve the problem successful in your opinion?
Solving coastal erosion problem is one of the most difficult tasks of all because the dynamic characteristics of the system. The attempts to solve the problem so far are both successful and unsuccessful. In some case, even the study in design process was elaborated carefully, the outcome unveiled unexpected adverse effect, and further mitigation had to be made. In my opinion, the knowledge and technology know-how especially the use of mathematical model used by expert are insufficient, and there is lots of room for improvement to sustainable mitigation against coastal erosion.

Have you tried anything to bring awareness to or to solve the problem yourself? Alone or in collaboration? Was it successful?
I have contributed in bringing awareness of coastal erosion and solution to it to the public by participating in collaboration and discussion in many platforms either formal collaboration or public hearing. In several occasions, I exchanged working experience to technical experts and shared awareness to students in academic institutions to certain successful extent.

Do you think the amount of beach available is enough?
It depends on which characteristics of beach are considered; for regular beach without tourist use, there is a need to prevent existing beach from erosion in order to protect damage on housing asset of stakeholders. Meanwhile, in case of tourist beach, despite the erosion rate might be minimal and rather insignificant, due to increasing demand from tourist, many beaches have been increasingly congested with visitors and various use on the beachfront. Therefore, there is a need to adopt beach nourishment on tourist beach as a measure to improve its recreational value.

What are your expectations for the future of the beaches?
According to the trend of solutions being applied inappropriately with the use of seawall and revetment as countermeasure against coastal erosion, there could be the long-term structural erosion on the sand in front of the structure.

What do you think about the following alternative solutions?(see pictures)
What is in your opinion the best alternative?
As abovementioned, the best solution comes with comprehensive study according to significant relevant factors. There is no typical design on this kind of erosion problem on the coast. From your reference alternatives, they are extensively applied along the Thai coast, some as stand-alone measure, and some as combined structures with additional measure of beach nourishment. My perception towards a good willing to solve erosion problem in Thailand is that the trend of solution has been gradually shifted from application of hard structure to mitigating continually with soft measure, such as beach nourishment instead.

Table I.1 | Overview of preferred solutions derived from interviews and questionnaires

Nr.	Description	"Do nothing"	Beach nourishment	Mangroves	Salt marshes	Bigger grain size	Gradual reclamation	New island in front of the beach	Hotels/recreatio n on breakwaters	Offshore breakwaters and groynes	Boulevard	Notes
1	Novotel Hua Hin Cha Am Beach Resort & Spa	-	+	+	+	-	o	+	-	-	-	
2	Chaamaran	+	+	-	o	-	+	+	+	+	+	
4	Blue Moon Cha Am	-	+	o	-	+	+	+	o	+	-	
5	Tourist Platoo Restaurant	-	+	+	o	-	-	-	-	+	-	
6	Tourist Cher Resort			+								1 preference given
8	Tourist Cha-Am beach	-	+	-	-	-	+	o	o	+	-	
9	Tourist Platoo Restaurant	-	+	-	-	o	o	+	+	+	-	
10	Restaurant/Shop owner Cha-Am		+	+		+			+	+		Only preferences
11	Restaurant/Shop owner Cha-Am							+		+	+	Only preferences
13	Restaurant/Shop owner Cha-Am		+	+								Only preferences
14	Restaurant/Shop owner Mrigadayavan Palace		+	+						+		Only preferences
15	Restaurant/Shop owner Cha-Am		+	+	+	+	+	+	+	+	+	
16	Local inhabitant										+	1 preference given
17	Local inhabitant		+									1 preference given
18	Local inhabitant		+								+	Only preferences
19	Local inhabitant									+		1 preference given
20	Fisherman	-	+	+	-	o	-	+	+	+	+	
21	Hobby fisherman	-	+	-	-	-	+	o/+	o	+	-	
22	University lecturer KMUTT		+	+								Only preferences
23	University lecturer KMUTT											More research needed, combination of solutions possible
24	Civil Engineer Marine Department											More research needed, preference for soft measures