Delft University of Technology

Oceanus International

Colciencias

Multidisciplinary Project

Vibeke van der Bilt
Floortje Roelvink
Tymen Olthoff
Rutger Komen
Tim Horst
Auke Tempel

Group P228

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Preface

As part of the curriculum of the Civil Engineering master at the Delft University of Technology the 'Project Group Colciencias' was created. Six students of the Hydraulic Engineering faculty formed this group to execute a multidisciplinary research project. Early on, an alliance was formed with Oceanus International about a redevelopment project in Playa del Carmen. However, about two weeks before our departure to Playa del Carmen, Mexico, the political situation in the province suddenly changed. The government had changed, leading to a drastic increase of violence. Our safety could not be guaranteed. So we canceled our project in Playa del Carmen and quickly discussed our possibilities with Pablo Besquin, our sponsor and CEO of Oceanus International, and Henk Jan Verhagen. Eventually we came to an agreement, Colombia it was! We were going to do a project about the coastal problems in the northern region of Colombia. In this project, the governments of the departments of La Guajira and Magdalena were involved, as well as their local Universities, the Universidad del Norte, INVEMAR and Oceanus International.

We would like to thank Pablo Besquin for inviting us to Colombia, for giving us the opportunity to work independently and for his flexibility about the project location. We would like to thank Oscar Sorza, representative of Oceanus International in Colombia, for accompanying us to presentations, appointments and the fieldwork in Ciénaga. Both Pablo Besquin and Oscar Sorza helped providing us with all the information and resources required to fulfill the project.

Furthermore, we would like to thank our helpful contacts at the University of Cartagena: Dalia Moreno and Javier Mouthon-Bello. They were willing to give us a detailed insight and overview of the coastal projects in Colombia and the way they are executed. Next to that, they openly discussed the political and economical situation in Colombia.

At last we would like to thank our two supervisors Henk Jan Verhagen and Sierd de Vries for helping us during the project.

Vibeke van der Bilt *Floortje Roelvink*
Tymen Olthoff *Rutger Komen*
Tim Horst *Auke Tempel*

Cartagena, September 2017

Abstract

Colombia's economy has been growing steady in the past decades, partly because of the increase in tourism. However, this tourism also has a downside. Hotels and restaurants are constructed one after another, preferably along the coast. This, combined with factors such as climate change and land subsidence and the fact that people tend to prefer living close to the coast, leads to a vulnerable and erosive coast, especially in the departments of La Guajira and Magdalena. Therefore, Project Colciencias was initiated by three local universities and two companies, a large scale study to improve and implement coastal projects in this area. Focus is on areas that experience critical erosion; erosion that puts local economy, environment and national heritage at risk (Oceanus, 2013). Ten objectives are formulated by the five different parties, e.g. characterization of the coast, development of pilot projects and socialisation of coastal projects.

The goal of this multidisciplinary research conducted by TU Delft students in cooperation with Oceanus International is to improve the Colciencias project by combining Dutch and Colombian expertise, technology, efficiency and theory. After analysing the political, cultural, social, hydraulic and environmental situation, and after consulting various stakeholders three research objectives were stated and elaborated.

The first goal is to create a framework to ensure a consistent and efficient implementation of the intended pilot projects. Not only does it cover the hydraulic aspects of a project, it also takes into account the socio-economic, environmental and legal factors. To support the part of the framework that comprehends the hydraulic analysis and the development of alternatives for coastal protection, a detailed document on numerical models is written. This is objective number two. Next to information on numerical models in general, the three main types of coastal models are discussed; coastline, regional - and local morphodynamic models. Eight specific models are then further highlighted, resulting in a decision tree that helps in choosing the best model for your specific engineering application. To test the framework, a case study was executed in one of the critical erosion zones, the village of Ciénaga. The framework was followed concisely to evaluate its effectiveness and efficiency. Among other things, a field trip was organised to carry out experiments and execute a survey to explore the socio-economic values of the region. Next to that, interviews were carried out with officials and local parties to obtain information on past projects and the local legal framework. From the case study it was concluded that the framework functions, but that it should be noted that the case study is only a test of the framework, and that much further research needs to be conducted for the actual design and implementation of the coastal plan for Ciénaga.

Lastly, our goal was to start a dialogue about the impact of integrated coastal zone management and coastal erosion problems. In practice this resulted in many interviews, a survey, attendance of local community meetings, presentations at the Universidad del Norte for stakeholders of the project and an informal gathering of students at the Universidad de Cartagena. Furthermore, the framework shall be distributed to possible stakeholders as well as an informative presentation along with an introductory movie.

Note to Reader

When reading this report, you should keep in mind that the setup of this report differs from the "standard" setup. This note will help you understanding the setup and will guide you through the report.
The report starts with an elaborated system analysis in part one. In this analysis, some background information about the project and the general research question are given. In order to answer and specify this question, different analyses about the area and the Colciencias project are done. A conclusion about these analyses is made in the end of part one. This conclusion contains an elaborating of the research question by three main objectives. These three objectives are worked out in part two, validated in part three and discussed in part four.
In part two, the plan policy, these new objectives are all integrated into a newly developed framework. This framework can be seen as the main product developed in the project, which necessity was shown in part one. Since the framework can be seen as a manual, you will notice that the used writing style switches from an academic style to a more instruction style. The rest of the report is written academically again.
In the third part a validation of the developed framework is done by a case study. It is tested that the framework functions properly. Furthermore this case can be used as an example for other users of the framework.
In the fourth and last part the project will be closed by means of a conclusion, a discussion and recommendations.

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Part I

System Analysis

1 Introduction

Background

The shape of a coastline inevitably changes over time due to changes in the coastal processes. However, the latest years the erosion rates have increased significantly due to human activities near coasts all around the world (van Rijn, 2011). The rise in activity can be attributed to many factors, e.g. housing, agriculture, industry, mining, tourism. In Colombia, tourism is increasing particularly fast due to the attractive coastline and favourable weather. In 2013 its contribution to the Gross National Product (GNP) amounted to 3400 million US dollars, 13% more than the year before (ANATO, 2017). This growth leads to high investments in construction and infrastructure near the coast to meet the demand for housing and recreation. Although regulations exist for building in close proximity to the waterline, the enforcement of these regulations is often weak. That is why you find many large hotels, small family homes and other real estate directly at the coastline. Whole ecosystems are destroyed to make way for these structures. At the same time, the current structural erosion leads to a decrease of beach area; at this moment, 50% of the Caribbean coast of Colombia is eroding. This combination endangers the coastal environment and increases the economical and societal risk of both storm induced -and structural erosion.

To mitigate these problems, interventions in the coastal system are made. However these measures are not always effective. A few previous projects are discussed in Appendix A. Many structures are placed under pressure of local authorities without considering the environmental impact on the long run. The erosion problems are thereby only solved locally by shifting the problem to the next-door neighbor. Furthermore, hard structures such as breakwaters and groynes downgrade the scenery which can eventually harm tourism income (Nelson Guillermo Rangel-Buitrago, 2015). This approach of coastal zone management could hinder economic growth in the future. Therefore, new methods and techniques are explored and research is conducted to ensure a sustainable development of the coastal area. One of these research projects is the so-called 'Project Colciencias', a study about the Caribbean coast of Colombia and research topic of this report.

The project

By analyzing satellite imagery of the Caribbean coast of Colombia, it can be concluded that between 1980 and 2014, most erosion was visible in the departments of La Guajira and Magdalena (Nelson Guillermo Rangel-Buitrago, 2015). In La Guajira erosion rates of up to 4m/yr were identified, and the Magdalene Department is even more extreme with a maximum erosion rate of 15 m/yr, see Figure 1.1.

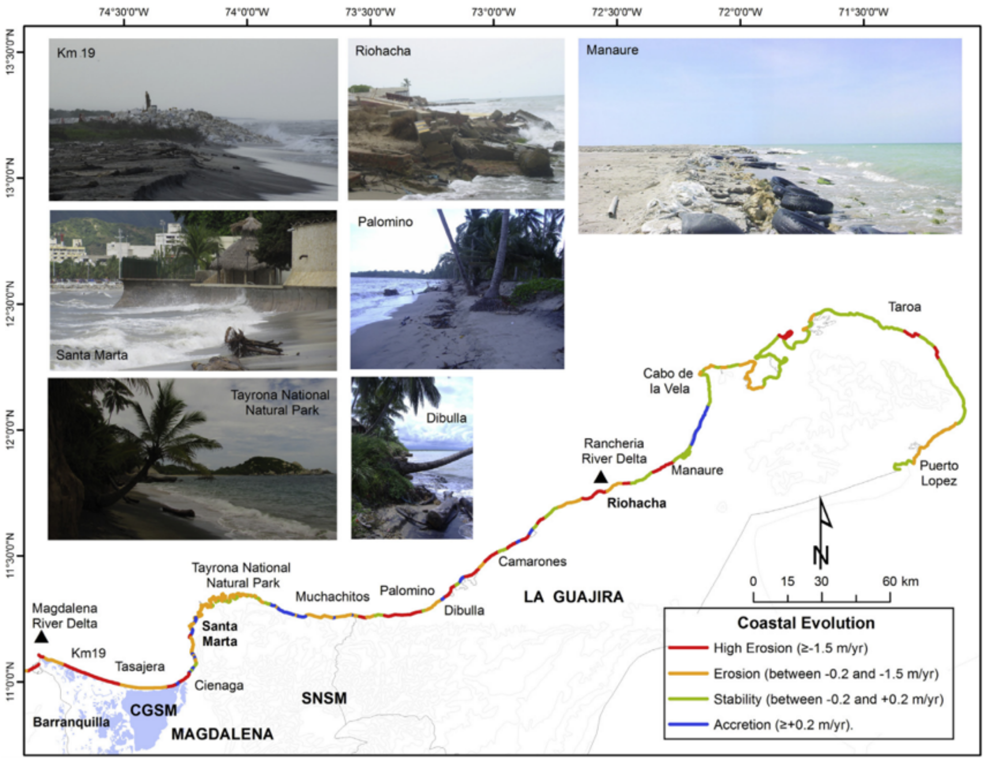


Figure 1.1: Coastal evolution trend for the 1983-2013 period and erosion examples along the La Guajira and Magdalene Departments (Nelson Guillermo Rangel-Buitrago, 2015)

Therefore Project Colciencias was initiated, a large scale study about the coast of Magdalena and La Guajira. Several Universities and private parties work together to develop tools for coastal protection and to implement them in pilot projects. Oceanus International, a Mexican engineering company, is one of the aforementioned stakeholders and sponsor of this TU Delft multidisciplinary research project. Essential in this cooperation is the combination of Dutch expertise on coastal zone management and the Colombian knowledge of local phenomena and other factors influencing local coastal projects. Therefore, the starting point of this research is formulated as follows:

"How can a Dutch student team contribute to the improvement of coastal protection measures along the coast of Magdalena and La Guajira?"

In the next chapter, analyses will be made of the Colombian (coastal) system after which the research objectives are formulated.

2 Analyses

Analyses about different systems are made to strengthen knowledge and perception of the different components that control and influence ICZM in Colombia. Understanding this system's functioning facilitates developing sustainable and pragmatic policies to management (Nelson Guillermo Rangel-Buitrago, 2015). The following subjects as part of the system, are covered in the next paragraphs: the Colciencias project, the involved stakeholders, Colombian's culture and politics, and the hydraulic and environmental aspects of the region. To enhance the readability and structure of the analyses, the goal of the analysis is described at the beginning of each new section.

2.1 The Colciencias Project

Since the project is commissioned by Oceanus International, one of the five parties of the Colciencias project, an elaborated understanding of the total project scope ensures the insight of where the possibilities of contribution are in the project. The focus of the analysis is about the objectives, the connections between the different parties and an overview of previous, future and on-going operations. With this analyses, problems and opportunities within the Colciencias project can be detected.

2.1.1 Context

Colciencias, also known as the Administrative Department of Science, Technology and Innovation, is a program which aims, since its founding in 1992 in Colombia, to support researchers to undertake high-level education programs in cooperation with the best universities in the country and around the world, through the financing of studies. Colciencias approved this project but has no further impact or influence on the project. It serves as a certificate.
The specific Colciencias project discussed in this report, is initiated by five different institutions, who all have their responsibilities. The different institutions are: Universidad del Magdalena, Universidad de la Guajira, Oceanus International (and thus TU Delft), Universidad Del Norte and Invemar. These different institutions are elaborated upon in the stakeholder analyses.

2.1.2 Objectives

The Colciencias project that is discussed here, focuses on parts of the coast that contain critical erosion, which puts at risk local economy, environment and national heritage (Oceanus, 2013). The main goal of the Colciencias Project is the protection and recovery of the coastal area in the Departments of La Guajira and Magdalena and the preservation of the national heritage.
This goal is elaborated with ten objectives, and executed by the different parties. Which parties are responsible for which objective, can be shown in Figure 2.1. All the objectives can be read in Appendix B, just like the corresponding obtained results. Since 2012 the project is on-going and results are retrieved. Note that the project is not finished, since not all desirable results are achieved yet.

With a critical look, the objectives and results that are the responsibility for the client Oceanus International are taken in consideration. This results in the following evaluation of the objectives:

- Objective 4 "Evaluate alternative wave dissipation technologies applicable to coastal protection on the beaches of the Departments of La Guajira and Magdalena, based on physical tests and scale" must be expanded. Not only wave dissipation technologies need to be evaluated, but also morphodynamic models that are applicable for the coast of Colombia. This leads to more accurate prediction of the sediment transport, which is still missing in the overall objective.
- Objective 5 "Design pilot and methodological projects for the protection and recovery of beaches in the Departments of La Guajira and Magdalena" is already executed for two pilot problems. This is done on two different critical erosion points executed by different parties with different approaches. Besides the execution of separated pilot projects, a general approach for projects needs to be developed. Through such a general assessment a more integrated and consistent approach in ICZM can be reached.

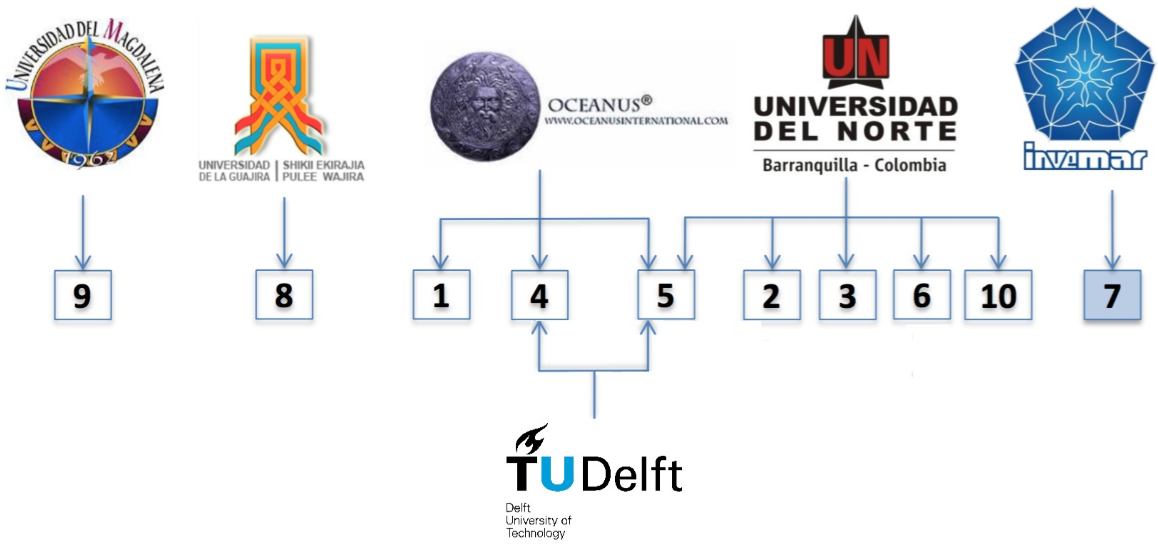


Figure 2.1: Responsibilities of each institution

2.2 Cultural and Political Analysis

When working in a unfamiliar environment, cultural and political differences can be of great influence on efficiency. Misunderstandings due to cultural and political differences can lead to unsolvable problems, delay of the project or simply offended employees. These negative consequences of a cross-cultural collaboration can be prevented by a cultural and political analysis.

2.2.1 Cultural Analysis

For the cultural analyses, two models are elaborated here. The Lewis Model and the GLOBE model. These two models combined, give an elaborated analysis.

The Lewis model judges a country on its behaviour. According to the model Colombians belong to the multi-active group on behaviour (Lubin, 2017). The multi-active group contains countries that act primarily on emotions. The Colombian behaviour is warm, emotional, loquacious and impulsive. Their behaviour is based on feelings and creating commotion which is quickly forgotten after an agreement is reached. The multi-active group does not plan or schedule extensively, but rather takes tasks that seem important and relevant at the time (Alythea Ho, 2014). A broader explanation and grouping of countries based on behaviour according to the Lewis model can be found in Appendix C.

The scientific and anthropological GLOBE model is used complementary with the Lewis model. The GLOBE model judges a country on 9 dimensions with a present -and value score. The value score represents the score that a country strives for, or the should be score that is desired by a culture. The practise score (as is score) is the value that is actually present at the moment. On top of these two scores, the value -and practice score range of all countries are shown. This enables an easy comparison between cultures worldwide. The cultural visualisation of Colombia is shown in Figure 2.2. (House. Et al., 2002)

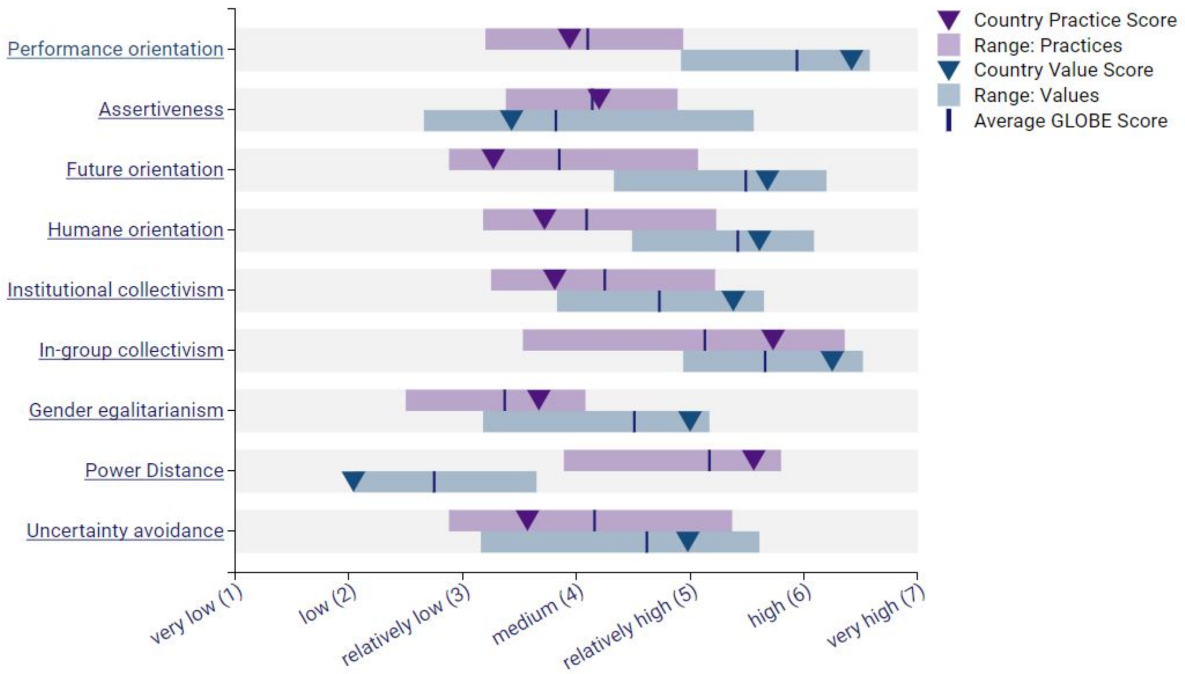


Figure 2.2: Cultural visualisation of Colombia. (GLOBE, 2017)

The most important conclusions from the GLOBE framework are discussed here. For a more elaborate explanation about each dimension, see the Appendix C. From the GLOBE framework, it can be concluded that the most important thing in the Colombian culture is loyalty towards social groups and family. The in-group collectivism dimension shows that the focus in the Colombian culture currently lies on friends and family and this scope will not change in the future. Although there is a desire to change towards performance, future and humane orientation, Colombia struggles with authorities, impulsive actions and inequality. Public rewards or evaluations of authorities barely occur and a reward system is barely present, although it is desired by the regular citizen. The spontaneous character of Colombians reduces the orientation towards the future. citizens live from day to day, although the corporate life demands more planning. The country's elite keeps power and wealth to itself, thereby increasing inequality and poverty. The power-distance relation is high, but should be low according to citizens. Genders are treated equally and have more or less the same chances in business life. Colombians are open for change, and desire a more equal society, less uncertainty and a more future orientated view.

2.2.2 Political Analysis

In this section, the political system is analyzed. Hereby the focus is about the regulation for the execution of a project. The current political system of Colombia consists of a presidential representative democratic republic. The department of Magdalena is one district which is subdivided into 30 municipalities. Each municipality is governed by a mayor and a municipal council, both democratic elected. The structure of the department of La Guajira is the same as Magdalena. The district La Guajira is subdivided into 15 municipalities. All the democratic elections are based on a 4-year term. After this 4-year term politicians cannot be re-elected. In this way it is hard to establish a long-term vision and is corruption tempting for politicians. Even though the government consists out of three parts; executive, legislative and judicial part, corruption still occurs. The corruption rate in Colombia is 37 out of 100 points (International, 2016).The executive branch is carried out by the government. A president is elected on a four-year term. The president is Chief of state and the Head of Government. The legislative is executed by both the government and by two chambers of congress; the senate and the house of representatives of Colombia. Both the chambers are elected on a four-year base. The judiciary power is executed by itself.

Regulation system Colombia
A National Development plan is made by the government of Colombia. Each municipality and state also has their own development plan. Depending on the kind of the project it concerns a municipality, state or the national government. Information about the regulation system is provide by professor Javier Mouthon Bello, September 15, 2017.
In order to execute a project in Colombia, three aspects has to be undertaken, shown in Figure 2.3.

Figure 2.3: Steps for executing a project in Colombia

Step 1: Proposal
Depending on the development plan, proposals have to be made in order to execute the project plan. The projects are made public and companies can bid on them. The design phase exists of three phases;

1. Pre-factibilidad (Prefeasibility)
2. Factibilidad (Feasibility)
3. Detallado (Detailed)

The companies bidding on the projects have to compete with each other on every stage of the design. When the final detailed design is chosen it needs approval from the government to obtain funding from the government.

Step 2: Approval
Projects for the state need approval from the governor, projects for a city from the mayor. Approval of a project requires a majority within the relevant government. In cities like Barranquilla and Medellin the governments are politically professional. If a project is proposed which is in favour of the community, the government will unanimously agree. For example in Cartagena it is harder to reach a majority within the government. The government is not professional and there is a social problem within the government. It can take a long time to reach a majority just because of the social issues within the government. If someone with political power is demanding the execution of a project, the vice president used to care about coastal protection, the whole process is accelerated enormously. The people with power basically decide which projects will get approval, without this approval it could take months to years. Approval is needed on the following aspects:

1. *Social acceptance*
   Local communities need to approve a project if they are directly involved. Civilians have been mistreated by the government for years, therefore a lack trust has arisen. If a project is proposed which is in favour of a community it is often hard to convince them. Civilians in Colombia do not trust the government that easily and are afraid to get scammed by a project. It takes a long time to let them understand that the government is willing to help. This is a large social problem. Every community needs to give their approval, information about and communication with those communities is difficult. At the start of a project approval can be given by a community and at the final stage their opinion may have changed and the process of approval can start over.
2. *Technical analysis*
   This part needs to be done by engineers.
3. *Environmental Impact Assessment (EIA)*
   EIA is a planning and management tool which focuses on the examination, analysis and evaluation of planned projects. EIA ensures a sustainable and an environmental responsible view. Colombia is one of the countries that has one of the highest biological diversity in the world. Human interventions are threatening the Colombian biodiversity at present. The EIA fights for the conservation of this. For activities required an EIA guideline is made by ANLA (La Autoridad Nacional de Licencias Ambientales), ANLA belongs to the Ministry of the Environment. These guidelines are, according to the rules of the International Industrial Uniform Codes Classification (IIUCC), made by the United Nations (UN). Environmental licenses are subdivided into three groups;
   - Standard environmental license;
     license for construction work that does not require special permission for the use, mobilisation, and exploitation of renewable natural resources.
   - Specific environmental license;
     license including permits for the project or activity;
   - Comprehensive environmental license;
     license that can be both standard and specific, depending on the nature of the con-

struction work or activities related to the exploitation of oilfields and gas deposits. The process of receiving an EIA can take a lot of time. Communication between governmental institutions is slow and they take all time they legally have. This drastically slows down the process. The scheme (see Appendix D) describes the process of receiving an EIA. (Javier Toro, 2010). Abuse of power by the government also applies to EIA. People with power are provided directly with a EIA when necessary. After approval, funding is needed by the senators. Because of corruption, not every senator is objective and it can be hard to receive funding.

Step 3: Funding
Projects are either funded by the government, licitacion publica, or by private investors, Asociaciones Público Privadas (APP). When a project is chosen by the government due to bidding it is also funded by the government. APP is a partnership between private actors like banks and public actors like governmental institutions. Project proposals funded by the APP are not chosen with bidding's between companies. The private actors chose which projects they want to fund. Local government's can fund projects with the money that they have been assigned to annually. They have to spend all the money in that year, penalties are given by national government if the money is not spent, this creates a problem.
An important project can already be funded by senators but not yet be approved by the government. When in this case the approval is delayed the senators are forced to spend the money on something else. Money can not be saved for later use. In this way lots of projects fail because of bed design. There are cities with no sewerage, hospitals or schools but with fancy bus station just because it was the only project that was ready. In these cases, the desperately needed money is wasted.

2.3 Stakeholder Analysis

This analysis is conducted to gain insight in the different parties involved in coastal zone programs. It can also be used as a management tool to identify necessary actions regarding stakeholders. Different stakeholders need to be interviewed, evaluated and classified to obtain both an overview of the organisational structure in Colombia, as well as the capacities, knowledge, involvement, influence and support for the project of the different stakeholders.

In this report, the stakeholder identification and analysis techniques of Bryson, (Bryson, 2004) are taken as reference. This includes a basic analysis, a power versus interest grid and a participation planning matrix.

2.3.1 Basic Analysis

The basic analysis is intended for identifying the various stakeholders and their corresponding relations. The list of stakeholders is further elaborated in Appendix E. In Figure 2.4 the most important stakeholders in the field of ICZM are mapped. Where the primary stakeholders are red coloured.

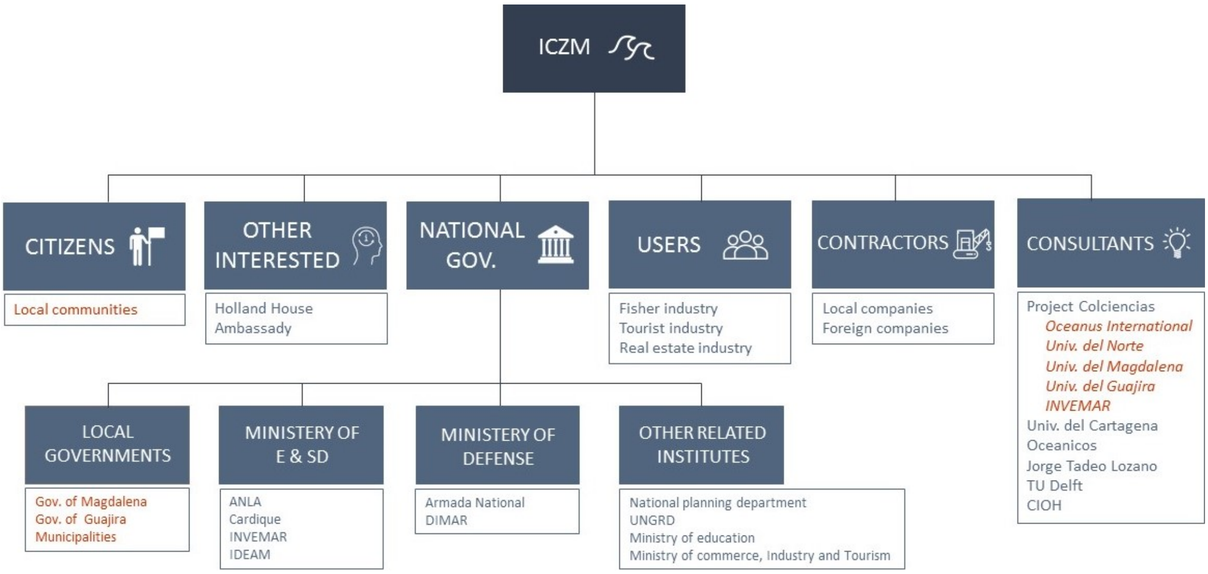


Figure 2.4: Stakeholder map

The primary stakeholders are further elaborated below. They are the initiators of the Colciencias project, the local communities and municipalities.

- *Oceanus International*
  Oceanus International is a Mexican-Colombian company that specialises in finding sustainable and integrated solutions to coastal problems such as coastal erosion, flooding, climate change and environmental impact. It has many contacts around the world, including Dutch institutes such as Deltares and TU Delft, American Universities and most important in this project, both local and national Colombian governments. A separate Colombian division was founded to expand the business in Colombia, to help create a resilient and invulnerable coastal system. It is led by Oscar Soza, a Colombian Industrial Engineer. Oceanus acts both as a consultant and contractor, depending on the type of

project.

- *Invemar*
  Invemar, the Institute for Marine and Coastal Investigations, is a semi-governmental organisation. It's aim is to carry out research to provide scientific knowledge for policy formulation, decision-making and development of plans and projects. This leads to the sustainable management of resources, to the recovery of the marine and coastal environment and to the improvement of the quality of life of Colombians. They have significant experience in the field of Integrated Coastal Zone Management.

- *Universidad del Norte*
  The Universidad del Norte is a non-profit, non-governmental institution that was founded by businessmen, with the aim 'to face the challenges of the advancement of science and the social needs of the region and country' (Bayona, 2017). They have ties to many European and American institutes, and have a large Hydraulic Engineering department (IDEHA).

- Government of Magdalena and Guajira
  The Departments of Magdalena and Guajira, situated on the northern, Caribbean coast, are governed by a Governor and a Department Assembly. They are again subdivided into municipalities, which are run by a mayor and a Municipal council. The wishes and concerns of the local and regional authorities do not always coincide, see Appendix F. Therefore, the Governments of the two departments are highly interested in the project, in order to show communities the benefits of an integrated approach of Coastal Zone Management, hoping to refrain them from intervening locally and hereby destructing the system further.

- *Local Communities*
  On a national or regional level, many institutions work together, as can be seen in the stakeholder map. These partnerships enhance cooperation on on the development, legislation and policy making of ICZM. It is at the local level that national policy directions are translated into action, and the cooperation of the local communities with ICZM is therefore essential. In practice, the commitment to ICZM is still not always present amongst local communities. A number of problems are identified (Hildebrand, 1997). First of all, local communities often have a lack of understanding of the associated risks of living in coastal areas. When problems do arise, even when warned beforehand, they blame the government and ask for support. Secondly, the emphasis of coastal protection should be on implementation and materialisation, which is in contradiction with the government's ICZM approach, where detailed analyses and studies have to be carried out first.

- *Municipalities*
  Although small in size, municipalities can be of major influence on legislation, law enforcement and implementation of projects. Not in the least due to the corruption problems that Colombia is facing. It is often decided locally whether projects continue. Part of ICZM is the determination of public and private area. The eviction of people from this private area is the responsibility of the Municipality. However, evicting people from the beach front, which is public terrain, is difficult. They fear opposition from both the hotel owners, part of the elite of Colombia and the poor people, see Appendix F. For this reason, Municipalities are a key player in this program.

2.3.2 Power versus Interest grid

To further characterise the stakeholders, a *power versus interest grid* is shown in Figure 2.5. On the horizontal axes, the interests of the stakeholder in the ICZM are plotted. The vertical axes are showing the stakeholder's power in a political sense. To elaborate the grid, a comprehensive report enhanced by interviews with the various stakeholders can be found in Appendix E. This grid can serve as a tool that gives insight in the different ways of approaching the stakeholders. The distinction in approach is: satisfy, manage, monitor and inform.

- Satisfy: These stakeholders are the ones that are closest related to the project and the greatest effort is needed to satisfy them.
- Manage: Since these people have also a lot of influence on the project, they need to stay satisfied. But since they are less interested, much contact is not needed.
- Monitor: Keep those people informed, since these group can be helpful with the details of the project.
- Inform: Keep those people informed, much contact is not needed.

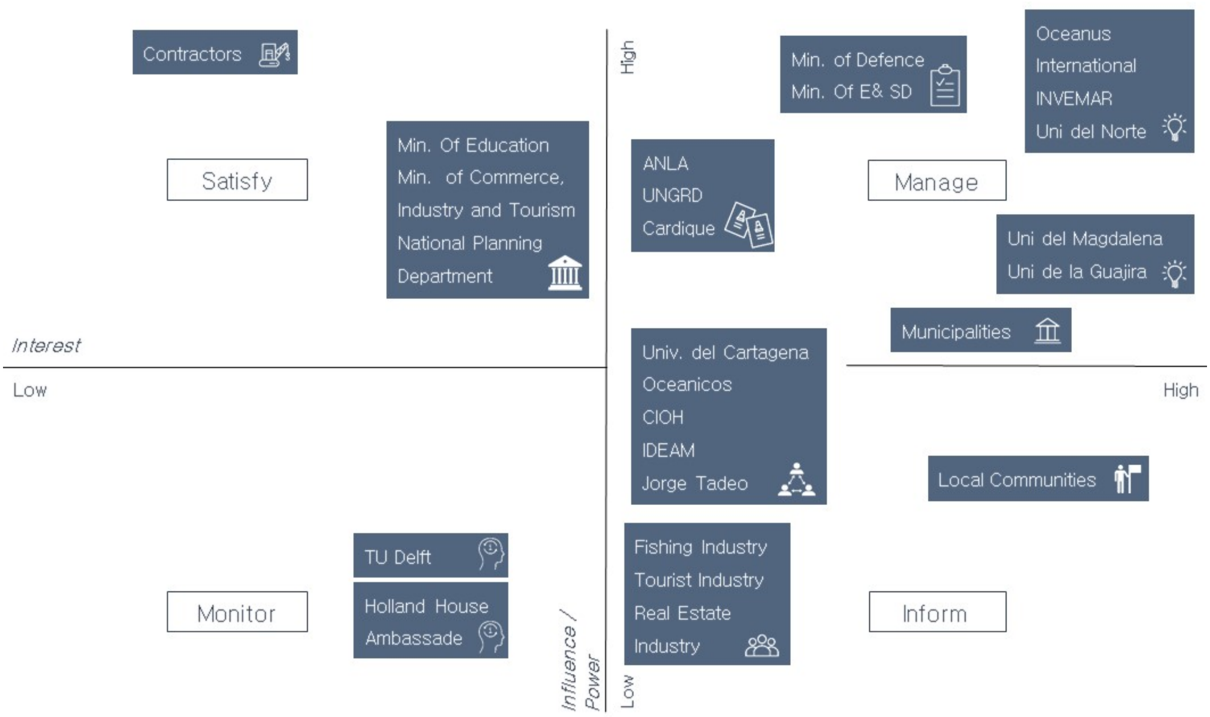


Figure 2.5: Power versus Interest

2.3.3 Participation Planning Matrix

To anticipate the stakeholders' engagement and participation in different phases of the project, the final step in the stakeholder analysis is the *participation planning matrix*. By visualizing their role in the project, stakeholders can be addressed or engaged appropriately, according to their type of participation. To successfully create and implement a ICZM program, this matrix is highly important, as the program will not succeed without the cooperation of the stakeholders, be it on local, regional or national scale. The participation planning matrix is shown in Figure 2.6.

	PROBLEM DESCRIPTION	PLAN AND POLICY MAKING	IMPLEMENTATION	MONITORING AND EVALUATION
INFORM		Users Contractor	Local communities Users	
CONSULT		CIOH, Univ. of Cartagena, TU Delft IDEAM, Oceanicos, Jorge Tadeo Lozano	Min. of Education	
INVOLVE		Municipalities Local Communities Local Governments	Univ. del Magdalena Univ. del Guajira	Local communities Users
COLLABORATE	Oceanus International, Universidades INVEMAR	Colciencias group	Contractors Municipalities	Universidades Oceanus International INVEMAR
CONTROL	Local Governments	DIMAR, ANLA, Cardique, Min of Commerce Industry and Tourism, Min of transport	DIMAR, ANLA, Cardique, Min of Commerce Industry and Tourism, Min of transport	DIMAR, Municipalities, Min of Commerce Industry and Tourism, Min of Transport

Figure 2.6: Participation Planning Matrix

As described during the several steps of the analyses, a lot of parties are direct or indirect involved in Integrated Coastal Zone Management. Though for specific projects, this involvement is not so straightforward. Due to a lack of knowledge and interest in combination with the still significant corruption, stakeholders need to be specified according to the details of a project.

2.4 Hydraulic Analysis

This analysis is conducted to obtain an understanding of the nature of the coastal system and its frequent problems, in order to assess the importance of interventions and coastal protection programs.

2.4.1 Introduction

The focus in this analyses lies on stating the general characteristics of the coastal environment along the Caribbean coast of Colombia. Thereafter a hydraulic analysis of the different problem areas within the project is made.

2.4.2 Caribbean Sea

The general coastline orientation of the coast between Barranquilla and the Venezuelan border is NE-SW with some slight differences around Santa Marta and a large turn at the head of the La Guajira peninsula. This part of the coastline can be subdivided into three different morphostructural sectors.

1. La Guajira Peninsula: this coast consists of granite and metamorphic rocks adjacent to large sand plains.
2. The Sierra Nevada de Santa Marta: coastal mountain with a range of 5800 m. The coast consists of granite rocks.
3. Magdalena River and Ciénaga Grande de Santa Marta: Delta plain with large fluvial sediment deposits

Rain seasons occur from April to May and from October to November with dry seasons in between. From June to November, the Caribbean area is often hit by hurricanes leading to high waves and elevated water levels. From January until March, swell waves caused by cold fronts can form a danger for the coast. Due to high waves, overwash, beach flattening and erosion can occur. The heaviest storm waves measured occurred in 2009 with a significant wave height of 2.5 m. The coast is exposed to a mixed semi-diurnal tide with amplitudes of 65 cm. The highest seasonally significant wave height occurs from November to July. A long-shore south-west current results in a net long-shore sediment transport in this direction. In the rain season, the long-shore transport has a north-east direction in the north-east of Colombia due to southerly winds. The coastline of La Guajira Peninsula is mainly made out of Neogene and Quaternary rocks. These rocky outcrops are the only protection of the low-lying coastline. At the foot of these outcropped cliffs, beaches develop and disappear again due to erosion.

Due to the coastal mountains of The Sierra Nevada de Santa Marta, the coastline in this area mainly exists of outcropped cliffs. Beaches develop in areas protected by cliffs and are fed by mountain landslides. Wide and long sandy bars develop near the mouth of the rivers fed by fluvial sediment.

Due to the large amount of sediment originating from the Magdalena river, the area around Barranquilla is dominated by river deltas. The area between the Sierra Nevada de Santa Marta and Barranquilla is located in the shade of the head of Santa Marta. The waves with a wave-climate orientated N-NE are diffracted by this head and cause erosion downstream (Nelson Guillermo Rangel-Buitrago, 2015) (Oceanus, 2013).

2.4.3 Coast shaping factors

Along the coastline of interest, numerous coastal problems occur. In general, erosion or accretion only occurs when there is a gradient in net long-shore sediment transport, S [$m^3/m/s$]. Gradients in the net long-shore sediment transport are caused by different factors. Each of the erosion problems is caused by one or a combination of these factors. Eight different factors are distinguished and discussed in Table 2.1.

1	Shoreline direction	(red)
2	River sediment input	(green)
3	Coastal caves and sinkholes	(magenta)
4	Tidal basin	(yellow)
5	Shadowing effects	(blue)
6	Man-made structures	(light blue)
7	Relative sea level rise (RSLR)	
8	Storm impact	(orange)

Table 2.1: Causes coastal problems

1. Shoreline direction;
   The net long-shore sediment transport induced by waves is highly dependent on the angle between the deep water wave angle and the coastline, ϕ_0. ϕ_0 can be related to the sediment transport through the following relation (S-ϕ_0 curve):

$$S \propto H_{s,b}^{2,5} * sin(2*\phi_0) \tag{2.1}$$

   A change in shoreline direction will thus result in either accretion or erosion.

2. River sediment input;
   The total amount of sediment that can be transported over the breaker zone can be calculated with the CERC formula:

$$S = \frac{K}{pg(s-1)(1-p)}(Enc)_b * cos\phi_0 * sin\phi_0 \tag{2.2}$$

   A beach in equilibrium will transport the amount S of suspended sediment in the water. When fluvial deposit rates deviate from the breaker zone transport capacity, erosion or accretion of the delta occurs.

3. Coastal caves and sinkholes;
   Underwater caves or sinkholes near the coast form a zero sediment bypass. Much of the sediment suspended in the water will disappear into these holes. The caves are common near leading coasts such as Santa Marta's coastal plain. Downstream of these areas the suspended sediment is below equilibrium, see Equation 2.2. This will result in erosion downstream. The same effect occurs with a very steep bathymetry.

4. Tidal basins;
   An imbalance in long-shore sediment transport can also be caused by tidal basins. A basin either has a net import or export of sediment. This depends on many factors inside the basin, outside the basin and in the inlet, which makes it a complex system. The import or export of sediment has an influence on the long-shore transport. The in- and outflow of water changes the long-shore current which influences the long-shore transport

(for instance outflow could create an offshore current which could result in sediment loss offshore).

5. Natural shadowing effects;
   A natural shadow zone is, due to the geographical shape of the coast, a zone 'protected' from waves. Downstream of coastal obstructions like headlands or islands it is common for shadow zones to occur. The shoreline in the shadow zone is not directly exposed to the wave climate. Depended on the geographical shape of the coast diffracted waves hit the shadowed shoreline in a different angle and with less energy. The amount of sediment that passes the barricade depends on the bathymetry of the area. The amount of sediment passing is important for the downstream evolution of the coastline. If a lot of sediment is trapped in an obstruction upstream it is likely one finds erosion downstream. If no sediment is trapped or the area upstream is already saturated, accretion is likely to occur downstream because of the decrease in wave energy E. A decrease in wave energy E will result in a lower net long-shore sediment transport, see Equation 2.2.

6. Man-made structures;
   Groins, (submerged) breakwaters and jetties are examples of man-made structures. The main purpose of building these man-made structures is to prevent erosion. The method of preventing this erosion is by trapping sediment by means of changing the local characteristics. For example concerning groins, the long shore current gets deflected and decelerated. This causes accretion on the upstream side but also erosion on the downstream side.

7. RSLR;
   The RSLR in this part of the Caribbean is 5,5 mm/y which matches the global trend. This sea level rise can form a future danger for the lower coasts concerning their ecosystems and flood events. Inundations are more likely to occur. During periods of rapid RSLR there might not be enough time to develop sufficient solutions to protect certain parts of the coast. This can lead to extreme erosion, overtopping or flooding events with corresponding consequences (Nelson Guillermo Rangel-Buitrago, 2015).

8. Storm-Impact;
   The main danger of storm events are the extreme wave events that come with them. These events can trigger beach flattening, erosion, overtopping processes, landslides and destruction of structures. Extreme wave events do a lot of damage to beaches due to their high amount of wave energy. If these events do not occur regularly the beaches are able to recover and reach their equilibrium again. If not, their equilibrium state will change, resulting in a different equilibrium shoreline.
   The most extreme storm of the last 15 years was in March 2009 and caused a significant wave height of 2.5 m. The relation between storm wave height and normal wave height determines the danger the storm forms for a certain beach (Nelson Guillermo Rangel-Buitrago, 2015).

2.4.4 Coastline Colciencias Project

In Figure 2.7 and Table 2.2 an overview of the coast and factors that shape the coast is displayed. A brief description about smaller areas is included in Table 2.2 to elaborate the chart in Figure 2.7.

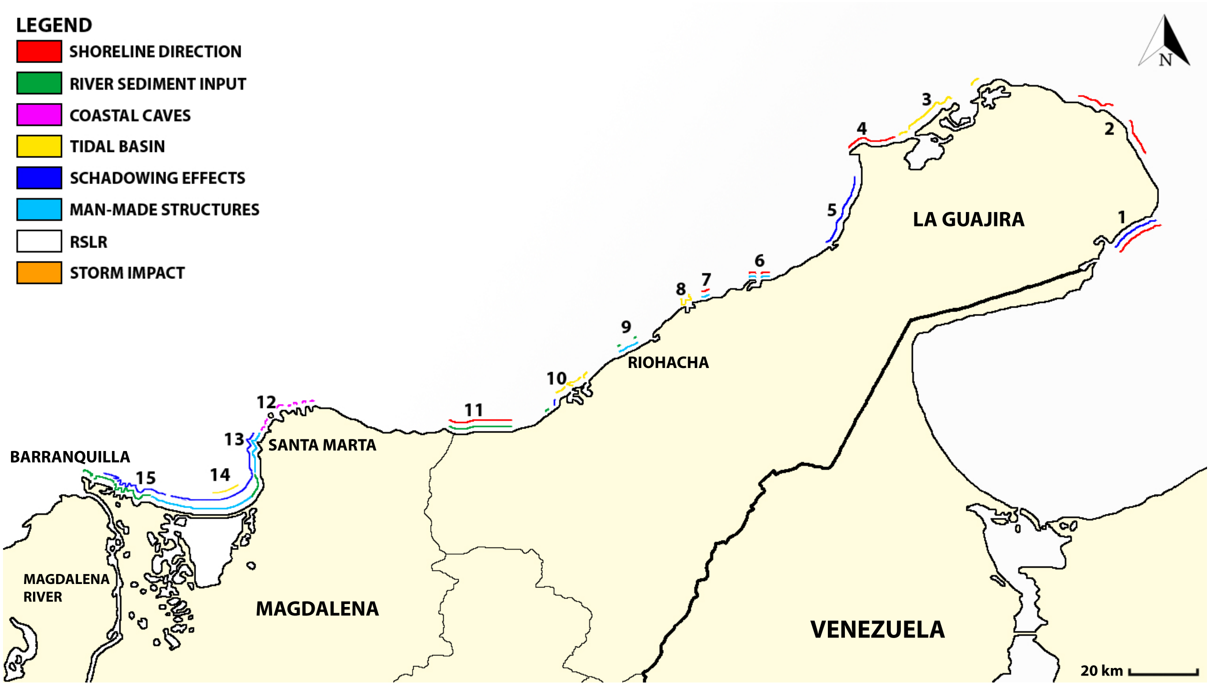


Figure 2.7: Problems per area within the Colciencias project. Numbers correspond with table 2.2

	Area		Problem Description
1	Puerto Lopez		The rocky outcrops that shape this coast function as natural groynes with upstream accretion and downstream erosion. The upstream headland diffracts the waves towards the coastline.
2	Puerto Estrella		Most northeastern point of the peninsula. Wave energy is shifted into alongshore southwest and northeast currents. This results in erosion both upstream as downstream.
3	Tidals Basins Bahia		Possible erosion due to an imbalance of the tidal basins, more research is needed.
4	Kashurop		Piece of land that is totally exposed to the wave climate. High wave impact and critical wave angle results in erosion.
5	El Cardon		Due to the protection of the headland of Kashurop a part of this coast is protected from wave impact. Eroded sediment from Kashurop is deposited behind the headland which results in accretion.
6	Manaure		Coastline parallel to incident wave angle, high alongshore net sediment transport. Human interventions interfere with the coastline which results in downstream erosion.

	Area		Problem Description
7	Pajaro Town		Coastline parallel to incident wave angle, high alongshore net sediment transport. Human interventions interfere with the coastline, which results in downstream erosion.
8	Tidal Basin Pajaro		Possible erosion due to imbalance of small tidal basin, more research is needed.
9	Riohacha		The factors that mostly shape the Riohacha area are the Rancheria river just northwest of the city and the man-made groins and breakwaters in front of the city. Most of this sediment is trapped by the groins in front of the city. These groins cause accretion over a small distance north-west of them and erosion over a large distance south-east of them.
10	Camarones		The tidal basins near Camarones cause a sediment imbalance which causes erosion over large parts in this area. This imbalance does also lead to accretion at some points. More research in this area is needed to determine the exact effect of these tidal basins.
11	Palomino		This area includes the delta of many small rivers supplying the area with sediment. On the eastern part erosion occurs due to the change of the shoreline direction. On the western part accretion occurs because of the same reason.
12	Tyrona Park		This area is an alternation of land abutments and bays. The land abutments have steep slopes leading to sediment loss. The bays are calm areas where almost no erosion occurs.
13	Santa Marta		Due to the shadowing effect of Santa Marta and probably sediment input from little rivers this part of the coast shows local accretion rather than erosion. Throughout the coast from Km19 to Santa Marta, the land abutment of Santa Marta gives rise to lower significant wave heights, causing less erosion relative to the eastern coast of Barranquilla. Different hard structures are situated at Santa Marta. Some of which result in local accretion and erosion.
14	Ciénaga		After creating route 90, thereby closing of the tidal basin of Ciénaga Grande de Santa Marta, a sediment imbalance was created. At Tasajeras the only lasting outlet is situated. Shadowing effects similar to those of Santa Marta Man-made structures main cause for problems. Due to building a road beside the coastline which isn't in morphological equilibrium, causing erosive features. Also the placement of breakwaters are a cause for local erosion/accretion.
15	Barranquilla		East coast of the Magdalena river delta; river sediment of the Magdalena river formed this delta. Nowadays it is eroding away due to incident waves which cause an alongshore transport from east to west. Severe erosive features due to the shadowing effect of the Santa Marta land abutment. The significant wave height is higher until the Km 19 site.

Table 2.2: Problems per area within the Colciencias project. Numbers correspond with Figure 2.7.

2.5 Environmental Analysis

This analysis is conducted to obtain information about both the vulnerability and richness of ecosystems. This gives an insight in the opportunities and restrictions imposed on coastal management by the environment.

2.5.1 Introduction

Colombia is one of the wealthiest countries in the world regarding biodiversity. The loss of biodiversity is occurring at high rates. Human activities endanger entire ecosystems (Javier Toro, 2010). When carrying out a project, the environment should be treated with great care. The Sistema Nacional de Áreas Protegidas (SINAP) is responsible for the sustainability and conservation of biodiversity. The SINAP has been the primary activity of the Colombian government past years (Sesana, 2006). In this chapter the most relevant ecosystems as well as conservation areas of birds and biodiversity will be discussed.

2.5.2 Ecosystems

The relevant part of the Colombian coast is divided by 3 different ecosystems: The tropical moist forest ecosystem, the tropical dry forest ecosystem and the desert ecosystem. In Figure 2.8 is shown how the coast is divided in these three ecosystems. Also mangroves are shown in the same Figure.

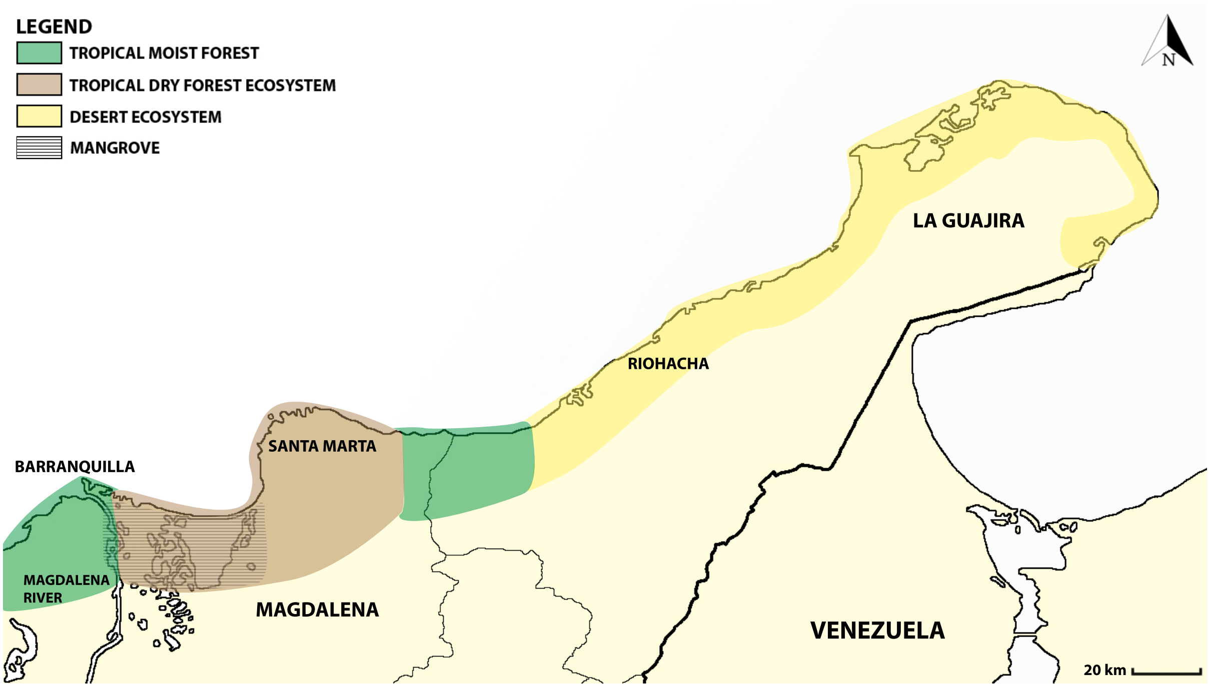


Figure 2.8: Different types of ecosystems near the Colombian coast (Sanchez Cuervo et al., 2012) (Nelson Molinares Amaya. Et al., 2017).

Tropical moist forest ecosystem
With an annual rainfall of 1100 - 1500 mm per year, this system is characterised for having elevations between MSL + 0 m and MSL + 500 m. The combination of rainfall and high temperature creates a very humid environment. The vegetation is characterised by low natural forest and dense packed trees. Moist forest systems account for the greatest diversity of animals and plants (Tracks, 2017) (Nelson Molinares Amaya. Et al., 2017).

Desert ecosystem
With average temperatures above 24 degree Celsius and an annual rainfall of 125 and 250 mm, the desert ecosystem is a very dry environment. With winds blowing in east and northwest direction, the desert area of La Guajira does not have mountains that can function as barriers to force the mass to condense its moisture, therefore remaining very dry. Having a flat terrain, wind erosion dominates the system and creates extensive sand dunes. Vegetation is scarce and consists mainly of cacti, trees, grasses and small thorny bushes (Nelson Molinares Amaya. Et al., 2017).

Tropical dry forest ecosystems
The dry forest ecosystem is characterised by a rainfall of 500 mm to 1000 mm per year with two rainy periods per year, from September to November and May to July. In the two dry seasons, most trees lose their leaves. The vegetation and animals show adaptations to store the water during the dry seasons, such as water conservation in spines, waxy leaves et cetera (Ceiba, 2017). The mountain Sierra Navada de Santa Marta, located Southeast of Santa Marta, influences the precipitation as it serves as a barrier to the persistent trade winds. Vegetation such as mangroves appear in areas close to water. Coconut plantations are also found near the coastline (Nelson Molinares Amaya. Et al., 2017).

Mangroves
Mangroves are found near the sheltered part of mostly moist, but also dry forests. Trees are able to grow in the brackish water, creating habitats for both land and water species. The roots of mangroves grow just above the waterline in order to keep the leaves and trunk above the tideline (Tracks, 2017). Nowhere else such a habitat is found. Terrestrial organisms are found in the trees, while the water is full of marine inhabitants. Mangroves also serve as feeding and nesting sites for many species (Nelson Molinares Amaya. Et al., 2017). On top of that, mangroves serve coastal protection by stabilizing the shoreline, reducing wave impact, controlling floods and reducing erosion.

2.5.3 Conservative areas

Colombia aims to create a national network of conservation areas in the country. The following locations are identified in the preliminary study as areas with increased priority with respect to the conservation of biodiversity. The names of the protected areas are given in Table 2.3 with corresponding locations given in Figure 2.9.

Areas of importance for the conservation of biodiversity	Area (Ha)
Sierra Nevada de Santa Marta	383000
Macuira	25000
Tayrona	15000
Bahia Portete Kaurrele	14080
Isla de Salamanca	56200
Los Flamencos	7000

Table 2.3: Areas of importance for the conservation of biodiversity

Figure 2.9: Biodiversity protected areas as defined in preliminary study. (Nelson Molinares Amaya. Et al., 2017)

2.5.4 Ecosystem services

Ecosystems and biodiversity can have a positive impact on human well-being. These natural systems are called ecosystem services when they are beneficial or valuable for human well-being. Table 2.4 corresponds to an overview of the different ecosystem services in coastal zones. The classification is mainly based on the results of Liquete et al., only here the ecosystem services are further specified based on the particular coastal stretch from Magdalena until La Guarijia (C.Liquete, 2006).

These ecosystem services can provide insight in attaining a solution which uses or even amplifies the natural way of a system. When one aims to make use of ecosystem services in the development of a hydraulic solution one must take on this broad view at the start of a project. In other words, these ecosystem services are shown here to provide the possibility of taking these elements into account when engineering a solution.

Type	Ecosystem service	Coastal component
Provisioning	Food	Fishery for seafood
	Water storage and provision	Coastal lakes, inlets, tidal basins
	Biotic material and biofuels	Industrial resourses
		Biomass (wood from mangroves)
Regulating	Water purification	Treatment by purification
	Air quality regulation	Absorbation of air pollutants
	Coastal protection	Natural protection against erosion
	Climate regulation	Dissolved inorganic carbon
		Formed organic carbon
	Weather regulation	Influence of coastal vegetation on air moisture
	Ocean nourishment	Production of organic matter
	Life cycle maintenance	Habitats and shelter
	Biological regulation	Control of fish pathogens
Cultural	Symbollic and aesthetic values	Local identity
		Traditions and religion.
	Recreation and tourism	Coastal activities
		(e.g. sunbathing, snorkeling, scuba diving)
		Offshore activities
		(e.g. sailing, fishing, whale watching)
	Cognitive effects	Inspiration for arts and application
		Material for research and education
		Information and awareness"

Table 2.4: Ecosystem services

3 Conclusion Analyses

After the analyses, several conclusions about the systems are derived. The main conclusions are summarised below.

The Colciencias project lacks in the realisation of several essential in-depth knowledge about the Colombian Caribbean coast. Morphodynamic models that are applicable need to be used in projects like this. A guideline needs to be developed for the use of this kind of models. Besides this guideline, a structural approach for ICZM is missing.

According to the cultural analysis, it can be concluded that the most important thing in the Colombian culture is loyalty towards social groups and family. The in-group collectivism dimension shows that people like to be part of solutions. This founding is from significant value for the implementation phase of coastal zone management.

In terms of politics, a lot of steps need to be undertaken to execute a project, hence it can be long-winded to get approval and funding.

As described during the several steps of the stakeholder analyses, a lot of parties are directly or indirectly involved in Integrated Coastal Zone Management. Though for specific projects, this involvement is not so straightforward. Due to a lack of knowledge and interest in combination with the still significant corruption, stakeholders need to be specified according to the details of a project.

Looking at the most recurrent factors for either erosion or accretion one must acknowledge the importance of human intervention. The occurring erosive features pose problems in populated areas. In these populated areas they wish for a shoreline which remains in one place, only this shoreline is not near its equilibrium. Besides, it is often the population itself which causes the problems to worsen by building man-made structures which withdraw sediment from the system in one place, creating a deficit in another. Opposite to these problem areas, one finds miles of coastline where human intervention does not play any role of importance. Here shoreline changes may be present as well, only they are part of a natural balancing system, neither endangering environment nor population.

The last conclusion found is that the Colciencias project comprises a large area of the northern Colombian coast. Within this large area multiple ecosystems are present. Each specific problem area entails different environmental characteristics, which require various conditions when it comes to preservation or expansion. Due to this variety in environment it is not possible to establish a single approach in establishing hydraulic solutions.

3.1 Problem description

By analysing all the elements within the Colciencias project a clear problem description can be composed. The concluding remarks of the analyses presented above show that the Colciencias project is a large and broad project containing many factors that contribute to different problem areas. The presence of multiple conditions along the coastal stretch like coastal shaping factors, multiple ecosystems, political, cultural and economical influences all contribute to a complex project.

Would one wish to solve these different problems whilst retaining the same vision, namely the Integrated Coastal Zone Management ideology, it is necessary to come up with a guiding approach. This approach needs to structure the course of developing solutions for different coastal problems.

3.2 Research objectives

As described in the introduction of this report the main research question of this project states the following:

How can a Dutch student team contribute to the improvement of coastal protection measures along the coast of Magdalena and La Guajira?

The problem description partly answers the main research question by establishing that there is a need for a guiding framework to assess different coastal problems within the Colciencias project and come up with long-term solutions that take into consideration both socio-economic and natural values. Only now execution remains and therefore the following research objectives are set:

I Create a framework which leads to a more consistent, transparent, sustainable and integral approach of coastal zone management.

II Develop a manual on software use to encourage the assessment of short and long-term morphological changes.

III Start a dialogue about the impact of integrated coastal zone management and coastal erosion problems.

Part II

Plan & Policy Development

4 Framework

Due to the increase of coastal resource extraction, growing industries and increasing tourism and urbanisation of coastal zones, coastal areas are increasingly exhausted. Negative impacts on the environment such as water degradation, excessive resource usage, accelerated erosion and decrease of biodiversity are common consequences of a non-integrated approach (Fabbri, 1998). To obtain a sustainable solution for the increasing pressure on coastal systems, a multidisciplinary and collaborative process is needed in the form of Integrated Coastal Zone Management. Many theories have been developed in this field that include general instructions on how to protect the coast in a sustainable manner. However, already in 1993 at the Study for the World Coast Conference (Jones & Westmacott, 1993), it was concluded that a general medicine for coastal protection does not exist, and that only very general guidelines are applicable to different social, economic and cultural situations.

The Project Colciencias delivers many tools and manuals to improve coastal protection measures and safeguard an integrated approach, and plans to apply them to the defined critical zones of the region. For this, general guidelines on coastal protection, using the ICZM approach would be most valuable for both the plan development and implementation phase of the pilot projects of the Colciencias project. Therefore a framework is created that helps to find a social, economic, sustainable, long-term orientated solution for coastal problems within the boundaries of the natural environment of the Caribbean coast of Colombia.

4.1 Goal

This framework serves as a tool with which the design phase and implementation of Colciencias' intended coastal programs, especially the design of the pilot projects, are streamlined and simplified. It can be used as a guideline or reference by local engineers. It will help to generate a broad, long-term perspective on coastal zone problems. The dimensioning of the final design is not included in the framework, the tool helps the user to make a substantiated decision about the solution for a specific coastal problem. Furthermore, the proposed framework can be used to create awareness on the importance of an integrated, well-studied approach amongst local authorities and decision makers such as the municipality, mayors and other stakeholders that influence decision making.

4.2 Approach

By conducting interviews, attending meetings of local stakeholders (see Appendix F.2), conducting research on previous projects in Colombia and by investigating different theories on ICZM, this framework was created. Next to this, site visits to pilot projects and again more research was required to validate and improve the framework. This framework incorporates a positive feedback mechanism; it enhances its own impact by the iterative procedure. Several feedback steps bring you back to earlier stages of the framework to improve and perfect the final solution. We encourage you to assess your results after each step to determine whether you can continue to the next step.

4.3 Structure and deliverables framework

In Figure 4.1, a general project timeline is given. As can be deduced from the Figure, the framework is used for plan and policy development. A problem description and research question should be determined beforehand. The implementation step depends largely on the subject of

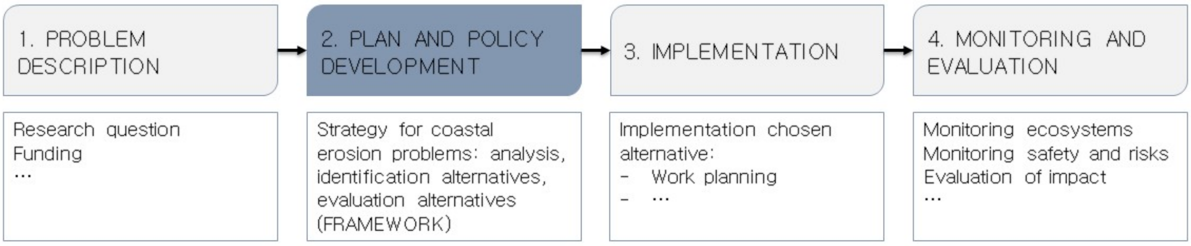


Figure 4.1: Context framework

the project and demands of the contractor and are therefore not included in the framework. However, it is indicated when the implementation step can be commenced. Evaluation of the plan and policy development phase is incorporated, but the evaluation and monitoring of the total project will again depend on the type of project and must be determined after the implementation phase.

The framework consists of the steps that are elaborated below. The phases are also shown in Figure 4.2 and the relations between the different phases are mapped in Figure 4.3.

Step A: Analysis

- Determine the natural and socio-economic boundaries of your study area
- Analyze the involvement of each stakeholder
- Analyze the different system elements
- Identify the development factors
- Identify the relation between system elements

Step B: Development Alternatives

- Identify alternatives for coastal protection
- Assess the morphological impact of alternatives
- Assess the environmental -and socio-economic impact of alternatives

Step C: Final Concept

- Make a substantiated decision between the alternatives
  - Economic feasibility study
  - MCA
- Determine an integral approach to implement the chosen alternative
- Dimension the final design

Step D: Evaluation

- Evaluate the project
- Evaluate the framework

Step E: Awareness

- Determine who you want to reach
- Determine how you are going to do it

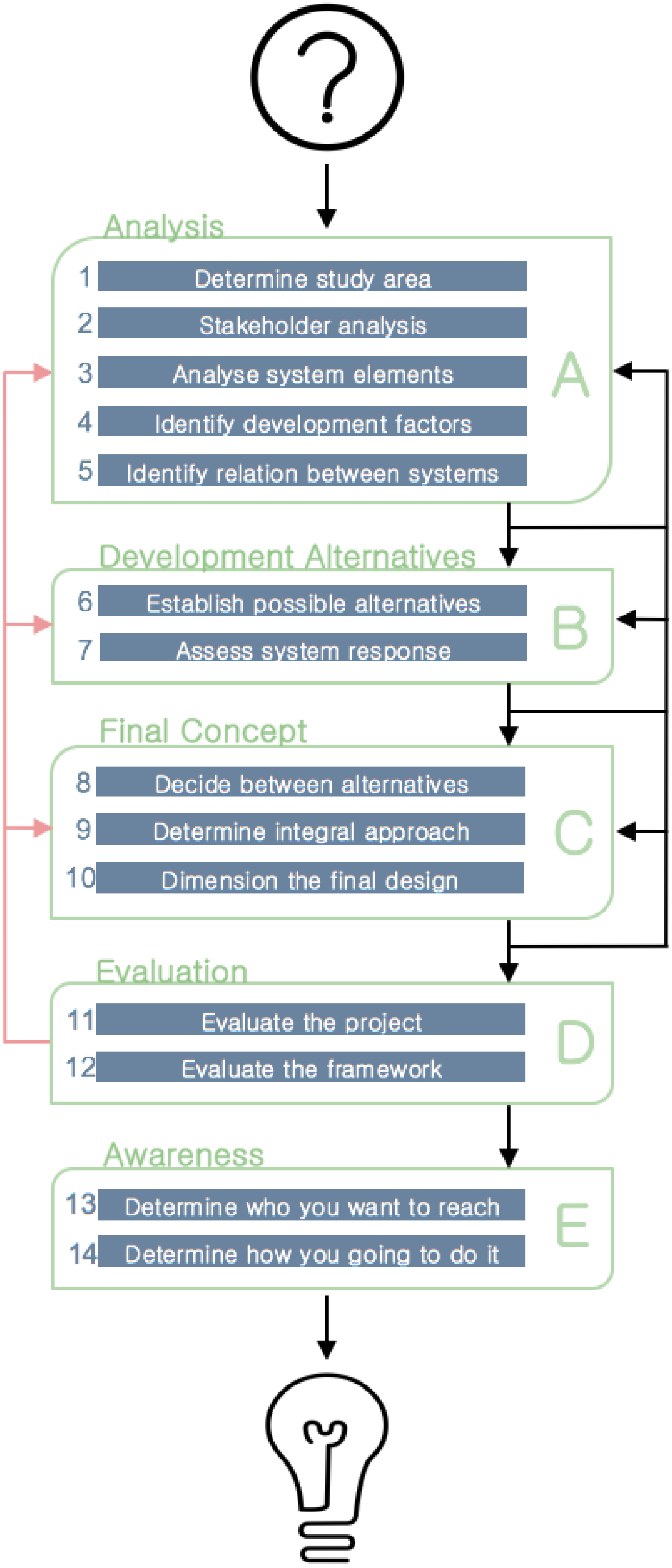


Figure 4.2: ICZM Framework

4.4 Step A: Analysis

The first step of the framework is the analysis of the system. The focus lies not only on the coastal system, but also other subjects such as socio-economic factors need to be treated. In this analysis, the user determines the natural and socio-economic boundaries. Next, you will create an overview of all participating stakeholders and determine their power and interest. Furthermore, each element of the coastal system will be analyzed in a hydraulic analysis and user functions will be identified. Next, development factors, both natural and socio-economic changes, will be investigated and finally you will identify the relations between system elements in the form of an organisational diagram. After Step A: Analysis is done, the user should have enough information to continue to Step B: Development Alternatives.

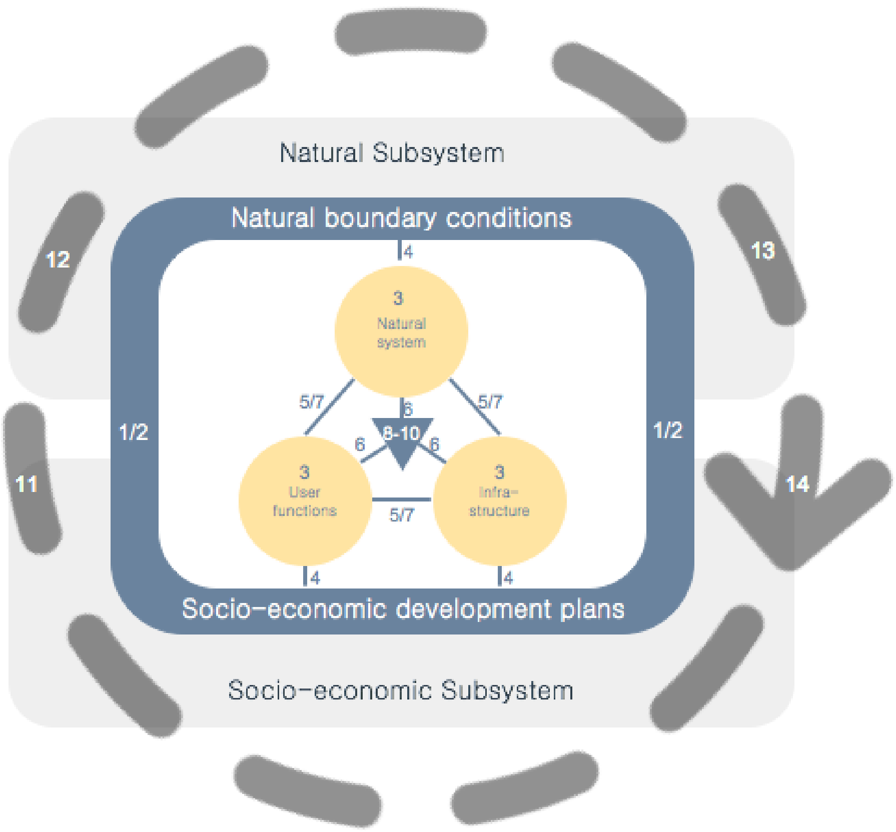


Figure 4.3: Steps within the ICZM Framework

4.4.1 A.1: Determine the natural and socio-economic boundary conditions of your study area

The analysis starts with the determination of the project boundaries that form the starting point of the project. Boundaries exist in different forms: geographically and socio-economic. The boundaries can either include regional, national or international systems. The following factors are helpful to take in consideration when determining the boundaries.

Natural boundary conditions

- Spatial - A description of the geographical setting of the study area. The study area is characterised with corresponding distances and visualised in an image.
- Temporal - The temporal scope of the project must be considered. The project should be designed for a minimum amount of years.

Socio-economic development plans

- Characterisation residents - A rough estimation of socio-economic values such as income, educational level, profession, religion and social class of inhabitants is mapped.
- Targets - Main interests and socio-economic values considered important by inhabitants, such as aesthetic value, safety, costs, et cetera are examined.
- Legislation and limitations - Areas that are limited for alterations are mapped. Legislation that applies to the study area is mentioned.

4.4.2 A.2: Analyse the involvement of each stakeholder

Now that the natural boundaries and socio-economic development plans are determined, all participating parties should be considered. Integrated Coastal Zone Management requires a broad range of cooperation as mentioned earlier. Each project, or different section of the entire coast, requires a detailed analysis of involved actors. This section provides different tools to do such an analysis. It consists of a broad indication method to specify each stakeholder, a power versus interest grid and lastly a planning participation matrix. The goal of the stakeholder analysis is to determine how to deal with the different parties. The tools are all based on the method of Bryson (Bryson, 2004).

Indicate relations
To analyze the involvement of each stakeholder, you start with an indication of all parties that have any influence on or are influenced by the project. After this, more information about the stakeholders is required. It is recommended to make a short overview of all participating parties. Indicate what is important to them, their involvement in the project[1], interest in the project, influence, impact of the project on the stakeholder, resources, and their position.[2] This can be listed in a table as shown in Figure 4.4. While indicating the stakeholders by filling in the table, the previously created list may be altered. Extra parties may come up or parties can have different characteristics than previously presumed. Therefore, creating this table should work as a feedback mechanism. After finalizing the stakeholder identification, the relations can be mapped in a stakeholder tree. This gives an overview of participating stakeholders and the hierarchy between each stakeholder. Dotted arrows can be added later to indicate cooperation between parties. The map of Figure 4.5 shows an example of a stakeholder tree.

[1]The roles of involvement can be: decision making, support, guidance, administration, feedback, creator or latent.

[2]position of a stakeholder indicates their overall attitude with respect to the project, it can be: promoter, defender, latent or supporter.

Stakeholder	Important for stakeholder	Involvement in the project	Interest in the project	Influence	Impact on stakeholder	Resources	Position

Figure 4.4: Model for stakeholder identification table

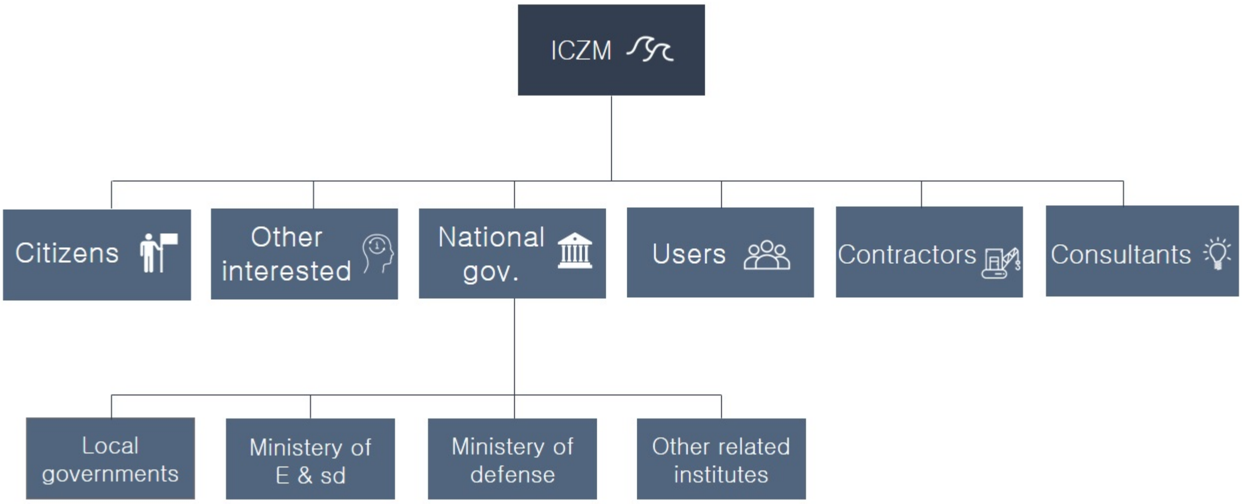


Figure 4.5: Stakeholder tool: Relation tree

Power vs. Interest grid

Now that the stakeholder tree is finished, it is important to get a better understanding of the treatment of different stakeholders. An excellent tool to gain this insight is a power versus interest grid. An empty model is shown in Figure 4.6. According to Bryson, a stakeholder can be divided into the four different categories that are elaborated below (Bryson, 2004):

- *Manage:* This group of stakeholders must be fully engaged in consultation and communication. They must be managed intensively because of their high interest and power.
- *Satisfy:* This group consists mainly of decision- and opinion makers. They have high influence but lower interest in the project. Therefore they only need to be satisfied about the progress of the project.
- *Inform:* The people in this section should be informed. Depending on the project and the project phase, their influence can possibly increase.
- *Monitor:* With respect to this section minimal effort is required. The stakeholders should only be monitored.

Figure 4.4 and 4.5 are a helpful tool to fill in the power vs. interest grid.

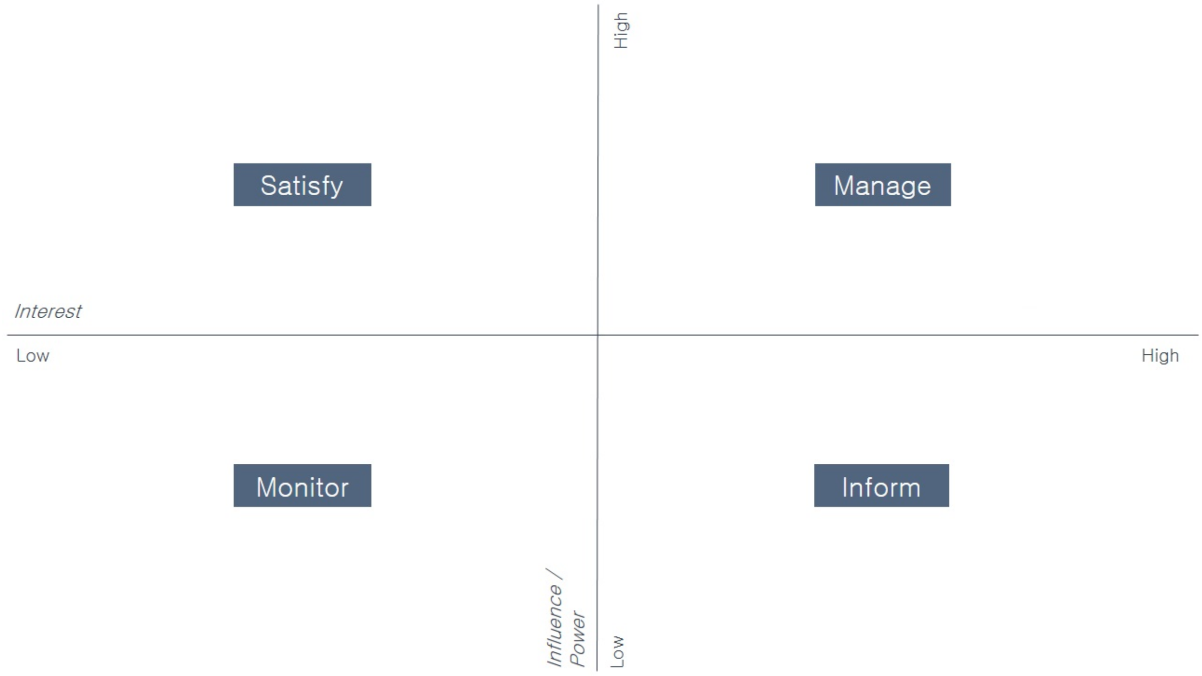


Figure 4.6: Stakeholder tool: Power vs. Interest grid

Planning-participation matrix

The power vs. interest grid gives a good overview of stakeholders who have interest in and influence on the project. However, to create a useful outcome of the previous analyses, the planning participation matrix shown in Figure 4.7 is developed. The tool indicates the importance of stakeholders per phase of the project. This give a quick and useful insight in the possible involvement of stakeholders in each phase.

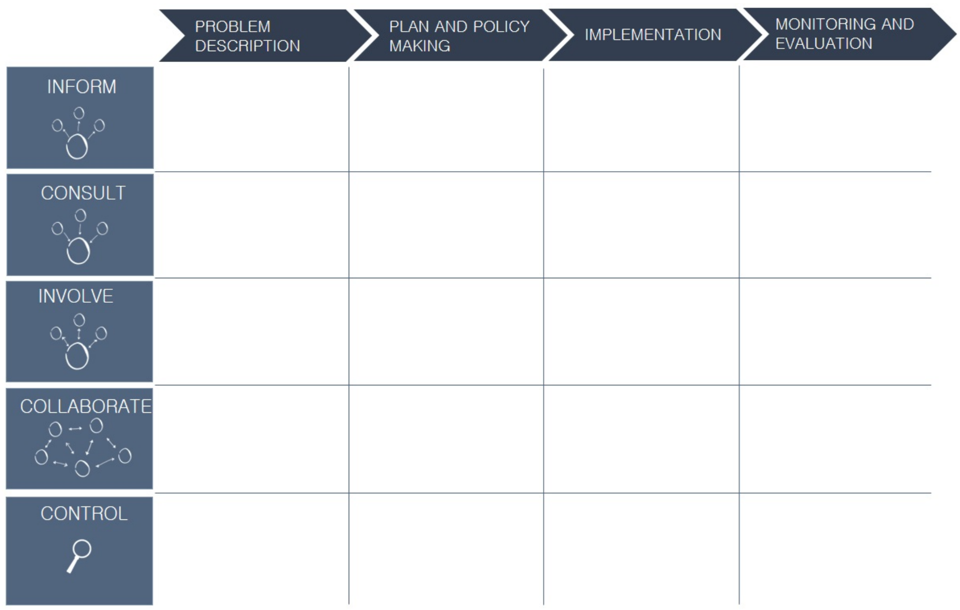


Figure 4.7: Empty planning participation matrix

4.4.3 A.3: Analyse the different system elements

After analyzing the boundary conditions and involved stakeholders, the user should analyze the three different system elements: The (hydraulic) natural system, the user function system and the structures system. These sections are further elaborated below. In Figure 4.3, these elements are indicated with yellow circles. For each system, a basic list of research topics is given, but this list can and should be expanded when working on a specific project. The results of the analyses of different system elements form the cornerstone of the project. The alternatives are developed based on the findings of these analyses.

Natural system
The analysis of the natural system consists of an elaborate hydraulic analysis. It commences with the identification of the coastal cell. Important is the definition of the outer boundaries. These boundaries are commonly chosen near river outflows, harbours and other large groyne extensions, or distinctive geographical features such as headlands. Phenomena outside the coastal cell can be taken into account by adjusting the boundary conditions. Inside a cell, the following actions are required:

- **Characterisation and explanation of historic coastline evolution and coast shaping factors**
  Erosion problems can have different causes. The causes are known as coast shaping factors. The natural system can be analyzed explaining the erosion problems by one of the coast shaping factors. A distinction between the following coast shaping factors is made:
  - Shoreline direction
  - River Sediment input
  - Coastal caves and sinkholes
  - Tidal basin
  - Shadowing effects
  - Man-made structures (see structures)
  - Relative sea level rise
  - Storm impact

  Several tools exist to establish a broad overview of the historic coastline evolution, taking into account the coast shaping factors. Most used are the coastline models, simple one-line numerical models to predict shoreline changes. But even with Google engine, a simple tool with which you can map the coastline per year, the evolution of the coast can be visualised.
- **Characterisation of wind, waves, tide, currents and other forcing conditions**
- **Characterisation of bathymetry and sedimentology**
- **Identification of possible changes to boundary conditions**
  If large changes occur outside the domain, the boundary conditions should be adjusted accordingly.

At the end of this step, one should know which processes drive morphological changes in your coastal system.

User function system

The coastal zone can be used for different purposes, all related to the human well-being. A helpful tool to consider these different purposes is a user function system. The assessment of a user function system is an important aspect of a multidisciplinary approach. Next to the technical solution for the coastal problem, one also takes into account the impact on user functions such as housing, fishery or infrastructure. The user-function system allows the consideration of multiple user functions when developing alternatives.

A distinction between different user functions can be made. In this model, four main categories are described, as shown in Table 4.1. Each category is followed by different functions and some examples. Functions may appear in different categories; take fishery as an example. The table shows that fishery contributes to local food supply of the coast, but from a more regional perspective, fishery also provides employment and therefore can be seen as an economic benefit. Note that the table does not provide functions that include the safeguard of the environment (Stive, 2015). This is discussed in Step B, the Environmental Impact Assessment. This table can be used as a starting point for identification of the user functions in a system, but should be adapted and extended to the project's specifics.

Main categories	Functions	Examples
Basic	Food	Agriculture, fishery
	Water supply	Drinking water, irrigation
	Energy	Power plants
Social	Housing	Residential quarters
	Recreation	Local: restaurants, pubs, theatres, sports facilities
Economic	Transport	Ports and Harbours, airports
	Mining	Extraction of minerals like oil, gas, salt, etc.
	Industry	Factories
	Agriculture	Cattle breeding, fruit plantations
	Aquaculture	Shrimp farms
	Fishery	Fishing on the high seas
	Recreation	Hotels, camping sites, marina's, nature reserves
Public	Mobility	Roads, railroads, cables and pipelines
	Defence	Naval base, shooting ranges
	Sewage	Sewer system, treating plant
	Solid waste	Incineration dumping (marine on land)

Table 4.1: User functions of coastal zone

Structures system

The structures system sums up all structures that are present in the project area. This system is closely related to the user function system. E.g.: The user function 'transport' is stimulating the economy by providing an infrastructure network for employment, trade and accessibility. However, the actual structures that provide this function (roads, bridges) belong to the structure system. The indication of structures is important when determining the social -and economic impact of coastal processes, e.g. erosion, on a particular stretch of the coast.

First, an inventory of all structures that can be affected by coastal processes is made. All pertinent data about the structures should be stored, including the location of buildings and infrastructure, coastal protection structures, sewerage outfalls and property ownership.

Next, the structures are categorised, using the following distinction:

- Hydraulic structures: groynes, dikes, channels etc.
- Infrastructure: (rail)roads, transportation systems, ports, airports etc.
- Buildings: houses and public buildings such as restaurants, malls, sport area's, hotels etc.

With this data, an insight is given in the social -and economic value of the region.

4.4.4 A.4: Identify the development factors

To ensure that possible solutions for your coastal problems are viable in the future, an identification of the development factors, possible natural -and socio-economic changes, must be made. The development of strategic plans should (partly) be based on this analysis. In Figure 4.3, it can be seen as the transition from the outer boundary to the inner systems. The driving forces for change are either natural processes (from the natural subsystem) or demand driven (from the socio-economic subsystem). They can influence a project on a regional, national or international level.

We refer to (Maack, 2011) for an accurate description of development factors. In his paper, he divides possible scenarios in the following categories:

- **Natural subsystem**
  - **a.** Environmental: Physical factors such as relative sea level rise and global warming, pollution and natural resources;
- **Socio-economic subsystem**
  - **a.** Social: Social priorities, land rights, migration patterns, wealth distribution, ethnic structures;
  - **b.** Economic: Impacts of global economy and development, macroeconomic and microeconomic conditions, market forces.
  - **c.** Political: Change in governmental development strategy and policy, legislation, change in structure and responsibility of ministries, likelihood of change in stability of government and corruption.
  - **d.** Technical: Future direction of research and technical education trends, change of level of technology;

Forecasting the change in the natural subsystem is mainly done by data analysis of historic developments. Forecasting of the socio-economic developments can be more difficult. Instead of forecasting, the technique of backcasting can be used. In this technique, you start at the point where you want to be in the future and try to adjust everything in the present according to the target that you want to achieve.

The above mentioned examples can help you make an inventory of the possible changes to your study area. This list should be expanded and adapted to your specific situation.

To prioritise the development factors, scenario plots can be made to provide some context around the different changes. Scenario plots should be built around high-impact/low-uncertainty issues (highly relevant issues with predictable future outcomes for which current planning must prepare) and high-impact/high-uncertainty issues (issues that could shape different futures which planning should take into account) (Maack, 2011). With this, different scenarios can be ranked based on their impact and uncertainty. To do this in a structured manner, an Impact/Uncertainty Matrix can be created. An example of such a matrix is shown in Figure 4.8.

The impact/uncertainty matrix is an illustration of how the ranking system can be used to narrow the list of possible changes.

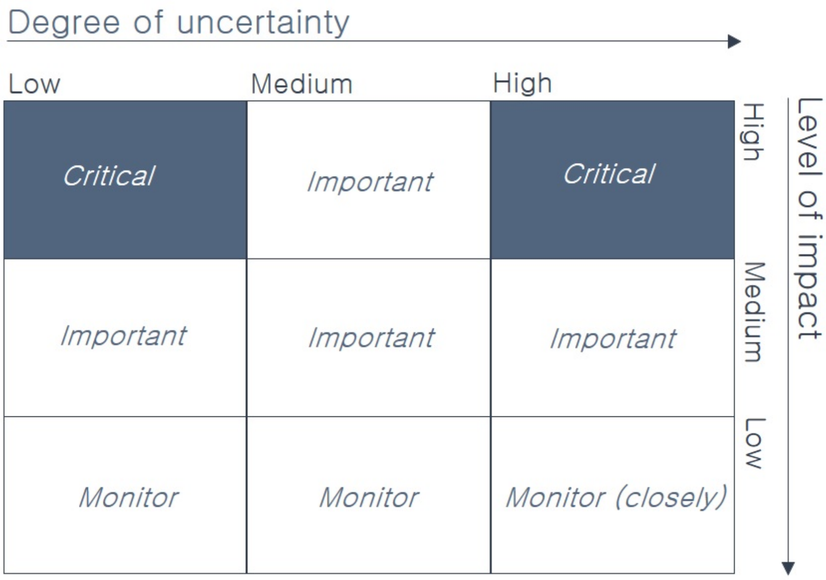


Figure 4.8: Example of Impact/Uncertainty matrix, a tool to prioritise different driving forces

4.4.5 A.5: Identify the relation between system elements

After the different system elements are determined with corresponding development factors, the relations between the systems must be determined. In the final step of the analysis, the user will use a compatibility matrix to prevent undesired consequences or to promote desirable consequences of linked system elements. A compatibility matrix is a tool to indicate the relations between the various elements of the system. In this model, the effect of changes in one system element on the other is described. The possible effects will be described both quantitatively (use +/o/- to indicate the effect) and qualitatively (briefly explain scenario).

Table 4.2: Example compatibility matrix, a tool to indicate the relations between the systems

		Natural	**User**	**Structure**
Natural	example 1			
	example 2			
	etc...			
User	...			
	...			
	...			
Structure	...			
	...			
	...			

4.5 Step B: Development alternatives

At this stage of the framework you will have thorough knowledge of the coastal processes that play a role in your designated study area, as well as an insight in the behaviour of the different stakeholders and the different activities in your study area. You will have defined the relations between the user functions, the actors in these functions, the structures and the natural environment. In Step B we will use this knowledge to identify the possible solutions for coastal problems. First, different alternatives are identified, whereafter the morphological impact of each alternative is simulated. Finally, the environmental -and socio-economic impact assessment evaluate the legal, environmental and social acceptance of an alternative.

4.5.1 B.1: Identify alternatives for coastal protection

The hydraulic analysis of Step A.3 should give you a clear idea of the physical geometry (e.g. bays and headlands), the coastal mechanisms (e.g. related to tide, wind and waves) and the human interventions present in the system. Combining this with basic knowledge on coastal dynamics, one should be able to develop concept schemes for coastal protection. Hereby it is essential to work with the natural processes to obtain a sustainable solution. An example is the Amager beach park in Denmark, where the coastline is perfectly oriented to the dominant NE and SE wave directions (Brøker, 2008), see Figure 4.9. In this way, long term erosion and accretion are minimised.

Figure 4.9: Amager beach park.

To deal with coastal erosion, management strategies are divided into three categories:

1. *Retreat*
   Do nothing and accept the erosion with its consequences.
2. *Accommodate*
   Adapt to the erosion situation in order to minimise the consequences.
3. *Protect*
   Take protective measures.

The chosen strategy determines which alternatives can be used. Given the poor state of the coastal zone in Colombia and the long-term trend of sea level rise, the strategies Retreat and Accommodate are in most parts of the coast no longer acceptable. Therefore mainly protective measures are required for the Colciencias project, as most problematic areas are near cities or roads that are either important for the accessibility of a region or expensive to move. Protective methods can be divided into two groups; soft measures and hard measures. With soft measures the natural erosion processes are undisturbed. The erosion will be compensated with supplied material. Hard measures can again be subdivided into two groups; structures that primarily influence structural erosion processes, like groynes and breakwaters, and structures that primarily prevent erosion during extreme events (episodic erosion), like sea walls, revetments and dikes. A list of possible protective measures is given in Appendix G. When developing alternatives, one should thus know whether the erosion is primarily structural (normal event option) or episodic (extreme event option). In practice, most coastlines are protected against both types of erosion; against episodic erosion to prevent large damage, inundation and flooding due to storms and hurricanes, and against structural erosion to maintain the current coastal zone.

Figure 4.10 gives an overview of possible alternatives, ordered from the problem towards the different alternatives available to cope with the problem. The scale gives the size of the coastal area that is affected by the measurement. Duration implies a time span in which the measurement is effective. Structures labeled with a 'Permanent' duration are meant to have a lifespan equal to the age it is designed for. A breakwater can for example be designed for a lifespan of 30 years. Afterwards, it needs revision or repetition.

Problem	Management strategy	First division	Second division	Different options	Purpose	Scale	Duration	Remark
Coastal erosion	Retreat				Cheap solution for strongly fluctuating coastlines	Large	N/A	
	Accommodate				Being able to keep using eroding areas	Large	N/A	
	Protect	Soft measurement	Nourishment	Shore face nourishment	Balance sediment transport	Large	Repetition needed	
				Beach nourishment	Repairing eroded beaches	Medium	Repetition needed	
				Dune nourishment	Strengthen dunes	Medium	Repetition needed	
			Bypass		Restore sediment blockage	Medium	Permanent	
		Hard measurement	Normal event option	Groynes	Sediment entrapment	Small	Permanent	Possible downstream erosion
				Offshore breakwater	Interfering with cross-shore sediment transport	Small	Permanent	Possible tombolo forming
				Jetty	Sediment blockage	Small	Permanent	Possible downstream erosion
			Extreme event option	Sea wall	Protection extreme events	Small	Permanent	Stability danger due to scour hole
				Revetment	Protection extreme events	Small	Permanent	Stability danger due to scour hole
				Sea dike	Protection extreme events	Small	Permanent	Stability danger due to scour hole

Figure 4.10: Available alternatives ordered

At the end of this step, you have generated a list of possible alternatives based on your understanding of the site specific coastal erosion processes (both structural and episodic) and basic knowledge about the impact of the different structures. Simple designs and outlays are made for each alternative, in order to assess the impact on the surrounding coasts.

4.5.2 B.2: Assess the morphological impact of alternatives

The reasonable alternatives obtained in the previous section need to be studied in detail to properly evaluate the functioning of the structure and its impact on surrounding areas. Various types of numerical models can be used for this. The choice of model depends on various factors:

- Spatial and temporal scales of the area to be modeled
- Relevant processes active in the system
- Purpose of the model (e.g. investigate structural erosion or simulate episodic erosion)

The scale and complexity of structures and processes determine which type of model has potential. In Figure and overview is given of the applicability of the different models. The models can be roughly subdivided into three groups:

- Coastline models: These simple models are an efficient tool to quickly evaluate the coastline response to coastal structures if the coastline is not too curved and the bathymetry not too variable.
- Regional models: These models are mainly used to calculate large ocean circulation. They have also been applied to the coastal zone, where they can accurately describe the spreading of pollutants or a river plume.
- Local morphodynamic models: These process-based models cover a large range of coastal processes and are used to simulate more detailed phenomena. Different models exist to account for different processes. Therefore, an understanding of the relevant driving factors of the coastal zone is essential.

In the first part of this step, a substantiated choice of numerical model must be made using your knowledge on coastal models, with the aid of the document on software in Appendix H. It is likely that not one but two (or more) models are required to simulate the different events (e.g. long-term erosion under a moderate wave climate and flooding due to storm impact). The second part of this step comprehends the model set up, computation and validation. When modelling a hydraulic problem, care should be given to the numerical consistency and stability and computational effort. We refer to the separate, extensive manuals of the models for a detailed description of their functioning. Furthermore, workshops can be arranged to obtain practical skills in modeling, not a luxury since numerical modeling can be rather time consuming when you're not familiar with the program. Validation can be done with physical model tests or by validating it with the historic coastline evolution. Lastly, the simulated impact of the alternatives needs to be studied to evaluate whether the structure has the desired effect.

Decision tool
Based on the descriptions and tables in Appendix H, a decision tool is developed to aid in the choice of model. For this, an assessment must be made of the assumptions and limitations of each model, and a consideration of the different steps to follow. It should be noted that a basic understanding of the underlying physics of each model is required, especially its assumptions and limitations.

The decision tree is divided into three main groups:

1. *Cross-shore transport and profile development*
   For bar development, dominant processes in cross-shore transport are wave skewness (shoaling zone), wave asymmetry (surf zone) and a return flow. For dune erosion, long waves, avalanching transports and flooding and drying formulations are important.
2. *Longshore transport and coastline changes*
   Various processes have a role in the longshore transport of sediment.
3. *Other applications*
   Such as river plumes, large ocean circulation and harbour extensions.

Based on the most stringent differences between the various models, a decision tree is developed. This decision tree helps to find the suitable model to your engineering problem. It can be found in Figure 4.13 and 4.14. The distinction between spatial and temporal scales used in this tree is shown in Figure 4.11, a Figure taken from (A. Roelvink J.A.and Reniers, 2011).

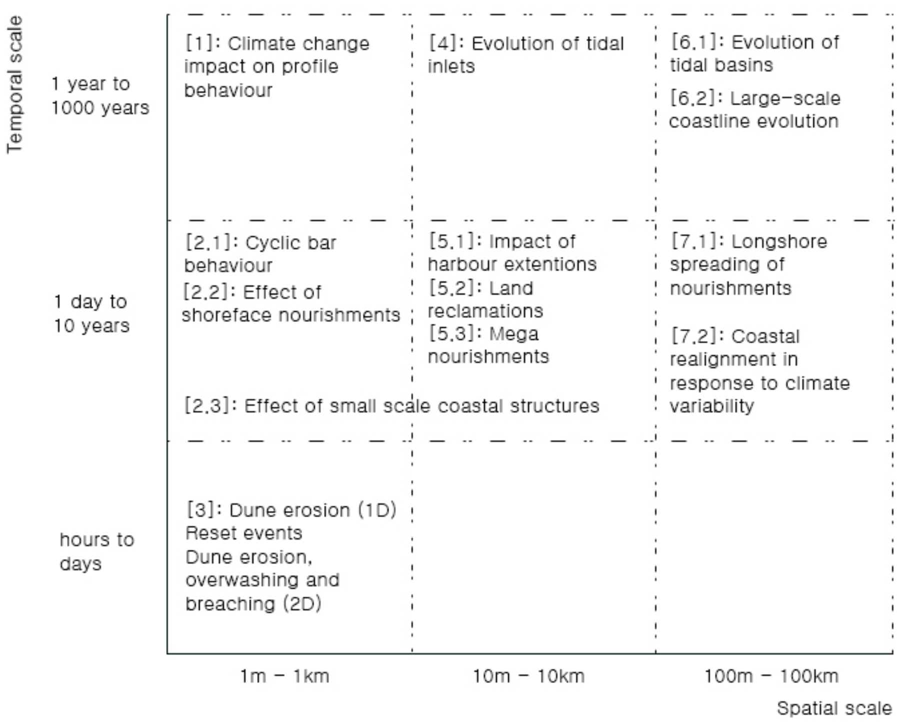


Figure 4.11: Spatial and temporal scales engineering applications (A. Roelvink J.A.and Reniers, 2011)

		UNIBEST	LITPACK	GENESIS
Short wave transformation				
Refraction	Due to differences iin depth along the crest, the wave rotates until parallel with the coastline. Important for heavily curved coastlines	YES	YES	YES
Shoaling	The water depth influences the propagation of waves. This causes an increase in wave height	YES	YES	YES
Diffraction	Bending of waves behind obstacles and structures. Important in ports and other sheltered areas	YES When coupled with SWAN	YES	YES
Reflection from structures		NO	NO	NO
Set-up and currents				
Wave-current interaction	Exchange of energy between current and wave. Important near ripcurrents, gullies and high velocity river outflows	YES	YES	NO
Longshore current	What other currents are accounted for?	Longuet-Higgins	Longuet-Higgens	NO
Sediment				
Sediment gradation	Can different grain sizes be used as input parameter?	YES	YES	NO
Wind-driven transport		YES	NO	NO
Cross-shore profile response tool (storm impact)	Is there coupling with other modules to account for episodic erosion?	YES	YES	NO
Model characteristics				
Documentation	Manual, theoretical documentation, training	YES	YES	YES
Model interface		UNIBEST-CL+	Mike Zero	CEDAS
Running time		Good	Good	Medium More intensive computations, increasing simulation time
Model grid	1-line models tend to evolve towards it's grid, therefore only applicable to (almost) straight coastlines	Curved	Linear	Linear Regional contour grid; possibility to insert predefined shape to which coastline evolves
Applications				
Revetment		Good	Good	Good
Offshore Breakwater		Good	Good	Good
Nourishment		Good	Good	Good
Groin (non-diffracting)		Good	Average, slightly modest erosion and accretion	Good
Groin (diffracting)		Good	Good	Good
Jetty		Good	Good	Good
T-head groyne		YES	YES	YES
Tombolo		YES	YES	YES
Trench		NO	YES	NO

Figure 4.12: Comparison different coastline models

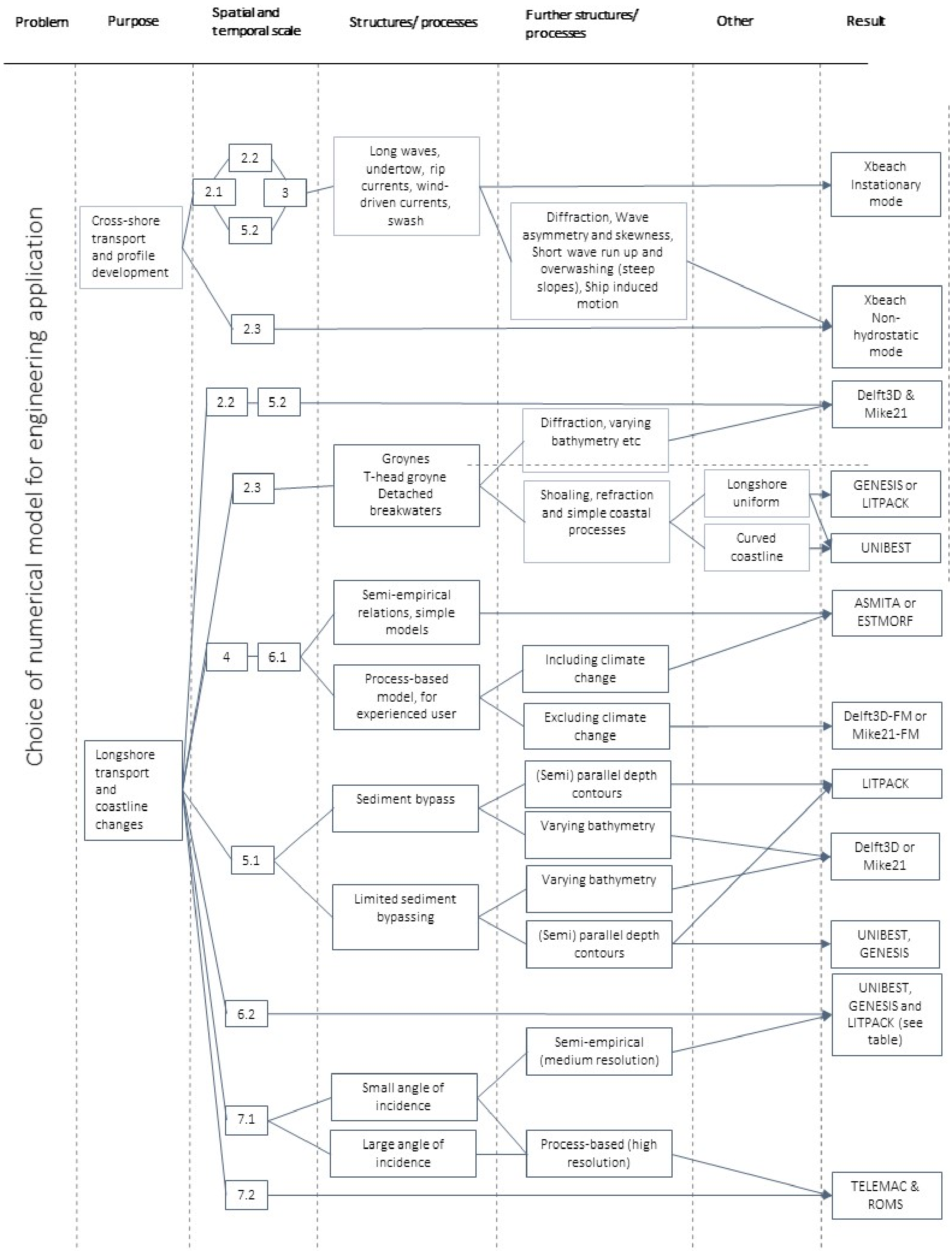


Figure 4.13: Decision tree for the use of a numerical model, part 1

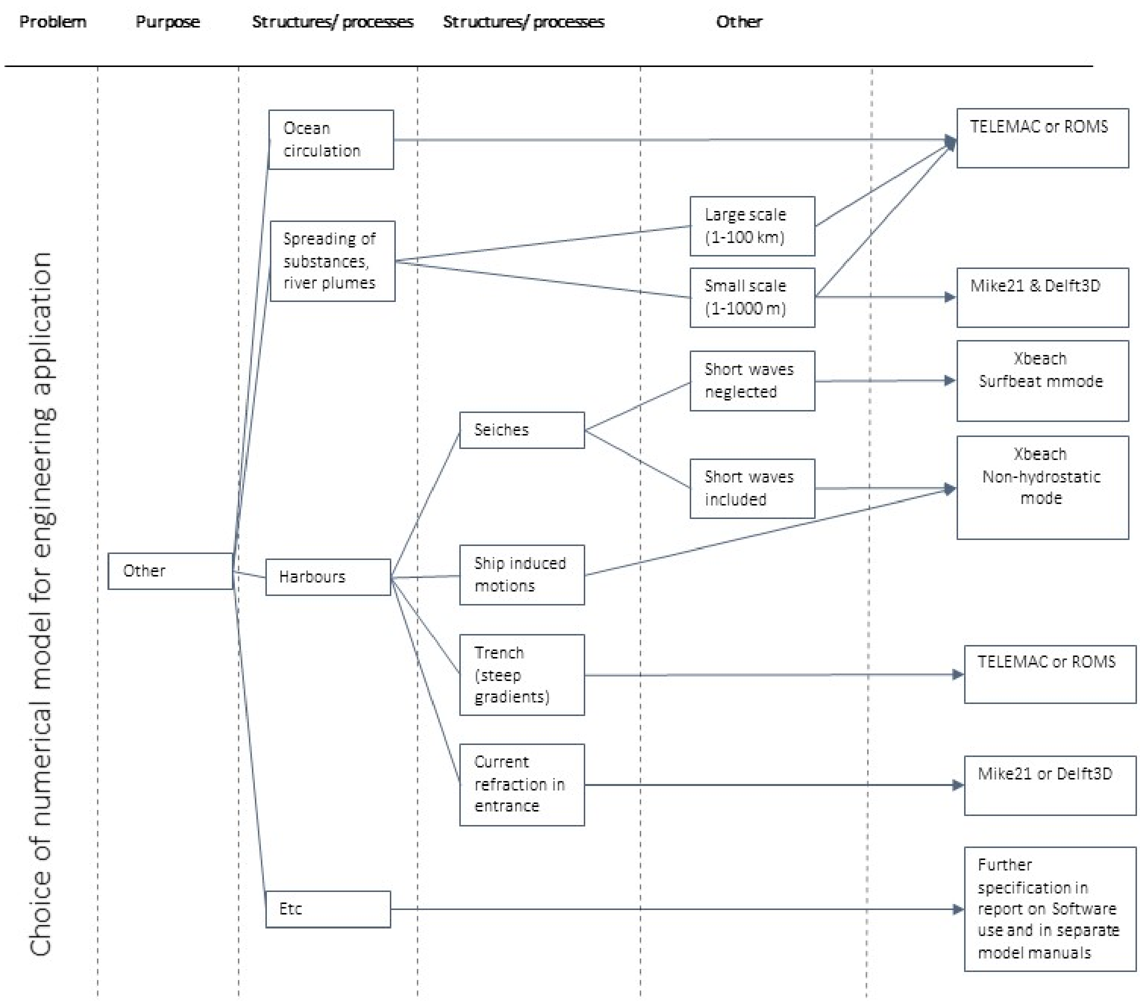


Figure 4.14: Decision tree for the use of a numerical model, part 2

4.5.3 B.3: Assess the environmental -and socio-economic impact of alternatives

The evaluation of the impact of human interventions is not limited to the simulation of the morphological response. Two other important impact assessments need to be executed. First of all, a person is legally bounded to make an environmental impact assessment (EIA) to get approval for the project. Furthermore, a socio-economic impact assessment is desired to ensure a broad social acceptance. Together, these two impact assessments help in making a well-founded decision.

EIA
The goal of an EIA is twofold; it is required for legal approval by the government, and it serves as a tool for engineers to evaluate the impact on ecosystems and milieu. We start with the latter. This one is not legally binding but helps to create a broader overview of the impact. It consists of four steps that are illustrated in Figure 4.15. The questions in each step are a guideline to create an EIA report.

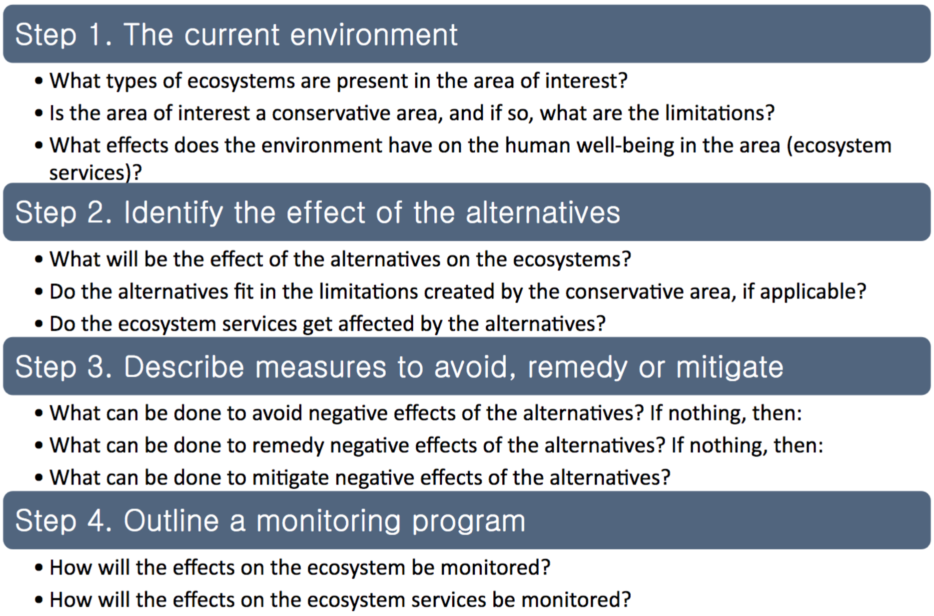


Figure 4.15: The four steps of the Environmental Impact Assessment.

A different format of the EIA is the document that is prescribed by ANLA (Autoridad Nacional de Licencias Ambientales). It ensures a sustainable and an environmentally responsible view on projects to combat the current threatening of the the Colombian biodiversity. The environmental licenses are subdivided into three groups:

1. Standard environmental license;
   License for construction work that does not require special permission for the use, mobilisation, and exploitation of renewable natural resources.
2. Specific environmental license;
   License including permits for the project or activity.
3. Comprehensive environmental license;
   License that can be both standard and specific, depending on the nature of the construction work or activities related to the exploitation of oilfields and gas deposits.

The full requirements can be found in the Environmental Impact Assessment Review (Javier Toro, 2010). Take note that the approval process of your EIA can be time consuming.

Socio-economic impact
Each alternative will have different effects on the various functions that are present in the study area. Furthermore, each alternative will react differently to natural -and socio-economic changes, the development factors. An example is the combination of widening the dune area (alternative) with a sharp increase in population (development factor). The large dune area will help protect the coast, however the space is also needed to accommodate the population growth. The alternative will be negatively influenced by the socio-economic development factor. Thus, in this final step the inventory of user functions and development factors that was made in Step A will be used to evaluate the socio-economic impact.

The impact of an alternative on the user functions of an area can be visualised using Table 4.3. The different user functions can be taken from Table 4.1 which you have already filled in and extended in Step A. The different alternatives can either have a positive, a negative or no effect on the user functions. In the table below, you can evaluate the impact by giving each combination a grade, be it a number or plus and minus signs.

	Recreation	**Transport**	**Tourism**	etc..	...
Alternative 1					
Alternative 2					
Alternative 3					
etc..					
...					

Table 4.3: Effect of the different alternatives on the user functions

To finalise the assessment, the effect of natural -and socio-economic changes on the functioning of the alternatives should be evaluated. The changes, or development factors, are identified in Step A.4. These factors can be used as input for Table 4.4, where they are again graded to form an opinion about its effectiveness. Both tables help in choosing the best alternative for coastal protection.

		Alternative 1	Alternative 2	Alternative 3
Natural	Sea level rise			
Socio-Economic	Population growth Change in wealth distribution			

Table 4.4: Effect of driving forces on the different alternatives

4.6 Step C: Final Concept

Step C describes the systematic approach to come to a final decision by assessing the alternatives different characteristics obtained in Step A and B of this framework.

4.6.1 C.1: Make a substantiated decision between the alternatives

To come to a well-founded and objective decision on which alternative to implement, various tools are available. Two of these are elaborated here, namely a feasibility study and a multi-criteria analysis (MCA). The analyses are required to come to a final design that can be used in an ICZM policy (Turner, Burgess, Hadley, Coombes, & Jackson, 2007). These tools do not only help the decision making process, but they can also convince policy makers of the value of a project.

Feasibility study
To narrow down the list of different solutions a feasibility study is performed. Here the TELOS study is discussed. This TELOS feasibility study consists of five pillars (Bause, Radimersky, Iwanicki, & Albers, 2014): technical, economic, legal, operational and schedule feasibility, as depicted in Figure 4.16.

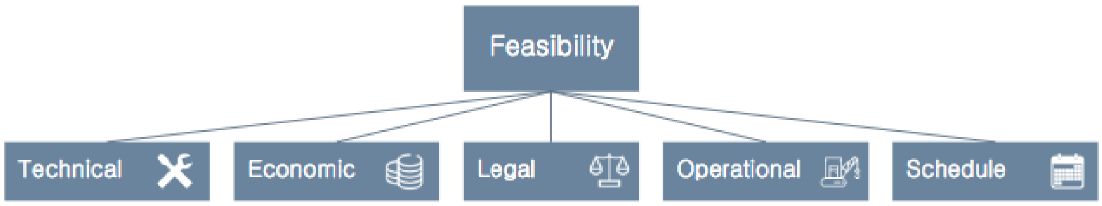


Figure 4.16: The five pillars of a TELOS feasibility study.

The first pillar concerns the used technology; its availability and applicability. Is an alternative possible to realise with respect to the present available construction techniques?

The second pillar investigates an alternative's economic viability. It is possible that an innovative solution - that is technically feasible as established in the first pillar - is opted, but that the economic limitations in a particular country can easily thwart the realisation of such an alternative. The total costs, including for example the employment costs, legal costs, construction costs and maintenance costs, need to be estimated and compared to the available budget.

The third pillar within the TELOS feasibility is legality. The scale on which a project is executed must be determined, c.q. the legal constraints on national or municipal level. Governmental bodies on both levels should be recognised and the necessity to take them into account. These subjects need to be thought trough to assure whether an alternative is legally viable.

The fourth part of the feasibility study contains the operation management within a project. A clear distribution of tasks among the cooperating parties is outlined in this pillar. Furthermore, the effectiveness of reaching the goals of the project is studied.

The last pillar focuses on the schedule feasibility. The project must be executed within the assigned time-frame. All parties must be able to fulfill their consecutive tasks within the given time-line. As project delay often has enormous financial impact, therewith endangering the general feasibility of a project, schedule feasibility plays an important role within the TELOS feasibility study.

Multi-criteria analysis
The assessments, both morphological and socio-economic, and the feasibility study of each alternative give a strong indication of the pros and cons of each alternative. Although some alternatives may already have a preference above others, the user is required to make a substantiated choice between alternatives. A general problem that occurs when judging characteristics of different alternatives is that different evaluation criteria cannot be expressed in the same value. Economic values such as implementation costs and emotional values such as aesthetic value are not easy to compare. A tool that aids decision-making is the multi-criteria analysis (Stive, 2015). Furthermore, where a traditional feasibility study or cost-benefit approach solely seems ineffective to deal with the usage of natural resources, an MCA is able to include these intangible aspects.
Based on the research of (Stive, 2015) and (Garmendia et al., 2010), socio-economical and a socio-ecological dimensions are chosen. Some examples of suitable and relevant criteria with respect to coastal dynamics are shown in Table 4.5 (Garmendia et al., 2010). All criteria are assessed in the foregoing steps of this framework, making them judgeable in an MCA.

Socio-economic	**Socio-ecological**
Technical feasibility	Esthetic value
Maintenance cost	Ecological preservation
Economic feasibility	Environmental impact
Uncertainty	Morphological impact
Legal feasibility	
Operational feasibility	
Schedule feasibility	
Basic user functions	
Social user functions	
Economic user functions	
Public user functions	

Table 4.5: Potential criteria for a multi-criteria analysis

Several steps have to be executed in an MCA. First, criteria that are considered important for the specific situation have to be listed. Based on previous analyses, the user should know which socio-economic and socio-ecological values have to be considered. Next, the relevance of the criteria must be judged in relation to each other. This results in a weighted score for each criteria. The third step is to judge each of the alternatives on all criteria with a score between 0 and 1, with 0 the lowest possible score and 1 the highest. Although this step is quite subjective, it must be carried out as objective as possible. After summing the weighted criteria with their corresponding scores, one alternative will be esteemed best fit for the particular situation. An example of a possible MCA analysis is given in Table 4.6.

Criteria	A.[a] 1	A. 2	A. 3	WF[b]		A. 1	A. 2	A. 3
Cost of implementation	...	...	...	0.5		...	...	...
Maintenance cost				0.3				
Project execution duration				...				
Uncertainty								
Future perspective								
Local influences and employment								
Aesthetic value								
Ecological preservation								
Compatibility with recreational activities								
Compatibility with navigation								
					Final score	**...**	**...**	**...**

Table 4.6: Example for possible MCA analysis.
[a] A. stands for alternative. [b] WF stands for weight factor.

4.6.2 C.2: Determine an integral approach to implement the chosen alternative

To make sure the implementation of the chosen alternative is not hindered by third parties, the different stakeholders have to be aware of what the proposed solution entails. In this step the proposed solution will be published and/or presented to the stakeholders, giving room for comments by means of the following steps.

1. *Publishing solution*
   In this step the proposed solution will be published and/or presented to the different stakeholders.
2. *Debate*
   The stakeholders have the opportunity to give comments on the proposed solution. Important is to emphasise the effectiveness of the project to convince attending stakeholders.
3. *Review feedback*
   Now all comments are given, a decision can be made. This decision can be: proceed with the proposed solution, make small adjustments to the proposed solution or reject the proposed solution.

This step is deliberately placed before the final design step; if opposition is too large, a different solution might need to be chosen. If reactions are positive, one can proceed with the framework. If small adjustments have to be made, this can be done without going through the whole framework again.

4.6.3 C.3: Dimension the final design

After the feedback of all stakeholders is reviewed and the decision has been made to proceed with the chosen alternative, the engineer can make the final design. The actual dimensioning of the final design is not included here, as the framework is mainly intended to help to decide which alternative or solution is optimal for a specific case. Furthermore, the final design steps are highly project specific. But in short, the engineer should discuss with the contractor what must be delivered to carry out the project. This could include technical drawings to scale, drawings made in a CAD program, material specifications and dimensions, all in sufficient detail for the contractor to understand the design. Based on the technical design the contractor should be able to make a cost proposal and execute the project.

4.7 Step D: Evaluation

At this stage of the project, the final concept is already made. This concept consists of the elaboration of an alternative with it's corresponding ICZM strategy and a rough final design. In this step, the final evaluation of the project must be performed. The evaluation consists of two independent parts, the project evaluation and the framework evaluation. The purpose, executors and content of these two parts are further elaborated in the sections 4.7.1 and 4.7.2. The guidelines and content of these section are based on evaluation research performed by the United Nations ("Guidelines for UNODC Evaluation Terms of Reference", 2017).

4.7.1 D1: Evaluate the project

The purpose of the evaluation of the project, is to inform project developers and assess the success and areas of improvement of an ICZM project which is performed on a basis of the framework. This evaluation is done after the final concept is designed, which is done in the previous step of the framework.

The evaluation of the project is preferable executed by a special evaluation team appointed by the Colciencias group and not (only) by the project developers. In this way the evaluation is more objective and consistent. Furthermore is it important for the evaluation team to involve the the beneficiaries of this evaluation at the beginning of the project evaluation phase. These beneficiaries are people who have something to do with the outcome of the evaluation, like project developers, engineers and local municipalities. In this way the evaluation team has got the opportunity to determine the exact purpose, planning and responsibilities of the evaluation, based on the needs of the beneficiaries. More explanation about the evaluation team can be found in the discussion in Chapter 7.

The evaluation team is expected to analyse all relevant information sources. The evaluators can use the conducted concept, interviews, surveys or any other relevant quantitative and or qualitative tools as a means to collect relevant data for the evaluation. It is their purpose to take a critical look at the objectives of the project and evaluate the corresponding outcome of the project.

The evaluation of the content of the project can be conducted on a basis of a few key criteria. The evaluation team must set up some key questions to tests these criteria, that are comprehensive and specific to the project. Consider which questions are particularly important to your specific project. A few general questions are already generated here. Answering these questions, maybe by first specify them more, is the starting point for your evaluation. On a basis of the United Nation evaluation research, the following criteria and corresponding key questions are determined ("Guidelines for UNODC Evaluation Terms of Reference", 2017):

1. Relevance: To what extent is the ICZM project suited to the priorities of the target group?
2. Efficiency: To what extent has the project inputs led to outputs in a timely effective manner?
3. Effectiveness: To what extent have the planned objectives in the project been achieved?
4. Impact: To what extent has the project contributed to long-term changes for stakeholders of the project?
5. Sustainability: To what extent has the project a sustainable (likely to continue after the project has been concluded) outcome?

6. Partnerships and cooperation (Integrity): To what extent has the cooperation that have been sought led to a integral policy for future development?

4.7.2 D.2: Evaluate the framework

This part of the evaluation is not done by the evaluation team but by the project developers them selves, and it is performed after each step in the framework. So in total this evaluation step is executed five times. Note that this step also needs to be done after the next phase of the framework, namely Step E: Awareness. In the end of the evaluation it gives an elaborated review on each step of the framework, based on the criteria: relevance, efficiency and effectiveness. These criteria are already discussed in the previous section.

This evaluation is important for the development of future projects that are going to be realised with the framework. The purpose of this evaluation is thus to indicate the functioning of the framework in a quantitatively and qualitatively way. The developers of the framework can use this information to further work on the content of the framework. With this section including in the framework, the framework can be seen as sustainable because it is self-improving. After each evaluation, the framework developers can choose to adapt the framework.

An evaluation template for the framework is made, to easily collect feedback about the framework while working with it. It consists of various multiple choice questions, to quantify the quality of the framework. It can also be used to see if the framework goes ahead after any adjustments and its associated new evaluations. The second part of the evaluation consists of a few open questions. The open questions are mainly based on agile development ("Start, Stop, Continue", 2017), known as the Start/Stop/Continue method. It helps to collect and categorise feedback. In that way, it can be targeted more effectively. The template of the evaluation form can be found in Appendix I. Also a further elaboration of what happens to the output is given in this Appendix.

4.8 Step E: Awareness

After carrying out the evaluation in the previous step, the development of the coastal protection strategy can be seen as completed. That does not mean that the project is already finished. Due to the difficulties that coastal zone management entails, creating awareness on this subject is desired. Thus, this last step of the framework has the purpose to convey the insights you have obtained by using this framework. This helps creating the awareness about ICZM and in particular the use of the framework. Below, general guidelines are given on creating awareness. In the discussion in Chapter 7, a proposal is given for the implementation of a platform to bundle experiences with the framework.

4.8.1 Develop plan of approach for creating awareness

In Figure 4.17, a proposal for a plan of approach is given. The different steps are elaborated below.

Figure 4.17: Plan of approach for creating awareness

1. Choose your audience
This can be done by taking a closer look at the parties affected by coastal erosion and coastal management strategies. Who do you want to reach by creating awareness? Determine if there are any parties with perspectives that are not aligned with the vision of integrated coastal zone management, or that are in need of education and raised awareness.

2. Define what you want to communicate
In this step you define what you want to make clear exactly. This choice is closely related to your type of audience. It can either have to do with the framework, coastal problems, climate change and so on. This can be interpreted broadly, and the choice is up to you.

3. Determine the medium you will use
What is a convenient medium depends on your audience and your own capacities. A few examples of types of media are: radio, television, music, movies, magazines, books, billboards, newspapers or internet. Internet can be further divided in: websites, apps, email, social media or blogs. Even though it is not a real medium, you can also choose the more traditional way of face to face education in the form of lectures or symposia.

4. Choose the frequency of your action
To complete your plan, try to determine the frequency of your action. This obliges you to take a critical look at the overview of the awareness process. It can for instance be convenient to convey your story in stages spread over time, because the content might be too much to process at once. Also, you can use the power of repetition to increase your impact.

5. Report on the platform
In the last step of the process, a summary of the project including the chosen action to raise awareness can be documented in a platform. In this way, a large archive is made which can help to inspire other people about the Integrated Coastal Zone Management strategy. The website will function as an interactive platform, where besides the elaboration of the framework, there is also room for discussion about ICZM and the possibility to post your own actions and accomplishments. The sharing of different experiences with ICZM projects can be evaluative

for the framework, instructive for local engineers and project developers and inspirational for citizens. The platform will challenge people to use the framework and share their experiences.

Part III

Validation

5 Case Study: Ciénaga

In Part III of this report the proposed framework, presented in Part II, is applied on a specific case. The analysis of the Colciencias project explicitly points out four critical areas which need immediate attention when it comes to coastal problems in these designated areas. By application of the framework to one of these four areas, the validity of using the developed framework to come to a final design is shown.

Ciénaga is situated to the south of Santa Marta. Similar to the Km19 site, as explained in Appendix J, this coastal town experiences eroding beaches. The main cause of these erosive features are local man-made structures. Two large and several smaller breakwaters cause erosion on the lee side of these structures thereby endangering the existence of the beaches in the near future.

5.1 Step A: Analysis

In order to make a full analysis of the Ciénaga area, fieldwork was executed. Within these two days of fieldwork different experiments were carried out by which basic hydraulic characteristics were established. Besides the experiments, a survey amongst the local citizens was done. This questionnaire along with conversations with representatives of the local community and municipality form the basis for the socio-economic findings within the analysis.

5.1.1 A1: Determine the natural and socio-economic boundaries of your study area

The starting point of any project is defining the spatial and socio-economic boundaries. For the assessment of Ciénaga the spatial boundaries are set. A small river in the north of Ciénaga, called Río Cordoba and an inlet to the Ciénaga Grande de Santa Marta basin south of Ciénaga enclose the coastal cell in this case study. The coastal stretch within this cell covers approximately 7 kilometres of beach, therewith encompassing the towns of Ciénaga and Pueblo Viejo as shown in Figure 5.4. Selecting a river mouth and a basin inlet as spatial boundaries gives one the opportunity to implement boundary conditions which are constant. In this way any hydrodynamic conditions which originate outside of the designated coastal cell can be imposed on the boundaries.

Beside defining spatial boundaries the temporal scale of the final solution needs to be opted. As the severe erosion problems in Ciénaga are situated locally - thereby affecting solely distinct coastal residents - an immediate solution is necessary. Conversations with local residents learned that different governmental bodies only implemented provisional solutions in the past. Proper assessments on these short term solutions were absent. In this respect a long term view needs to be present in any new solution that is presented. Concluding, Ciénaga needs a solution which is effective immediately and resolves current coastal problems as well as one which provides a constructive solution for the future.

In Chapter 2.2 it is analyzed that Colombians in general are warm, emotional, loquacious and impulsive in behaviour, which holds for the majority of the citizens in Ciénaga as well. The population of Ciénaga amounts approximately 105.000 citizens.

Through conversation with representatives of different stakeholders, see stakeholder meeting Appendix K, one learned that extensive local regulation with respect to coastal development is

not present in Ciénaga. In the past any large scale coastal adjustments are often made by the mayor or a higher governmental body. These structures - think of large groynes and submerged breakwaters - lack a thorough foregoing study and impact assessment, they thereby often fall short of expectations.
The placement of smaller adjustments is done freely and without any counteraction. For example, the placement of small groynes made out of sandbags, see Figure 5.10. These groynes are placed by local residents and as they have little knowledge on the functionality of such structures, erosive features arise. These sandbag groynes are neither fulfilling their intended purpose nor are they forbidden or removed by any governmental institution. Foregoing shows the lack of local regulation and limitation when it comes to coastal preservation and protection.

Natural boundary conditions	
Spatial	7 km coastal stretch
Temporal	30-50 years
Socio-economic development plans	
Characterisation residents	Mainly poor and under educated
Legislation and limitations	Little to none

Table 5.1: Distinction of natural and socio-economic boundaries.

5.1.2 A2: Analyze the involvement of each stakeholder

Concerning the Ciénaga case study the following stakeholders will be discussed.

Community of Ciénaga
The community of Ciénaga represents all their inhabitants. The municipality counts 105.000 inhabitants. Within the community there are all kinds of different groups with different interests. The for coastal erosion most important groups will be discussed in the further analyses. Every small group within the community can express their dissatisfaction. On their own they do not have power but together they can form a real danger for the municipality. Due to a survey filled in by the locals of Ciénaga their main interests and opinions are investigated. The survey can be seen in appendix L, Figure L.1. It consists out of three parts; knowledge investigation, general interests and interests in a possible solution. Three questions were asked about their knowledge; what is coastal erosion, what causes coastal erosion and do you suffer from coastal erosion. The general interests was investigated due to five human values that had to be sorted from most to least important; safety, money, education, human welfare and nature. The interests due to a possible solution was investigated in the same way with the following values; long term solution, fast solution, price solution, ecological conservation and solution not in my interest. The results of the survey are shown in Figure 5.1.

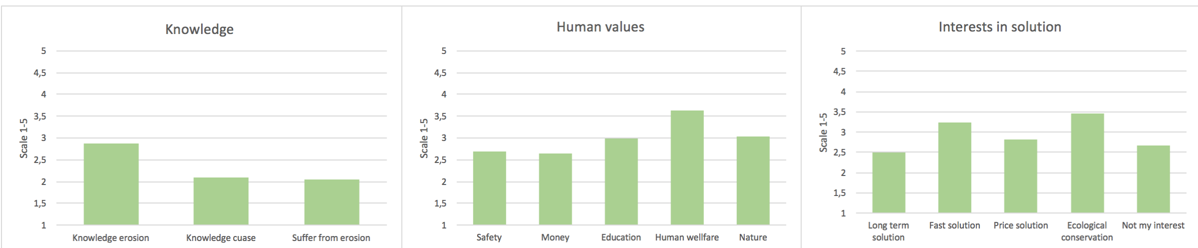


Figure 5.1: Survey results

The knowledge concerning coastal erosion is very poor among most of the local people. People living close to the coast do know that they suffer from coastal erosion. People living further away from the coast do not seem to care about it, mostly because they do not know what the consequences are.
In general, human well fare has the highest priority, followed by education and nature. Safety and money do not have a high priority. If this is compared to the interests concerning coastal erosion a trend can be seen. The ecological conservation is the most important factor, the costs of a solution are not important. If the interests in a fast or long time solution are compared with the political and cultural analysis, it matches the general short term view the people in Colombia maintain.

Department of Magdalena
The government of the state Magdalena represents all the citizens of the state. A main development plan is written by the state concerning all the municipalities. This development plan is written in the best interest of the whole state. The main interest of the state is the protection of citizens and guarantee a sustainable economic and social growth. The department has high influence on the project, the project needs to be approved by the government and other regional institutes that fall under jurisdiction of the regional government. In many cases the department provides the funding for the project.

Personera municipal de Ciénaga
Personera municipal de Ciénaga, the municipality, has the same interests as the state. The difference with the state is that Ciénaga is their only interest so the stakes are a lot higher for the municipality. The community of Ciénaga can exert pressure on the municipal to fasten the process. In the past the combination of a lot of pressure from the community and a municipality with a short term view and insufficient research has led to the realisation of a number of man-made structures. These mad-made structures only moved the problem downstream. To prevent this in the future the municipality has to maintain a long-term view and has to be assisted by experts.

Local fishermen
Local fishermen make use of fishnets strained perpendicular to the coast. These nets are in a range of within 100 meters of the coast. Their main interest is to maintain their fishing industry. A groyne, nourishment or off-shore emerged/submerged breakwater will interfere with the currents and the bathymetry. As long as these interventions do not negatively interfere with the fishing possibilities or sufficient alternatives are provided the local fishermen will be satisfied. These requirements have to be implemented into the solution. When unsatisfied, the local fishermen can pressure the government for a better solution, but due to the size of the stakeholder it's power is limited.

Tourism
The tourism industry in Ciénaga is small in comparison with the neighbour city's. The tourism industry mainly consist out of domestic tourists. Their main interest is recreation spots likes hotels, restaurants and beaches. The tourists itself are a latent in the enabling of the project.

Hotel & Catering Industry
The hotel & catering industry can be subdivided into two groups; industries located near the erosion problem and industries in Ciénaga but not directly endangered by coastal erosion. Both the groups strongly depend on the local economy, a sustainable economical growth is important for these industries. Sustainable economical growth provides employment for all kinds of industries. Local industries located near shore are directly depended on the coastal

development. Erosion endangers the real-estate whereas coastal conservation and wider beaches positively effect the local revenue of all the local industries. When unsatisfied, this group can pressure the government. When this group feels their business is endangered by the erosion they can take matters in own hand and built their own groynes, this can cause large downstream erosion problems.

Local recreation
An attractive large beach area which is stable, stimulates local recreation and thereby stimulates the economy. A stable long time solution must provide and stimulate this. The happiness of the inhabitants of Ciénaga is important for a stable community. As recreation is a large part of human life-stile, it is important to satisfy this need.

Other stakeholders
Stakeholders like Oceanus International, Invemar, Universidad del Norte and DIMAR are already discussed in Part I, the System Analysis. That is why it is not necessary to discuss them here again.

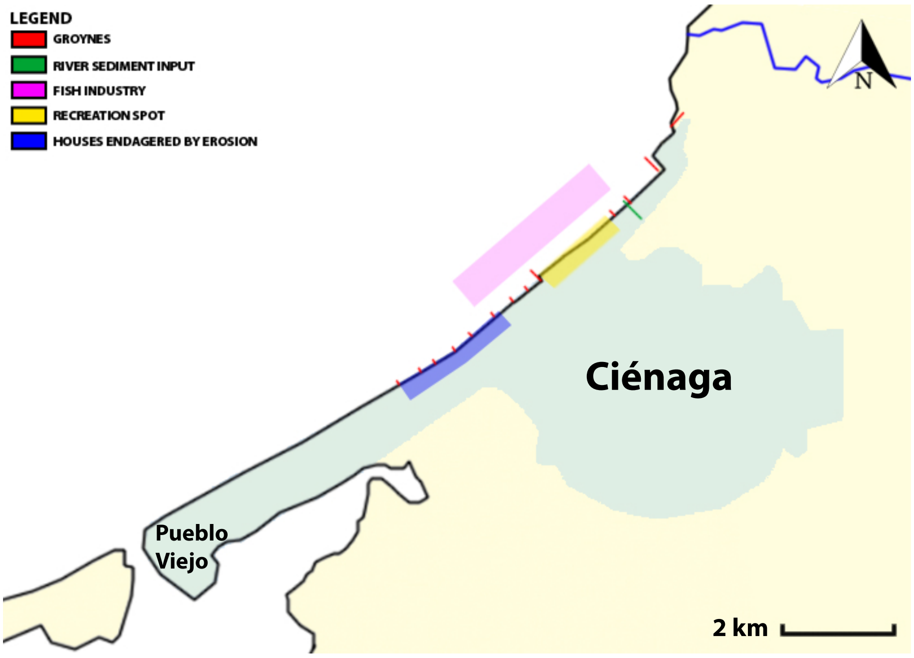


Figure 5.2: Location of user functions Ciénaga

Indicate relations
To analyze all the stakeholders and to indicate their relations the Table 4.5 is filled in. In Appendix L Table L.1 is added.

Power vs. Interest

Now that all the stakeholders are identified the power vs. interest grid can be filled in. This can be seen in Figure 5.3.

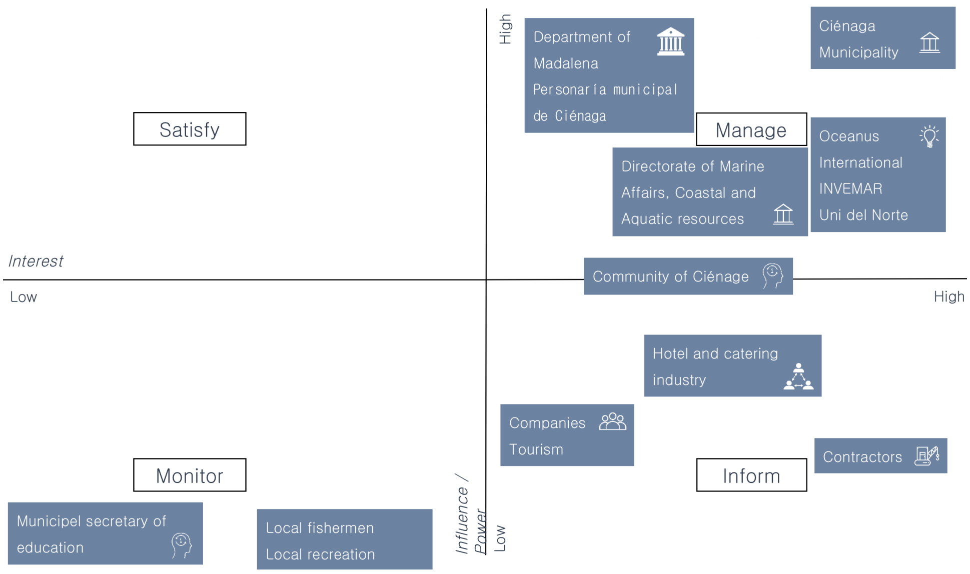


Figure 5.3: Power vs. interest stakeholders Ciénaga

5.1.3 A3: Analyze the different system elements

Natural system

In Chapter 2.4 of the framework all the possible coastal erosion problems are described. The main cause of the erosion in front of Ciénaga is a breakwater constructed in 2010, which has a shape of half a square. Sediment that got inside the breakwater was trapped, there is no sediment by-pass. This led to a sediment deficit, with a corresponding sediment gradient, downstream of the breakwater. In the area inside the breakwater, accretion occurred rapidly until it reached the tip of the breakwater. To protect Ciénaga against the erosion, sandbags were placed at critical places. These sandbags had very limited effect, the area of Ciénaga is drastically in need of a more regional solution. The diffracted waves from Santa Marta, the tidal basin and the coastal caves should be taken into account. A zoomed-in overview of all coastal shaping factors are shown in Figure. 5.4.

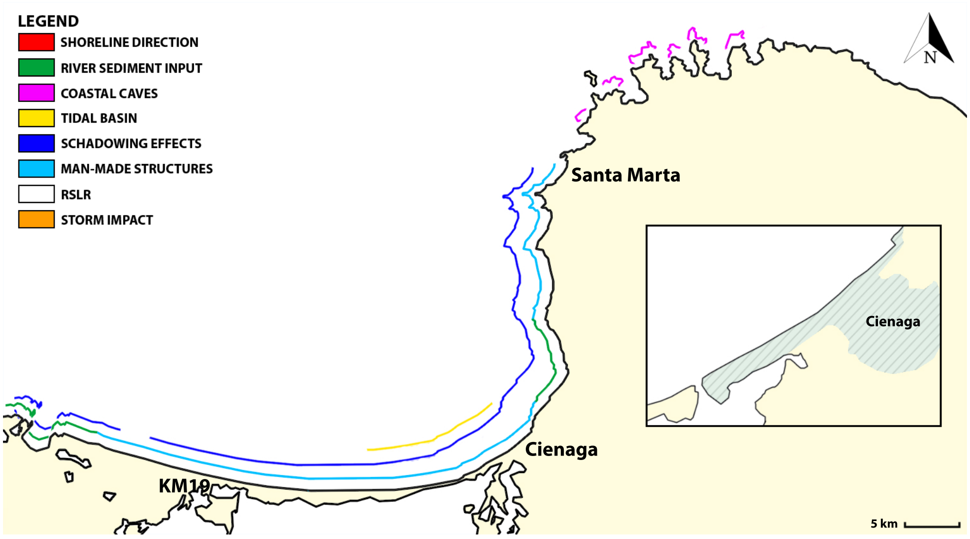


Figure 5.4: Coastal processes near Ciénaga.

Characterisation of wind, waves, tide, currents and other forcing conditions
The dataset provided by BMT ARGOSS (www.waveclimate.com) is used to obtain offshore wind and wave conditions. The timeseries contain data starting at 1 January 1992 to end date 31 December 2016 with time steps of 3 hours. The dataset of ARGOSS is available for 8250 euro per year or for 40 euro per voucher (credit), sold in packages of 10 vouchers. The amount of vouchers needed differ from 12 for a timeseries textfile (complete dataset) to 2 for a directional rose plot (ARGOSS, 2017a). Wave models such as SwanOne transform these boundary condition from offshore to nearshore. Further must be noticed that tropical storms do occur in this area and are not well represented in the wave data. Their effects must be analyzed separately (ARGOSS, 2017b). The **location of data** obtained by ARGOSS (Advisory Research Group on Geo Observation Systems and Services) is given in Figure 5.5 (ARGOSS, 2017b) with corresponding coordinates 11°50'N 74°30'W. The offshore dataset is assumed to hold for any offshore location close to the location of observation.

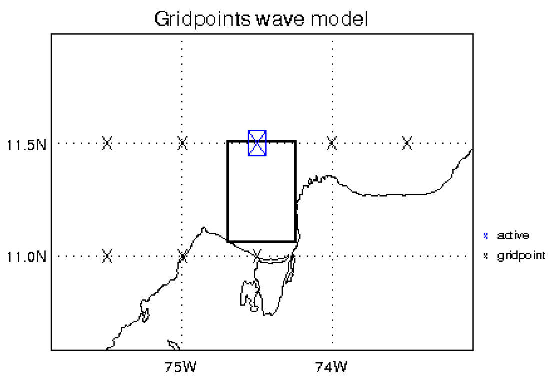
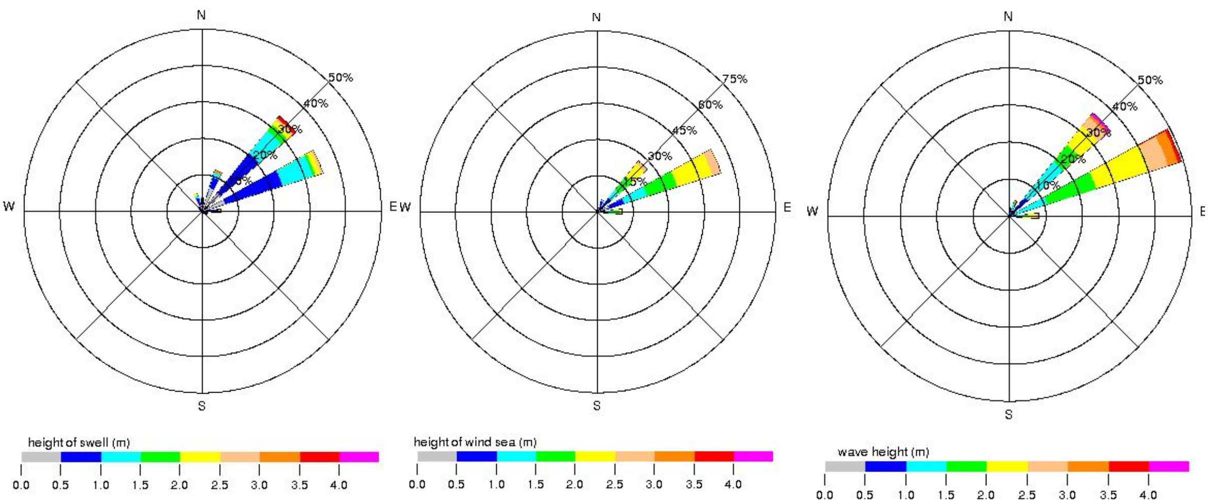


Figure 5.5: Location Data (ARGOSS, 2017b)

To determine the **dominant wave direction**, a distinction must first be made between wind-sea and swell waves. The distinction between these waves is made according to their wave periods (or frequency). The wave roses of the swell, wind-sea and total wave climate are shown respectively in Figures 5.6a, 5.6b and 5.6c (ARGOSS, 2017b).



(a) Wave rose swell waves. (b) Wave rose windsea waves. (c) Wave rose all waves.

Figure 5.6: Wave roses of swell, windsea and all waves offshore of Ciénaga (ARGOSS, 2017b).

It can easily be seen that both the dominant windsea wave direction as the dominant swell direction will not reach the coast of Ciénaga directly. Because of the headlands at Santa Marta, Ciénaga is located in a shadow zone. The diffracted waves have a rather large distance, approximately 30 km as can be seen in Figure 5.4, to travel before they reach the coast. To calculate the wave height near the coastal zone of Ciénaga, diffraction and refraction should be taken into account. A 2D approach with SWAN would solve the problem partly as SWAN does not include diffraction, but uses directional spreading methods to gain a pretty accurate result. The directional spreading method assumes that a part of the wave groups energy deviates from the principal wave direction. Therefore, not all energy is blocked when encountering for example a headland. Some of the energy is moving in another direction. How much energy that actually is, can be found in Godas diagrams in Appendix M.

Modeling a 2D model with refraction and diffraction is however very time consuming, that is why it is chosen to model a 1D model with SwanOne and diffraction approaches using the method of Goda, which calculations are similar to the directional spreading method of SWAN. For diffraction near a large island or headland, the Goda method is most accurate. The Goda method does not assume monochromatic waves, but uses directional wave spectra, which should give a more realistic height development (Goda, Takayama, & Suzuki, 1978). The Goda method is elaborately explained in Appendix M. From the elaborate calculations in the Appendix using Godas diagrams, Godas directional spreading method and elaborate calculations with SwanOne, a significant wave height $H_s = 0.22m$ with a (diffracted) direction of 5 degrees from true north was found.

Dominant wind direction and velocity influence the transition from offshore to nearshore wave height. The dominant wind direction is shown in Figure 5.7.

Characterisation of bathymetry and sedimentology.
During fieldwork, see Appendix K, cross-shore sediment samples were taken in different location in the sea. These locations were chosen to characterise all the different parts of the cross-shore profile. The cross-shore profile, until 20 meter off-shore, was characterised by human observations. It looked like Figure 5.8. It is an estimation of the real beach, the picture is not to scale. The location of the samples are with length and depth indication.

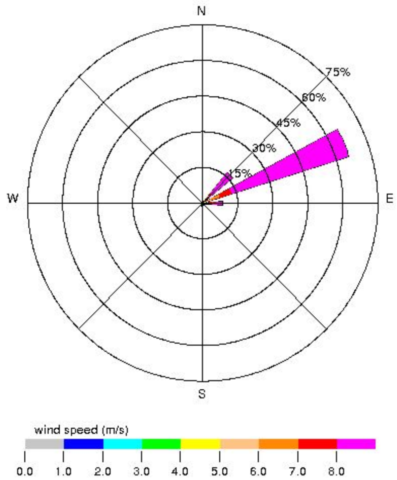


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Figure 5.7: Wind rose offshore of Ciénaga (ARGOSS, 2017b).

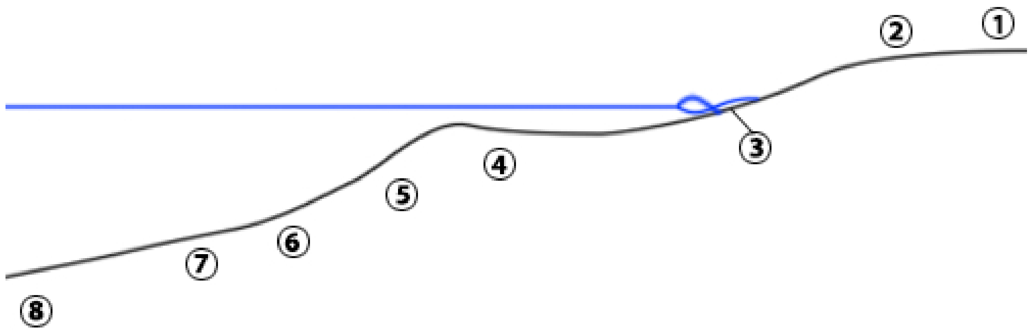

Figure 5.8: Ciénaga cross-shore beach profile

On locations 1 until 8 sediment samples were taken. These samples were dried and the characterisation of the sand with corresponding grain size was obtained with observations with the human eye. The characterisation of the samples was made by comparing them with known sediment samples and their grain sizes. The grain sizes at the different locations can be seen in Table 5.2.

Nr.	Place	Size range	Aggregate name
1	Beach (on-shore)	0,25-5 mm	Medium sand
2	Beach berm (on-shore)	0,25-5 mm	Medium sand
3	Mid swash zone (0 m off-shore)	0,25-5 mm	Medium sand
4	Berm inside (8 m off-shore)	2-4 mm	Very fine gravel
5	Berm outside (10 m off-shore)	125-250 μ m	Fine sand
6	Water depth: 1m (15 m off-shore)	125-250 μ m	Fine sand
7	Water depth: 1,5m (20 m off-shore)	125-250 μ m	Fine sand
8	Water depth: 2m (30 m off-shore)	63,5-125 μ m	Very fine sand

Table 5.2: Sediment samples

Identification of possible changes to boundary conditions.

Nearshore wave characteristics.
Although the process-based software programs only require offshore wave data, because their connection to a wave model such as Swan does the transformation from offshore to nearshore, coastline models do require nearshore wave characteristics. To obtain these characteristics, SwanOne, a 1D modelling software version of SWAN, is used. The application of SwanOne is added to Appendix M. The result of the modelling of the nearshore wave climate is a significant wave height of 0.22 m.

User function system

Basic
As the name suggests, basic user functions are the first necessities like food and housing. The coastal zone in Ciénega is characterised by houses that are build really close to the ocean, especially in the south-western part of the city. The houses located in that area are threatened by coastal erosion. An example of that can be seen in Figure 5.9. Also medical and education facilities can be seen as basic user functions. A few of these functions are located in the coastal area.

Social
The social user function represents the opportunity of the gathering of people. Concerning the Ciénaga coastline this mostly means restaurants and bars located near the coast. Also some hotels could be seen as part of the social functions. Furthermore the entire beach can be seen as a gathering place and thus as a social function.

Economic
In the area of interest, the economic user functions overlaps the social functions in most cases. Here one can think about the bars, hotels and restaurants that also stimulate the local economy. The coastline also is used for fishery. Because this fishery is not a main source of food for the area, it is classified as an economic function and not as a basic function.

Public
There are no public user functions in the area of interest. The only public function that is close to the coast is the road between Barranquilla and Santa Marta, but it is far enough away from the coast that it will not be affected by the coastal erosion or any of the possible alternatives.

An overview of the different user functions is given in Table 5.3. Because there are no public user functions, this part is deleted from the table.

Main categories	**Functions**	**Examples**
Basic	Housing	Small family houses
	Medical	Medical centre, pharmacies
	Education	School
Social	Recreation	Restaurants, bars, hotels, night club, beach
Economic	Recreation	Restaurants, bars, hotels, night club
	Local economy	Local supermarket, Local small shop
	Fishery	Fishing near the coast

Table 5.3: Use of coastal zone in Ciénaga

Figure 5.9: Example of houses at the Ciénaga coast

Structures system

Hydraulic structures
The coastal zone of Ciénaga is characterised and partly shaped by some hydraulic structures. First of all there are the two groynes perpendicular to each other in the north-eastern part of the area. If one walks down the beach from there to the south-west, first a sequence of large sand bags put on a stack to function as a small groyne can be seen. This can be seen in Figure 5.10. Walking further to the south-west will lead to another small groyne. After this, again multiple sand bag groynes are placed. This sequence of small groynes stops at the point the housing area stops. After this point, no hydraulic structures can be found until the boundary at the inlet.

Infrastructure
No important infrastructure is located near the coast in this area. Therefore this will not be treated any further.

Buildings
The main type of building characterising the coastal zone is family houses, especially in the part south-east of the recreational part of the beach. Furthermore some bars, restaurants and hotels are build near the coast.

Figure 5.10: Groyne made out of sandbags at the Ciénaga coast

5.1.4 A4: Identify the development factors

Natural subsystem

The relative sea level rise in the Caribbean is around 5,5 mm/year, this number matches the global sea level rise. This number has a low level of uncertainty as it is a global trend with no local deviations. The global warming is associated with the RSLR and also has a low level of uncertainty.

The whole coast of Colombia is threatened by pollution. The pollution is mostly due to waste dump and bad sanitation. There are very large local deviations concerning pollution. It forms a danger as it effects drinking water and local ecology. How the pollution develops is very uncertain. It is very important to include it in the coastal zone management.

Ciénaga has a large export industry of bananas, it is important for the economy in Ciénaga. The harvest is depended on the weather and is thus uncertain from time to time.

Socio-economic subsystem

The local economy near the shoreline is highly depended on the state and stability of the coast. It generates employment, recreation and business. Due to the coastal erosion there is a high level of uncertainty.

The politics in Ciénaga are based on period of 4 year, democratically elected. When the government changes, not only the governor or the mayor changes but everybody involved is being re-appointed. This causes a short term view which had let to on-thoughtful choices. Due to

this 4-year change there is a high level of political uncertainty.
To the east of Ciénaga is a high alluvial terrace, it is known as the banana zone. It is the main export product of the region and thus generates a lot of employment for Ciénaga. However, this area is not close to the coastline and it would not be effected by any changes near the shore.
Concerning the technical aspect, the technology available to deal with coastal erosion is developing worldwide. This is not a local improvement but it will help with the problem. The lack of knowledge in the area is also a development factor that influences the problem. One of the goals of this project is to deal with this lack of knowledge and to improve it.

5.1.5 A5: Identify the relation between system elements

After describing the development factors, the effects of some development factors on the different system elements are listed in Table 5.4.

		Natural	**User**	**Structure**
Natural	Relative sea level rise		-	-
	Pollution		-	-
User	Short term view politics	-		-
	Corruption	0		-
Structure	Development technology	+	+	
	Lack of knowledge	-	-	

Table 5.4: Compatability matrix

5.2 Step B: Development alternatives

5.2.1 Identify alternatives for coastal protection

By means of Figure 5.11 a list of alternatives which are realistic for this case, is made. Concerning the management strategy, it is not yet possible to delete options, although a clear preference is present, namely protect. When taking a look at the first division, both options (hard an soft measurements) are possible at this moment. At the second division, two options can be deleted. A bypass is not suitable for this case (that would counteract the use of the groyne, so deleting the groyne would than be more logic), so are the extreme event options (the coast does not need protection against extreme events). In the next step the option dune nourishment will be deleted, simply because of the absence of dunes. This leads to the following options, which need further investigation: retreat, accommodate, shoreface nourishment, beach nourishment, groynes, offshore breakwaters and jettys (and comparable options which have the same effect).

Now the different options are identified, they need to be placed in the area. The different options and places are listed below. An overview can be seen in Figure 5.11

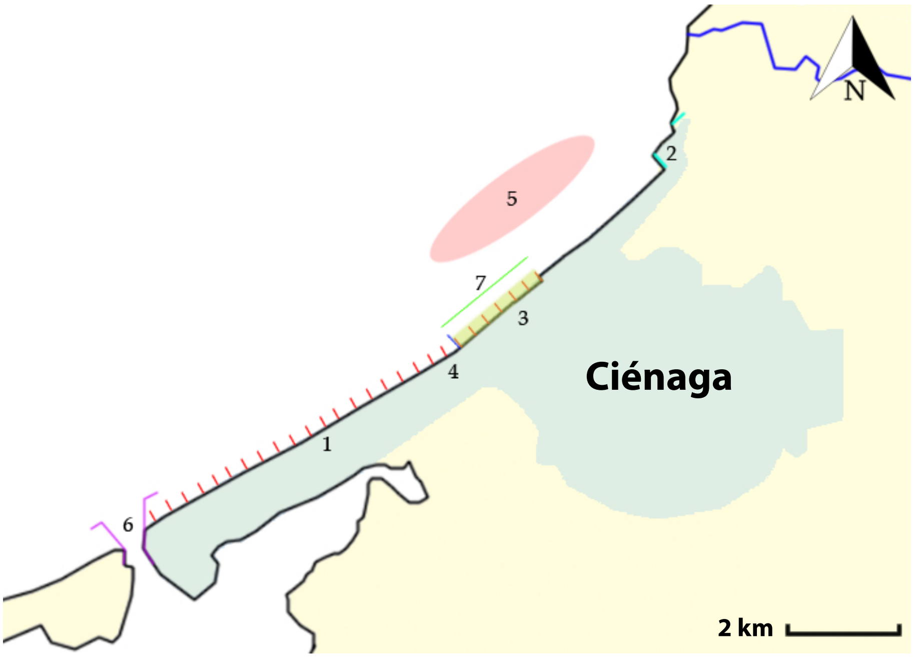

Figure 5.11: List of alternatives Ciénaga

1. Wooden groynes like at the Eastbourne coast (see Figure 5.12)
2. Remove existing groynes (or partly remove them)
3. Beach nourishment in combination with placing rocks (like what is done before in Ciénaga)
4. (Small) groyne in front of junction Calle 7 and Carrera 1
5. Shoreface nourishment
6. Jetties at the tidal inlet
7. Offshore breakwater in front of the critical area
8. Retreat
9. Houses on poles (accommodate)

Figure 5.12: Wooden groynes in Eastbourne

Most likely the final solution will not just be one of the options but a combination of some of these options. The most logical combinations are listed below. None of the combinations are already calculated, they are based on general coastal engineering knowledge. The combinations (or single options) listed below are the alternatives. Between brackets the numbers of the options can be seen.

1. (1+2) more sediment in system due to removal of groyne. This sediment can accrete in the new build wooden pillar groynes.
2. (3+4) Rocks in combination with the groyne will keep the nourished sand in place at the critical area.
3. (5+6) Shoreface nourishment will lead to more sediment in the system, Jettys will make sure the tidal inlet will not get sedimentated.
4. (2+7) Removing groynes leads to more available sediment, which can be trapped behind the breakwaters.
5. (2+4) More sediment in system due to removal groyne, This sediment can be trapped by the small groyne which will lead to accretion at the critical area.
6. (1) Wooden pillar groynes will trap the passing sediment leading to accretion.
7. (8) Accept the erosion, people have to move.
8. (9) Accept erosion and adapt houses.

5.2.2 Assess the morphological impact of alternatives

To study the morphological impact of the alternatives obtained in the previous section, it is necessary to simulate the impact by means of software modeling. However, since the duration of this project is not long enough to model each alternative, no substantiated decisions can be made regarding morphological impact. Before actually executing a project like this, it is highly recommended to calculate the detailed impact by means of software models. In this section, the software tool as presented in in the Part II: Assess the morphological impact of alternatives of the framework in Figures H.6 and H.7 is used to choose a model for each of the alternatives. Each alternative will be questioned on a few topics, which results to the correct modelling program according to the software tool.

The topics of each alternative that require answering are:

1. Purpose
2. Spatial and temporal scale
3. Structures/ processes
4. Further structures/ processes
5. Other

We are dealing mostly with the retreat and advance of coastlines and not with the detailed movement of sediments in small scales. The temporal scale can vary between years to decades for the longshore transport. The spatial scales vary around 5 km. Based on these assumptions it is expected that for most alternatives coastline models would suffice to determine the coastal evolution. Episodic events as storms and hurricanes must however be modelled separately. The answering of these topics with the corresponding result is shown in Table 5.5 for each alternative. The spatial and temporal scale numbers are given in Table H.4. For some options it is possible to model using UNIBEST, LITPACK and GENESIS. The preference of the user may be determative. For alternatives 2, 7 and 8 the choice of the program must be revised in more detail depending on Table H.5. This table compares the three coastline modelling software applications. From this table can be concluded that for alternative 2 also UNIBEST, LITPACK and GENESIS can be used. For alternative 7 and 8 it is preferred to use UNIBEST or LITPACK due to the running time of the model.

Alternative	Characterisation	Purpose	Spatial and temporal scale	Structures/ processes	Further structures/ processes	Other	Result
-	Storm and hurricane impact	Cross-shore transport and profile development	3	-	-	-	Xbeach (instationary mode)
1	Wooden groynes and removal groynes	Longshore transport and coastline changes	2.3	Groynes	Shoaling, refraction and simple coastal processes	Longshore uniform	UNIBEST, LITPACK or GENESIS
2	Nourishment, rocks and small groyne	Longshore transport and coastline changes	2.3	Groynes	Shoaling, refraction and simple coastal processes	Longshore uniform	UNIBEST, LITPACK or GENESIS
		Longshore transport and coastline changes	7.1	Small angle of incidence	Semi-empirical (medium resolution)	-	UNIBEST, LITPACK or GENESIS (see table)
3	Shoreface nourishment and jetties	Longshore transport and coastline changes	2.2	-	-	-	Delft3D & Mike21
		Longshore transport and coastline changes	2.3	Jetties	Shoaling, refraction and simple coastal processes	Longshore uniform	UNIBEST, LITPACK or GENESIS
4	Removal groynes and offshore breakwater	Longshore transport and coastline changes	2.3	Detached breakwaters / groynes	Shoaling, refraction and simple coastal processes	Longshore uniform	UNIBEST, LITPACK or GENESIS
5	Removal groynes and small groyne	Longshore transport and coastline changes	2.3	Groynes	Shoaling, refraction and simple coastal processes	Longshore uniform	UNIBEST, LITPACK or GENESIS
6	Wooden groynes	Longshore transport and coastline changes	2.3	Groynes	Shoaling, refraction and simple coastal processes	Longshore uniform	UNIBEST, LITPACK or GENESIS
7	Retreat	Longshore transport and coastline changes	7.1	Small angle of incidence	Semi-empirical (medium resolution)	-	UNIBEST, LITPACK or GENESIS (see table)
8	Adapt	Longshore transport and coastline changes	7.1	Small angle of incidence	Semi-empirical (medium resolution)	-	UNIBEST, LITPACK or GENESIS (see table)

Table 5.5: Decision to determine software applications for each alternative

5.2.3 Assess the environmental- and socio-economic impact of alternatives

Environmental Impact Assessment
When solving coastal erosion problems there will be interfered with the longshore and cross-shore sediment transport. Interfering and making adjustments in a stable ecosystems can have large impact on these ecosystems. To prevent this an EIA report is written starting with the steps in Figure 4.15 in the framework.

Step 1
The area around Ciénaga consists out of tropical dry forest and a mangrove ecosystem, see Figure 2.8. The largest lagoon complex of Colombia, Ciénaga Grande De Santa Marta, lies south-west of Ciénaga. This lagoon consists out of a network of small lagoons connected with each other. It is an area with a lot of mangroves and a very high biodiversity. In 1964 parts were declared a natural park named Vía Parque Isla de Salamanca. The lagoon functions as a basin with a lot of salt water exchange with the sea. The road between Barranquilla and Santa Marta, built around 1950, disturbed the exchange of salt water with the lagoon which resulted in a enormous loss of biodiversity. One of the few connection with the sea and Ciénaga Grande De Santa Marta lies close to Ciénaga. For the preservation of the biodiversity the tidal inlet is essential and need to be maintained.
The area north and west of Ciénaga mainly consists out of a tropical dry forest. It does not have any direct connection with the coastal problems around Ciénaga.
The ecosystems do have a large impact on the human well-being around Ciénaga. In table 5.6 all the ecosystem services with their benefices are shown.

Type	**Ecosystem service**	**Component**
Provisioning	Food	Fishery for seafood
	Water storage and provision	Coastal lakes, inlets, tidal basins
	Biotic material and biofuels	Commercial or Industrial resourses
	Water purification	Treatment by purification
Regulating	Air quality regulation	Absorbation of air pollutants
	Coastal protection	Natural protection against erosion
	Climate regulation	Dissolved inorganic carbon
		Formed organic carbon
	Weather regulation	Influence coastal vegetation on air moisture
	Ocean nourishment	Production of organic matter
	Life cycle maintenance	Habitats and shelter
	Biological regulation	Control of fish pathogens
Cultural	Symbollic and aesthetic values	Local identity
		Traditions and religion.
	Recreation and tourism	Coastal activities
		(e.g. sunbathing, snorkeling, scuba diving)
		Offshore activities
		(fishing)
	Cognitive effects	Inspiration for arts and application
		Material for research and education
		Information and awareness

Table 5.6: Ecosystem services

Step 2
The main danger for the Vía Parque Isla de Salamanca is the closure of the tidal inlet near Ciénaga. This is possible to happen when a surplus of sediment forms downstream of Ciénaga. With the removal of the upstream groynes the trapped sediment will be included in the system and this can cause downstream accretion. For both the beach and the shoreface nourishment, sediment is added to the system and will lead to an accretion of the beach but this can also lead to sedimentation in the tidal inlet. Sedimentation in the tidal inlet is not likely to happen with upstream groynes or breakwaters.
The fish industry can be endangered by any change in current induced by adjustment of the coastal area. As viewed in Figure 5.2 the fishing area is close to shore. Any man made structures, breakwater or groynes, built in this area will affect the fishing industry.
The water storage, habitats and shelter are directly connected with the lagoon which is depended on the tidal inlet as explained before.

Step 3
Sedimentation of the tidal inlet can be prevented with the help of jetty's near the entrances of the inlet. The jetty's have to reach outside of the shoreface in order to protect the inlet against all long-shore sediment transport. A sediment by-pass is necessary in order to prevent erosion downstream of the inlet and entrapment of sediment in front of the jetty. All the possible dangers for the ecosystems can be prevented so with proper research there should not be any limitations for the alternatives.
Adjustments in the current have to be investigated in order to conclude that it will have negative effects on the fishing industry. If so adjustments in the design can be done or fishing alternatives can be made available. When man-made structures are built directly in the fishing zone the consequences have to be investigated. The only of remedy is to search for alternatives.

Step 4
When the measurements are approved by the ANLA and are ready for realisation the effects on both the ecosystem and ecosystem services need to be monitored. An committee, of for example INVEMAR or ANLA, needs to be responsible for the monitoring of these possible negative consequences. Important is that all the pre-made agreements are respected. This committee needs to independently defend the interests of all the stakeholders. Experts need to be involved in the monitoring of the ecosystems in order to preserve these ecosystems. These experts need to be able to make adjustments if that is required for preservation. For the preservation of the ecosystem services, their functions need to be clear and be preserved. This can be done by preservation of the ecosystems or alternatives for their functions need to be found.

Socio-economic impact

In Table 5.7 the effect of the different alternatives on the user functions in the area is shown. A plus means a positive effect, a zero means that the effect will not be positive or negative, a minus means a negative effect. In Table 5.8 the effect of the development factors on the alternatives is shown.

	Housing	Medical	Education	Local economy	Fishery	Recreation
1	+	+	+	+	0	-
2	+	+	+	+	0	+
3	+	+	+	+	0	+
4	+	0	0	+	-	-
5	+	+	+	+	0	+
6	+	+	+	+	0	-
7	-	-	-	-	0	0
8	+	-	+	-	+	0

Table 5.7: Effect of the different alternatives on the user functions

		1	2	3	4	5	6	7	8
Natural	Relative sea level rise	-	-	-	-	-	-	0	-
	Pollution	-	0	0	0	0	-	0	0
Socio-economic	Short term view politics	-	-	-	-	0	-	0	-
	Corruption	0	-	-	0	0	0	0	-
	Development technology	+	+	+	+	0	+	0	+
	Lack of knowledge	-	-	-	-	-	-	0	-

Table 5.8: Effect development factors on alternatives

5.3 Final Concept

5.3.1 Feasibility study

In a normal case all the requirements of the project are available in this stage. The available budget, time schedule and all other requirements are known for the feasibility study. In this non existing pilot case, this information is not available but the feasibility study can be done in general. All the different subjects will be rated on a scale 1-10, with 1 in favour and 10 not in favour on the alternative.

Technical

Alternatives nr.	Technical
1	3) Spacing, angle and length of groynes have to be modeled for optimal result. Technology for installation is availability and applicability
2	4) Removal of groynes functions as nourishment, to predict the outcome modelling is needed. Technology for removal of groynes is available and applicable
3	4) Characterisation of rocks and sediment needs to be modeled. Technology for installation is availability and applicability
4	5) Groyne need to be modeled carefully. Technology for installation is availability and applicability
5	8) Complicated modulation needed for determining characteristics shoreface nourishment. For installation technology and is available, equipment availability is unknown. Dredging ships are needed.
6	6) Tidal inlet needs to be modeled along with other solution, can be complicated. Technology for installation is availability and applicability
7	7) Solution with large impact on hydraulic system. Lot of modeling needed to minimise this. Technology for installation is availability and applicability
8	1) Nothing is needed
9	10) Impossible solution. Not profitable.

Table 5.9: Technical feasibility

Economic

Alternatives nr.	Economic
1	4) Single time expenses
2	2) Single time expenses
3	6) Depending on nourishment and rocks. Possible repeatable expenses
4	3) Single time expenses
5	8) Multiple expenses. Nourishment expensive
6	4) Single time expenses
7	5) Single time expenses
8	1) No expenses
9	10) Depending on houses, really expensive. Not profitable

Table 5.10: Economic feasibility

Legal
For legal feasibility analyse is not enough information available. To compare each alternative with the legal feasibility the zoning plan of the local government need to be known. Assumed is that because of the importance of a solution the alternatives are legal feasible.

Operational

Alternatives nr.	Operational
1	4) Simple operation. Lot of repetition of same operation. No future operations needed if correctly executed.
2	2) Small operation. No repetition, no future operations
3	6) Small nourishment, requires ships/trucks and possible repetition
4	3) Simple single groyne, no repetition or future operations
5	9) Small nourishment, requires ships and future repetition
6	5) Single operation. No future operations needed.
7	7) Single operation. No future repetition. Ships required for installation
8	1) no operation
9	10) depending on houses, lot of operation

Table 5.11: Operational feasibility

Schedule

Alternatives nr.	Schedule
1	3) Repetition of operations can be repeated fast
2	2) Removal of groyne can be done is short time
3	5) Depends on if repetition is needed.
4	3) Small groyne can be made in short time
5	5) Small nourishment is done fast, repetition can cause more operations
6	4) With right equipment operation can be done in short time
7	4) With right equipment operation can be done in short time
8	1) No operation
9	10) depending on houses, lot of operation

Table 5.12: Schedule feasibility

Total

Alternatives nr.	Technical	Economic	Legal	Operational	Schedule	Total
1	3	4	-	4	3	14
2	4	2	-	2	2	10
3	4	6	-	6	5	21
4	5	3	-	3	3	14
5	8	8	-	9	5	30
6	6	4	-	5	4	19
7	7	5	-	7	4	23
8	1	1	-	1	1	4
9	10	10	-	10	10	40

Table 5.13: Total feasibility

Alternatives 1 until 7 all need further investigation in order to decide which one is the best. Alternative 8 is logically not possible because it will not fix the problem. Alternative 9 is not profitable and can be neglected.

5.3.2 MCA

In the multi-criteria analyses the different alternatives will be tested on weighted criteria. They will be tested on the following criteria: Technical feasibility, Economic feasibility, Operational feasibility, Schedule feasibility, these criteria are already treated in the feasibility analysis. The remaining criteria are: maintenance cost, uncertainty, interference with basic user functions, interference with social user functions, interference with economic user functions, interference with public user functions, environmental impact and the esthetic value. These criteria are all compared to each other and in this way a weighted factor can be calculated.

	Technical feasibility	Economic feasibility	Operational feasibility	Schedule feasibility	Maintenance cost	Uncertainty	basic user functions	social user functions	economic user functions	public user functions	Environmental impact	Esthetic value	total	WF
Technical feasibility	1.0	1.0	2.0	5.0	1.7	1.1	1.7	0.5	0.5	3.3	1.0	3.3	22.1	0.10
Economic feasibility	1.0	1.0	2.0	5.0	1.7	1.1	1.7	0.5	0.5	3.3	1.0	3.3	22.1	0.10
Operational feasibility	0.5	0.5	1.0	2.5	0.6	0.6	0.8	0.3	0.3	1.7	0.5	1.7	10.8	0.05
Schedule feasibility	0.2	0.2	0.4	1.0	0.2	0.2	0.3	0.1	0.1	0.7	0.2	0.7	4.3	0.02
Maintenance cost	0.6	0.6	1.2	3.0	1.0	0.7	1.0	0.3	0.3	2.0	0.6	2.0	13.3	0.06
Uncertainty	0.9	0.9	1.8	4.5	1.5	1.0	1.5	0.5	0.5	3.0	0.9	3.0	19.9	0.09
basic user functions	0.6	0.6	1.2	3.0	1.0	0.7	1.0	0.3	0.3	2.0	0.6	2.0	13.3	0.06
social user functions	2.0	2.0	4.0	10.0	3.3	2.2	3.3	1.0	1.0	6.7	2.0	6.7	44.2	0.19
economic user functions	2.0	2.0	4.0	10.0	3.3	2.2	3.3	1.0	1.0	6.7	2.0	6.7	44.2	0.19
public user functions	0.3	0.3	0.6	1.5	0.5	0.3	0.5	0.2	0.2	1.0	0.3	1.0	6.6	0.03
Environmental impact	1.0	1.0	2.0	5.0	1.7	1.1	1.7	0.5	0.5	3.3	1.0	3.3	22.1	0.10
Esthetic value	0.3	0.3	0.6	1.5	0.5	0.3	0.5	0.2	0.2	1.0	0.3	1.0	6.6	0.03

Figure 5.13: Weighted MCA factor calculation

This factor is used to determine the importance of each criteria. With this factor and the known criteria the multi criteria analyses can be done. The results of the MCA are shown in Figure 5.14

	A.1	A.2	A.3	A.4	A.5	A.6	WF
Technical feasibility	0.6	0.5	0.3	0.4	0.5	0.7	0.10
Economic feasibility	0.7	0.4	0.4	0.4	0.8	0.8	0.10
Operational feasibility	0.7	0.5	0.3	0.5	0.7	0.6	0.05
Schedule feasibility	0.7	0.5	0.6	0.7	0.8	0.7	0.02
Maintenance cost	0.6	0.5	0.2	0.8	0.7	0.6	0.06
Uncertainty	0.4	0.8	0.5	0.4	0.5	0.3	0.09
basic user functions	1.0	1.0	1.0	1.0	1.0	1.0	0.06
social user functions	0.8	0.6	1.0	0.7	1.0	0.8	0.19
economic user functions	0.8	0.9	0.6	0.4	0.8	0.8	0.19
public user functions	1.0	1.0	1.0	1.0	1.0	1.0	0.03
Environmental impact	0.6	1.0	0.8	0.5	0.6	1.0	0.10
Esthetic value	0.5	0.8	1.0	0.5	0.7	0.5	0.03
Total	0.71	0.71	0.65	0.56	0.77	0.75	0.00

Figure 5.14: Results MCA

The highest score in in MCA is alternative 5 which is a combination of the removal of groynes with the building of one or more small groynes near the critical area in order to have accretion.

5.3.3 Determine an integral approach to implement the chosen alternative

Because this case is just an example of how the framework should be used, and because it is not complete, it will not be published or presented to the different stakeholders.

5.3.4 Dimension the final design

As can be seen in the results of the MCA, the final solution will be a combination of placing a small groyne at the junction of Calle 7 and Carrera 1 as well as removing the groyne in the north-east. By removing this groyne in the north-east, more sediment will be available for the entire coastline. This can be seen as a nourishment. The small groyne is needed to create a beach at the critical area. For now, the junction of Calle 7 and Carrera 1 looks like a logic place to construct the groyne, but modelling should determine the exact location and should determine if one groyne is enough. Also, modelling should determine if the speed at which the new beach gets formed is fast enough. The rocks obtained from removing the groyne in the north-east can be used to build the new groyne or groynes.

The new formed beach serves multiple functions. The most important is that the houses near that beach, the houses in the critical area, are not threatened by erosion anymore. This of course was the main purpose of the project. Furthermore it creates the opportunity for the area to become an attractive place for citizens of Ciénaga or for tourists from outside Ciénaga, just like the beach to the north-east. This creates lots of economic opportunities for the area, like for instance restaurants and hotels.

5.4 Step D: Evaluation

5.4.1 Evaluate the project

This step is meant for when the framework is fully executed. For this case, without the modeling, it is not useful to do this evaluation.

5.4.2 Evaluate the framework

For the evaluation of the framework, the evaluation form is filled in. This can be seen in Appendix N.

5.5 Step E: Awareness

The following plan, Figure 4.17 will be executed in order to develop more awareness.

1. Choose your audience
Out of the survey, Figure 5.1, is concluded that the whole society of Ciénaga, living near or further away from the coast, has a lack of knowledge concerning coastal problems in general. The awareness plan focuses on the whole society of Ciénaga. This means that all levels in society will be included, poor or rich and old or young.

2. Define what you want to communicate
In the survey the question: *"What is coastal erosion?"* was a question most of the locals could not answer. The knowledge about coastal problems is very poor. The different kinds of impact of coastal erosion on ecosystems, the environment, the economy and local housing should be addressed. To show the impact on a larger scale, instead of only be concerned about the local housing, should seek attention of more people because they can be personally effected by these effects. Important is to address these issues in a very basic and simple way so that all people can understand it, not only the higher classes in society because they have had good education.

3. Determine the medium you will use
In our case we have chosen for a video. With short movies problems can be explained in a simple and understandable way. For us, a group of six Dutch students we had to deal with another issues which is the language barrier. Movies can be easily translated to Spanish. Movies can be spread fast and easily trough the internet, a disadvantage of this is that not all the inhabitants of Ciénaga have excess to internet. Video's can be shared on YouTube, Facebook and other social media.

4. Choose the frequency of your action
A video is always accessible once it is online. The most important thing to do is to create a platform on social media which is accessible by as much as people as possible. It is smart to have some kind of continuity in the platform with a weekly update or new explained problem in order to keep the platform active. Also a cooperation with high schools and community meetings could contribute to the awareness.

5. Report on the platform
In the last step of the process, a summary of the project including the chosen action to raise

awareness can be documented in a platform. In this way, a large archive is made which can help to inspire other people about the Integrated Coastal Zone Management strategy. The website will function as an interactive platform, where besides the elaboration of the framework, there is also room for discussion about ICZM and the possibility to post your own actions and accomplishments. The sharing of different experiences with ICZM projects can be evaluative for the framework, instructive for local engineers and project developers and inspirational for citizens. The platform will challenge people to use the framework and share their experiences.

Part IV

Project Closure

6 Conclusion

In Chapter 3 of Part I the research question was defined as:

"How can a Dutch student team contribute to the improvement of coastal protection measures along the coast of Magdalena and La Guajira?"

The answer to this research question expressed itself in three research objectives:

I Create a framework which leads to a more consistent, transparent, sustainable and integral approach of coastal zone management.

II Develop a manual on software use to encourage the assessment of short and long-term morphological changes.

III Start a dialogue about the impact of integrated coastal zone management and coastal erosion problems.

To reach objective I, a framework is created that does not only consider hydraulic engineering problems, but also takes into account socio-economic and natural values. Each chapter serves as an aid in the decision-making process and serves as a management tool during the plan and policy development. Some notes on the consistency, transparency and sustainability of the framework are mentioned below, as well as whether the approach is integral:

- As several theories on Integrated Coastal Zone Management are used while developing this framework, it can be concluded that the framework will lead to a more integral approach of projects.
- The level of consistency between projects that are designed using the framework is harder to check. In the framework, only outlines of specific steps are drawn. It is partly up to the user to define the level of detail of each step, depending on the type of project. The consistency can thus foremost be checked after projects that are designed with the framework have been executed and evaluated. For now, it can be concluded that it is highly likely that consistency will be enhanced because overall the same steps are executed.
- With the use of the framework, the project developers use a fixed step-by-step approach which can be checked and is easy to understand. This makes these projects more transparent.
- The framework is sustainable in the sense that it is self-improving; each time someone uses the framework it is evaluated and then further improved.
- A major step towards consistency, transparency and sustainability would be to create a platform or website, where all stakeholders are able to comment about current developments within the project. This is further discussed in Chapter 8.

The framework is validated by means of a present-day case in Ciénaga. From this case study it can be concluded that the framework could possibly function; steps seem logical and easy to implement. However, for a full assessment of the framework, actual projects should be designed with it. Only then, smaller details, difficulties and mistakes can be observed in the framework.

In the framework a software tool is implemented to guide and encourage local hydraulic engineers with little knowledge of modelling software programs. The manual as referred to in the second goal does not only encourage the assessment of short and long-term morphological changes, but serves as a tool to choose and to help understand the required software application. In this way, an engineer does not have to study every possible software model but can easily find the suitable one. To evaluate the functioning of the decision tree, it is applied to the different alternatives that are explored in the case study. Comparing the outcomes with past experiences with numerical models, it can be concluded that the decision tree gives a reasonable outcome.

The final goal is starting a dialogue about the impact of ICZM. While it is hard to assess the impact of such a dialogue, attempts have been made to create awareness as much as possible. In practice this resulted in many interviews, a survey, attendance of local community meetings, presentations at the Universidad del Norte for stakeholders of the project and an informal gathering of students at the Universidad de Cartagena. Thus it can be concluded that a dialogue is started but that the impact of the dialogue is not known.

Coming back to the original research question as formulated above, it can be concluded that it was possible to contribute to the improvement of coastal protection measures, in the way that is described above.

7 Discussion

Here the relevance of the project's outcomes are discussed. After establishing the need for a structural approach to different coastal problems within the Colciencias project a guideline was presented in the form of a framework. Along with a validation through the application of the framework to a case study, this framework provided an answer to the main research question.

During the development and validation of the framework it became clear that certain steps of the framework could be difficult to execute in practice. For example the gathering of information on previously realised projects and information in general is easier said than done. Most information is attained through oral communication. Often good documentation is absent. As this already posed a problem in establishing this report, it will also form a problem during the development of a hydraulic solution using the framework.
Also, in the case study presented in this report there was little time to do an extensive hydrodynamic assessment. Due to the lack of these outcomes it is difficult to ensure the framework is properly reviewed for usage. To strengthen the applicability of the framework it should be used multiple times, whilst adjusting where necessary.
Furthermore, multiple issues come to mind when assessing the actual use of the framework. Firstly, how does one make sure the framework is used by the right people? It is meant for the hydraulic engineers within the Colciencias project, especially when executing the modelling part of the framework. The question is whether the client will distribute the framework to the right engineers.
Secondly, these engineers need to possess basic knowledge on hydraulic engineering. Not just any engineer would be able to use the software tool and understand the provided background information on the different software.
Lastly, using the framework might be difficult in a foreign country like Colombia due to the language barrier, which will always be present when writing a guideline in English. One might be a fully educated coastal engineer and at the same time experiencing large difficulty in using the framework solely due to a lack of knowledge on the English language. Therefore, the framework should be translated in Spanish for further distribution.

8 Recommendations

The recommendations of this report follow from the conclusion and discussion. It is a summary of the created ideas that were generated while working on the project. It could be used as content for a follow-up project.

As stated in the conclusion, the validation of the framework will be time consuming as many projects are required to do so. The second problem is the applicability of the framework; The method is written in English, there is no (or not yet a) future alliance between TU Delft and Project Colciencias and the evaluation phase is still rather unstructured. Two ideas that help solving these problems are elaborated below. This includes the idea of founding a platform and an evaluation team.

8.1 Develop of a platform

The platform will offer a stage for the framework. To bridge the gap between the partly missing validation and the future potential of the framework, a platform needs to be developed. The concept of the platform is as follows:

An open source educational website that serves as an interactive tool to educate people on ICZM and to improve coastal projects by grouping all experiences with the framework.

To give more content to this idea, a few objectives for the platform are generated. They are elaborated in the following summary:

- *Educational:*
  The main goal of the platform is providing education by clearly addressing the framework, its goal and the different steps to be executed. All information about the framework, the case studies and possibly projects executed with the framework will be shared to encourage local engineers to use the framework and stimulate cooperation.

- *Inspirational:*
  The platform serves as a database where all ICZM projects, solved with the method of the framework, can be reported. Due to a lack of long term vision and understanding of the necessity of ICZM in Colombia and due to the difficulties that coastal zone management entails, creating awareness on this subject is desired. With this awareness, local engineers and citizens can be inspired.

- *Constant exchange:*
  The platform can be (optionally) led by a TU Delft Multi Disciplinary Project team. The result is a constant exchange of knowledge and experience between the Netherlands and Colombia.

- *Sustainable:*
  Developing the platform led by a TU Delft team results in a sustainable use of education and research. This framework will be improved by usage and validation.

- *Interactive:*
  The platform is going to be interactive. It will offer room for a discussion about different coastal topics. It also brings attention to the impact of coastal erosion.

8.2 Evaluation team

The next recommendation is to appoint a special evaluation team within the Colciencias project. In the current project description of Colciencias, the evaluation process is not discussed. The evaluation part of the project is highly valuable in terms of the improvement of coastal management methodology. For maintaining a constant and objective evaluation, it is necessary that the evaluation is done by a team that is independent of the initiators of the project.

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A Previous Projects

A.1 Case: groins in Riohacha

Riohacha is a city at the coast La Guajira with nearly 300.000 inhabitants. It is located at the deltaic system of the Rancheria river. The coast suffered on erosion the past 40 years, with rates up to 4m/yr (Nelson Guillermo Rangel-Buitrago, 2015). In 2006 the local government approved a part of a coastal erosion plan which contained the construction of twelve groins and one seawall. Six of the groins were built at the end of 2007, all of them with a length of 150m, width of 13m, height of 6m and separated 250 meters from each other. As a result, beaches with a width of up to 200 meter were created at the northern part of the groins. On the counterpart, erosion rates south of the groins increased, up to 5m/yr. As a reaction the local government plans to build six more groins, as in the original plan, making the total costs US$ 10 million. These six extra groins will not resolve the problem but will only move it more southward, resulting at an even stronger erosion there. The predictions are that within a short time parts of the city have to be moved, resulting in severe socio-economic problems. The groins will never be successful without a sand bypass, allowing the large amount of sand at the northern part to move southward (Rangel-Buitrago, N., et al., 2017).

Figure A.1: Riohacha Guajira study case. a-b) groins building along city promenade. c-d) erosion related damages after groin construction (oblique photos, Satellite and Terraserver images for 2006-2016 period) (Rangel-Buitrago, N., et al., 2017)

A.2 Case: kilometer 18-21 between Santa Marta and Barranquilla

Two for the Colombian economy important port cities, Santa Marta and Barranquilla, are connected with a road near the coast that suffers severe erosion. The road is essential because the alternative is a road around Ciénaga Grande de Santa Marta, which triples the travel time. The erosion is the most between kilometer 18 and 21, reaching rates up to 21m/yr the past 20 years (Nelson Guillermo Rangel-Buitrago, 2015). In 2010 a design of three breakwaters, each with a length of 120m, width of 10m, height of 2.5m, all separated 300m from each other and located 125 meters of the coast, were designed. In 2011 the construction of the breakwaters started, but during the construction the position and dimensions of the breakwaters changed, under the political pressure, many times, leading to breakwaters with lighter rocks and 40m of the coast instead of the designed 125m, costing US$ 7 million. In January 2014 a series of storms events occurred, which caused extreme erosion and the destruction of the breakwaters. Only 3 meters of land separated the road of collapse. As a first response, 350m of concrete bags were placed to prevent further erosion. After that, national and local authorities agreed on fast availability of money for this part of the coast because of the urge. US$ 8 million was invested in building a rock revetment of 348m, being unsuccessful so far. West of the structures a land retread of 60m occured (Rangel-Buitrago, N., et al., 2017).

Figure A.2: Km 18-21 study case. images shows the evolution of the area as well the revetment construction evolution during the last 3 years (oblique photos, Satellite and Terraserver images for 2004-2016 period) (Rangel-Buitrago, N., et al., 2017)

B Colciencias Objectives and Results

1. *To characterise the marine-coastal conditions of the coast of the Departments of La Guajira and Magdalena:*
2. Characterization of the marine-coastal conditions of the littoral of Department of Magdalena. The characterization consists out of; bathymetric surveys, beach profiles, Sedimentological characterization, Point measurements of sediment concentration, Geological and geomorphological characterization, analysis of coastline variability, Hydrological characterization, Inventory of existing coastal protection works, Geo-electrical study 15 sectors and Biological characterization.
3. A scientific article
4. *Design systems of alternative wave dissipation technologies applicable to the Coastal protection on beaches of the Departments of La Guajira and Magdalena from numerical modeling:*
5. Three designs of alternative waves dissipation technologies applicable to the coastal protection on the beaches of the department of La Guajira and Magdalena
6. Plans of technologies designed
7. Results of numerical modeling
8. Flow 3D software workshop
9. COMSOL software workshop
10. A scientific article
11. *To develop concrete resistant to marine environments from materials of the region:*
12. Design of three types of concrete for marine environments
13. Two scientific articles
14. *Evaluate alternative wave dissipation technologies applicable to coastal protection on the beaches of the Departments of La Guajira and Magdalena, based on physical tests and scale:*
15. Three wave dissipation technologies evaluated to be applied to the coastal protection in beaches of the Departments of La Guajira and Magdalena
16. Two scientific articles
17. *Design pilot and methodological projects for the protection and recovery of beaches in the Departments of La Guajira and Magdalena:*
18. Design of two pilot projects for the Department of La Guajira
19. Design of a pilot project for the Department of Magdalena
20. Two environmental impact assessments
21. Methodological guide of regional reference for the realization of studies, designs and monitoring of protection works
22. Scientific article
23. *Develop an Expert Coastal Zone Modeling System that integrates database and calibrated models for conditions of the Departments of La Guajira and Magdalena:*
24. Database (Bathymetries, waves, Sea level, wind fields)
25. Expert System of Coastal Modeling
26. Meteo-marine monitoring module
27. Workshop of the MOHID model
28. Two scientific articles
29. *To characterise the threat of phenomena of marine-coastal origin and to analyze the vulnerability and risk of coastal erosion for critical sectors in the Departments of La Guajira and Magdalena:*

30. Database with data associated with the threats (rainfall, sea level, seismicity, etc.) for the Dept. del Magdalena
31. Preliminary characterization report of marine-coastal threat for the Dept. of Magdalena
32. Methodological guide for the determination of the threat of coastal erosion
33. Coastal erosion threat map for critical sectors of the Dept. of La Guajira and Magdalena
34. Vulnerability map for coastal erosion for critical sectors of the Dept. of La Guajira and Magdalena
35. Risk map for the coastal erosion for critical sectors
36. Two scientific articles
37. *Develop and socialise a coastal zone environmental planning model associated with anthropogenic impacts in coastal populated areas of the La Guajira Dept. characterization and evaluation of impacts of discharges and contamination foci:*
38. Socioeconomic and quality maps to identify the potential of the Beaches according to use
39. Characterization of risk associated with the presence of solid waste and liquid spills in the coastal area
40. Planning strategies for handling spills in coastal areas
41. Proposal for the creation of a committee of Mayors with influence on the coastal zone to unify criteria, efforts and policies for the adequate handling of them
42. A scientific article
43. *Develop and implement a hydrodynamic model of water and sediment quality for the coast of the Dept. Magdalena as support to environmental authorities for the management of beaches and mitigation of coastal environmental risk:*
44. System of regional model of water and sediment quality for the Department of Magdalena
45. Map of the ecological risk and map of exclusion areas for contact primary and secondary on the coastal front of Magdalena
46. Management measures to minimise the effects of dumping and disposal of domestic wastewater
47. Modeling workshop with ROMS
48. Two scientific articles
49. *Train human talent at master's and doctoral level:*
    Not relevant
50. Training of human talent at the master's level (4 students)
51. Support in the training of human talent at the Doctorate level (2 students)

C Cultural Analysis

Many models exist to analyse the cultural differences between countries. Based on ease of usage, accessibility and the agreement with the working environment of the project the Lewis model on behaviour and the anthropological GLOBE model are used to make a helpful overview of the Colombian culture. The application of these models are more elaborately explained here.

The Lewis model is used to establish an initial overview of how cultures and their behaviour differ. This rough estimation is useful when trying to understand communication issues between cultures. This model falls short in business applicabilities as it is quite superficial. This is where the GLOBE model comes in. The GLOBE model is used to make a scientific and anthropological model. The model is an expansion of Hofstedes model, using information from midlevel managers from 825 organizations in 65 countries. It takes into account various dimensions which give a more detailed survey than the Lewis model. Together these models result in a complete cultural analysis (Sult, 2013).

C.0.1 Lewis model on Colombian culture

The Lewis model is one of the latest models to gain world-wide recognition in recognizing cross-cultural differences. The model is created by Briton Richard Lewis, who visited 135 countries. During working in more than 20 of these countries Lewis concluded that a cultural difference can be of great influence based on behaviour. Data is obtained by almost a quarter million online questionnaires to 68 different nationalities. It is also based on the views of multiple ten thousands of executives. The model's three dimensions are: linear-active, multi-active and reactive (Culture", 2017).

The linear-active group consists mostly of the English speaking countries in the world. Northern Europe, Britain and the US are linear-active and are factual, value control and plan ahead by using schedules. Efficiency is a valuable concept for these countries.

Asia is tending towards the reactive group. Relationships are, as well as the multi-active group, important for this group. The difference is that this group seeks harmony rather than confrontation.

The multi-active group contains countries that act primarily on emotions. These countries are divided across the world. South -and Middle America, parts of Southern Europe, some cultures in the Middle East and large parts of Africa are multi-active cultures. According to the Lewis model, Colombians can be seen as a multi-active group. The Colombian behaviour is warm, emotional, loquacious and impulsive. Their behaviour is based on feelings and creating commotion which is quickly forgotten after an agreement is reached. The multi-active group does not plan or schedule extensively, but rather takes tasks that seem important and relevant at the time (Alythea Ho, 2014).

It is important to know cultural differences while co-working on a project. In figure C.1 detailed characteristics of each group are given as well as a distribution of most counties over the groups.

C.0.2 Lewis - Appendix

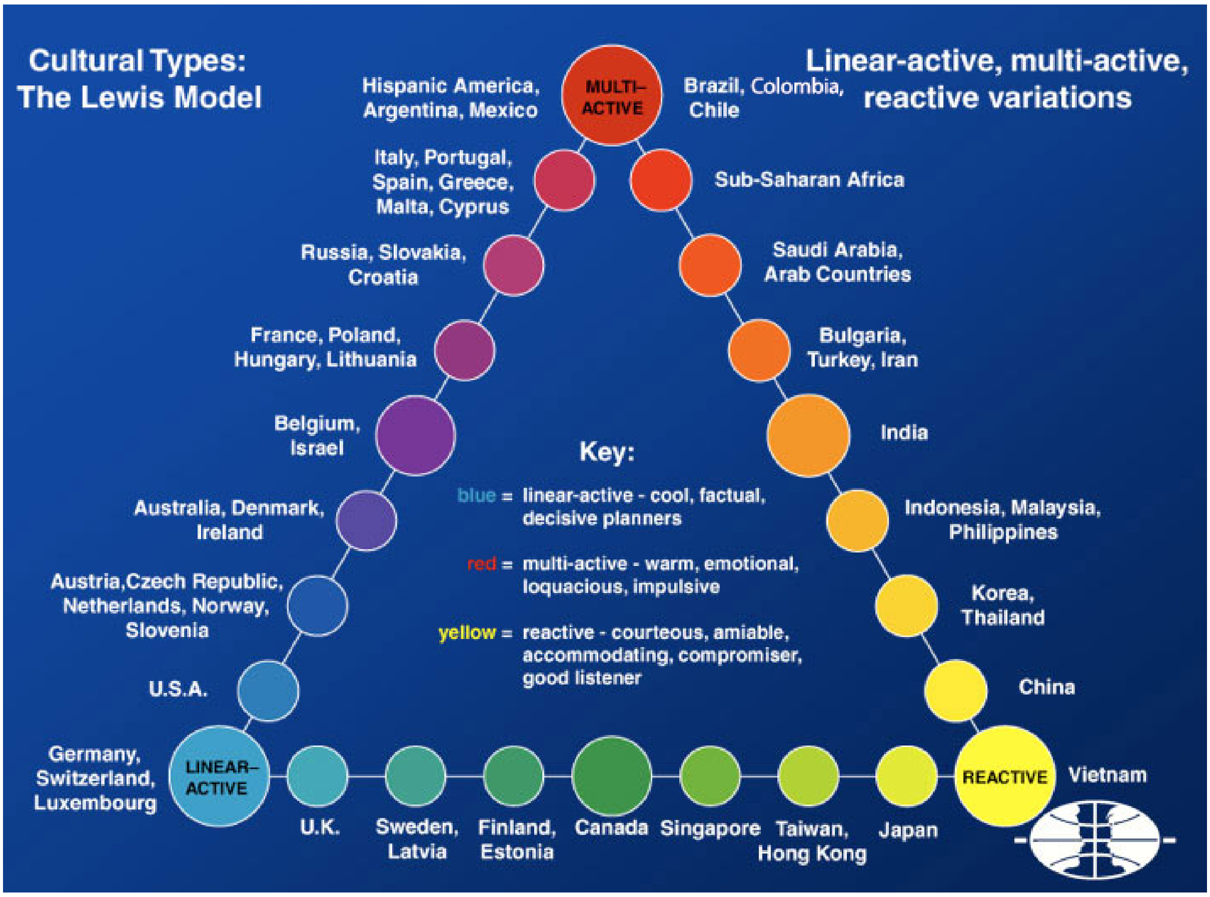


Figure C.1: Cultures divided in the three dimensions of the Lewis Model (Culture", 2017).

More detailed characteristics of each dimension are listed in Table C.1.

Linear-active	**Multi-active**	**Reactive**
Talks half the time	Talks most of the time	Listens most of the time
Does one thing at a time	Does several things at once	Reacts to partner's action
Plans ahead step by step	Plans grand outline only	Looks at general principles
Polite but direct	Emotional	Polite, indirect
Partly conceals feelings	Displays feelings	Conceals feelings
Confronts with logic	Confronts emotionally	Never confronts
Dislikes losing face	Has good excuses	Must not lose face
Rarely interrupts	Often interrupts	Does not interrupt
Job-oriented	People-oriented	Very people-oriented
Sticks to facts	Feelings before facts	Statements are promises
Truth before diplomacy	Flexible truth	Diplomacy over truth
Sometimes impatient	Impatient	Patient
Limited body language	Unlimited body language	Subtle body language
Respects officialdom	Seeks out key person	Uses connections
Separates the social and professional	Mixes the social and professional	Connects the social and profession

Table C.1: Behavioural characteristics as defined by Richard Lewis (Culture", 2017)

C.0.3 GLOBE framework on Colombian culture

The GLOBE framework is a more scientific approach, used complementary with the Lewis model. The model uses data, obtained mostly from midlevel managers, from almost thousand organizations in 65 countries. The GLOBE model is an elaboration of the Hofstede model, a model created by Dutch anthropologist Geert Hofstede. The model visualises both cultures and leadership characteristics. In this study, interest lies in the cultural visualization. The results of the cultural GLOBE framework is shown in 9 dimensions, definitions are given as House. Et al. formulated (House. Et al., 2002):

Performance orientation The degree to which a collective encourages and rewards group members for performance improvement and excellence.

Assertiveness The degree to which individuals are assertive, confrontational, and aggressive in their relationships with others.

Future orientation The extent to which individuals engage in future-oriented behaviours such as delaying gratification, planning, and investing in the future.

Humane orientation The degree to which a collective encourages and rewards individuals for being fair, altruistic, generous, caring, and kind to others.

Institutional collectivism The degree to which organizational and societal institutional practices encourage and reward collective distribution of resources and collective action.

In-group collectivism The degree to which individuals express pride, loyalty, and cohesiveness in their organizations or families.

Gender egalitarianism The degree to which a collective minimises gender inequality.

Power distance The degree to which members of a collective expect power to be distributed equally.

Uncertainty avoidance The extent to which a society, organization, or group relies on social norms, rules, and procedures to alleviate unpredictability of future events.

If the value and practice score are equal or close to each other, the score is ideal for a culture. How the country scores in comparison with other countries gives insight in cultural differences. A large difference between practice and value score indicate the ambition of a culture, showing norms and values that are considered important. It also shows a disagreement between the current situation and the should be situation.

C.0.4 GLOBE conclusions

Although Colombia shows a very high value score in the performance orientation, it scores medium in the practice score. However the majority of Colombian companies do evaluate their employees on their performance for promotion or increase of salary, there is no incentive such as public recognition or prices. The educational system does rate students based on performances, yet the rewards system is minimal. Feedback systems towards professors and teachers are not accepted either, because of the authoritarian function these professions have in the Colombian culture. Some universities that did include feedback and evaluation systems by students have even lost academic appearance. Incentives such as public recognition or rewards are minimal, although desired by Colombians. The dangerous environment the average Colombian live in and aggressive character the average Colombian has would seem a problem in their culture.

Yet on assertiveness the practice score is surprisingly low. In practice Colombia scores slightly above average and admires a score somewhat less assertive, yet the employees seem satisfied in this dimension.

The future orientation dimension shows a large disagreement between practice and value score. While a high future orientation is admired, Colombia is one of the worst scoring countries within the Globe framework. The Lewis model places Colombia in the multi-active group, where impulsive actions take the lead over constructive plans and schedules. Secondly, Colombia is not a wealthy country. Constructive, multiple year plans are more difficult to carry out, because as soon as resources are available they are spent on short-term solutions. Colombians are spontaneous by nature. It is a cultural habit to live from day to day. The corporate life however increasingly requires future orientation.

On the dimension humane orientation the practice value scores medium, but low compared to other countries. Colombia actually values humane orientation relatively high. Poverty can be seen as the major contributor to this problem. Streets in Colombia are filled with beggars, mental patients garbage recyclers etc. Colombia is Catholic by origin and charity is part of their culture. There are institutions that provide homeless with free meals and beggars are able to survive as well. Yet many Colombians oppose this behaviour, because in their view it only increases poverty. Colombia does have special mental institutions and schools for physically and mentally impaired. This is seen as a first step towards humane orientation, yet ordinary life does not accommodate the physically or mentally impaired.

Institutional collectivism is valued high, but scores below average. In-group collectivism is practices and values very high and these scores lie close together. Family is one of the most important values in the Colombian culture. It is completely normal for matured children to stay with their parents, or even when unmarried or widowed. Elderly are not placed in nursing houses but are taken care of by their family.

Gender egalitarianism is above average for Colombia, yet is strived for even more equality between genders. The Colombian business life is seen as highly collectivistic and elite by the Hofstede study. This does however not count for the gender inequality. Managers both male and female indicate that different genders have different chances. The power distance dimension scores a high practice score while a low value score is preferred. The difference is remarkable. The social inequality in Colombia is enormous. Most power lies in the hands of a small powerful elite. Daily life jobs are unequal. Difference in wages is huge.

Uncertainty avoidance is valued above average, yet scores below average. This can be explained by the living from day to day culture, instead of planning ahead. An improve in uncertainty avoidance is desired by the citisens. Coming late at meetings is becoming less acceptable. (Ogliastri, 2005)

D Policital Regulation

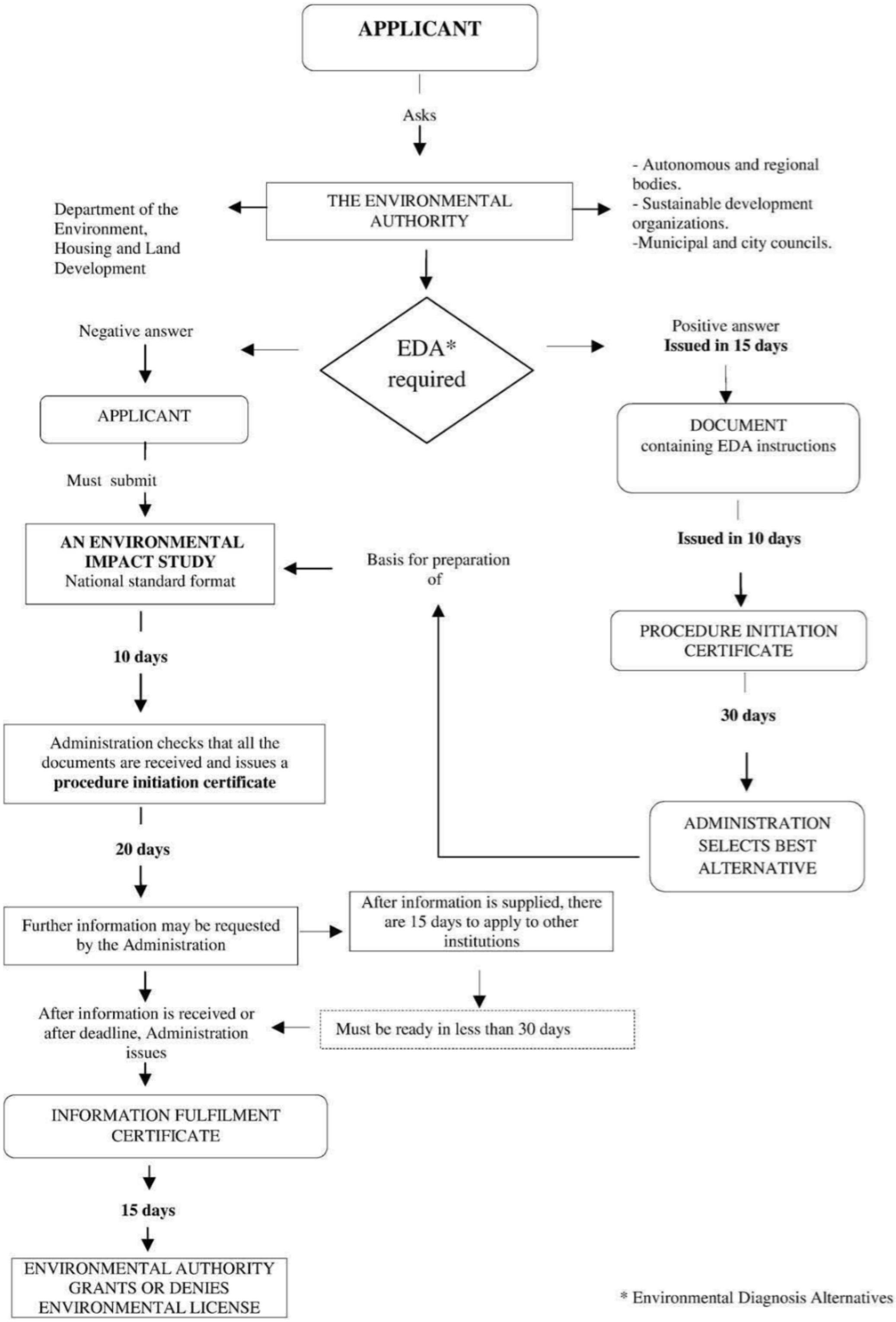


Figure D.1: EIA Process

E Background information stakeholders

		What is important to stakeholder?	Involvement in project	Interest in project	Influence	Impact What impact does the project have on the stakeholder	Resources	Position
Consultants	Oceanus International	Improving marine conditions International publicity Profit	*High* *Primary Stakeholder* *Creators of the project*	*High* Financial Interest Project serves as reference for future projects in Colombia	*High* *Main Stakeholder in project*	*Medium* *No direct personal impact, but a good fullfillment of the project is required for expansion of the business in Colombia*	*High* Financial resources Indepth knowledge	Promotor
	Invemar	Provision of knowledge for policy making and project plan development	*High* *Primary Stakeholder* *Creators of the project*	*High* ICZM is highly related with policy making and a major point of interest	High Main Stakeholder in project	*Medium* As a semi-government institution, the success or failure of the project can be projected to a company and its employees	*High* In depth knowledge Strong relations with governments	Promotor
	Univ. del Norte	Education of future (hydraulic) engineers Knowledge expansion by research	*High* *Primary Stakeholder* *Creators of the project*	High Increase knowledge on ICZM	High	Medium Uni del Norte is an independent foundation so they are not controlled by the government. The Financial impact is also not very high	Medium In depth knowledge FInancial resources	Promotor
	Univ. del Magdalena	Education of graduates and post graduates Protection of regional environment and citizens	*Medium* *Primary Stakeholder* *Less involvement than first three parties*	High Improvement of Coast region Knowledge expansion	Medium to High	Medium As a government institution, the success or failure of the project can be projected to a company and its employees	*Medium* Knowledge of environmental issues, no hydraulic engineering department	Promotor
	Univ. de la Guajira	Education of graduates and post graduates Protection of regional environment and citizens	*Medium* *Primary Stakeholder* *Less involvement than first three parties*	High Improvement of Coast region Knowledge expansion	Medium to High	Medium As a government institution, the success or failure of the project can be projected to a company and its employees	*Medium* Some financial resources No Civil Engineering Department so little knowledge	Promotor

	Univ. de Cartagena	Education of future (hydraulic) engineers Creating awareness for coastal problems	*Medium to High* Provision of knowledge and working space	*Medium* No direct link to this project but the project can serve as guidance for future projects Contact with the TU Delft	Low	*Low* *No direct link to project, only a guiding role*	Medium In depth knowledge Research facilities Working space	Supporter
	Oceanicos	Education of future hydraulic engineers Creating awareness for coastal problems	*Medium* Provision of knowledge	*Medium* No direct link to this project but it can serve as guidance for future projects	Low	*Low* *No direct link to project, only a guiding role*	*Low to Medium* Knowledge	Supporter
	CIOH	Facilitate the protection of the marine environment and the integrated management of the coastal areas	*Medium* Provision of knowledge	*Medium* No direct link to this project but it can serve as guidance for future projects	*Low to Medium* They have power of jurisdiction in the coastal areas. However, the law enforcement is difficult, see Appendix X.	*Low* No direct link to project, only a guiding role	High A research department working on ICZM. Three other departments working in the field of hydraulic engineering	Supporter
	IDEAM	Providing technical and scientific support to the National Environmental System	*Low*	*Medium* No direct link to this project but it can serve as guidance for future projects	*Low*	*Low* No direct link to project, only a guiding role	*Low to Medium* Knowledge	Supporter
	Jorge Tadeo Lozano				*Low*	*Low* No direct link to project, only a guiding role	*Low to Medium* Knowledge	Supporter
	TU Delft	Connections with Colombia for exchanges both on educational and working level	*Medium* Student team of TU Delft works as consultant for Oceanus International *Feedback*	*Medium* *Different students and professors have been working in the field of ICZM of Colombia*	*Medium* No influence on what happens with the project and what is done with the results of the research, but Dutch students and academics are highly trusted in Colombia, see Appendix X.	*Low* No special impact	*High* As the leading University in the field of Hydraulic Engineering, the TU Delft serves as a good resource for reference projects and studies	Latent
Local Governments	Gov. of Magdalena and Guajira	Protection of citizens Guarantee sustainable economic and social growth	*High* Financers of the project	*High* The project is in line with the goals of the government	*High* The project needs to be approved by the government and other regional institutes that fall under jurisdiction of the regional government	*High* Improvement of quality of life inhabitants Reduction of risks and damages to environment of the region Increase of popularity	*High* Financial resources Law enforcement agencies required for possible implementation ICZM (See Appendix X)	Promotor
National Government	Ministry of Education	To ensure equitable access to quality education	*Medium* *Education is an important factor in creating awareness on coastal problems and climate change*	*Medium*	*Medium* Governing body of a few institutes and universities involved	*Low*	Financial resources for universities and institutions	Promotor and decision making

	Ministry of E & SD	To ensure protection and conservation of the environment	*Medium to high* Some departments of the ministery are involved (ANLA)	High Coastal area hugh impact on rest of environment	*High* Decionmaking in approval of projects	*Medium* As a government institution, the success or failure of the project can be projected to a company and its employees	Financial resources for some universitiets and institutions	Promotor and decision making
	ANLA	to ensure protection and conservation of the enviornment	*High* The project must adhere to restriction of the ANLA	High	*High* Licencing of projects	*Medium* As a government institution, the success or failure of the project can be projected to a company and its employees	Financial resources for some universitiets and institutions	Promotor and decision making
	UNGRD	Directs and coordinates the Disaster Risk Management in Colombia	*Low* Providing expertise and knowledge	*Low* Not specificly interestedin this project	*Low* No influence right know, but can be at service in the future	*Low* No personal impact	knowledge about risk assesment	Feedback
	Ministry of Commerce, Industry and Tourism	To promote economic growth, create jobs and generate wealth	*Medium* Passivly involved, ICZM can have a great impact	*Medium* Passivly interested, not always aware of the influence that ICZM can have	*Low*	*High* Maintaining the coastal area's has a indirect impact on this sector	*Low*	Latent
	Ministry of transport	Strengthen Colombia's transportation connectivity	*Low*	*Low*	*High*	*Low*	*Low*	Decision making
	Ministry of Defence	Protect the security, independence and interests of the country	*Medium*	*Medium*	*Low*	*Low*	*Medium*	Support and Decision making
Citizens	Local Communities	Protection of their places of residence	*Low*	*High*	*Low* Not much political influence	*High* Risk of flooding for the structures	*Low*	Divided
Users	Fishing Industry Real estate Industry Tourist Industry	Generation of Profit Uphold desirable reputation	*Low* Not involved in ICZM on the longterm Only short term vision	*Low - Medium* Only interested when things occur what are in their way of using	*Medium* Pressure on the government to prevent awareness about coastal issues to indirectly prevent lowering of land prices	*High* Risk of flooding for the structures	*Low*	Divided
Other Interested	Holland House Ambassade	To promote Dutch companies in Colombia To promote collaboration To promote the Dutch Water Sector	*Low*	*Medium* 'Holland House Water Platform' is one of the main sectors of the institution	*Low*	*Low*	*Medium* Offers connections to involve the Dutch expertise	Supporter

Figure E.1: Background information of stakeholder involved in ICZM

F Stakeholder meetings

F.1 Meeting 1: Javier Mouton

Stakeholders attending:

- Javier Mouton
- TU Delft group members

Location: University of Cartagena
Date: September 12
Time: 09:00

Subject: Regulation system Colombia

Main questions to stakeholder:
What steps should be taken in order to realize a project, from the beginning until the end.

Proceedings: A National Development plan is made by the government of Colombia. Each municipality and state also has their own development plan. Depending on the kind of the project it concerns a municipality, state or the national government. Information about the regulation system is provide by professor Javier Mouthon Bello, September 15, 2017.
In order to execute a project in Colombia the following three aspects has to be undertaken; Proposal, Approval, Funding.
Proposal
If a project is proposed which is in favour of the community, the government will unanimously agree. For example in Cartagena it is harder to reach a majority within the government. The government is not professional and there is a social problem within the government. It can take a long time to reach a majority just because of the social issues within the government. Approval is needed on the following aspects: Social acceptance, technical analysis, Environmental Impact Assessment (EIA) If someone with political power is demanding the execution of a project, the vice president used to care about coastal protection, the whole process is accelerated enormously. The people with power basically decide which projects will get approval, without this approval it could take months to years.
Approval
Projects for the state need approval from the governor, projects for a city from the major. Approval of a project requires a majority within the relevant government. In cities like Barranquilla and Medellin the governments are politically professional. If a project is proposed which is in favour of the community, the government will unanimously agree. For example in Cartagena it is harder to reach a majority within the government. The government is not professional and there is a social problem within the government. It can take a long time to reach a majority just because of the social issues within the government. Approval is needed on the following aspects: Social acceptance. Technical analysis, Environmental Impact Assessment (EIA).
Funding
Projects are either funded by the government, licitacion publica, or by private investors, Asociaciones Pblico Privadas (APP). When a project is chosen by the government due to bidding it is also funded by the government. APP is a partnership between private actors like banks and public actors like governmental institutions. Project proposals funded by the APP are not

chosen with bidding's between companies. The private actors chose which projects they want to fund.
Local government's can fund projects with the money that they have been assigned to annually. They have to spend all the money in that year, penalties are given by national government if the money is not spent, this creates a problem.
An important project can already be funded by senators but not yet be approved by the government. When in this case the approval is delayed the senators are forced to spend the money on something else. Money can not be saved for later use. In this way lots of projects fail because of bed design. There are cities with no sewerage, hospitals or schools but with fancy bus station just because it was the only project that was ready. In these cases, the desperately needed money is wasted.

F.2 Meeting 2: Presentation Invemar

Stakeholders attending:

- Oscar Soza (Oceanus International)
- Universidad del Norte
- Invemar
- Government of Magdalena
- Government of Guajira
- Mayor of Ciénaga
- Activist groups of Ciénaga
- Citizens of Ciénaga
- All TU Delft group members

Location: Invemar, Santa Marta
Date: September 18
Time: 08:00

Subject: Socialization and update of the Colciencias project

Main questions to stakeholder:
What is the current state of affairs?
What is the reaction of citizens to the project?

Proceedings:
This meeting was one with many stakeholders concerning the Colciencias project. First Invemar opened with a general introduction of the project and a short introduction of all the stakeholders which are executing studies to analyse the problems and come up with solutions in the end. Invemar also explained the problems which were social and political related. They explained that all stakeholders are trying to come up with an integral solution. After this short talk of Invemar, different representatives of the universities of Magdalena and del Norte gave a short explanation on the more technical hydrodynamic studies they had been executing. After these presentations there was a moment for all the representatives of the different communities to ask questions and have a discussion about what they thought was best for the local communities. After the meeting Oscar explained that these representatives are happy that the project is being realised, but the want matters to go faster. Most of them emphasised that people are scared the studies will take to long and when solutions are ready for execution the government will not pay for the projects any longer.

F.3 Meeting 3: CIOH

Stakeholders attending:

- Ricardo Torres, Director of CIOH
- Fernando Afanador, Chair of ICZM group
- TU Delft group members: Floortje & Vibeke

Location: CIOH, Cartagena
Date: September 19
Time: 14:00

Subject: General information coastal projects and management of the coastal zone.

Main questions to stakeholder:
What are the objectives of CIOH?
What is the cooperation between different institutes and CIOH?
Which difficulties do arrise to CIOH?

Proceedings:
DIMAR is a governmental ministry, their general tasks are functioning as the national port authority, doing fieldwork and research. They have two research institutes: CIOH (covers the Caribbean coast) and the CCCP (covers the pacific coast). CIOH has four departments in the field of hydrology, oceanography, ICZM and Marine Protection.
One of their biggest tasks is to indicate, maintaining and controlling the line between public and private goods. Everything that is built on public terrain needs permission from DIMAR. This permission is only released after a check of the ministry of environmental and sustainable development, the ministry of transport and lastly, the local major has to agree with the proposal.
A few difficulties are detected while fulfilling these tasks. Even though it is forbidden to build on public terrain without permission, a lot of structures are built and people are unwilling to leave the area afterwards. DIMAR tries to convince local majors to participate with them and make the people migrate from the terrains with the help of police. Due to corruption of the rich and dissatisfaction of the poor, this is still an unsolved problem. The corruption causes that problems as erosion and relative sea level rise stay undiscussed, because this will influence the house prices on these terrains. A lot of property belongs to investors with a lot of power and pressure is putted on the local municipalities. Since majors are only allowed to be in function for four years, there is a lack of long-term vision on this problem.
Another difficulty is the conflict between politics and research. The research studies and the corresponding measures are not rigorous enough according to R. Torres, this is due to a lack of political will. This should be solved by people and researchers pushing the authorities more to work on these problems. DIMAR works on their risk assessment by writing articles and diaries on these subject, trying to make the people push more. The problem is that this information is only written by a small (intellectual) part of the society. R. Torres is afraid that a major disaster must occur before the realization of the problems are understood by the society.

F.4 Meeting 4: Dutch Consulate in Cartagena

Stakeholders attending:

- Mauricio Villegas Gerdts, Honorary Consulate
- All TU Delft group members

Location: Conculate, Cartagena
Date: October 13
Time: 11:00

Subject: General information on the Dutch consulate in Cartagena and conformation on our views on Colombian culture.

Main questions to stakeholder:
What are the main activities of the Dutch consulate in Cartagena?
Is our analyses of Colombian culture and their way of doing business correct?
Are there any relations of the Dutch consulate which can be of use to us?

Proceedings:
Mauricio explained at first that the consulate in Cartagena was reopened in 2015. The tasks of the consulate in Cartagena are threefold:

1. Increasing Dutch tourism to Caribbean. If these tourist encounter problems, this consulate can help them.
2. Medical services for the Dutch island, mostly Curacao. As Curacao does not have a hospital, medical tourists mostly are brought to Colombia in order to be treated there. This mostly hold for premature births and other pregnancy related problems.
3. The consulate endeavors to increase the bilateral relations between the Dutch islands and Colombia. As the Dutch islands are situated near Venezuela, these islands also encounter the same problems as Venezuela does. The Dutch consulate in Cartagena attempts to persuade Colombian companies to provide the Dutch islands with basic goods.

Thereafter Mauricio told us how he thinks Colombia will develop in the years to come. The treaty with the FARC is one of the main issues which will have a large influence on Colombia and its people. Colombian citizens are divided when it comes to their trust in this treaty. Also there will be elections next year. Governmental change always mean uncertain times for Colombians. As foreign investors notice these uncertainties, Colombian economy is not growing as it did before. Only 3% of economic growth was established in 2016. This is much less than the foregoing years which showed an economic growth of 5 to 6%.
Lastly he introduced us to an Association of Architects and Engineers in Cartagena. He found we should convey our final outcomes of the project to this party, as he thought that they would be interested in our project.

F.5 Meeting 5: Dutch Ambassador in Colombia

Stakeholders attending:

- Jeroen Roodenburg, Dutch Ambassador
- The wife of the Dutch Ambassador
- All TU Delft group members

Location: Plaza San Diego, Cartagena
Date: October 15
Time: 10:30

Subject: Informal conversation about Colombia in general and the Colombian-Dutch relation.

Main questions to stakeholder:
What is your opinion of Colombian culture in general and the way they do business?
What is the general opinion of Colombians when it comes to Dutch people and their activities in Colombia?

Proceedings:
Our group of six went for an informal cup of coffee with the Dutch ambassador and his wife on Sunday. The ambassador and his wife were in Cartagena for just two days. He explained that he now has been the Dutch ambassador for over a year. He will be the Dutch ambassador for another three years. They normally reside in Bogota and visit the Netherlands two times per year.
The ambassador acknowledged the same problems as the consulate did two days before. For example the economical segregation which Colombia has always suffered from, will not easily be resolved as the elite are satisfied. Therefore the will probably not thrive for change when it comes to this matter. Nevertheless he was more convinced that the treaty concerning the FARC and its surrender would have a positive impact on Colombia in general. Also he also had the opinion that this situation brought a lot of uncertainty with it. Definitely the current political system, with the changing governmental bodies, are still a difficult situation when thriving for the implementation of different economical, educational, infrastructural or political development plans. For the ambassador it is always a matter of finding the right person, often the mayor of a village or city, for the job. Besides every major has its own main objectives and it is still difficult to achieve multiple goals at the same time.
The Dutch and Colombian relationship is rather good, explained the ambassador. Colombians mostly accept Dutch opinions, especially when it comes to hydraulic engineering. We as Dutch engineers had the feeling that Colombians are fairly open towards Dutch people, which the ambassador acknowledged.

F.6 Meeting 6: Fieldwork Cinaga

Stakeholders attending:

- Representative of local community
- Representative of local municipality
- Environmental consultant
- Oscar Sorza
- Total TU Delft team

Location: Ciénaga
Date: 23 October
Time: 12.00 - 16.00 hours

Subject: Social and economic development of Cinaga

Main questions to stakeholder:
What happened with the area the past twenty years?
What are the thoughts on the development of the area?
What kind of economy has the area?
How are coastal projects organized around Cinaga?
What is the biggest interest of the local community?

Proceedings:
The big groyne upstream was designed in 2010 and finished in 2012. It was built commissioned by the former mayor. It recovered 100 meters of coast in the upstream direction of the groyne, but unfortunately not a lot of activities take place on that side of the city. Therefore it can be stated that the impact is not fully desirable. A lot of erosion problems occurred downstream on the same time. In 2015 a new groyne was built, a submerged one, nearby Pueblo Viejo. This groyne is again a local solution, but not a regional solution. Locals see the changes in the coast line, but they are not really aware of the corresponding risks. Local owners of houses in front of the coast, they claim refunds by the mayor, but keep building their houses near by the shore. As a response the local government relocates a lot of houses. The coast has a major social meaning for the citizens. it is the biggest recreation place in town. Festivals are organized here and the whole coastline is full of little eating facilities. On holidays, the whole city comes together at the beach. For these reasons, the representatives of the local community puts a lot of pressure on the mayor and municipality about the coastal development. The representative of the local municipality told us that there is still no knowledge or experience in working on these kind of coastal problems with an integral approach. Her point of view is that a lot of meetings are required to overstep this shortcoming. The local community works in the field of mining, agriculture and bananas. Further they have a small fishing industry. Coastal projects are still locally organized in Cinaga.

G Coastal Measures

G.1 Soft measures

G.1.1 Nourishment

Nourishment's can be done with the following purposes;

1. Compensate for structural erosion
2. Protection against flooding and storm events
3. To broader beaches or create new beaches (recreation)

Nourishment's can be placed on different locations, on the foreshore, beach or dunes. Beach nourishment's are to create wider beaches. Dune nourishment's are to strengthen dunes. For a foreshore nourishment's sand is sprayed off-shore. The amount spayed off-shore will be distributed a long a large part of the coast due to the wave climate. The position, shape and size of the nourishment highly depends on the bathymetry and wave climate. Nourishment are temporarily, depending on the characteristics of the nourishment it has to be repeated every couple of years.

G.1.2 Bypass-system

After the realization of constructions like harbours it can happen that all the upstream sediment is trapped in front of the construction. This results in accretion upstream and erosion downstream. A bypass system can transport the upstream trapped sediment downstream of the blockage, this can prevent undesirable accretion and erosion.

Figure G.1: Example of a mega nourishment.

G.2 Hard measurements

G.2.1 Groynes

Two different types of groynes can be distinguished.

1. Impermeable, high-crested groynes;
   These groynes are used to keep the sediment between the two groynes and thus prevent erosion. In each component the shoreline direction will develop perpendicular to the dominant wave direction.
2. permeable, low-crested groynes;
   These types of groynes are used for area with small sediment deficit. The function of these groynes is to slightly reduce the horizontal drift to reduce the sediment deficit.

Figure G.2: Groynes with saw-tooth shaped beach

G.2.2 Detached shore-normal Breakwaters

The main purpose of breakwaters is to reduce the alongshore sediment transport in the shadow of the breakwater. Both emerged as submerged breakwaters can easily solve structural coastal erosion problems. Salients or tombolo's will arise in the shadow of the breakwater. If a tombolo arises depends on the breakwater length, distance to the shore and distance of gap with other breakwater, if existed. Often downstream erosion occurs when breakwaters are used. When breakwater are build for private institutions like hotels they often do not investigate the downstream consequences, which can lead to serious erosion. In figure G.3 an example of a tombolo, salient with their downstream is given.

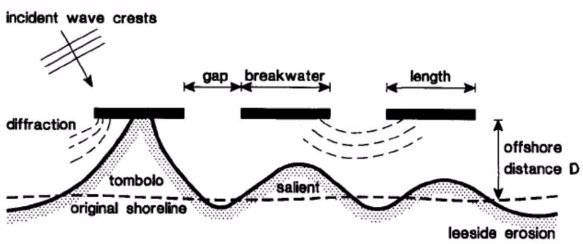


Figure G.3: Detached shore normal breakwaters (Stive, 2015) H10

G.2.3 Jetty's

Jetty's are emerged structure perpendicular to the coast, often used near harbour and rivers. The crest height of a jetty is well above MSL. Jetty's are used with the following functions:

1. Blockage of sediment in order to prevent sediment settling in dredged channels
2. River-mouth stabilization
3. Preventing sediment settling near the mouth of rivers with high sediment supply
4. Preventing erosion near tidal inlet

Figure G.4: Jetty for river-mouth stabilization

G.2.4 Sea walls

Seawalls are nearly verticals structures to protect the higher mainland or dunes. Mostly the function of a sea-wall is protection against extreme events. Important is that the foundation of the sea-wall is relatively deep, due to the erosion large scour holes can form in front of the sea-wall and endangers the stability. In figure G.5 and example of a sea-wall with a scour hole is shown.

G.2.5 Revetment

A revetment is kind of sea-wall but with a more gentle slope. Beaches occur in front of the revetment. Revetments protect the shoreline during extreme events. The surface of a revetment can be either smooth or rough. Also for revetment scour holes form a great danger for its stability.

G.2.6 Sea-dike

Sea-dikes are revetments without a beach in front of them. Sea-dikes next to a river are often used to prevent flooding.

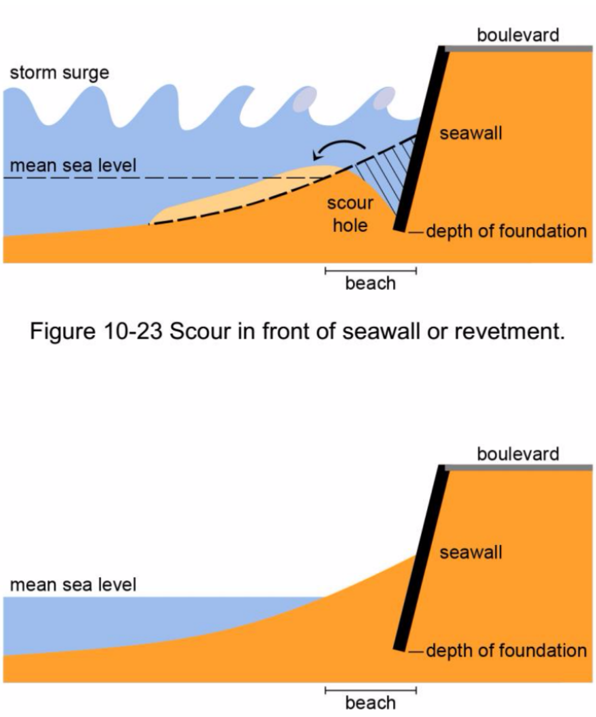


Figure G.5: Sea-wall with scour hole (Stive, 2015) H10

Table G.1: Summary alternatives

Alternatives	**Purpose**	**Scale**	**Duration**	**Remark**
Shoreface-nourishment	Balance sediment transport	Regional	Repetition	Permanent
Beach-nourishment	Repairing beach	Regional	Repetition	
Dune-nourishment	Strengthen dunes	Regional	Repetition	
Bypass system	Restore blockage	Regional	Permanent	
Groynes	Sediment entrapment	Local	Permanent	Possible downstream erosion
Breakwater	Interfering cross-shore sediment transport	Local	Permanent	Tombolo
Jetty	Sediment blockage	Local	Permanent	
Sea Wall	Protection extreme event	Local	Permanent	Scour hole
Revetment	Protection extreme event	Local	Permanent	Scour hole
Sea Dike	Protection extreme event	Local	Permanent	Scour hole

H Software Implementation

Modelling a hydraulic-related problem is a task that requires both an understanding of the physics of the problem, as well as knowledge of the model and its numerical approximations. An understanding of the problem includes a determination of the desired *spatial -and temporal scales* of the area to be modelled, and an insight in the *physical processes* that play a significant role in the particular engineering application. Knowledge of numerical approximations is required to optimise the resolution of a model in time and space, by examining the *numerical consistency, accuracy and stability.*

Goal
This manual serves as a tool for assessing the applicability of different numerical models in the context of the Colciencias project. Based on the assumptions, limitations, physical processes and purpose of a model, a guidance in the choice of model is given. This is essential when assessing the morphological impact of human interventions and natural hazards, as a wrong choice of model can lead to disastrous mistakes in coastal protection measures or just to incredible amounts of work.

Approach and structure
In this document, first some general aspects of numerical models are discussed, i.e. upscaling and downscaling, the different submodules of coastal models and a distinction in coastal model types (coastline, regional and local morphodynamic). After this, the most used numerical models of each coastal model type are elaborated (e.g. Delft3D and UNIBEST-CL+). To conclude the document, the different models are compared to give an insight in the different application zones.

H.1 General information numerical models

H.1.1 Semi-Empirical vs Process-based

The modelling approach of software is either semi-empirical or process-based. The semi-empirical model considers a morphological equilibrium, for which equilibrium relationships are used. Consequently, a criterion for the semi-empirical models is that an equilibrium exists or is forced. Long-term processes are used and interpreted on shorter time scale to form the boundary conditions for shorter scale coastal development (S. de Vries, 2017) This is commonly referred to as the downscale approach. These models are often used for longer temporal -and spatial scales. The scheme of the semi-empirical model is shown in Figure H.1. An example of a semi-empirical model is UNIBEST-CL+ (S. de Vries, 2017).

A process-based model uses the upscale approach. This approach describes elementary processes of flow and sediment transport in which the equilibrium is not known beforehand. The process-based models are typically applied to short and medium timescales to give a detailed representation of the coastline development. The scheme of the process-based model is also shown in Figure H.1. Examples of process-based models are Delft3D, Xbeach, Mike21 and Telemac.

H.1.2 Submodules

Coastal models comprise of different modules to account for the various processes and phenomena present in a coastal system. They can often be described both semi-empirically and process-based. Below a distinction is made between wave models, flow models and models for

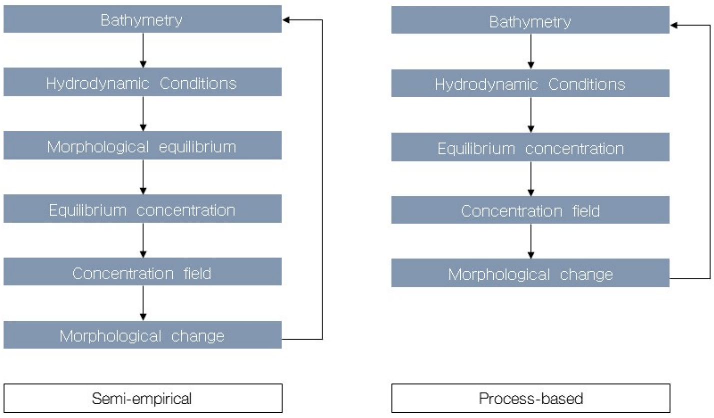


Figure H.1: The scheme of the semi-empirical and process-based model (S. de Vries, 2017)

sediment transport. These models, in combination with wind, tide and bathymetry form the hydrodynamic model. The morphodynamic modelling complex simulates the mutual adjustment of the models in an efficient manner.

1. Wave models

Modelling waves is based on the concept of energy and momentum conservation. Both offshore to nearshore transformation, refraction, diffraction and reflection from structures are described by this. Based on the area of application and local phenomena, a choice between the following models must be made (Balakrishna & Kanetkar, 2007):

1. Direct Solution of 3-D Euler or Laplace Equations
2. Depth integrated equations based on momentum concept
   (a) Non-linear shallow water equations
   (b) Boussinesq equations
   (c) Mild-slope equations
3. Transport equations based on wave energy concept
   (a) Spectral wind-wave models

The Direct Solution requires much computational effort and is therefore not applied to waves in coastal areas. The spectral wave model (item 3a), or phase averaging model, is a very efficient tool when large areas need to be covered with a relatively high accuracy. Contrary to other models, it can simulate the effect of currents and the growth and decay of short waves (Brøker, 2008). An example of a spectral wave model is SWAN, whose functioning is explained below. However, it does not perform ideally when diffraction is an important driver of nearshore processes, in which case phase-resolving equations are better suited, above mentioned option 2. In mild-slope models, the spatial scale is smaller and the combined effect of diffraction and refraction is included. With this, irregular waves propagating over varying bathymetry and in interaction with boundaries such as breakwaters and seawalls can be described. The original elliptic mild slope formulation is implemented for simulation of for instance detached breakwaters or resonance in a harbour, including wave-current interaction, steep bed slopes and wave non-linearity. The simplified parabolic mild slope equations describe the directional spreading of waves, with approximations for diffractive patterns (Copeland, 1985). The Boussinesq equations assume a balance between non-linearity and frequency dispersion, making them foremost applicable to intermediate water depth; in deep water frequency dispersion dominates, whereas non-linear effects such as wave skewness and asymmetry are important in shallow water. Therefore, these equations are mainly used for wave disturbances in ports and intermediate coastal areas (Balakrishna & Kanetkar, 2007).

Xbeach has an inbuilt spectral wind-wave model, whereas Delft3D, ROMS, TELEMAC and UNIBEST-CL+ are coupled to the spectral wind-wave model SWAN. Mike21 has two options, a spectral-wind wave model and the Boussinesq model.

SWAN (Simulating WAves Nearshore), developed at Delft University of Technology, is a modelling software which is used to model propagation of waves in time and space by taking into account influences of wind, currents and depth, but also linear wave-wave interaction, breaking of waves and dissipation due to whitecapping. Because no assumptions are made about the spectral evolution, the full spectral model can be run, commonly referred to as a third-generation model. This implies that Swan uses the governing equations of the fluid flow. SWAN however has its limitations, as it does not properly account for diffraction (e.g. near harbours and breakwaters) and wave-induced currents. For quadruplet wave-wave interactions and triad wave-wave interactions approximations are used, which function reasonably except for long-crested waves (Team et al., 2007). In many programs Swan is the incorporated wave module, creating wave conditions and boundary conditions. This module is then coupled to flow and sediment modules to obtain the morphological evolution.

2. Flow models

The flow below a free surface in a fluid is described by the shallow water equations (hereafter SWE), which are derived from the Navier-Stokes equations. Depending on the type of problem, solutions should be found in different dimensions, either 1D, 2D or 3D, see Figure H.2. Simulation of the full Navier-Stokes equations, Direct Simulation or Full Simulation, is computationally expensive and only executed for very small scale turbulent motions. Therefore, they are (not yet) applied in coastal dynamic simulations. Assumptions need to be made to decrease the complexity of the equations in order to decrease the computation time and size.

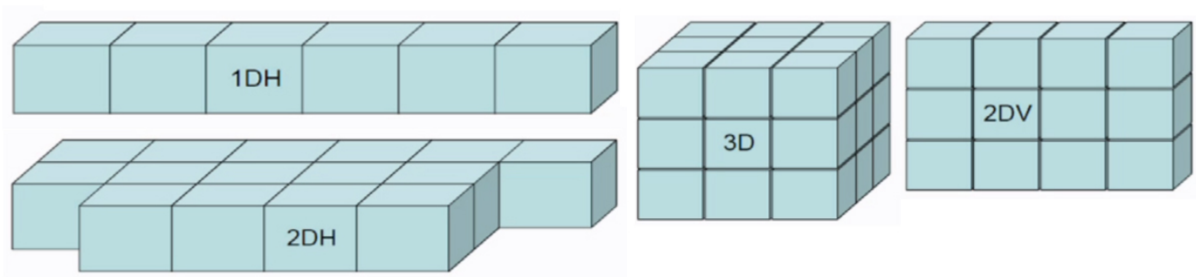


Figure H.2: Different model dimensions

The most simple model is the 1D model. Here, variation in the vertical plain and the y-plain are negligible. It is mainly applied in rivers, channels and simple harbour set-ups. With the assumption of a hydrostatic pressure distribution, incompressibility and a uniform velocity over depth, the 2DH SWE are obtained, see equation H.1, H.2 and H.3. They are the most common application of SWE in the current coastal models. Examples of applications of 2D modelling are tidal basins, estuaries and lakes.

$$\frac{\partial \zeta}{\partial t} + \frac{\partial hu}{\partial x}\frac{\partial hv}{\partial y} = 0 \tag{H.1}$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} - v_h\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) = g\frac{\partial \zeta}{\partial x} - \frac{\tau_{b,x}}{\rho_0 h} + fv + \frac{\tau_{w,x}}{\rho_0 h} - \frac{1}{\rho_0}\frac{\partial p_{atm}}{\partial x} \tag{H.2}$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} - v_h\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) = g\frac{\partial \zeta}{\partial y} - \frac{\tau_{b,x}}{\rho_0 h} + fu + \frac{\tau_{w,x}}{\rho_0 h} - \frac{1}{\rho_0}\frac{\partial p_{atm}}{\partial y} \tag{H.3}$$

When the variation of flow characteristics over depth becomes important, 3D models are required. They comprehend variations of horizontal flow over the vertical and non-hydrostatic flows. Applications of 3D modelling are: baroclinic forcing, wind driven flow, salt wedges, turbulent mixing in the vertical and wave simulations. Several numerical models have a hydrostatic and non-hydrostatic mode to take 3D effects into account when necessary.

3. Sediment transport

Sediment movement poses a variety of challenges to coastal engineers. It is a very complex field of study and its formulations are still mainly based on empirical relations. To model sediment transport, the sediment characteristics and flow conditions need to be understood. The transport is separated into three categories; bed load, suspended load and total load.

Bed load describes the transport of sediment grains in the vicinity of the bed, including processes such as rolling, sliding, and jumping. Its magnitude is a function of the bed shear stress. Equations of Engelund-Hansen, Einstein-Brown and Bijkers are common bed load transport formulas. Suspended load contains fine sediments that are kept in suspension by turbulence. From the conservation of sediment, the equilibrium sediment concentrations can be derived. Another approach is to consider the total sediment transport, where there is no distinction between the suspended and bed load. The sediment formulations that are often used in the software modules are given in Table H.1. Here, the column 'waves' indicates whether wave effects such as turbulent mixing and streaming are included (D. Deltares, 2006).

Transport	Formulation	Waves
Total transport	Engelund-Hansen (1967)	No
	Engelund-Fredsøe (1976)	No
	Mayer-peter and Müller (1984)	No
	AshidaMichiue (1974)	Yes
	Dibajnia and Watanabe (1992)	Yes
	Hunziker (1995)	No
Bedload transport	WilcockCrowe (2003)	No
	Gaeuman et al. (2009) Trinity River calibration	No
	Gaeuman et al. (2009) laboratory calibration	No
	Einstein-Brown (1950)	No
	Van Rijn (1984)	No
Bedload + suspended load	Van Rijn (1993)	Yes
	Soulsby Damgaard	Yes
	Soulsby-Van Rijn (1997)	Yes
	Bijker (1971)	Yes
	Bailard (1981)	Yes

Table H.1: Sediment formulations used in coastal models

4. Morphological modelling complex
To evaluate the combined effect of flow, waves and sediment transport, a morphodynamic model needs to be defined, where the different modules are linked to each other. Recent research focuses on the relation between the short-term variation of hydrodynamic -and sediment transport processes and the long(er)-term change in morphology, (J. Roelvink, 2006). Between these earlier mentioned upscale techniques, a distinction is made between tide-averaging, RAM and online coupling models. An apprehensive study and evaluation of these techniques can be found in (J. Roelvink, 2006).

H.1.3 Coastal models

Coastal models can be divided into three groups based on their spatial -and temporal scales. The simplest but widely applied model is the coastline model. It covers large scale shoreline developments. Regional models such as ROMS and TELEMAC are used to simulate ocean flows and are adequate for simulating for instance the spreading of substances along coastal regions. Local morphodynamic models focus on certain essential processes and are used at smaller length scales. Due to the increase in computational capacity and improved insight in morphodynamic complexes, time frames cover both short and long time scales.

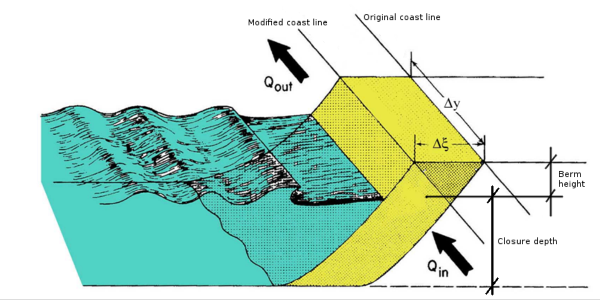
1. Coastline models This single-line software is a straightforward and efficient tool to model the coastline response to structures. In situations with a straight to slightly curved coastline and fairly uniform depth contours, these models can map the historic evolution of elements such as beaches, islands and bays and in the same time predict future morphological scenarios around structures such as groynes, breakwaters and revetments. It is very efficient in calculating the equilibrium orientation of a coastline. Its common spatial scales range from 1 to 100 km and its time frame is of the order of months to decades (Thomas & Frey, 2013).

Observations show that even though cyclic changes in dune shape occur, deviations from the average cross-shore profile are minimal. Shape and slope are assumed to be constant. Therefore, the single-line theory assumes a constant cross section, where the coast can be described by one simple shoreline. Erosion and accretion are viewed as a translation of the shoreline, either shoreward or seawards. Transport of sediment occurs between two defined outer boundaries, the depth of closure (D_b) at the seaward end and the top of the berm (D_c) at the landward end. Formula H.4 gives the expression for the change in coastline,

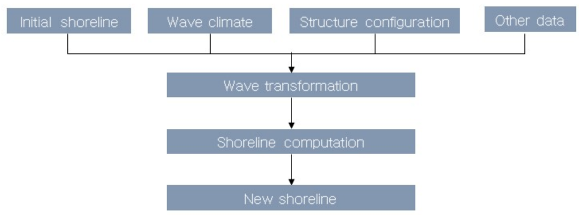
$$\frac{\Delta y}{\Delta t} + \frac{1}{D_b + D_c}\frac{\Delta Q}{\Delta x} = 0 \tag{H.4}$$

where Δ y is the change in cross-shore direction, Δx in longshore direction and ΔQ the gradient in longshore sediment transport over two consecutive cells (Fredsøe & Deigaard, 1992). The process is visualised in Figure H.3a. An important aspect of coastline modelling is the derivation of longshore sediment transports with S-ϕ curves. This curve gives the relation between the sediment transport S and the wave angle of incidence ϕ, thus taking into account the coast-orientation and its influence on sediment transport. Figure H.3b gives an overview of the modelling steps of the one-line model. Further assumptions underlying the single-line theory are:

1. The supply of sediment is infinite
2. Detailed nearshore processes are not taken into account



(a) Visualisation coastline evolution, , (Montanari, 2017)



(b) Modelling steps

Figure H.3: One-line theory

2. Regional models When studying relatively large ocean circulations, different time and space spectra are of interest, depending on the type of problem. This variability in research scale asks for computationally efficient tools that are able to apprehend both coastal processes on smaller time scales (minutes to days), as well as future climate change scenarios on the scale of decades. This constrains a complex, robust three-dimensional model that envelopes processes such as turbulent mixing, temperature and salinity variations, biochemical response, sea ice development and sediment transport processes (Haidvogel et al., 2008). They are mainly used to simulate physical oceanographic phenomena such as river plumes, the Kelvin wave, upwelling and downwelling and the Coriolis effect. The spreading of pollutants is also accurately mapped by regional models. Examples of regional models are TELEMAC and ROMS.

3. Local morphodynamic models When dealing with more complex planforms, situations and processes, advanced numerical models are required to assess the morphological changes in a coastal system. These process-based tools help to develop an understanding of the complex nature of areas such as strongly curved coastlines, river mouths, tidal inlets, harbours and bays. Generally, they comprise of the mathematical submodules described in Section H.1.2 to account for the local phenomena that are active in a system.

H.1.4 Evolution of tidal basins

The easiest way to model the long-term evolution of tidal basins is to use the empirical tidal-prism relationships for the ebb tidal delta, channel volume and cross-sectional area shown in Equations H.5, H.6, H.7 (Stive, 2015). A semi-empirical model such as ASMITA would be excellent to model these kind of relationships. The ESTMORF model is a dynamic and empirical model used to compute estuarine morphology. It is developed by Deltares and Rijkswaterstaat. By using a 1D-network and a tidal flow relations as flow module, it is used to predict morphological impact on tidal systems of human interferences. For the morphological equilibrium empirical relations are used and for the long-term averaged concentration the advection-diffusion equation is used (S. de Vries, 2017). A new idea however is that process-based models can also be successful when modelling long-term solutions (Dastgheib, Roelvink, & Wang, 2008). While semi-empirical models only model the sediment household of different element of a system, process-based models can use tides and waves as the driving forces of a tidal system. Since the process-based models require a lot of computational power for a long term prediction, input reduction is necessary (Cayocca, 2001).

$$A_{eq} = CP^q \tag{H.5}$$

$$V_{od} = C_{od}P^{1.23} \tag{H.6}$$

$$V_c = C_V P^{3/2} \tag{H.7}$$

in which A_{eq} is the minimum equilibrium cross-section of the entrance channel, V_{od} is the sand volume stored in the outer delta, V_c is het equilibrium total channel volume, q, C, C_V and C_{od} are empirical coefficients and P is the tidal prism.

H.1.5 Input reduction

The number of considered processes and the number of wave forcing input values are inversely proportional to each other. It is recommended to keep the model as simple as possible, since increasing complexity may introduce errors. When more processes are required, it is necessary to reduce the amount of input values to reduce the computational cost. The aim of the reduced wave climate is to have the same morphological prediction as the original full wave climate. The input reduction is usually done in 4 steps (Walstra, Hoekstra, Tonnon, & Ruessink, 2013):

1. Determine target - Can be longshore -or cross-shore transport, sedimentation erosion patterns, stirring, sediment transport vectors and brute forcing predictions.

2. Reduction level - What is the maximum available number of conditions that is needed to reduce the computation time?

3. Select conditions - Various ways exist to reduce the amount of wave input values. Preferable is the method of grouping with an equal distribution. For a more elaborate explanation of this reduction method, see the article of Walstra et al. about input reduction.

4. Scale conditions to represent target

H.2 Description specific models

H.2.1 Coastline models

UNIBEST-CL+
UNIBEST-CL+ is a 1D, open source, semi-empirical model that is developed by Deltares. Several modules account for different coastal processes, such as refraction, set-up driven currents, sheltering, shoaling and wave breaking.

The modelling cycle of UNIBEST-CL+ includes the following steps (S. de Vries, 2017):

1. Calculate alongshore sediment transport.
2. Construct S/phi curves.
3. Calculate gradients in sediment transport.
4. Calculate changes in coastline.

A range of sediment transport formulae describe transport mechanisms under different assumptions. Both empirical formulations by CERC and Kamphuis, process-based formulations by Van Rijn and adapted formulae for gravel beaches by Van der Meer are implemented (Deltares, 2011). The cross-shore profile as formulated by (Dean, 1991) describes the cross-section as a function of the cross-shore distance. Both in UNIBEST-CL+ and LITPACK waves are transformed by shoaling and refraction, after which depth induces the onset of breaking, following the wave dissipation theory of (Battjes & Janssen, 1978). Although UNIBEST-CL+ does not internally compute diffraction around structures, the reduced wave heights can be inserted manually or retrieved with SWAN. This application increases the physical accuracy around structures such as detached breakwaters and groyne fields. UNIBEST-CL+ is typically used for the simulation of historic coastline evolution and the change of a coastline as a result of coastal structures such as groynes and simple breakwaters. Due to its grid, it can simulate fairly curved coastlines compared to the other two coastline models. Because of its simple formulation, the model is computationally efficient but care should be given to the physical accuracy of the results.

LITPACK
LITPACK, or LITtoral Processes And Coastline Kinetics, is a commercial coastline model powered by the Danish Hydraulic Institute (DHI). The different modules (STP, LITDRIFT AND LITLINE) consider coastal processes fully deterministic and theoretically, which improves the accuracy of the model according to its authors (Szmytkiewicz et al., 2000). STP is the process-based sediment transport model for non-cohesive sediment under the combined action of currents and waves (A. Roelvink J.A.and Reniers, 2011). The littoral drift is described by LITDRIFT by combining a hydrodynamic model with the sediment transport module STP. This model is based on momentum balance equations in long -and crossshore direction, solving the crosshore distribution of the wave height, the longshore current and the set-up. The shore-parallel current and resuspension of sediment by breaking waves, and thus the littoral drift are accurately described with this(Szmytkiewicz et al., 2000). The final description of the shoreline location and evolution of the coastline is described by LITLINE. This apprehensive combination of modules enables the application to a wide variety of situations; optimisation of coastal zone redevelopment, study of the morphological baseline, and review and impact assessment of coastal structure such as harbours, groynes and revetments. Note that the increased complexity does increase the computational effort.

GENESIS
Genesis, GENEralized model for SImulating Shoreline change, is an open source coastline model of the joint development of the Department of Water Resources Engineering of the University of Lund (Sweden) and the Army Waterways Experiment Station (USA). The model' s central concept is the use of wave energy windows. A distinction is made in coastal cells, where structures form the boundary at outer ends. Incident waves need to pass through this window to be included in the nearshore processes. An adapted CERC formula is implemented to account for the increase in sediment transport due to the wave-induced set up. Diffraction from and transmission through structures, combinations of structures and beach fills and wave trains are all accounted for. Therefore, GENESIS can accurately describe tombolo development behind detached breakwaters, groins, jetties, beach fills and seawalls (University, 2017). Genesis is mostly used on scales for 1 to 100 km long coastlines for periods of 1 to 100 months (Szmytkiewicz et al., 2000).

H.2.2 Regional models

ROMS
ROMS, Regional Ocean Modeling System, is an open source, process-based, three dimensional, free surface regional ocean circulation model. The incorporated wave model is SWAN and the hydrodynamic model approximates the Reynolds averaged Navier-Stokes equations with a finite-difference scheme. The sediment bed is composed of different layers, and for each layer the bed shear stress and bed roughness are compared to their critical values to obtain erosion and deposition rates. The bed load transport can be approximated by either the formulations of Meyer-Peter Müller or by Soulsby & Damgaard. Suspended sediment transport is incorporated by an advection-diffusion scheme. Furthermore, it uses a terrain-following grid with several horizontal layers to account for variations over the vertical. Its algorithmic design ensures the applicability across a range of spatial and temporal scales and in various marine environments (Haidvogel et al., 2008). Several coupled modules account for complex processes, such as the biochemical, sea ice, sediment, atmospheric -and wave model and the vertical mixing parametrisation. It offers a range of eco-system submodules to evaluate the influence of nitrogen, ammonium, phytoplankton, detritus et cetera. Examples of engineering applications are the study of the high-latitude coastal seas and oceans, tidally driven estuaries, seasonal cycle simulations and large scale mid-latitude ocean circulation.

TELEMAC
The TELEMAC-MASCARAET system (short TELEMAC) is a suite in ownership of the Laboratoire National d'Hydraulique et Environment of the RD group Électricité de France. The process-based software is open source and consists of various coupled modules. The flow can be described in two dimensions, in 2D and 3D. The TELEMAC-2D module solves the Saint-Venant equations whereas the TELEMAC-3D module solves the shallow water equations in 3D. An alternative to the 3D SWE is to include the dynamic pressure in the governing equations. By doing this, much shorter waves can be incorporated than in shallow water context (if wavelength $> 20 \cdot$ water depth). This non-hydrostatic formulation is useful to model flows over trenches or steep slopes (TELEMAC, n.d.) where sharp gradients in density and velocity occur.

The sedimentology is described in the coupled SISYPHE (Sediment transport and bed evolution) module. The user can choose between various transport formulae: Meyer-Peter and Müller (1984) (Default), Einstein-Brown (1950), van Rijn (1984), Engelund-Hansen (including modification by Chollet and Cunge, 1967), Bijker (1971), Bailard (1981), Didajnia and Watanabe (1992), Soulsby-van Rijn (1997) and Hunziker (1995) (Villaret & Tassi, 2010). TELEMAC uses the Boussinesq approximation for the momentum. This means that density is taken as a constant and its variations are not included in the gravity term. The model consists of 2 waves modules: ARTEMIS (Numerical simulation of wave propagation towards the shore and agitation into harbours) and TOMAWAC (Wave propagation in coastal areas). ARTEMIS is incorporated in the TELEMAC-MASCARET system and simulates progagating waves towards the coast or into a port. TOMAWAC uses the finite elements method and calculates wave propagation in coastal areas. TELEMAC also supports other modules: NESTOR (modelling dredging operations in the river bed) and MASCARET (1-Dimensional free surface flow modelling) (TELEMAC, n.d.). This makes TELEMAC very suitable to execute studies of: dam bursts, floods, port installations and disturbances (waves), hydraulic structures, estuaries, water quality, thermal circulation, dredged dumping, river restorations and hydrosedimentary studies (Mensencal, 2012). TELEMAC distinguishes itself from other modelling systems by its flexibility and efficiency of the finite elements method. As it has optimised numerical schemes and uses parallel methods in combination with current computational power of computers, morphological changes can be computed on scales up to 100 km for years to decades. No hydrodynamic filtering methods are necessary (Villaret, Hervouet, Kopmann, Merkel, & Davies, 2013).

H.2.3 Local morphodynamic models

Delft3D

Delft3D, a 3D modelling suite created at Deltares in Delft (The Netherlands), is a process-based open source software consisting of the linked modules FLOW, MOR (Morphological) and WAVE. Other modules are WAQ (Water quality) and PART (Particle tracking). The multidimensional FLOW module is the main program of Delft3D. This flow module is used to calculate non-steady flow and transport phenomena based on the full Navier-Stokes equations. These 3D shallow water equations are solved on a rectangular or curvilinear grid. The wave module is coupled with the TU Delft open-source program SWAN, which includes wave propagation, linear wave-wave interaction, dissipation and generation by wind. The MOR module computes both suspended and bed sediment load and morphological bed changes. It updates the FLOW and WAVE modules with a dynamic feedback system, updating local morphological changes and allowing simulations of timescales from days to centuries. Delft3D enables the user to implement any sediment transport formula in the FLOW module. The user can also choose between default formulas that are built-in: Van Rijn (1993, 1984), Soulsby-Van Rijn (1997), Soulsby (1997), Engelund-Hansen (1967), Meyer-Peter-Muller (1948), Bijker (1971) including the Bailard-approach, AshidaMichiue (1974), WilcockCrowe (2003), the Gaeuman et al. (2009) laboratory calibration and Gauman et al. (2009) Trinity River calibration (D. Deltares, 2006). A recent development of Delft3D is the use of a flexible mesh. This mesh enables the use of unstructured grids in 1D, 2D and 3D. In this way, grids may consist of various forms, such as triangles, quads, pentagons and hexagons (Melger, 2017), which makes is very easy and computationally efficient to set up the simulation. Because of the broad selection of modules Delft3D is appropriate for the modelling of flows, sediment transports, waves, water quality, morphological development and ecology. It is suitable for artificial environments such as groins and ports, but also for natural environments such as coastal, lake, estuarine -and river environments (Deltares, 2014).

Mike21

Mike21 is a commercial application for coastal modelling powered by the Danish Hydraulic institute (DHI). The accessibility of the process-based Mike21 program is subdivided into different coupled modules. The Mike 21 hydrodynamic module calculates hydrodynamics in a 2D or 3D environment. This module is mainly used for complex situations concerning oceanographic, coastal or estuarine environments. A flexible mesh is used, which "provides an optimal degree of flexibility in the representation of complex geometries and enables smooth representation of boundaries. Small elements may be used in areas where more detail is desired" (DHI-headquarters, 2015a). This model is suitable for global and regional scales. The model equations are based on Reynolds averaged Navier-Stokes equations . The wave module Mike21 SW models swell and wind-generated waves in off-shore and coastal areas. In the wave module processes such as white-capping, bottom friction, depth-induced wave dissipation, refraction, shoaling and non-linear wave interaction are included. Mike 21 SW is applicable for local and regional scales, to indicate the domain a mesh is used. Wind waves are described by the wave action density relation, N(σ,Θ). The phase parameters are the relative angular frequency, σ=2*π*f and wave propagation direction, θ. The dispersion relation gives the relation between relative angular frequency, σ and the absolute angular frequency, ω. From the action density relation the energy density relation can be derived. MIKE 21 SW uses two different formulations: Fully spectral formulation based on the wave action balance equation and directional decoupled parametric formulation based on parameterisation of the wave action conservation equation. Both derivations can be found in MIKE 21 Spectral Waves FM Short Description, (DHI-headquarters, 2015c). Both wave and hydrodynamic modules are coupled with the module Mike21 sediment transport.The main focus of this module is to calculate the sediment transport capacity and bed level changes due to waves and currents. For the modelling of this a flexible mesh is used, the hydraulic and wave data is provided by the Hydrodynamic Module and the MIKE 21 SW. The sediment module can be used for local areas up to areas of 10 km. To enable long-term morphodynamic simulations a up-scaled bed change is included such that feedback on the bathymetry can be given and a morphodynamic evolution can be simulated. Different sediment formulas can be chosen by the user: Engelund-Hansen (1967), Engelund-Fredsøe (1976), Van Rijn (1984??) and Mayer-Peter and Müller (1984). Other modules that can be added are: Water quality and ecology, Coastal flooding, MIKE 21 Mooring Analysis, MIKE 21 GPU and Performance and parallel computing (DHI-headquarters, 2015b).

Xbeach

Xbeach is an open source, public-domain, two-dimensional model that was developed by a joint cooperation of Deltares, TU Delft, UNESCO-IHE and the University of Miami. It started as a special tool for modelling storm impact on sandy coasts, but has since been extended to many fields of application and to other time scales than its original storm time frame. The model consists of numerous submodules to solve the horizontal equations for flow, wave propagation, sediment transport and changes in bathymetry (J. Roelvink et al., 2009). Here, short wave transformation processes, long waves, overwash, inundation and wave-induced set-up are included, some of which are shortly explained below.

Wave model

Both the long and the short waves have a significant impact on the shape of the dunes. However, in many models the effect of low-frequency waves is excluded. Research has been conducted to the effect of wave groups on dune erosion. Amongst others, (J. v. T. de Vries, Van Gent, Walstra, & Reniers, 2008) concluded that excluding long waves amounts to an underestimation of the dune erosion of approximately 30 %. One reason for this is the energy transfer from high-frequency waves to the long waves. Secondly, long waves are dominant during storm conditions. These are the waves that actually run far up the dunes and possibly overtop. In combination with amongst other drying/flooding and sediment transport formulations, the wave groups are also accounted for in the process of dune erosion, overwashing and inundation. In order to implement this phenomenon in the numerical scheme, a wave action balance is coupled to a roller energy balance.

Flow model
The shallow water equations are used for the mean -and low frequency flow. Undertow, the offshore directed return flow near the bed as a result of wave induced mass-flux in shoreward direction, is modelled by formulating the SWE as a Generalized Lagrangian Mean (hereafter GLM). There are three hydrodynamic options:

1. Stationary mode
   Variations on wave-group scale, the long waves, are neglected. This is a valid assumption when dealing with small and short waves, often combined with tide and under a moderate wave climate. Morphological changes as a response to structures can be easily mapped with this.

2. Instationary, surfbeat mode
   Infragravity waves and unsteady currents are solved by the non-linear SWE. This enables the simulation of both wave -and wind driven currents and swash zone processes. Storm impacts and hurricanes can be simulated with this mode.

3. Non-hydrostatic mode
   The dynamic pressure by short waves is included, by evaluating the non-linear, non-hydrostatic shallow water equations. With this, a short wave action balance is not required, but spatial and temporal scale need to be small to ensure a stable and consistent numerical model. Compared to the instationary mode, the overwashing of short waves, diffraction, wave asymmetry and skwewness, are now resolved. This is essential on steep slopes (gravel beaches), and near structures where diffraction is an important process. Furthermore, ship induced waves can be modelled to account for smaller scale changes in morphology.

Sediment transport
Sediment transport rates by Soulsby-Van Rijn are implemented to account for the stirring of sediment by for instance roller energy and for the transport by the orbital velocities. Furthermore, to model dune erosion, it is important to adequately solve the interface between water and dune area, taking into account avalanching and breaching. To incorporate the effect of sediment slumping down a slope, a critical slope is defined for which the bed is no longer stable. In this way, using avalanching sediment transports, the offshore directed sediment transport due to undertow can be described accurately, as the model constantly adjusts the dune profile for inundated parts and in this way transports the sediment down the slope. What is more, special interest is given to the process of breaching of a dune. With Xbeach, the sensitivity of this lower dune part and the underwater morphology to storms can be modelled.

Applications of Xbeach include:

- Long term evolution and storm impact of curved islands (J. Roelvink, Den Heijer, & Van Thiel De Vries, 2013)
- Offshore breakwaters
- Tidal inlets
- Sedimentational patterns in harbours, including ship-induced motions and refractive and diffractive patterns around breakwaters(Bolle, Mercelis, Roelvink, Haerens, & Trouw, 2011)
- Gravel beaches

H.3 Comparison different models

(Szmytkiewicz et al., 2000) gives a concise comparison between the three coastline models:

- All three can models obtain realistic output on longer time scales
- GENESIS limits the amount of modifications to the model. Although this is easy to use, it makes the model less flexible and therefore not suited to every location.
- LITPACK has an extensive model for hydrodynamics and sediment transport. More complex planforms can be described with this model. The resolution of the modules however is not really compatible with the vigorous approach of the one-line model. UNIBEST-CL+ is more computationally efficient and has many degrees of freedom, making this a good model option as well.

Table H.5 gives an overview of the differences between the models in detail.

The main differences between TELEMAC and ROMS are:

- TELEMAC uses a unstreamed finite element grid, whereas ROMS uses a curvilinear finite difference grid.

- The morphological updating method is online for ROMS and offline for TELEMAC.

Small differences exist between Delft3D and Mike21, so it's mainly a matter of experience with the model and of your economical situation that determines which model is best to use.

H.3.1 Decision tool

Based on the descriptions and tables above, a decision tool is developed to aid in the choice of model. For this, an assessment must be made of the assumptions and limitations of each model, and a consideration of the different steps to follow. It should be noted that a basic understanding of the underlying physics of each model is required, especially its assumptions and limitations.

The decision tree is divided into three main groups:

1. *Cross-shore transport and profile development* For bar development, dominant processes in cross-shore transport are wave skewness (shoaling zone), wave asymmetry (surf zone) and a return flow. For dune erosion, long waves, avalanching transports and flooding and drying formulations are important.
2. *Longshore transport and coastline changes* Various processes have a role in the longshore transport of sediment.
3. *Other applications* , such as river plumes, large ocean circulation and harbour extensions.

Based on the most stringent differences between the various models, a decision tree is developed. This decision tree helps to find the suitable model to your engineering problem. It can be found in Figure H.6 and H.7. The distinction between spatial and temporal scales used in this tree is shown in Figure H.4, a figure taken from (A. Roelvink J.A.and Reniers, 2011).

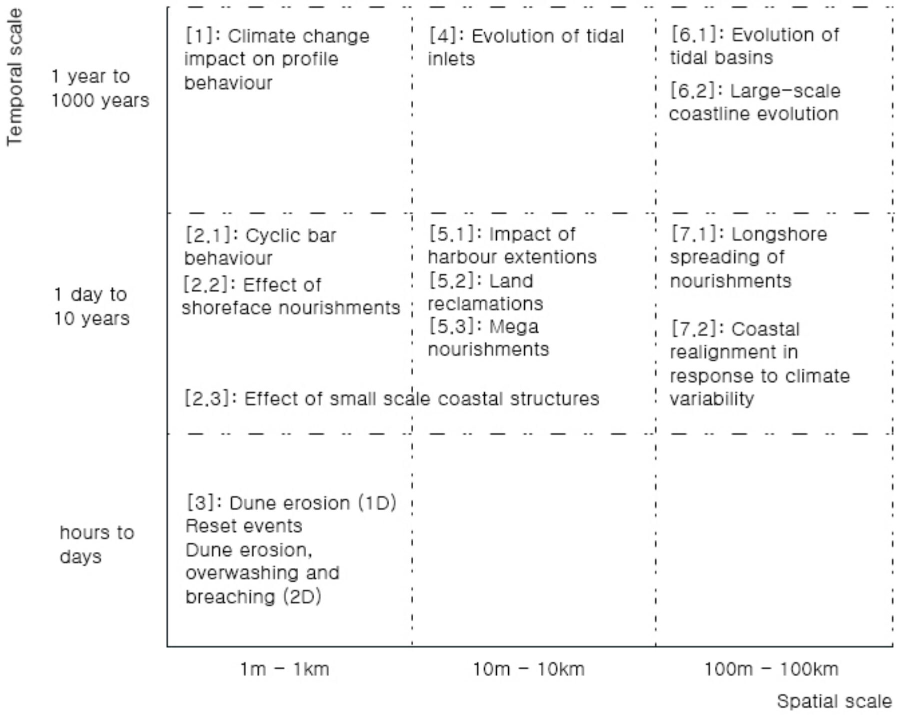


Figure H.4: Spatial and temporal scales engineering applications (A. Roelvink J.A.and Reniers, 2011)

		UNIBEST	LITPACK	GENESIS
Short wave transformation				
Refraction	Due to differences iin depth along the crest, the wave rotates until parallel with the coastline. Important for heavily curved coastlines	YES	YES	YES
Shoaling	The water depth influences the propagation of waves. This causes an increase in wave height	YES	YES	YES
Diffraction	Bending of waves behind obstacles and structures. Important in ports and other sheltered areas	YES When coupled with SWAN	YES	YES
Reflection from structures		NO	NO	NO
Set-up and currents				
Wave-current interaction	Exchange of energy between current and wave. Important near ripcurrents, gullies and high velocity river outflows	YES	YES	NO
Longshore current	What other currents are accounted for?	Longuet-Higgins	Longuet-Higgens	NO
Sediment				
Sediment gradation	Can different grain sizes be used as input parameter?	YES	YES	NO
Wind-driven transport		YES	NO	NO
Cross-shore profile response tool (storm impact)	Is there coupling with other modules to account for episodic erosion?	YES	YES	NO
Model characteristics				
Documentation	Manual, theoretical documentation, training	YES	YES	YES
Model interface		UNIBEST-CL+	Mike Zero	CEDAS
Running time		Good	Good	Medium More intensive computations, increasing simulation time
Model grid	1-line models tend to evolve towards it's grid, therefore only applicable to (almost) straight coastlines	Curved	Linear	Linear Regional contour grid: possibility to insert predefined shape to which coastline evolves
Applications				
Revetment		Good	Good	Good
Offshore Breakwater		Good	Good	Good
Nourishment		Good	Good	Good
Groin (non-diffracting)		Good	Average, slightly modest erosion and accretion	Good
Groin (diffracting)		Good	Good	Good
Jetty		Good	Good	Good
T-head groyne		YES	YES	YES
Tombolo		YES	YES	YES
Trench		NO	YES	NO

Figure H.5: Comparison different coastline models

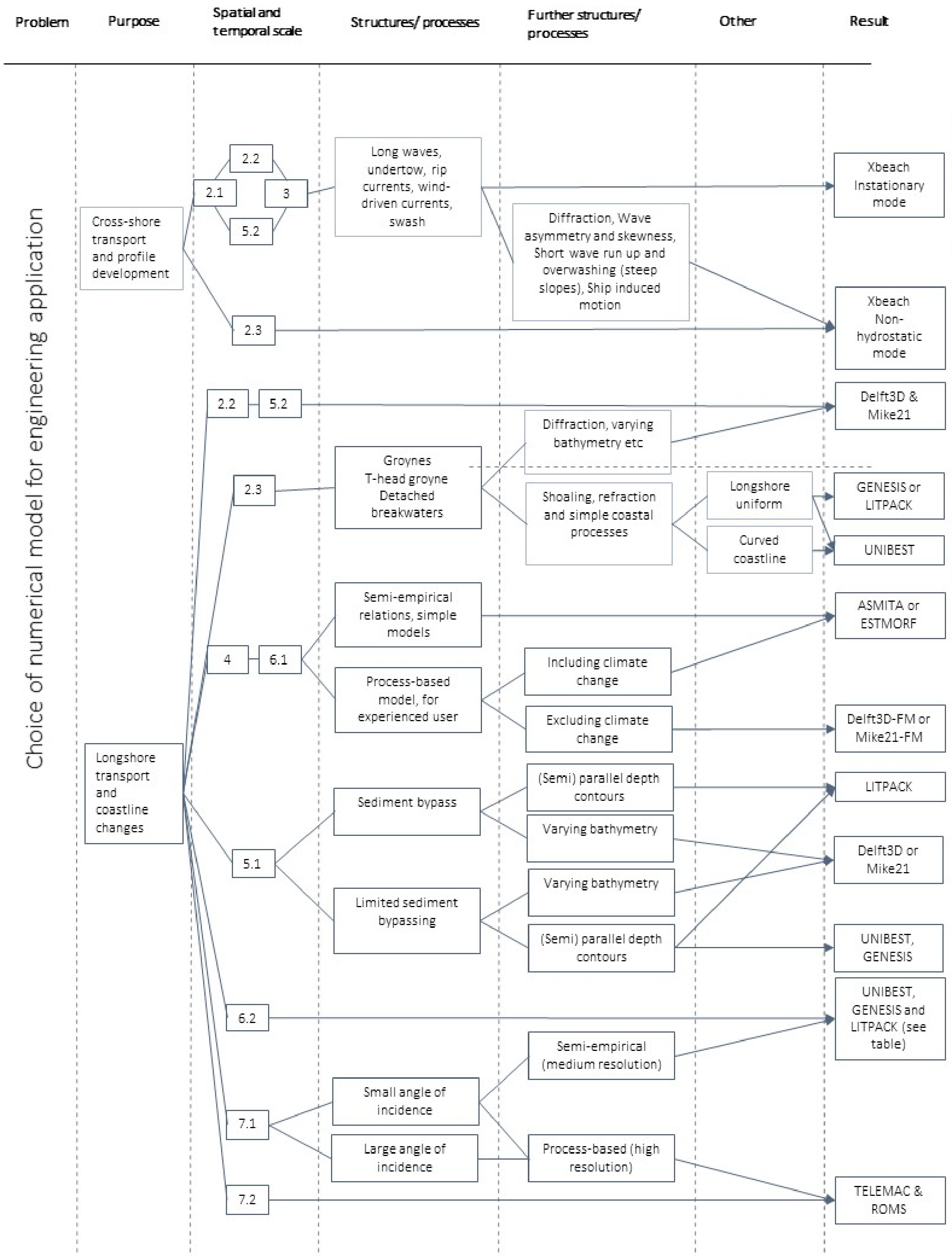


Figure H.6: Decision tree for the use of a numerical model, part 1

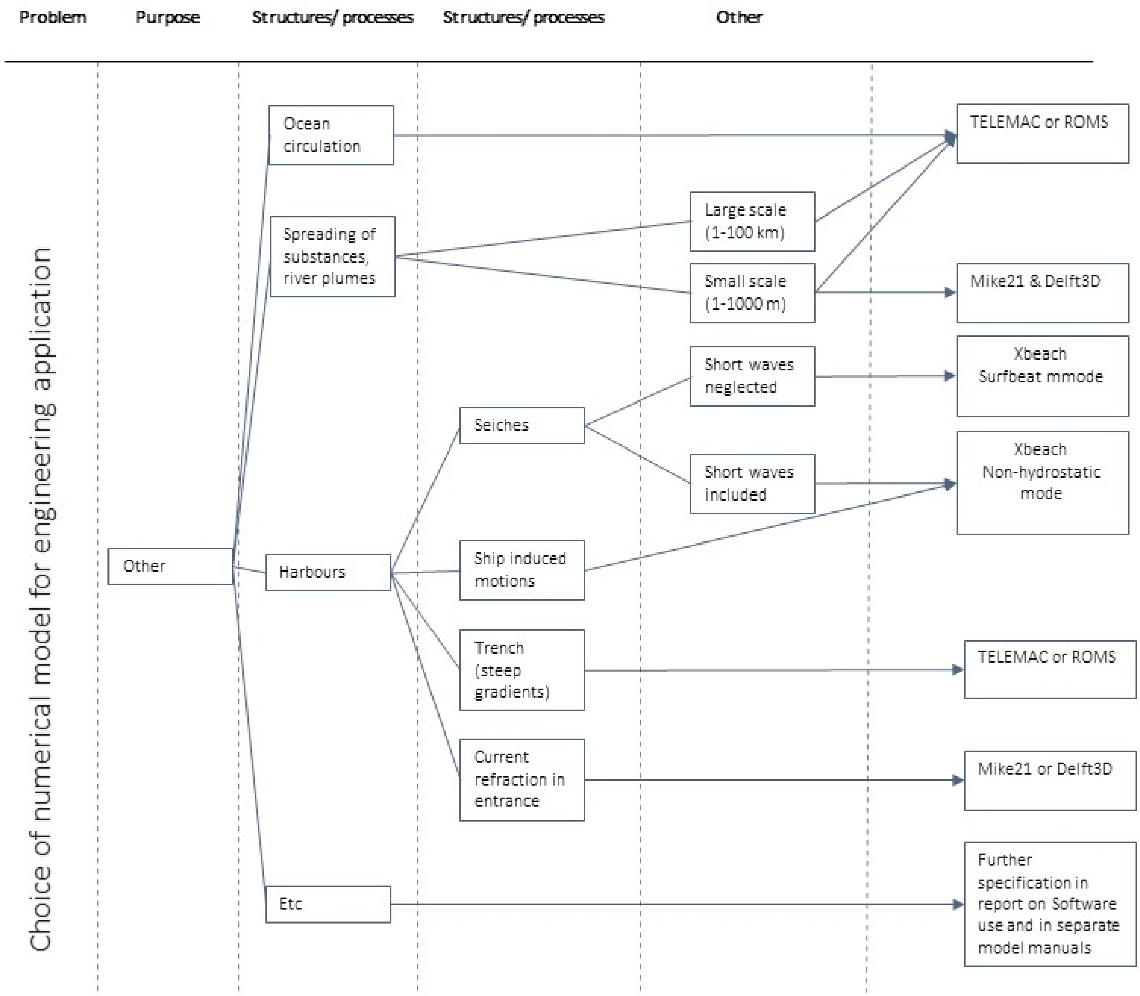


Figure H.7: Decision tree for the use of a numerical model, part 2

I Framework Questionnaire

FRAMEWORK SURVEY

Name:
Project description:

This survey is intended to improve the Integrated Coastal Zone Management framework. When answering the questions, you can share your personal experience. The numbers you can circle include the following:
1 = bad
2 = inadequate
3 = sufficient
4 = good
5 = great

Step A: Analysis	**Scale**				
Multiple choice questions					
Determine the natural and socio-economic boundaries of your study area					
1. To what extent do you find the steps in this phase appropriate?	1	2	3	4	5
2. To what extent do you find the steps in this phase effective?	1	2	3	4	5
3. To what extent do you find the steps in this phase efficient?	1	2	3	4	5
Analyze the involvement of each stakeholder					
4. To what extent do you find the steps in this phase appropriate?	1	2	3	4	5
5. To what extent do you find the steps in this phase effective?	1	2	3	4	5
6. To what extent do you find the steps in this phase efficient?	1	2	3	4	5
Analyze the different system elements					
7. To what extent do you find the steps in this phase appropriate?	1	2	3	4	5
8. To what extent do you find the steps in this phase effective?	1	2	3	4	5
9. To what extent do you find the steps in this phase efficient?	1	2	3	4	5
Identify the development factors					
10. To what extent do you find the steps in this phase appropriate?	1	2	3	4	5
11. To what extent do you find the steps in this phase effective?	1	2	3	4	5
12. To what extent do you find the steps in this phase efficient?	1	2	3	4	5
Identify the relation between system elements					
13. To what extent do you find the steps in this phase appropriate?	1	2	3	4	5
14. To what extent do you find the steps in this phase effective?	1	2	3	4	5
15. To what extent do you find the steps in this phase efficient?	1	2	3	4	5

Open questions
16. Are there particular features that you miss in this step? What are they?
17. Are there particular features that you found unnecessary in this step? What are they?
18. Are there particular features that you found explicitly useful in this step? What are they?
19. Do you have any further comments on this phase? (about the clearness, the sequence, readability, and so on.)

Step B: Development Alternatives	**Scale**				
Multiple choice questions					
Identify alternatives for coastal protection					
20. To what extent do you find the steps in this phase appropriate?	1	2	3	4	5
21. To what extent do you find the steps in this phase effective?	1	2	3	4	5
22. To what extent do you find the steps in this phase efficient?	1	2	3	4	5
Assess the morphological impact of alternatives					
23. To what extent do you find the steps in this phase appropriate?	1	2	3	4	5
24. To what extent do you find the steps in this phase effective?	1	2	3	4	5
25. To what extent do you find the steps in this phase efficient?	1	2	3	4	5
Assess the environmental - and socio-economic impact of alternatives					
26. To what extent do you find the steps in this phase appropriate?	1	2	3	4	5
27. To what extent do you find the steps in this phase effective?	1	2	3	4	5
28. To what extent do you find the steps in this phase efficient?	1	2	3	4	5
Open questions					
29. Are there particular features that you miss in this step? What are they?					
30. Are there particular features that you found unnecessary in this step? What are they?					
31. Are there particular features that you found explicitly useful in this step? What are they?					
32. Do you have any further comments on this phase? (about the clearness, the sequence, readability, and so on.)					

Step C: Final Design	**Scale**				
Multiple choice questions					
Make a substantiated decision between the alternaties					
33. To what extent do you find the steps in this phase appropriate?	1	2	3	4	5
34. To what extent do you find the steps in this phase effective?	1	2	3	4	5
35. To what extent do you find the steps in this phase efficient?	1	2	3	4	5
Determine an integral approach to implement the chosen alternative					
36. To what extent do you find the steps in this phase appropriate?	1	2	3	4	5
37. To what extent do you find the steps in this phase effective?	1	2	3	4	5
38. To what extent do you find the steps in this phase efficient?	1	2	3	4	5
Dimension the final design					
39. To what extent do you find the steps in this phase appropriate?	1	2	3	4	5
40. To what extent do you find the steps in this phase effective?	1	2	3	4	5
41. To what extent do you find the steps in this phase efficient?	1	2	3	4	5
Open questions					
42. Are there particular features that you miss in this step? What are they?					
43. Are there particular features that you found unnecessary in this step? What are they?					
44. Are there particular features that you found explicitly useful in this step? What are they?					
45. Do you have any further comments on this phase? (about the clearness, the sequence, readability, and so on.)					

Step D: Evaluation	**Scale**				
Multiple choice questions					
Evaluate the project					
46. To what extent do you find the steps in this phase appropriate?	1	2	3	4	5
47. To what extent do you find the steps in this phase effective?	1	2	3	4	5
48. To what extent do you find the steps in this phase efficient?	1	2	3	4	5
Evaluate the framework					
49. To what extent do you find the steps in this phase appropriate?	1	2	3	4	5
50. To what extent do you find the steps in this phase effective?	1	2	3	4	5
51. To what extent do you find the steps in this phase efficient?	1	2	3	4	5
Open questions					
52. Are there particular features that you miss in this step? What are they?					
53. Are there particular features that you found unnecessary in this step? What are they?					
54. Are there particular features that you found explicitly useful in this step? What are they?					
55. Do you have any further comments on this phase? (about the clearness, the sequence, readability, and so on.)					

Step E: Awareness	**Scale**				
Multiple choice questions					
Create the plan of approach for your action plan (Who, What, Medium, Frequency)					
56. To what extent do you find the steps in this phase appropriate?	1	2	3	4	5
57. To what extent do you find the steps in this phase effective?	1	2	3	4	5
58. To what extent do you find the steps in this phase efficient?	1	2	3	4	5
Open questions					
59. Are there particular features that you miss in this step? What are they?					
60. Are there particular features that you found unnecessary in this step? What are they?					
61. Are there particular features that you found explicitly useful in this step? What are they?					
62. Do you have any further comments on this phase? (about the clearness, the sequence, readability, and so on.)					

J Hydraulic Background

Figure J.1 shows an overview of the northern part of Colombia with an indication of the location of the sectors.

Figure J.1: Area of interest

Figure 1.1 shows the area of interest containing sites which show erosion problems. Within the Colciencias projects these sectors are designated as the most threatened parts when it comes to erosion. Subsequently these erosive features will possibly have a severe impact on infrastructure, therewith effecting local economies in the future.

J.1 Sectorial Problems

When looking at the Colciencias project the stakeholders have designated four sections containing the most alarming problems (Oceanus, 2017b). The sections shown in Figure J.1 correspond to the following parts:

Section 1	Kilometre 19	Section 3	Area de Pajaro
Section 2	Costa Verde Ciénaga	Section 4	Zona de Riohacha

The outcomes of the hydraulic analysis - executed by Oceanus International - concerning these four sections are stated below.

J.1.1 Kilometre 19

Section Kilometre 19 (hereafter Km 19) is a part of the road from Barranquilla to Santa Marta and is located 19 kilometers West of Barranquilla. This road is endangered by severe erosion of the beach on which it is constructed. Aerial photographs made from 2009 to 2015 show more than 15 meters of erosion per year (Oceanus, 2017b). In an attempt to protect the road a rock barrier is installed. Currently this barrier is in danger of being undermined due to the erosion which the barrier was not able to withhold. As Route 90 is an important connection when it comes to connecting the port of Barranquila to Santa Marta and subsequent Northern parts of Colombia, the loss of this road would have negative effects on local accessibility and economy.

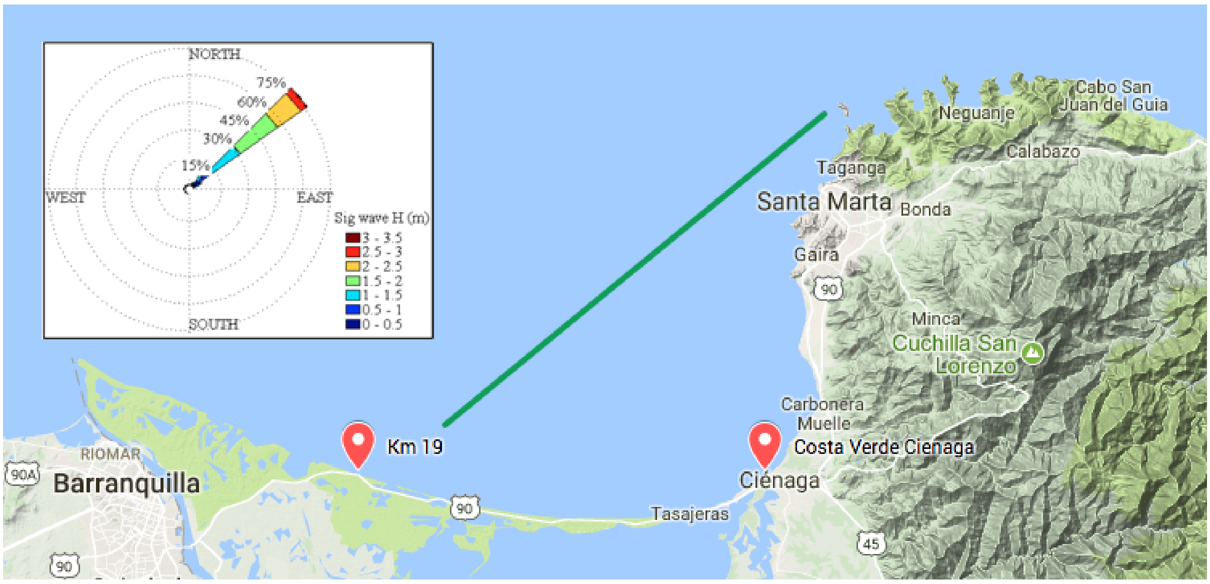


Figure J.2: Km 19 and Costa Verda Ciénaga sites

Despite the relatively calm sea conditions, wave heights are higher at the 19 km site and diminish more to the West. Due to the incidence of these waves a Western littoral transport is present resulting in erosive features at the Km 19 site. These erosive features are probably the most prominent at Km 19 due to the shadowing effect - illustrated by the green line in Figure J.2 - caused by the land abutment of Santa Marta.

J.1.2 Costa Verde Ciénega

To the East of Km19 Ciénaga is situated. Similar to the Km19 site this coastal town experiences eroding beaches. Nevertheless the causes of these erosive features are caused by man-made structures. Two large and several smaller breakwaters cause erosion on the lee side of these structures thereby endangering the existence of the eroding beaches in the near future.

J.1.3 Zona de Riohacha

Riohacha is the capital of La Guajira, in this area of the coast the dominant incident wave angle is N-E. The study area exists out of 20 km coast. Most of the area is heavily developed, inland as well as marine. The coastline of this area lies parallel the the dominant incident wave angle. This results in a persistent long-shore sediment transport along the coast. Interventions of the coastline can lead to high erosion or accretion rates. In a pilot project a groyne field was made along a stretch of the coast. Accretion occurred in the groyne field while extensive erosion occurred downstream. (Oceanus, 2017a)

J.1.4 Área de Pajaro

Pajaro lies 50 km upstream of Riohacha. rea of Pajaro contains a stretch of 20 km. Two shoreline humps occur in the middle of the area. The dominant incident wave angle and the angle of the coastline are the same as at Riohacha. Because of this an longshore transport from south the east occurs at this part of this beach with high erosion rates near interventions in the coastline.

At some parts at both Zona de Riohacha and rea de Pajaro the erosion rates are alarming and a solution have to be found to protect the inland. In figure J.3 and J.4 the offshore significant wave height and wave rose are shown. (Oceanus, 2017b)

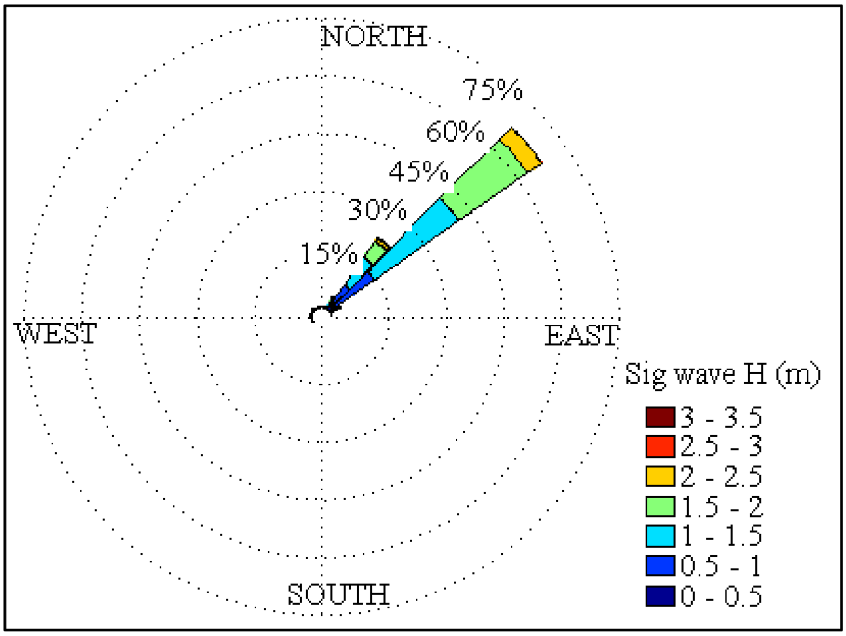


Figure J.3: Wave rose of Riohacha and Pajaro

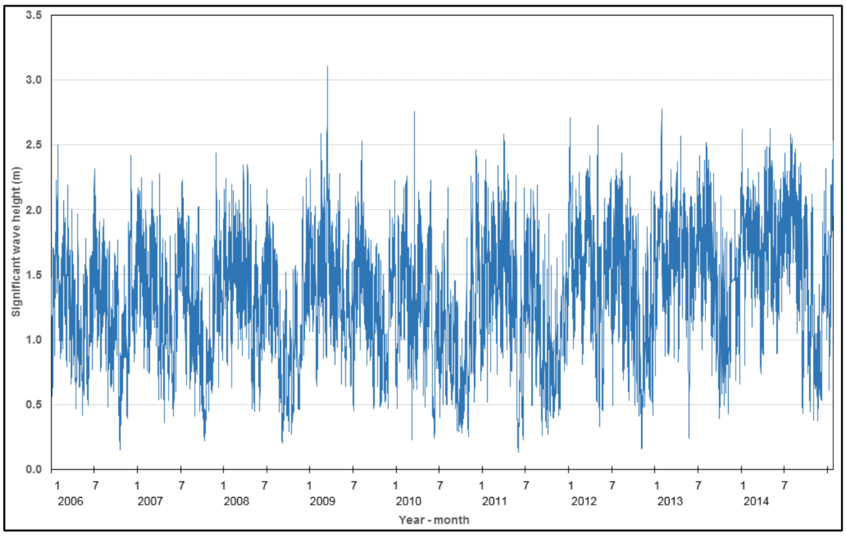


Figure J.4: Offshore significant wave height Riohacha and Pajaro

K Fieldwork Ciénaga

On 17-10-2017 and 18-10-2017 fieldwork was done in Ciénaga to improve the elaboration of the case. In this appendix the preparation and execution of the fieldwork will be discussed.

K.1 Preparation

In order to determine which information we needed to be retrieved from this two day of fieldwork, a plan of approach was established containing the following steps:

1. Go trough the framework to see what is necessary to know concerning the case.
2. Find out what information we already have.
3. Find out what information we can already obtain beforehand.
4. Find out what information we can obtain during the fieldwork.
5. Make a plan for the fieldwork.

From this plan of approach we formulated multiple actions of which we thought were possible to carry out during a window of two days time and of which we believed it was possible to gain the most relevant information. These actions are:

1. Longshore Current Experiment: Elaboration in appendix K.2.
2. Ciénaga Questionnaire: A questionnaire for the inhabitants of Ciénaga. By surveying as many residents of Ciénaga as possible we gained insight in local values, standards and demands.
3. Interviewing multiple representatives of both municipality and community. Elaboration in appendix F.6.
4. Estimation of native sediment and its characteristics.
5. Capturing drone footage of Ciénaga's shoreline and erosive features in order to compose an awareness clip.

K.2 Longshore Current Experiment

To estimate the longshore current speed in Ciénaga an experiment was executed. With the use of oranges it was possible to establish a longshore current speed.
The experiment was executed by four persons, all of which took on a different responsibility. Prior to execution a distinct distance is demarcated on the beach, as shown in figure K.1. Also, two persons both held on to two ropes, which were shorenormal orientated, to indicate the start and finish of the oranges. The fourth person writes down the time it takes for an orange to float from start to finish. With these floating time slots it is possible to determine the longshore current speed at different cross-shore distances.

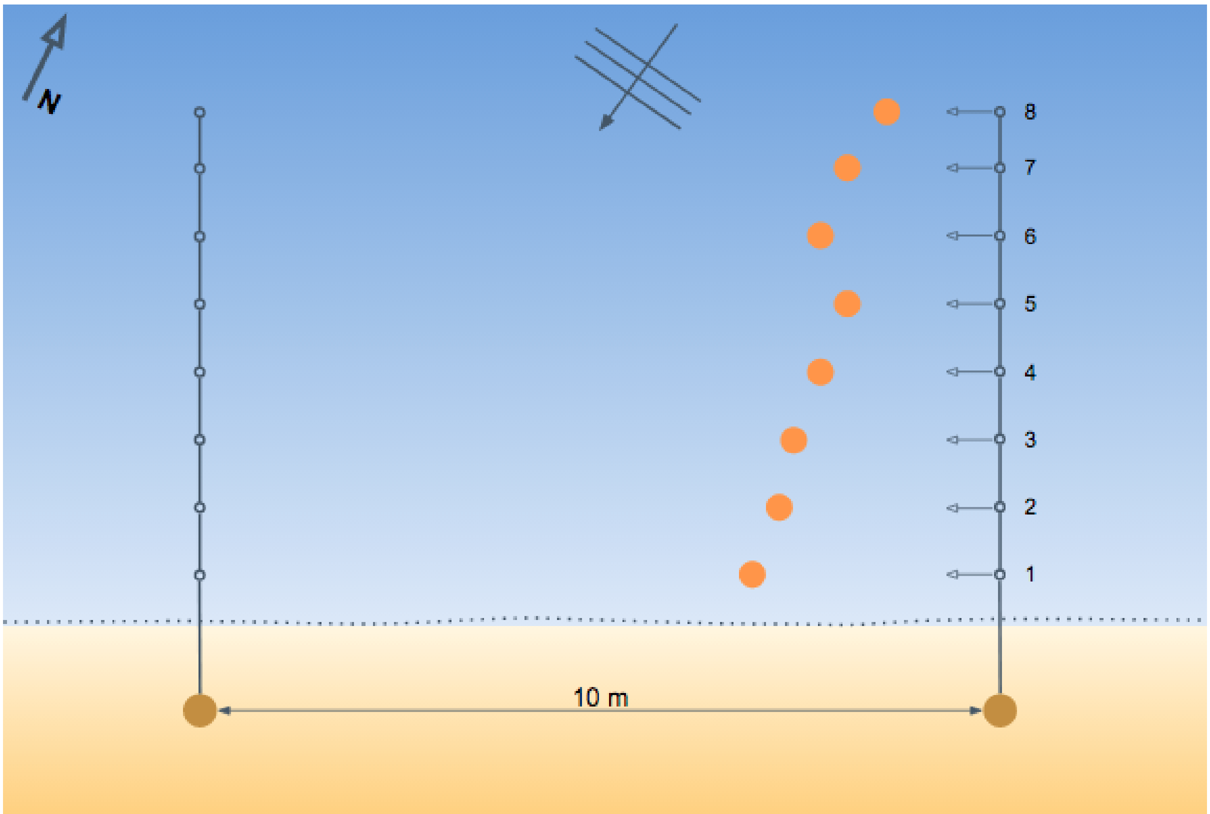
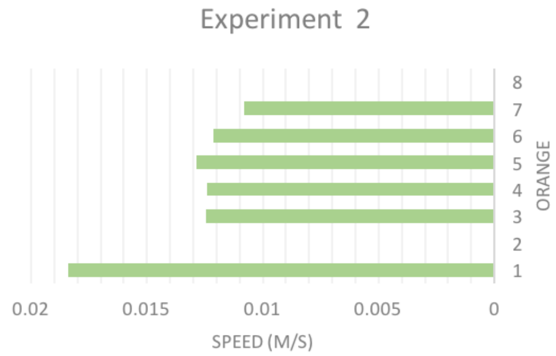
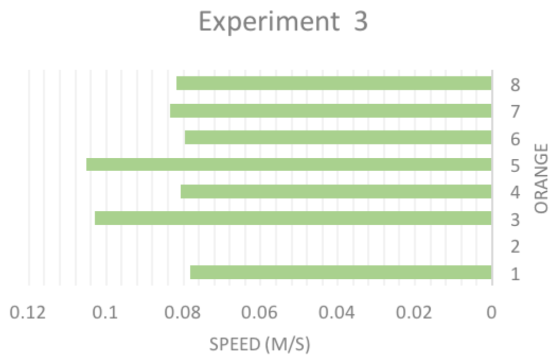


Figure K.1: Longshore current experiment set up

(a) Experiment 1: executed at 11:00 over 10 m.



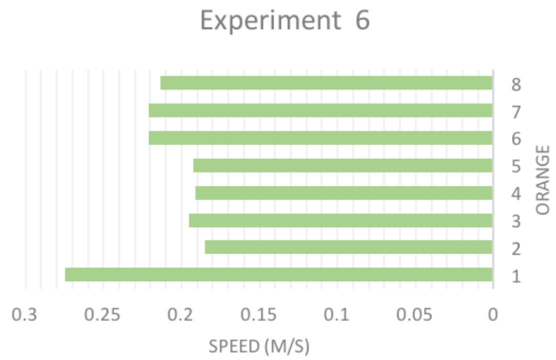
(b) Experiment 2: executed at 12:15 over 10 m.



(c) Experiment 3: executed at 13:00 over 18 m.

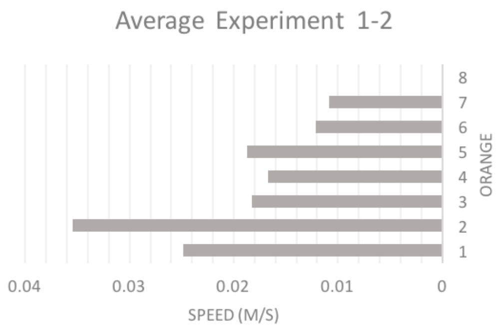
(d) Experiment 4: executed at – over 18 m.

(e) Experiment 5: executed at 15:00 over 18 m.

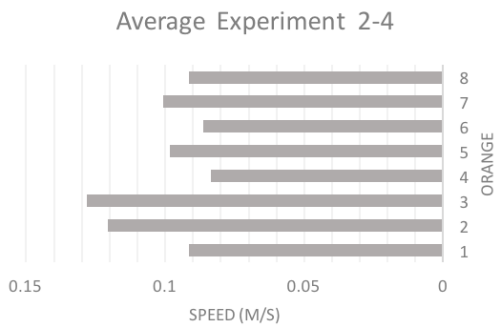


(f) Experiment 6: executed at 15:15 over 25 m.

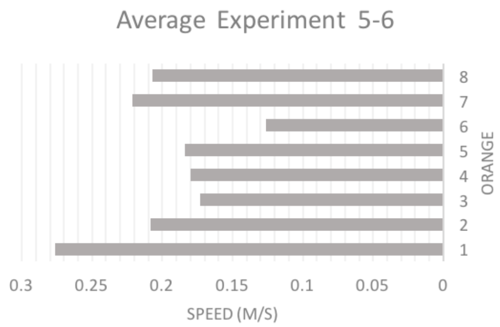
Figure K.2: All longshore current speed experiment results



(a) Average experiment 1 & 2



(b) Average experiment 3 & 4



(c) Average experiment 5 & 6

Figure K.3: Averages longshore current experiments

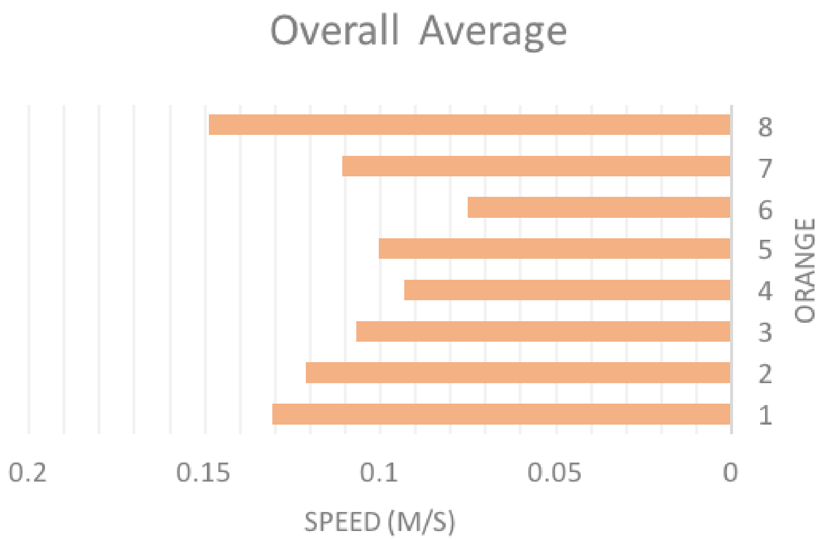


Figure K.4: Overall average longshore current speed

K.3 Fieldwork Ciénaga Questionnaire

EROSIÓN COSTERA CIÉNAGA CUESTIONARIO

Años:	
Empleo (si/no):	Profesión:

Estamos investigando un proyecto sobre erosión costera desde Barranquilla hasta Venezuela. Como proyecto piloto, estamos investigando los problemas de erosión alrededor de Ciénaga. Estamos interesados en el conocimiento y la opinión de los residentes locales. Sería de gran ayuda si pudiera responder a las siguientes preguntas. Muchas gracias.

Descripción	**escala**				
	No		**Un poco**		**Sí**
1. Sabías sobre los problemas de erosión costera de Ciénaga? Breve explicación:	1	2	3	4	5
2. Sabes qué causó estos problemas? Breve explicación:	1	2	3	4	5
3. Sufres de los problemas de erosión? Breve explicación:	1	2	3	4	5
Ordene los siguientes valores humanos por importancia (5 alto - 1 bajo)					
4. (1) La seguridad	1	2	3	4	5
5. (2) Dinero	1	2	3	4	5
6. (3) Educación	1	2	3	4	5
7. (4) El bienestar humano	1	2	3	4	5
8. (5) Naturaleza / Ecología	1	2	3	4	5
Ordena los valores de una solución para la erosión costera por importancia (5 alto – 1 bajo):					
9. (1) Solución de largo plazo	1	2	3	4	5
10. (2) Solución rápida	1	2	3	4	5
11. (3) Precio de la solución	1	2	3	4	5
12. (4) Conservación ecológica	1	2	3	4	5
13. (5) No es de mi interés	1	2	3	4	5

COASTAL EROSION CIÉNAGA QUESTIONNAIRE

Age:	
Employment (yes/no):	Profession:

We are doing research for a project concerning coastal erosion from Barranquilla until Venezuela. As a pilot project we are investigating the erosion problems around Ciénaga. We are interested in the knowledge and opinion of the local residents. It would be really helpful if you could answer the following questions. Many thanks.

Description	**Scale**				
	No		**A little**		**Yes**
1. Did you know about the coastal erosion problems of Ciénaga? Short explanation:	1	2	3	4	5
2. Do you know wat causes these problems? Short explanation:	1	2	3	4	5
3. Do you suffer from the erosion problems? Short explanation:	1	2	3	4	5
Sort the following human values by importance (5 high – 1 low):					
4. (1) Safety	1	2	3	4	5
5. (2) Money	1	2	3	4	5
6. (3) Education	1	2	3	4	5
7. (4) Human welfare	1	2	3	4	5
8. (5) Nature	1	2	3	4	5
Sort the values of a solution for the coastal erosion by importance (5 high – 1 low):					
9. (1) Long term solution	1	2	3	4	5
10. (2) Fast solution	1	2	3	4	5
11. (3) Price of the solution	1	2	3	4	5
12. (4) Ecological conservation	1	2	3	4	5
13. (5) Problem not in my interest	1	2	3	4	5

L Case study: Stakeholders Ciénaga

Domain stakeholders	Stakeholders	What is important to stakeholder	Involvement in project	Interest in project	Influence	Impact on stakeholder	Resources	Position
Citizens	Communitie of Ciénaga	Long-time solution	Low: Latent	High: Own well being	low/Medium: Pressure the government	Medium: erosion impact	Low	Supporter
Other Interested								
Governmental institutions	Government of Magdalena	Long-time solution	High: Decision making and financing	Medium: Economic wellbeing project in line with development plan	High Governmental approval	High wellbeing inhabitants	High Financial resources	Promotor
	Personería municipal de Ciénaga	Long-time solution	High: Decision making and financing	High: Overall wellbeing of the city	High Governmental approval	High wellbeing inhabitants	Medium	Promotor
	DIMAR	Sustainable Use of Marine Ecosystem Services, Coastal and Island	Medium: Guidance	Medium: Preservation of ecology	High: authorization	Medium: Pursue of their interests	High: Objection	Defend
Users	Local fishermen	Preservation of fishing	Latent: not involved in ICZM	Divided: only when their interests are affected	Low: pressure on government	depended on their interest	Low	Defend
	Hotel & Catering Industry	employment	Latent: not involved in ICZM	Medium/high: Enable employment and business	Medium/high: matters in own hands	Medium. Profit from long time solution	medium/low: Pressure government	Promotor
	Tourism	Recreation	Latent: not involved in ICZM	Medium: Recreation	Low	Medium	Latent	Latent
	Local retreaters	Protection of the shoreline	Latent: not involved in ICZM	medium: Enable more tourism and recreation	Low: pressure on government	Medium	low: Pressure government	Promotor
Consults	INVEMAR	Sustainable solution	Support	Contracted by government for research	High	Low	High: Research	Supporter
	Univ. del Norte	Sustainable solution	Support	Contracted by government for research	High	Low	High: Research	Supporter
	Oceanus	Sustainable solution	Creator	Contracted by government	High	Medium	High: execution	Supporter

Figure L.1: Stakeholders Ciénaga

M SwanOne, including Goda Method

M.1 Methodology

SwanOne is a 1D modelling software, written both on Matlab routines as a stand-alone version, which can be used to convert hydraulic boundary conditions from offshore to nearshore. SwanOne is the one dimensional version of the multidimensional software SWAN. The model assumes depth contours parallel to each other and perpendicular to a certain directional line. The orientation of this line is chosen in different directions towards the coast and should have a small angle with the dominant wave direction. If this is not the case, SwanOne cannot compute the nearshore wave conditions. The parameters, e.g. offshore wave height, wind direction, currents etc., result in different values for each orientation line nearshore. The model assumes a JONSWAP spectrum, calculated from the wave height and direction. These different values are compared and the decisive value is chosen. SwanOne does account for wind, current and depth (shoaling) influences, as well as and wavebreaking and dissipation. SwanOne does however not account for diffraction. This must be calculated by hand if needed. The hand calculation changes the wave direction and height and enables SwanOne to continue the calculation. SwanOne uses the following hydrodynamic relations to convert the offshore boundary conditions to nearshore (Sepehr Eslami Arab, 2016).

M.2 Input values

Bathymetry is added to the software in the form of a bottom depth file, with a direction of normal to the coast. This analysis is done with the help of the Navionics Webapp. Using the caliper tool and the given water depth lines a bottom profile can be determined. Since SwanOne converts deep water characteristics to nearshore characteristics, the orientation line should start in deep water to get the most accurate result. The relation for deep water $1/2 = \frac{h}{L}$ is used with the wavelength $L = \frac{g*T^2}{2*\pi}$ to obtain the deep water depth.

The **boundary conditions** consist of the water depth, wind velocity and direction and the wave characteristics. The offshore wave and wind characteristics can be found using the dataset provided by Argos. The water depth consists of a tidal range and an added storm surge. Storm surge can be chosen to be included or excluded. Wave characteristics can either be input as a spectrum or a significant wave height and period. The wind parameters consist of a velocity and direction only. The dominant wave direction or mean wave direction is used.

Currents can also be included in the calculation if the coastal system is influenced by them. Currents need to be defined in magnitude and direction.

M.3 Goda Method

To determine the wave height of the diffracted waves that approach the shore of Ciénaga, the Goda method is applied. The Goda method uses directional wave spectra instead of monochromatic waves to determine the wave height development. Goda distinguishes between wind waves, 'short' swell waves (large steepness) and 'long' swell waves (small steepness). These different types of waves each have their own dimensionless frequency (spreading) parameter s_{max}, namely respectively 10, 25 and 75. The spreading parameter influences the percentage of wave energy that is maintained while diffracting as a function of the angle with the main direction (Goda, 2010). First, Godas method using the cumulative distribution of relative wave energy will be used to determine the wave height ratios of different scenarios. The results will be validated using Godas simplified diffraction diagrams, which do not only give wave height ratios but also wave period ratios after diffraction. After the normative values are known, the SwanOne calculation can continue with diffracted wave results. The cumulative distribution of relative wave energy can be seen in Figure M.1. The relative wave energy is dependent on the wave direction compared to the geometric shadow line.

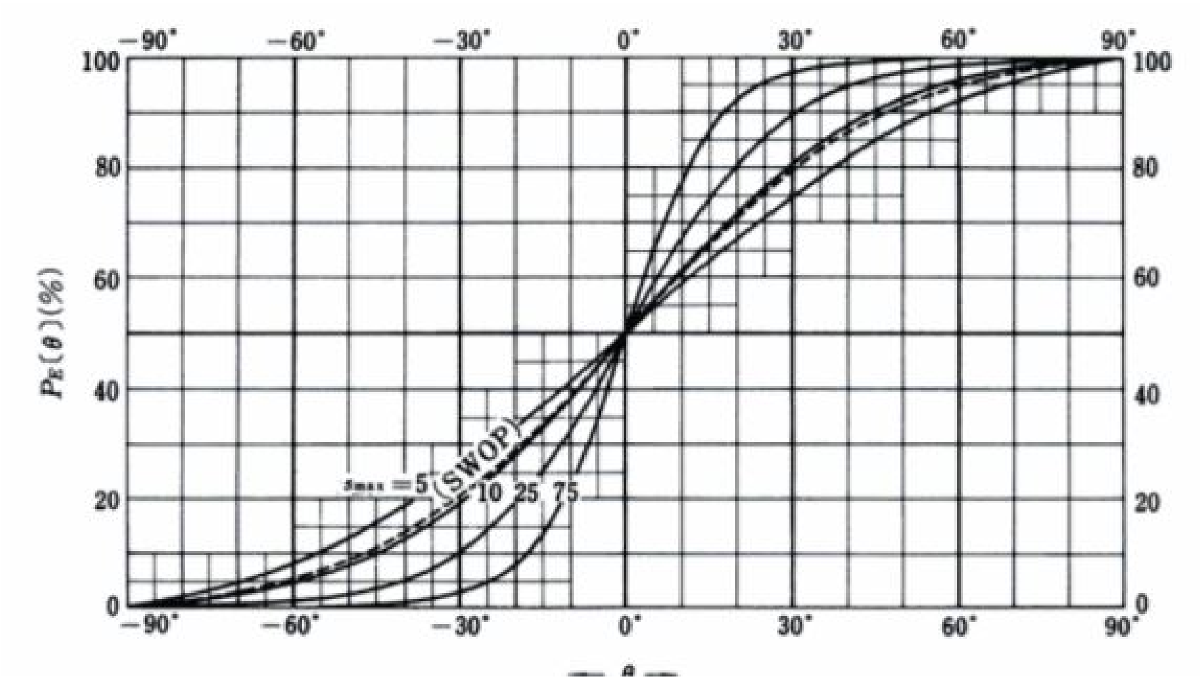


Figure M.1: 'Cumulative distribution of relative wave energy with respect to azimuth from principal wave direction' according to Goda (Goda, 2010)

Different situations will be considered to calculate the significant wave height at the coast of Ciénaga. Each situation consists of either windsea of swell waves, from either NEE or NE direction. This sums up to 4 situations. The wave roses in Figures 5.6a and 5.6b may clarify this. In Figure M.2 the situation is sketched for the NE incoming wave direction for both swell and windsea waves. In the figure, the angle between the geometric shadow line and the principal wave direction θ_1 is equal to 40 °. All waves ranging from -90° to -40° reach the coast of Ciénaga, all waves ranging from -40° to +90° are blocked by the headland and do not reach point O. This holds for both windsea (s_{max}=10) and swell waves (s_{max}=75). In Figure M.1 can be seen that the cumulative energy ratios are given by $P_{E,swell}(-40\circ) = 0,02$ and $P_{E,windsea}(-40\circ) = 0,13$. This is the energy ratio that reaches point O, the wave height ratio is therefore determined by: $K_{d,swell}(-40\circ) = \sqrt{0,02} = 0,14$ and $K_{d,windsea}(-40\circ) = \sqrt{0,13} = 0,36$. The same can be done for dominant wave direction NEE for both windsea and swell waves (situation 3 and 4), this is not visualized but uses the same method as Figure M.2. Then all waves ranging from -90° to -62,5° reach the coast of Ciénaga, all waves ranging from -62,5° to +90° are blocked by the headland and do not reach point O. In Figure M.1 can be seen that the cumulative energy ratios are given by $P_{E,swell}(-62,5\circ) = 0,00$ and $P_{E,windsea}(-62,5\circ) = 0,045$. Their corresponding wave height ratio are then determined by: $K_{d,swell}(-62,5\circ) = \sqrt{0,00} = 0,00$ and $K_{d,windsea}(-62,5\circ) = \sqrt{0,045} = 0,30$. The wave height ratios of the incoming waves and diffracted waves at the coast of Ciénaga according to Godas method using the cumulative distribution graph can be summed up:

- Swell, NE - $K_{d,swell,NE}(-40\circ) = \sqrt{0,02} = 0,14$

- Windsea, NE - $K_{d,windsea,NE}(-40\circ) = \sqrt{0,13} = 0,36$
- Swell, NEE - $K_{d,swell,NEE}(-62,5\circ) = \sqrt{0,00} = 0,00$
- Windsea, NEE - $K_{d,windsea,NEE}(-62,5\circ) = \sqrt{0,045} = 0,21$

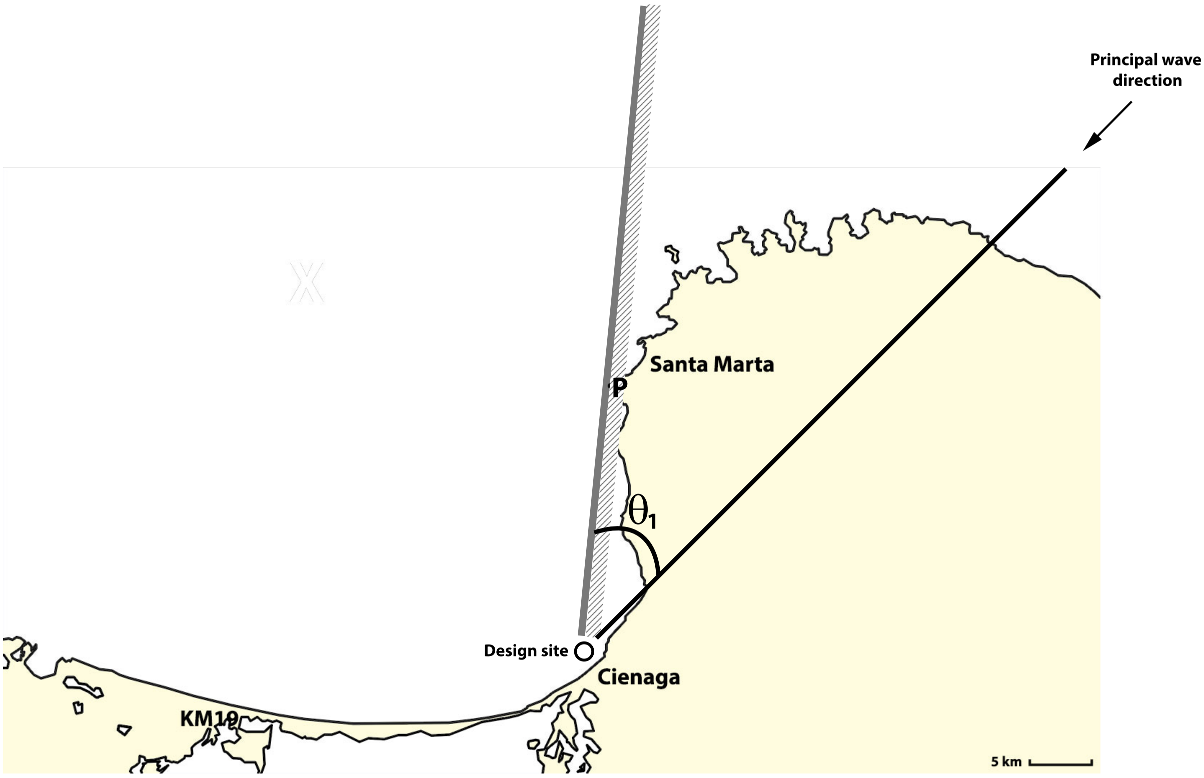


Figure M.2: Dominant wave direction and geometric shadow line of Ciénaga

Before continuing to validate the findings of Godas simplified method with Godas diagrams, it is necessary to obtain significant waveheight of the waves of all 4 situations.

The significant waveheight $H_{s,windsea}$ of the windsea waves is defined as the mean of the highest one-third of the waves and is calculated with Formula M.1 (Stive, 2015). The dataset obtained by BMT ARGOSS has already computed the significant wave height (ARGOSS, 2017b). The corresponding mean period of these waves is used as the significant wave period T_s. This is also done for swell waves. A distinction is made between directions NE and NEE by only considering waves from that direction, thus removing waves from other directions. Swell and windsea wave are measured independently and occur at the same time. That is why the percentages do not add up. The mean of all significant wave heights with corresponding periods are calculated with the dataset. The results are shown below:

- Swell, NE - Occuring 33 % of the time - $H_{s,swell,NE}$ = 0,62 m, $T_{s,swell,NE}$ = 9,79 s
- Windsea, NE - Occuring 27% of the time - $H_{s,windsea,NE}$ = 1,89 m, $T_{s,windsea,NE}$ = 5,83 s
- Swell, NEE - Occuring 35 % of the time - $H_{s,swell,NEE}$ = 0,31 m, $T_{s,swell,NEE}$ = 10,61 s

- Windsea, NEE - Occuring 55% of the time - $H_{s,windsea,NEE}$ = 1,76 m, $T_{s,windsea,NEE}$ = 5,62 s

$$H_s = \frac{1}{N/3} \sum_{j=1}^{N/3} H_j \tag{M.1}$$

The reduced wave height calculated with Godas method as can be seen above will be validated with Godas diffraction diagrams, see Figure M.4. Godas diagrams assumes waves that are normal incident, but advises for non-normal incident waves to read the graph under the angle of incidence. In this case, in the diagrams will be read for both s_{max} values of 10 (windsea) and 75 (swell) under the angles 40 and 62,5 degrees. The horizontal axis describes the headland over wavelength ratio, with the left graphs being used for relatively small scales and the right graphs for large scales, depending on the wavelength. The length from the point of interest to the point of diffraction at Santa Marta is approximately 30 km. The smallest water depth the waves enter before diffraction is approximately 70 m, see Figure M.3. Whether the waves are in deep water or shallow water is given by the relation $h/L > 1/2$ for deep water and $h/L < 1/20$ for shallow water. With the depth of h = 70m, deep water occurs for waves smaller than 140 m and shallow water for waves larger than 1400 m. We can quickly conclude that the windsea waves are in deep water and the swell waves are in intermediate water.

The length of the windsea waves (considered deep water) is calculated with Equation M.2 (Holthuijsen, 2010). The length for waves with a period of 5,7 s is 50,73 m. The swell wave length can be calculated with the formula for intermediate water as can be seen in Equation M.3 (Holthuijsen, 2010). Solving this iterative equation for swell waves with a period of 10 s results in a wave length of 155,06 m. This means that if we look to the x-axis in the Goda diagrams in Figure M.4, for the windwaves (s_{max} = 10) holds x/L = $30000/50,73 = 591,37$ and for the swell waves (s_{max} = 75) holds x/L = $30000/155,06 = 193,47$. Both values are even too large for the right diagrams, representing the large scale and will therefore be read at x/L = 100. Considering the diffraction degrees 40 and 62,5 (read 50 and 27,5 degrees from top) for both windsea and swell results in the following values for the situations, K_d for wave height ratio and R_d for wave period ratio:

- Swell, NE - $K_{d,swell,NE}(-40\circ) = 0,09$, $R_{d,swell,NE}(-40\circ) = 0,7$
- Windsea, NE - $K_{d,windsea,NE}(-40\circ) = 0,35$, $R_{d,windsea,NE}(-40\circ) = 0,86$
- Swell, NEE - $K_{d,swell,NEE}(-62,5\circ) = 0,04$, $R_{d,swell,NEE}(-62,5\circ) = 1,15$
- Windsea, NEE - $K_{d,windsea,NEE}(-62,5\circ) = 0,19$, $R_{d,windsea,NEE}(-62,5\circ) = 0,80$

$$L = \frac{gT^2}{2\pi} \tag{M.2}$$

$$L = \frac{gT^2}{2\pi} * tanh(2\pi\frac{d}{L}) \tag{M.3}$$

The final results of the validation of both method is given in Table M.1. Note that swell waves from the NEE can be neglected and windsea waves from NEE are smaller than windsea waves

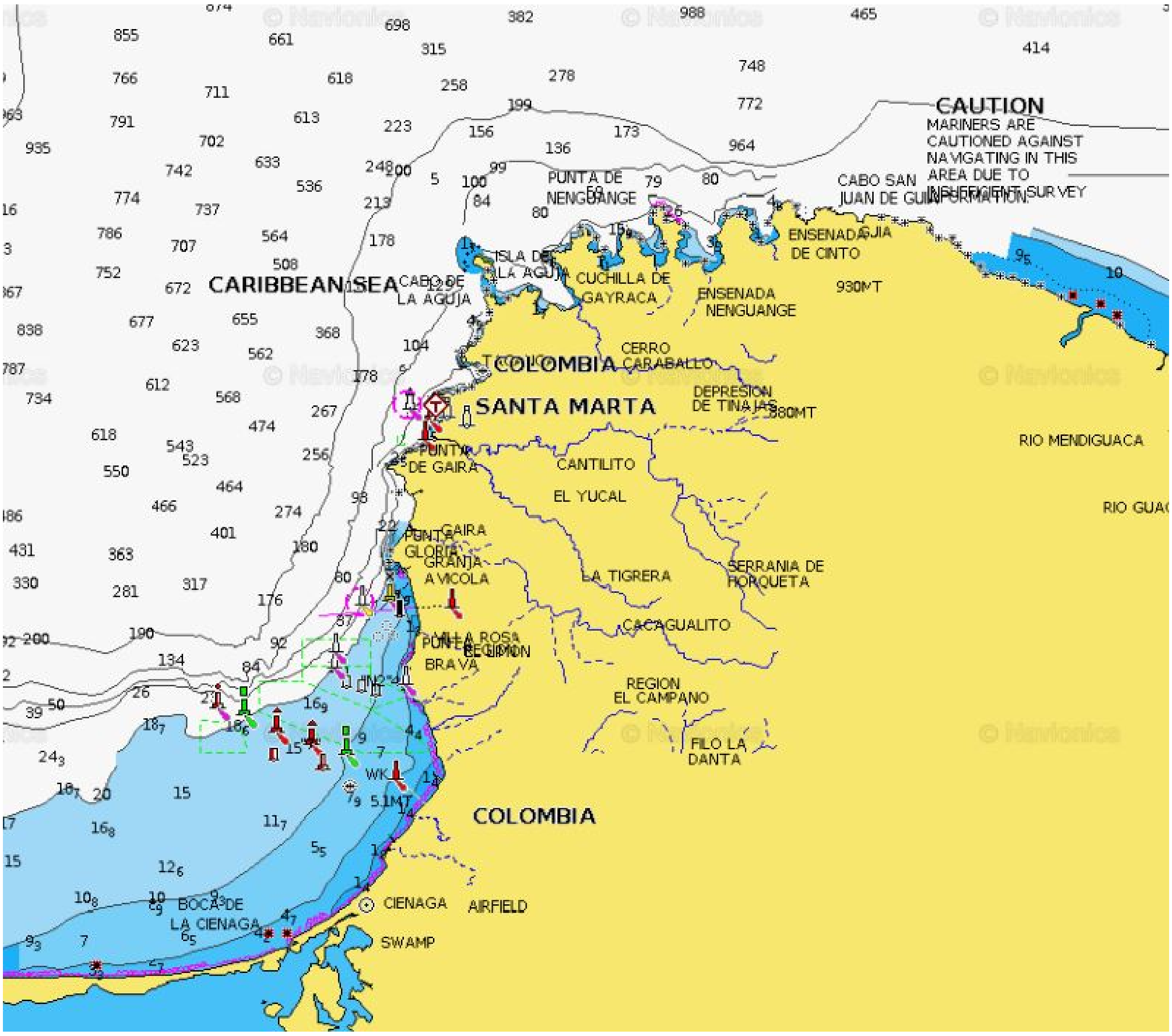


Figure M.3: Depth profile according to the Navionics Webapp (Navionics, 2017)

from NE. The SwanOne calculation will continue with the normative values for both swell and windsea waves from NE.

	Goda method		**Goda simplified diagram**		**Normative value**		**Dataset finding**			**Input Swanone**	
Type of waves	Kd [-]	Rd [-]	Kd [-]	Rd [-]	Kd [-]	Rd [-]	Time present [%]	Hs [m]	Ts [s]	Hs [m]	Ts [s]
Swell, NE	0,14	-	0,09	0,7	0,14	0,7	33	0,62	9,79	0,09	6,85
Windsea, NE	0,36	-	0,35	0,86	0,36	0,86	27	1,89	5,83	0,68	5,01
Swell, NEE	0,00	-	0,04	1,15	-	-	35	0,31	10,61	-	-
Windsea, NEE	0,21	-	0,19	0,80	0,21	0,80	55	1,76	5,62	0,37	4,50

Table M.1: Table with diffracted wave characteristics, ready for SwanOne

M.3.1 SwanOne calculation

Now that the diffracted wave height and wave period are known for both windsea and swell waves from the NE, the SwanOne calculation can be continued. We continue the SwanOne calculation to include refraction and shoaling effects. Since the influence of a longer period is not exactly known, the calculation is done for both the higher windsea waves as the lower but longer swell waves, see Table M.1.

First, the **depth profile** will be determined with the Navionics Webapp. The distance of the depth profile will be chosen until a distance that both windsea as swell waves are in deep water to include the entire shoaling effect. For the swell waves with wave length of 155 m before diffraction according to deep water relation $h/L > 1/2$, a depth of approximately 300 m should be enough for the diffracted waves. The depth profile is given in Table M.2, and the direction of the diffracted waves is shown in Figure M.5.

‘

x-value	**Depth**	**x-value**	**Depth**	**x-value**	**Depth**
0	-300	21060	-50	40970	-5
4380	-200	24620	-50	43110	-2
17750	-100	26450	-30	44000	0
19980	-50	28180	-20		
20460	-40	34200	-10		

Table M.2: Depth profile SwanOne

The **wind direction and velocity** can easily be seen with the wind rose in figure 5.7. The dominant wind direction is NEE and the average wind speed is 6,99 m/s. The wind speed however has peaks up to 16 m/s. SwanOne neglects the headland as water and the wind velocity contributes as if waves are coming from the NEE and setup by the wind. A wind contribution would therefore not be accurate in this diffracted calculation of SwanOne, because the headland would block this effect. Results in SwanOne are calculated with the average wind velocity in dominant direction, and the influence of these wind effects is considered by adding and removing them.

The **tidal** range near Ciénaga is at maximum 0,46 m (Forecast, 2017) and is filled in under the water depth tab in SwanOne. The water depth consists of the tidal range and an added storm surge. Since Ciénaga is not influenced by the direct dominant wave direction, the added storm surge is considered to be of no importance. The maximum tidal range is considered normative for the added water depth.

Currents are not known to be of importance in this area and are neglected in the calculation.

After many calculations with SwanOne to calculate the nearshore significant wave height, it can be concluded that the nearshore wave height is mostly determined by the windsea waves and that the wind does not influence the wave height much. In figures below, for both windsea and swell and with or without wind effect the significant wave heights for the last 100 meter towards the shore are plotted.

From these figures can be concluded that a significant wave height of Hs = 0,22 shall be used for calculations nearshore.

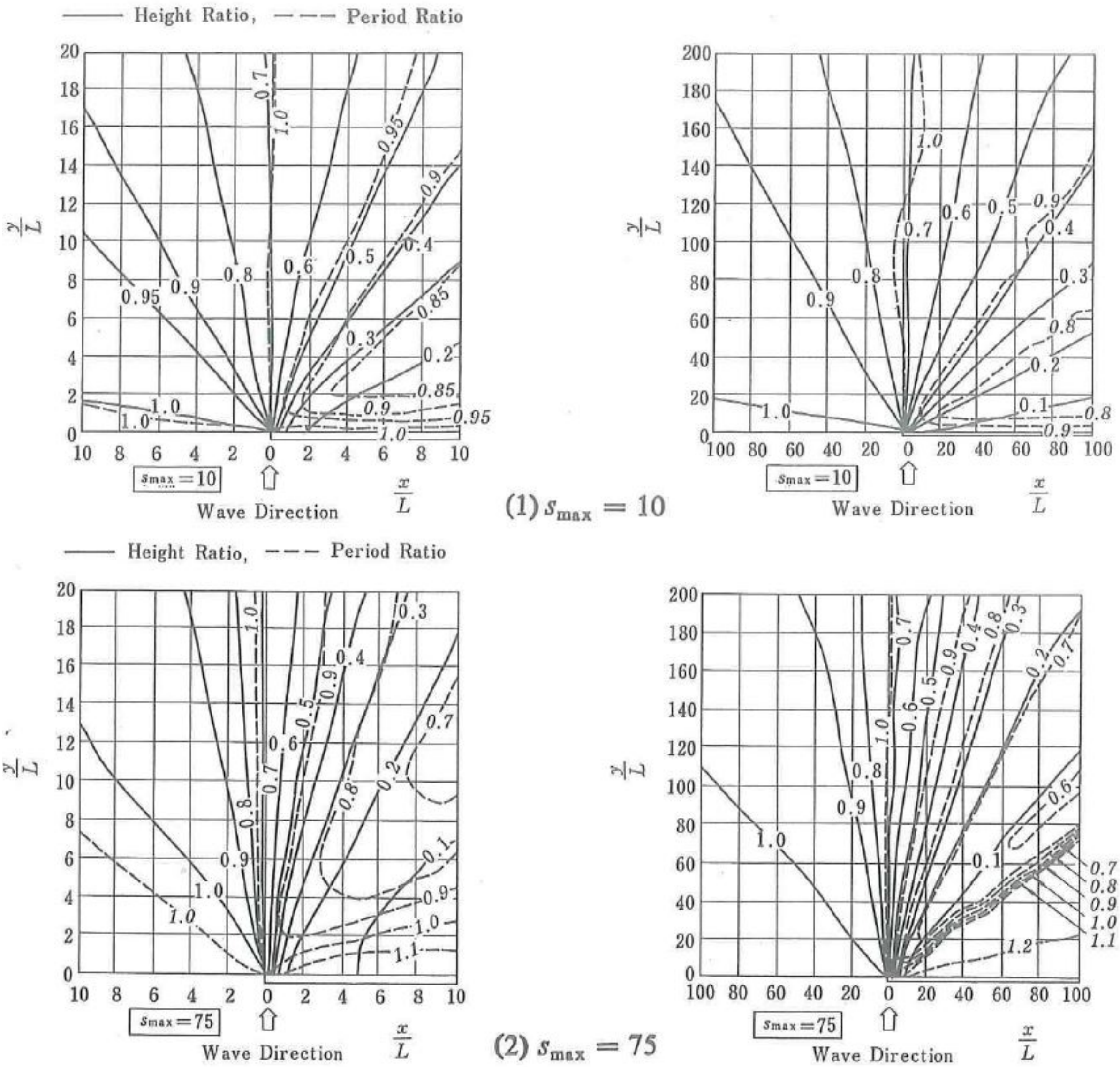


Figure M.4: 'Diffraction diagrams of a semi-infinite breakwater for random sea waves of normal incidence' according to Goda (Goda, 2010)

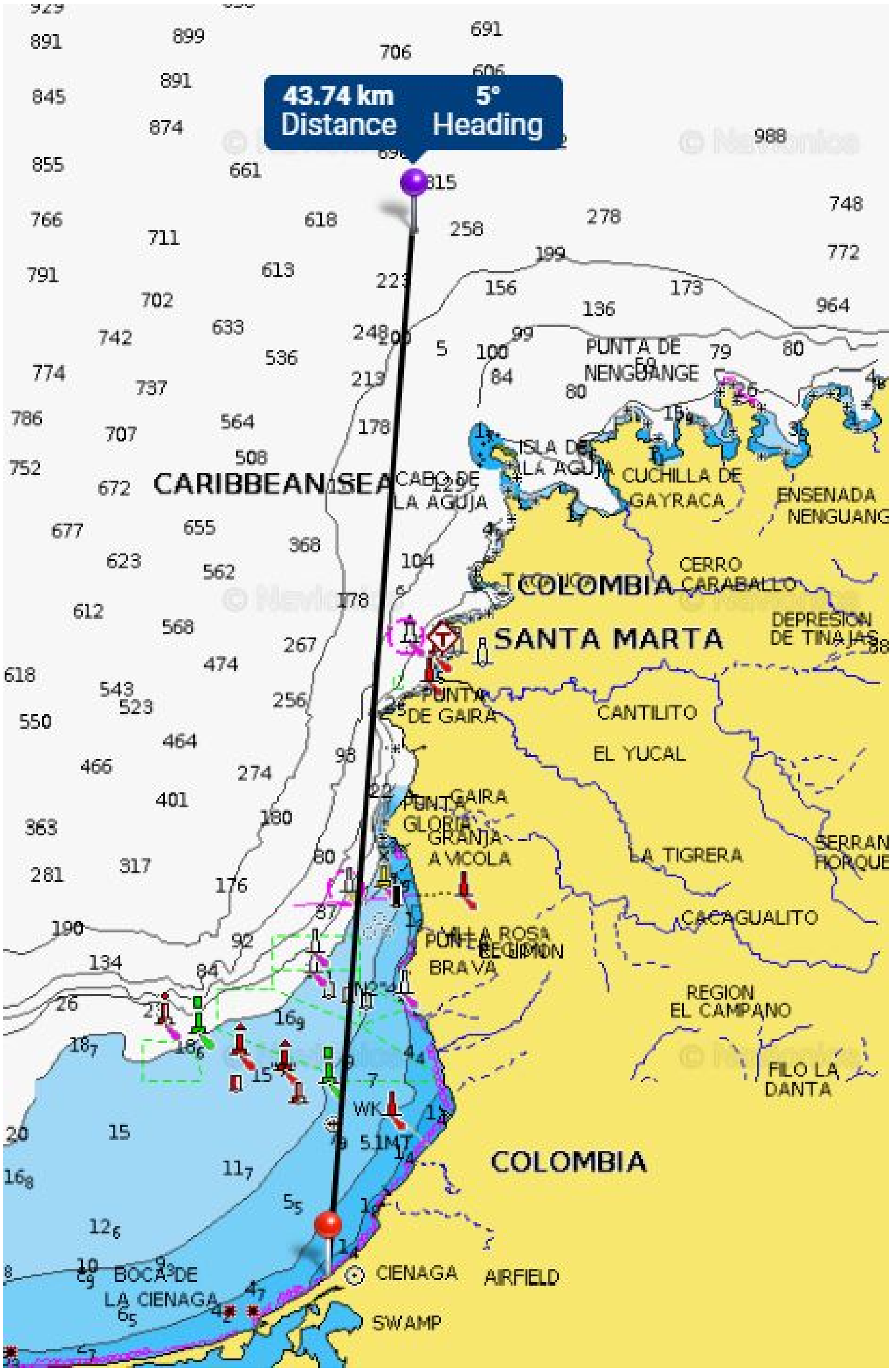
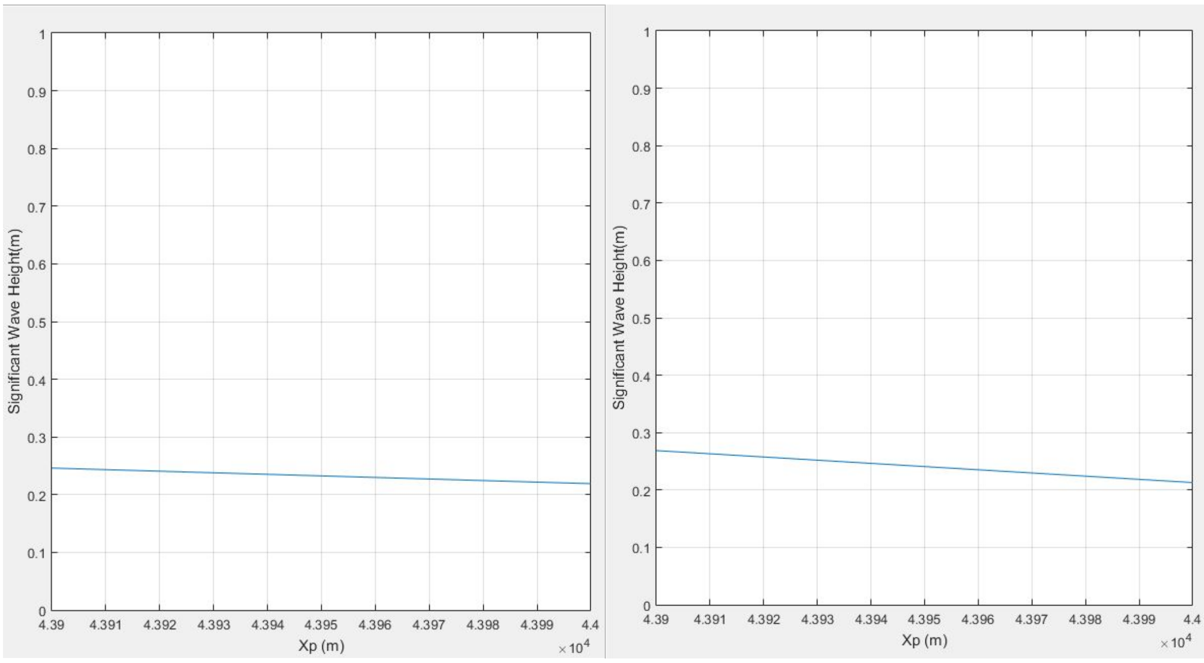


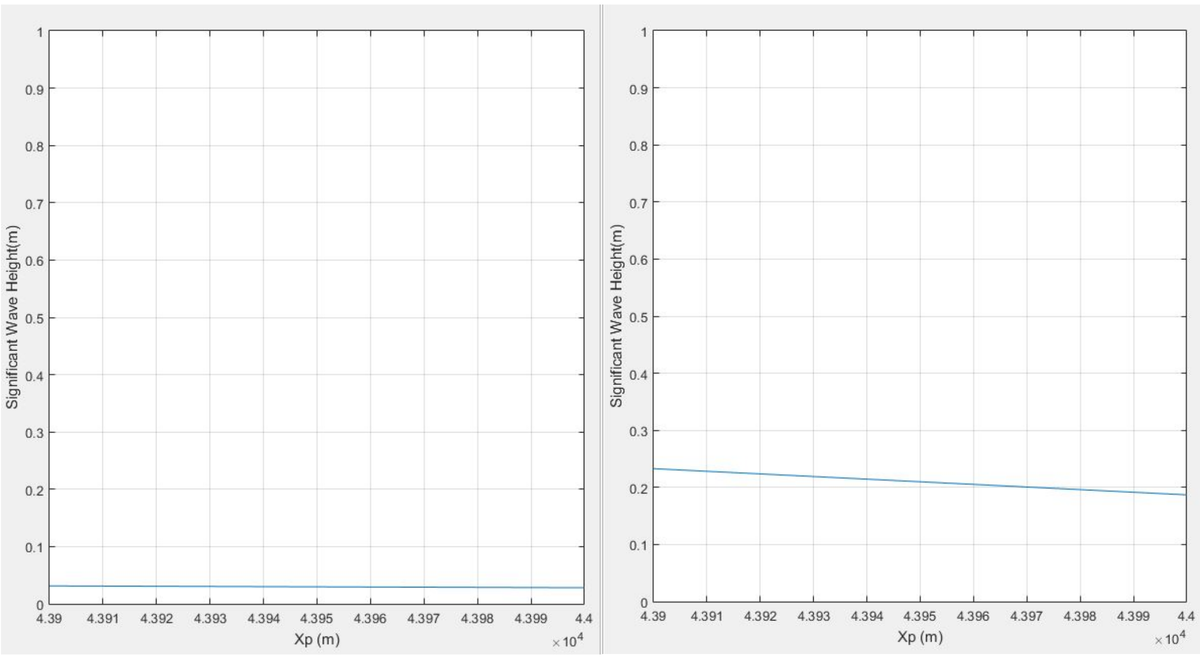
Figure M.5: Direction of calculation with diffracted waves in SwanOne



(a) Windsea waves without wind effects

(b) Windsea waves with wind effects

Figure M.6: Significant wave height of windsea waves 100m towards coast with and without wind influence



(a) Swell waves without wind effects

(b) Swell waves with wind effects

Figure M.7: Significant wave height of swell waves 100m towards coast with and without wind influence

N Framework Survey

FRAMEWORK SURVEY

Name: Group P228
Project description: Erosion Cienaga

This survey is intended to improve the Integrated Coastal Zone Management framework. When answering the questions, you can share your personal experience. The numbers you can circle include the following:
1 = bad
2 = inadequate
3 = sufficient
4 = good
5 = great

Step A: Analysis	**Scale**				
Multiple choice questions					
Determine the natural and socio-economic boundaries of your study area					
1. To what extent do you find the steps in this phase appropriate?	1	2	**3**	4	5
2. To what extent do you find the steps in this phase effective?	1	2	3	**4**	5
3. To what extent do you find the steps in this phase efficient?	1	2	3	**4**	5
Analyze the involvement of each stakeholder					
4. To what extent do you find the steps in this phase appropriate?	1	2	3	**4**	5
5. To what extent do you find the steps in this phase effective?	1	2	3	4	**5**
6. To what extent do you find the steps in this phase efficient?	1	2	**3**	4	5
Analyze the different system elements					
7. To what extent do you find the steps in this phase appropriate?	1	2	3	**4**	5
8. To what extent do you find the steps in this phase effective?	1	2	**3**	4	5
9. To what extent do you find the steps in this phase efficient?	1	2	3	4	**5**
Identify the development factors					
10. To what extent do you find the steps in this phase appropriate?	1	2	3	**4**	5
11. To what extent do you find the steps in this phase effective?	1	2	3	**4**	5
12. To what extent do you find the steps in this phase efficient?	1	2	**3**	4	5
Identify the relation between system elements					
13. To what extent do you find the steps in this phase appropriate?	1	2	3	**4**	5
14. To what extent do you find the steps in this phase effective?	1	2	**3**	4	5
15. To what extent do you find the steps in this phase efficient?	1	2	3	**4**	5

Open questions
16. Are there particular features that you miss in this step? What are they? Better guidance on how to define the boundaries.
17. Are there particular features that you found unnecessary in this step? What are they? The compatibility matrix.
18. Are there particular features that you found explicitly useful in this step? What are they? The analyses of the different system elements
19. Do you have any further comments on this phase? (about the clearness, the sequence, readability, and so on.) Leave the compatibility matrix out of the framework.

Step B: Development Alternatives	Scale				
Multiple choice questions					
Identify alternatives for coastal protection					
20. To what extent do you find the steps in this phase appropriate?	1	2	3	4	5
21. To what extent do you find the steps in this phase effective?	1	2	3	4	5
22. To what extent do you find the steps in this phase efficient?	1	2	3	4	5
Assess the morphological impact of alternatives					
23. To what extent do you find the steps in this phase appropriate?	1	2	3	4	5
24. To what extent do you find the steps in this phase effective?	1	2	3	4	5
25. To what extent do you find the steps in this phase efficient?	1	2	3	4	5
Assess the environmental -and socio-economic impact of alternatives					
26. To what extent do you find the steps in this phase appropriate?	1	2	3	4	5
27. To what extent do you find the steps in this phase effective?	1	2	3	4	5
28. To what extent do you find the steps in this phase efficient?	1	2	3	4	5
Open questions					
29. Are there particular features that you miss in this step? What are they? No					
30. Are there particular features that you found unnecessary in this step? What are they? Effect of driving forces on alternatives.					
31. Are there particular features that you found explicitly useful in this step? What are they? The available alternatives scheme.					
32. Do you have any further comments on this phase? (about the clearness, the sequence, readability, and so on.) No					

Step C: Final Design	**Scale**				
Multiple choice questions					
Make a substantiated decision between the alternaties					
33. To what extent do you find the steps in this phase appropriate?	1	2	3	4	5
34. To what extent do you find the steps in this phase effective?	1	2	3	4	5
35. To what extent do you find the steps in this phase efficient?	1	2	3	4	5
Determine an integral approach to implement the chosen alternative					
36. To what extent do you find the steps in this phase appropriate?	1	2	3	4	5
37. To what extent do you find the steps in this phase effective?	1	2	3	4	5
38. To what extent do you find the steps in this phase efficient?	1	2	3	4	5
Dimension the final design					
39. To what extent do you find the steps in this phase appropriate?	1	2	3	4	5
40. To what extent do you find the steps in this phase effective?	1	2	3	4	5
41. To what extent do you find the steps in this phase efficient?	1	2	3	4	5
Open questions					
42. Are there particular features that you miss in this step? What are they? Implementation guidance.					
43. Are there particular features that you found unnecessary in this step? What are they? No					
44. Are there particular features that you found explicitly useful in this step? What are they? MCA					
45. Do you have any further comments on this phase? (about the clearness, the sequence, readability, and so on.) No					

Step D: Evaluation	Scale				
Multiple choice questions					
Evaluate the project					
46. To what extent do you find the steps in this phase appropriate?	1	2	3	4	5
47. To what extent do you find the steps in this phase effective?	1	2	3	4	5
48. To what extent do you find the steps in this phase efficient?	1	2	3	4	5
Evaluate the framework					
49. To what extent do you find the steps in this phase appropriate?	1	2	3	4	5
50. To what extent do you find the steps in this phase effective?	1	2	3	4	5
51. To what extent do you find the steps in this phase efficient?	1	2	3	4	5
Open questions					
52. Are there particular features that you miss in this step? What are they? No					
53. Are there particular features that you found unnecessary in this step? What are they? No					
54. Are there particular features that you found explicitly useful in this step? What are they? This form.					
55. Do you have any further comments on this phase? (about the clearness, the sequence, readability, and so on.) No					

Step E: Awareness	**Scale**				
Multiple choice questions					
Create the plan of approach for your action plan (Who, What, Medium, Frequency)					
56. To what extent do you find the steps in this phase appropriate?	1	2	3	4	5
57. To what extent do you find the steps in this phase effective?	1	2	3	4	5
58. To what extent do you find the steps in this phase efficient?	1	2	3	4	5
Open questions					
59. Are there particular features that you miss in this step? What are they? No					
60. Are there particular features that you found unnecessary in this step? What are they? No					
61. Are there particular features that you found explicitly useful in this step? What are they? No					
62. Do you have any further comments on this phase? (about the clearness, the sequence, readability, and so on.) No					