Sedimentation in the mouth of the Magdalena river

Improving navigability in the port of Barranquilla

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"Navegaban muy despacio por un río sin orillas que se dispersaba entre playones áridos hasta el horizonte. Pero al contrario de las aguas turbias de la desembocadura, aquellas eran lentas y diáfanas, y tenían un resplandor de metal bajo el sol despiadado. Fermina Daza tuvo la impresión de que era un delta poblado de islas de arena.
- Es lo poco que nos va quedando del río - le dijo el capitán.
Florentino Ariza, en efecto, estaba sorprendido de los cambios, y lo estaría más al día siguiente, cuando la navegación se hizo más difícil, y se dio cuenta de que el río padre de La Magdalena, uno de los grandes del mundo, era solo una ilusión de la memoria."

— Gabriel García Márquez, El Amor en los Tiempos del Cólera

"They were sailing very slowly up a river without banks that meandered between arid sandbars stretching to the horizon. But unlike the troubled waters at the mouth of the river, these were slow and clear and gleamed like metal under the merciless sun. Fermina Daza had the impression that it was a delta filled with islands of sand.
- It is all the river we have left - said the Captain.
Florentino Ariza, in fact, was surprised by the changes, and would be even more surprised the following day, when navigation became more difficult and he realized that the Magdalena, father of waters, one of the great rivers of the world, was only an illusion of memory."

— Gabriel García Márquez, Love in the Times of Cholera

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Disclaimer

It is important to stress that this project is performed by students of the TU Delft as part of their master's degree and should not be considered as a professional consultancy report. This multidisciplinary project was executed with the goal of requiring information and analysing the current situation of the Magdalena River and the port area of Barranquilla. The results have to be used in this perspective and do not form a basis for decision-making on direct measures.

Preface

Project Bocas de Ceniza
Delft, January 2018

In front of you, you have the final report of 'Project Bocas de Ceniza'. This multidisciplinary project was carried out as part of the master tracks Hydraulic Engineering and Construction Management Engineering at Delft University of Technology. With a team of four hydraulic engineers and two construction management engineers, we stayed for eight weeks at the Universidad del Norte in Barranquilla, Colombia. During our time in Colombia, we met with several local authorities and companies to gather necessary information and data to carry out our research.

In this project we focused on the sedimentation at the mouth of the Magdalena River, which is called the 'Bocas de Ceniza'. To work on a current issue and be able to visit the research location was a great experience for us. In this way, we were able to get a better idea of the dimensions of the problem we were working on and it gave us the chance to combine our theoretical knowledge with practical experiences.

We are very grateful for all the help we had during our project. First of all, we would like to thank the Universidad del Norte, Humberto Avila and the Hydraulic Engineering Department in Barranquilla for accommodating our working space, answering all our questions, setting meetings for us and organising a field trip. Our supervisors, Erik Mosselman, Jan van Overeem and Martijn Leijten, were of great help to initiate the project and guide us throughout the entire process.

Furthermore, we would like to thank our sponsors, without whom this project would not have been possible. A special thanks to Erik Waumans of Van Oord, who helped us to arrange our stay in Barranquilla, and provided us with necessary information and guidance. We also want to thank Pieter Becker of Damen, who was able to put us in contact with Andrew, Christopher and Robert Williams of the Barranquilla based dredging company SDC. They were very kind to take us on a boat trip on the river and the Ciénaga de Santa Marta, and arrange visits to several river authorities for us. We also want to express our gratitude to all stakeholders that took the time to share their perspective with us and were willing to answer our questions.

It was a great opportunity for us to be able to carry out this project in the vibrant city of Barranquilla. The Colombian people and environment really turned this project into a wonderful and unforgettable experience.

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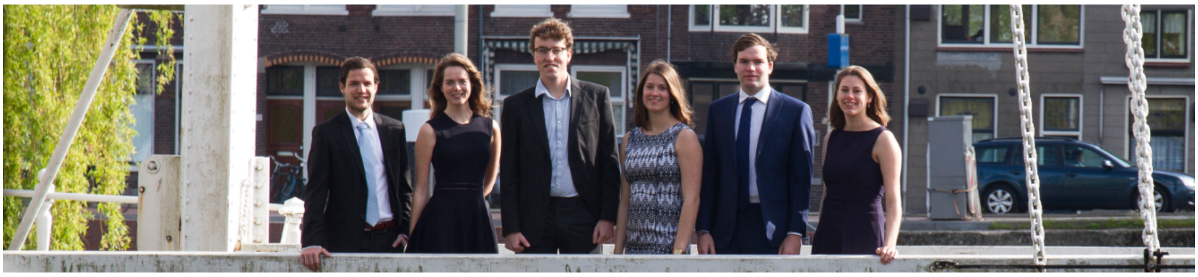

Summary

For decades rivers have been utilised as important transportation networks. With the arrival of more modern transportation networks such as highways and railways the utilisation of rivers has decreased. However, the power of these natural highways should not be underestimated. In a country like Colombia, with the Magdalena river stretching all the way from the Caribbean coast to the main inland near important cities such as Bogotá and Medellín, a multi-modal transportation network can be profitable. Especially since the current costs for transporting goods from the inland to the coast by trucks are extremely high. The city of Barranquilla can play an important role in the establishment of this multi-modal network. The freight of the large seagoing vessels can be transferred onto smaller barges to navigate further inland. Currently however, issues with navigable depth in the river mouth (Bocas de Ceniza) make it difficult for the larger vessels to enter the port area. Resolving these issues will increase the navigability of the Magdalena river which in turn will help Barranquilla bloom as a port city. The aim of this research is to analyse the various sedimentation processes and to explore the possibilities for mitigation measures.

In order to gain more insight into the processes which affect the sediment transport in the first 38 km of the Magdalena river a morphological model is developed using Delft3D software. However, to understand and capture the essence of the issue also the socio-political context is researched. This is done by analysing both the stakeholders and the previous unsuccessful Magdalena recovery project. The combination of both the physical and more organisational aspects formed the input to come up with multiple intervention ideas to solve navigability issues. To evaluate these interventions a multi-criteria analysis (MCA) is conducted with both technical and managerial criteria. Finally, also an engagement plan is constructed as a guideline to have successful stakeholder management in a future river project.

From the exploration of the physical part of the issue it can be concluded that there are both natural and anthropogenic aspects which influence the river system, hence the sedimentation issue. With regard to the natural aspects, high discharge variability, stratification and wave action are selected to be further investigated with the Delft3D model. Model results show that sedimentation and erosion rates increase in the access channel above a discharge of around 5000 m^3/s. For discharges below this value, the salt intrusion length increases faster than for higher discharges. This salt intrusion leads to a low flow velocity at the bottom that is directed upstream, making the reach over which salt intrudes susceptible to sedimentation. Waves mainly influence bar formation in the river mouth and are not important further upstream.

The analysis of the non-physical aspects leads to a few important conclusions as well. First of all it is concluded that the stakeholder network, in which this problem exists, is a fairly complex one. Therefore stakeholder and process management are key elements in making a future river project successful. Furthermore hypotheses on the success factors of setting up a public private partnership (PPP) in Colombia are formed based on research by Koppenjan (2003), cultural differences between the Netherlands and Colombia and interviews with important stakeholders. These hypotheses are that corruption, political stability and openness for change are also important factors in setting up a successful PPP in Colombia.

Possible interventions to mitigate the sedimentation issues in the first 38 km of the Magdalena river have been assessed separately for three different sections. For the first section (reaching from 0 km to 8 km), the most promising intervention resulting from the MCA is water injection dredging. This would efficiently improve the navigation conditions, capital investments are relatively low and it is also an adaptable solution. For the next section (from 8 km to 22 km), a fixed bottom layer is considered a promising intervention since it will lead to erosion of the relatively shallow inner bend and therefore increase the navigable width. As for the last section (from 22 km to 30 km) it can be concluded from the MCA that none of the assessed training works score better than the current situation.

It should be emphasised that this research and especially the assessed interventions are exploratory. It can function as a starting point for future research on more detailed designs of river training works and their effects on the behaviour of the river. This is also the case for the stakeholder management aspect: the proposed success factors and engagement plan are not a blueprint for the success of a future project.

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Introduction

1.1. Motivation

Ever since the Spanish set foot on Colombian ground, over 400 years ago, the Magdalena river has provided the main route from the coast to the inland core region (Townsend, 1981). The river, which originates in the south of Colombia, has been a crucial link between the Caribbean coast, including the ports of Barranquilla and Cartagena, and large cities such as Medellín and the capital Bogotá (see Figure 1.1). However, the Magdalena river has ceded its importance as a mode of transportation to road over the last decades. This is largely due to the difficulty to navigate the river, in some reaches seasonal, in others throughout the year (De Pietro, 2013).

Figure 1.1: Map of the Magdalena river basin (after Asoportuaria (2011)).

In the meantime, the vessel size has been increasing rapidly over the last decades (Sys et al., 2008), thus requiring a larger and larger water depth. Developments such as the recent expansion of the Panama Canal forces ports worldwide to accommodate larger vessels in order to stay competitive (Muirhead et al., 2015). The rapidly growing economy of Colombia (GDP growth rate averaged 1% over the last 16 years (Trading Economics, 2017)) forms another reason for the increasing need to navigate the river, as both export and import are growing with it.

The navigability issues of the Magdalena river increasingly act as a bottleneck for transportation. In 2011, the cost of importing goods was with $2,800 per container 43 % higher in Colombia than in other Latin American countries (De Pietro, 2013). Making the river navigable over at least the lower reach of approximately 250 km would enable inland shipping between the Caribbean coast and the main cities, whereas an improved navigability at the mouth would be beneficial to the port of Barranquilla to act as a transshipment port.

1.2. Problem definition

Although Colombian authorities recognise the need to improve the navigability of the Magdalena river, efforts to reach this goal have not been successful so far. The complex morphological behaviour of the river (see Chapter 3), in combination with failing leadership and lack of cooperation between authorities, has led to numerous failed attempts to improve the situation. Especially at the mouth of the river, the situation is pressing. Here, heavy sedimentation hinders large sea-going vessels to enter the port of Barranquilla. To guarantee a sufficient navigable depth in the entrance channel, costly dredging operations are required throughout the year. The dynamic behaviour of the river mouth is poorly monitored and understood, which makes it impossible to develop a long-term maintenance strategy. Dredging often occurs ad hoc, which drives up the costs even more.

1.3. Goal

To obtain more insight into the hydro-morphological behaviour of the river, the Universidad del Norte in Barranquilla set up the 'Observatorio del Río Magdalena' (Uninorte, 2017). The goal of this observatory is to gain more insight into the behaviour of the river, by monitoring and collecting data on the hydro- and morphodynamics. In this way, authorities can adequately respond to the dynamics of the river and thus serve the needs of society with regard to it. The goal of this research is to advise the observatory about the sedimentation problems in the port area of Barranquilla and to elaborate on several mitigating measures.

1.4. Research questions

From the goal as defined in Section 1.3, the main research question of the project is formulated as follows:

Which processes influence the sedimentation of the first 38 kilometers of the Magdalena river and what scenario is considered the most suitable to improve the navigability in this reach?

The following sub-questions support the main research question:

- Which processes influence sedimentation in the river mouth?
- Which stakeholders can be identified, to what extent are they involved in the sedimentation problem and how are they interrelated?
- Which possible alternatives to improve the navigability can be identified?
- What is the performance of the selected solutions, when approached integrally and keeping the socio-economic criteria in mind?

1.5. Scope and approach

Several steps need to be undertaken in order to answer the research questions. Firstly, an analysis of the system in which the research area is located is performed. Here, a distinction is made between the physical and the socio-political system. The socio-political system can be understood by carrying out a stakeholder analysis. This analysis is limited to the actors that are affected by or interested in the navigability of the port area. The physical system consists of the first 38 km of the Magdalena river, from Puerto Pimsa to Bocas de Ceniza, and the coastal zone influenced by the river (extending 35 km offshore). Combining the results of a literature study and personal communication with experts on the Magdalena river, the main processes affecting sediment transport in the mouth of the river can be identified. Furthermore, an analysis of available data on this part of the river will be carried out. Subsequently, using Delft3D software, a morphological model of the area will be developed, that includes the main processes affecting sediment transport. This model is calibrated using the results of the data analysis. Using the results of the physical analysis and the morphological model, several promising interventions can be identified. Subsequently, various design alternatives to mitigate the sedimentation issues can be formulated, each consisting of a combination of interventions. In order to evaluate the selected alternatives, the knowledge gathered from the stakeholder analysis, the physical analysis and the Delft3D model has to be used in an integrated way. Only then, substantiated decisions on human interventions in this estuarine system can be made (De Jonge et al., 2014). To be able to evaluate the design alternatives from both a technical and a management point of view, a Multi-criteria analysis will be used. In this way, the design alternative with the highest probability of success can be selected. Furthermore, using the research results, recommendations can be given to both the Observatorio del Río Magdalena and other involved stakeholders. A more precise description of the structure of the report can be found in section 1.6.

1.6. Reading guide

To make this technical report more accessible, the report is divided in five parts (Figure 1.2). The second and third part are specialised chapters. This means that they both serve as "separate" input for the subsequent parts. Therefore, the two parts are placed in parallel in Figure 1.2. A short description of each part is included below.

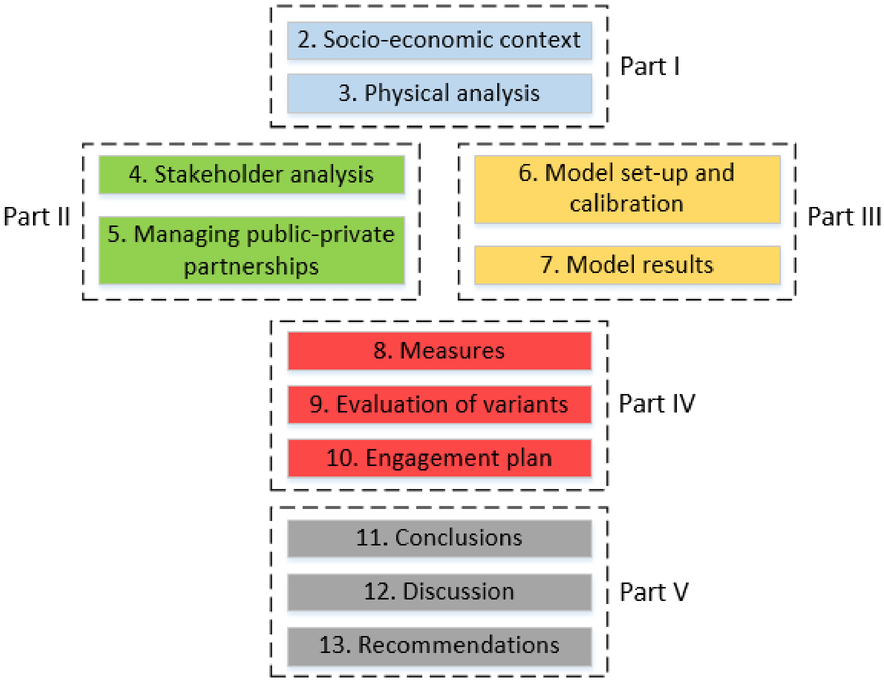


Figure 1.2: Reading guide overview

- **Part I: Analysis**: This part is about information gathering. In the first chapter, the historical and economical context of the city of Barranquilla and its port are treated, to get an understanding of the problem area. It continues with the physical analysis of the area, to understand which processes are important and locate the specific problems. It concludes with a description of the input data that is used in the Delft3D model.
- **Part II: Stakeholders**: In this chapter the stakeholders are identified. Subsequently, the stakes, interests and interactions of the stakeholders are mapped. Public-private partnerships are important partnerships in this particular environment. Therefore the old, current and future collaborations are explored as well.
- **Part III: Model**: Another core part of our report is the Delft3D model. The set-up and the results of the numerical model are discussed in this part.
- **Part IV: Interventions**: After locating the problem areas, possible measures are elaborated in this part. First, an overview is given of all the possible measures, followed by the proposed measures for each river section. These measures are then evaluated by means of a multi-criteria analysis.
- **Part V: Conclusion, discussion and recommendations**: In this final part, all the information and work that has been done is combined to give an answer to the research questions. The conclusion of the report is followed by a discussion about the critical points in the performance of this research. The report concludes with recommendations for further research in this topic.

I

Analysis

2
Socio-economic context

The challenge currently faced by the city and ports of Barranquilla concerning the limited depth in the mouth of the Magdalena river is a complex problem. A sustainable future solution is not only technical, it would encompass several social and political aspects as well. Therefore in this paragraph the socio-political context of the problem will be discussed. First of all a short summary of the history of the navigation problem is given. Subsequently social, political and economic aspects of this issue will be discussed.

2.1. History

The city of Barranquilla was, unlike many other old cities in Colombia, not founded as a colonial city of Spain. Although unsure about the real year of establishment, 1629 is often mentioned as the year in which people first settled in Barranquilla (Nichols, 1954). The city expanded as more farmers and fishermen came to the river.
In the early 19th century the city started to trade significant amounts of goods over the river through traditional canoes. However, the city did not operate as a seaport yet due to difficulties navigating the river mouth. The role of seaport was fulfilled by the small settlement of Sabanille, just west of Barranquilla. Operating as a duo the two ports were growing rapidly, however as Nichols (1954) put it:
"The problems of communication between the mutually dependent ports were almost as great as those of ocean ships sailing through the Bocas de Ceniza to reach Barranquilla."
During these times the Canal del Dique, which connects Cartagena with the Magdalena river, was in great need of dredging. This issue gave a new impulse to the development of the ports of Barranquilla and Sabanille. With the rise of steamboats, that made it impossible to reach the seaports of Cartagena and Santa Marta from the river, and the construction of a railroad between Barranquilla and Sabanille the competitive advantage grew even more. This resulted in the fact that by the mid 1870's Barranquilla became the largest port of Colombia and the Caribbean.
This success was however jeopardised by various problems in the satellite seaports of Barranquilla: Sabanille and Salgar. Therefore in 1936 it was decided to do something about the sandbank at the mouth resulting in the history of the Bocas de Ceniza, described in more detail in Appendix A.1. This finally made Barranquilla the true hub between the sea, thus the international trade, and inland transportation over the Magdalena river (Oxford business group, 2013).
The end of the 1950's marked the turning point for Barranquilla. The city got into an economic crisis, worsened by the municipality not being able to face the social unrest in the city (Iragorri, 2011). A long political crisis followed. The crisis in combination with large masses of migration from rural areas to Barranquilla worsened the situation even more (Baca-Mejía & Parada, 2017; Oxford business group, 2013).
However, since the start of the 21st century Barranquilla is on the road to prosperity once again. Increase in the sale of properties, lower unemployment rates and the attraction of some high-end projects all played an important role in this development (Oxford business group, 2013).
2013 was for Barranquilla as a port city an exciting time. Cormagdalena, the river authority, contracted a mega project in a public private partnership. The goal of this partnership, worth almost 1 billion US dollars, was to not only dredge the mouth of the river but also to revive the transportation of cargo over the Magdalena river to upstream ports and cities.
Unfortunately, as for the present day the Magdalena river is not in the condition it should be in as agreed upon in the partnership. This is caused by the fact that the main contracting party Odebrecht, a Brazilian construction company, was involved in corruption scandals making it impossible for them to finance the work (Oxford business group, 2017).

2.2. Social aspects

In an issue like the one analysed in this report, a vast amount of parties are involved. This complicates the social aspect of working towards a future solution. To analyse which parties are involved and what their stake is in the problem, a stakeholder analysis is conducted. The results of this analysis can be found in Chapter 4. Other social aspects which are important in the context of this problem will be discussed next.

First of all the demographics of Colombia are shown in table 2.1. One of the interesting facts is the rate of urbanisation. The group of people living in non-urban areas often have different interest than the people living in the urbanised area. It is, specifically in this issue, important that the interest of this minority is also taken into account.

Table 2.1: Demographics of Colombia (Index Mundi, 2017)

Aspect	Numbers
Inhabitants Colombia	47,220,856
Growth rate	1.02%
Inhabitants Barranquilla	1,991,000
Urban population	76.4% of total population
GDP	282.5 billion USD

Another important social aspect is culture. Colombia's culture descends from the colonial era during which the country was a colony of Spain. After the independence this culture naturally changed little by little eventually forming the culture of today. More information on the specifics of this culture can be found in paragraph 5.3.1.

2.3. Political aspects

The political system of Colombia can be defined as a presidential democratic republic. This means that the president is chosen democratically and this president is both the head of the government and leading the executive branch. Furthermore it can be noted that in these kind of systems the government of a country is considered to be a public matter. As in many other political systems the principle of 'trias politica' is applied. The executive, legislative and judicial power are divided into three separate branches with the idea that in this way the power is not concentrated at a single branch (Honorary Consulate of the Republic of Colombia, 2017).
Ever since the independence from Spain was declared Colombia has followed this presidential democratic system. The country however had to deal with many extremely difficult challenges including civil wars, the guerrilla war and the many violent drugs cartels. This made it very hard to have a stable government, and briberies and other ways of corruption within the government were common during this period (LeGrand, 2003).
In Appendix E.2 an illustration of the governmental organisations who are involved in the sedimentation issues in the port of Barranquilla is given. The hierarchical structure of these governmental stakeholders is also shown in the figure.

2.4. Economic aspects

2.4.1. Transport on the Magdalena river

From mid 2nd century transport by road became more economical than via the river. One of the reasons for the economical advantage of the road, is the fact that in the last century, navigation on the Magdalena river became more difficult far upstream. Until 1946, navigation was possible till Girardot, at K1135. For the last 50 years, Puerto Salgar at K921 was still accessible, but at present day Puerto Berrío at K765 is the furthest point that can be accessed. In 1940, the river still transported 30% of the cargo (by weight), compared to 40% by road and 30% by rail. By the time of 1980, these numbers completely changed. 80% of the cargo went by road, 17% by river and 3% by rail. At present day, the share of the river has decreased drastically to a percentage of less than 1.2% (Ortega, 2008; Louis et al., 1948).

2.4.2. The port of Barranquilla

To understand the situation and development of the port of Barranquilla, it is necessary to zoom out and look at it in relation to other ports in the area. On national level, the ports of Cartagena and Santa Marta play an important role. On international level, also the ports of Panama and Venezuela should be considered.

Since 1997, the port of Colón, Panama, has risen to the leading transshipment port in the Caribbean region (Wilmsmeier et al., 2014). With a container throughput of more than 3.2 million TEU, it is the second biggest transshipment port on the continent of South America, after Santos in Brazil. In the Caribbean region, it is followed by the container terminal of Cartagena, with a container throughput of 2.3 million TEU. In comparison with these ports, the port of Barranquilla is a small one, with a container throughput of 160,000 TEU (ECLAC, 2017). For bulk transport, like coal and oil, the ports of Puerto Cabello and Guaira in Venezuela and Santa Marta in Colombia are important competitors.

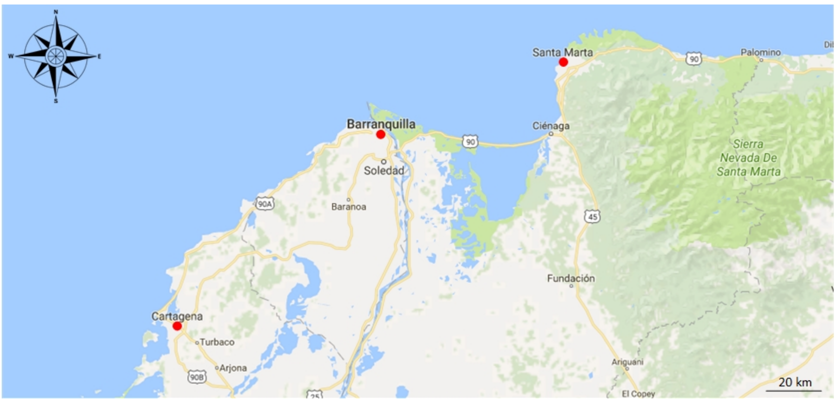


Figure 2.1: Location of Colombian ports along the Caribbean coast (Google Maps, 2017).

The geographic position of the port of Barranquilla is favourable in comparison with Santa Marta and Cartagena, due to the direct connection to the Magdalena river (Figure 2.1). This gives a good opportunity to be the main transshipment port for containers and bulk transport to the inland of Colombia. The main challenge of the port however is to guarantee sufficient depth. Where the ports of Santa Marta and Cartagena have a berthing depth of 18 and 13.5 meter respectively, the port of Barranquilla struggles to guarantee sufficient depth for large seagoing vessels. Parts of the river mouth and port area are continuously silting up, with a reduced depth as a result. The bigger seagoing vessels are not able to enter the port and move to the ports of Santa Marta and Cartagena. From there, the cargo is transported to the inland, mainly by road. The cargo trucks from Cartagena which are intended for the inland even pass Barranquilla.

2.4.3. Vessel characteristics

In its maintenance plan for the Magdalena river (CORMAGDALENA, 2013), Cormagdalena specifies a push-tow with six barges as the design vessel for the reach between Puerto Salgar and Barranquilla. The maximum dimensions of a combination with 6 barges are: 240 m long, 26 m wide and 1.80 m draught. The maximum capacity of the combination is 6000 t.
Naturally, the dimensions required for the port area of Barranquilla are much larger. At the moment however, the port restricts the transit of ships with a draft more than about 8.5 m (Patiño, 2017). The goal of current dredging operations is to deepen the access channel to 9.7 m. As a long term goal, the Master plan for the port of Barranquilla (Rotterdam Maritime Group, 2012) specifies a design depth of 12.2 m. However, it is recognised that this depth cannot be reached in certain port areas. Therefore, the plan distinguishes between three areas, based on the type of vessel that can be allowed:

- **Km 5 - 11.5** is considered suitable for vessels up to 50,000-60,000 DWT (Supramax), as a navigable depth of 14 m is assumed to be reachable here;
- **Km 11.5 - 16** is not considered suitable for port activities due to the limited depth in the inner bend (<4 m);
- **Km 16 - 22** has to allow vessels up to 30,000 - 35,000 DWT. These so-called handysize vessels typically have a draught of about 10 m (Connector, 2017).

Furthermore, the Master plan proposes the development of a deep-water port, the so-called 'Superport', at the mouth of the river, which should have a navigable depth of 19 m and should be able to accept vessels up to 150,000 DWT.

2.4.4. Dredging

Dredgers are used to maintain the necessary depth for navigation. An overview is made of the dredging activities between 2001 and 2015 (Table 2.2). During 2011, an extreme la Niña event took place which corresponded with heavy sedimentation. The total volume of sediment that was dredged is unclear. Estimates indicate a volume of 2,100,000 m^3 (Lequerica Otero et al., 2016).

Table 2.2: Dredging practices Magdalena river (2001-2015) (Lequerica Otero et al., 2016).

Year	Exchange rate USD-COP	Cost [COP]	Total volume [m^3]	Price [COP / m^3]
2001	2,299	$ 1,351,911,917	819,900	$ 1,652
2002	2,508	$ 1,669,402,481	324,150	$ 5,150
2002	2,508	$ 457,184,693	265,806	$ 1,720
2003	2877	$ 2,161,015,464	832,828	$ 2,594
2005-2006	2,358	$ 7,009,487,663	2,427,587	$ 2,890
2006-2008	1,967	$ 4,869,249,968	1,599,967	$ 3,040
2009-2010	1,898	$ 7,982,063,298	926,746	$ 8,610
2011	1,848	$ 23,830,000,000		
2011	1,848	$ 2,631,536,213	304,401	$ 8 ,650
2012	1,798	$ 4,130,257,429	325,000	$ 12,708
2013-2014 Pedro (1) Hondius (2)	1,896	$ 20,055,084,121	 619,597 268,167	 $ 11,652 $ 47,863
2015	2,746	$ 29,835,100,00	1,460,000	$ 20,435

(1) dredged by Draga Pedro Álvarez Cabral
(2) dredged by Draga Hondius

3 Physical analysis

The Magdalena river has a length of 1612 km. Its catchment area lies between the Central and Eastern Cordillera, which are parts of the Andes. The total reach of the river can be divided into 3 parts; an upper reach, having a length of 565 km, a middle reach of 540 km and a lower reach with a length of 430 km. These reaches have different characteristics, an overview of which is given in Table 3.1.

Table 3.1: Characteristics of the three distinct reaches of the Magdalena river (after Restrepo et al. (2006b)).

Reach	Length [km]	Discharge [m^3/s]	Sediment Load [Mt/yr]	Suspended Sediment [kg/m^3]
Upper	565	1390	51,2	1,07 ± 0,64
Middle	540	4230	81,5	0,60 ± 0,25
Lower	430	7100	144,2	0,65 ± 0,78

When looking into the sediment load of the Magdalena river it is relatively high compared to other rivers in the world. Another notable characteristic is the steepness, which is for example quite high in comparison to the Amazon river (which has a similar sediment load). In the lower reach the slope varies from 0.39 [m/km] at Carare to 0.04 [m/km] at Bocas de Ceniza (Townsend, 1981). Furthermore the river can be described as very dynamic, with a meandering pattern in the lower reach with alternating bars, and islands that grow and erode with time. Because of the continuous change in land forms, the connections between the river channel and coastal lagoons are also changing. Depending on the soil conditions, the resistance of sediment to erosion varies as well. This is illustrated in Figure A.1 in Appendix A.

The sediment load in the Magdalena river is highly variable (Restrepo et al., 2006b; Higgins et al., 2016). Both increases and decreases are noticed on a time scale of decades. This variation can be related to different processes that control the transport of sediment along the river. These processes can be divided in natural and anthropogenic influences, including effects on runoff and climate. Furthermore, characteristics of the drainage basin are important, such as size, morphology, geology and vegetation (Restrepo et al., 2006b). In the next sections the natural and anthropogenic influences are discussed consecutively.

3.1. Natural influences

The behaviour of the river is largely determined by natural factors that influence, among others, the discharge, sediment load and position of the river bed. On the smallest time scale with the largest impact, seismic activities can alter the bed level. This happened in 1935 and 1963 when the main channel was naturally deepened (Koopmans, 1971).

The discharge is dependent on the precipitation. There are two distinct wet seasons in which the most rain falls. The first is from April till June and the second is from September till November. This happens because in these times the Inter Tropical Convergence Zone (ITCZ) shifts from North to South and vice versa (Poveda, 2004). On the interannual time scale a lot of variability occurs in the amount of rainfall. The most important variations are the El Niño and La Niña periods. During the El Niño period, the average air temperature increases and the soil moisture and rainfall decreases (Hoyos et al., 2013). As a result of this, the average flow in the Magdalena river decreases to 5512 m^3/s. With a decreasing flow also the sediment load decreases, to an average transport rate of 256 $\cdot 10^3$ t/d. During the La Niña period, the cold period, the opposite of this phenomenon is happening. Due to heavy rainfall in this period, the average flow increases to 8747 m^3/s, which frequently causes flooding. The sediment transport rate of $511 \cdot 10^3$ t/d is also high in comparison with the El Niño period, as observed at the Calamar measuring station during the period 1975-1995 (Restrepo and Kjerfve, 2000).

Figure 3.1 gives an historical overview of the Oceanic Niño Index (ONI). It can be seen that the most recent La Niña period happened in the period 2010-2011. As a result, the water level in Calamar was very high for five consecutive months, even above the level of overflow (see Figure 3.2).

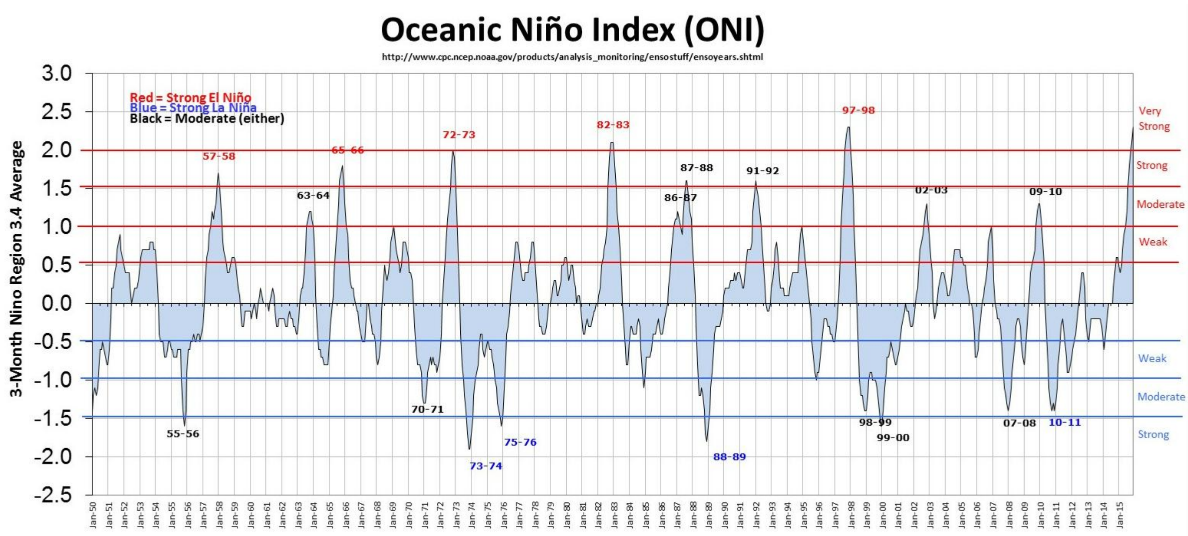


Figure 3.1: Oceanic Niño Index 1950-2016 (NOAA, 2016).

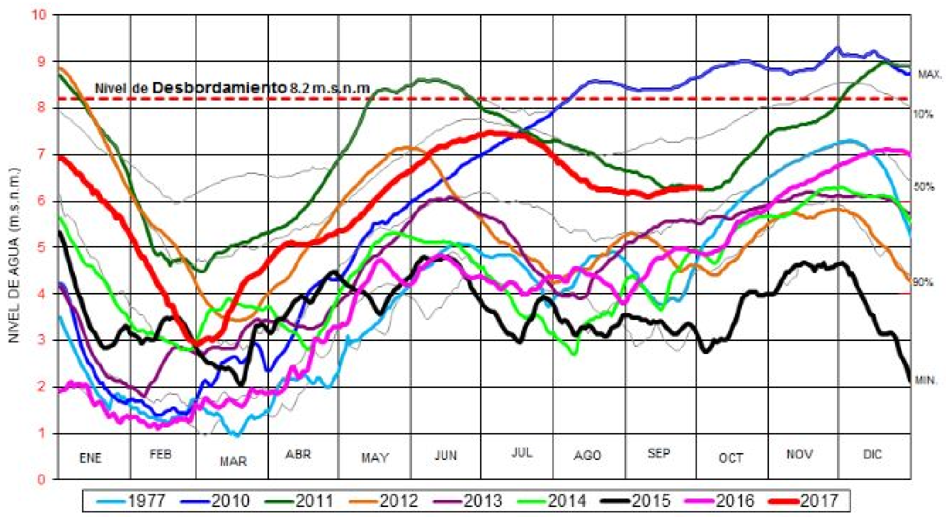


Figure 3.2: Water levels of characteristic years at the Calamar gauging station.

This long period of high discharge resulted in some drastic changes in the course of the river. In the section focused on in this report, an important change happened near the Isla San Jose. Before 2010, the course of the main channel was on the east side of the island (see Figure 3.3). But as a result of the La Niña period, the river created a shortcut and shifted its main channel to the west of the island (see also Figure A.5). This change resulted in a sharp bend just north of the island. To get back to its natural meandering pattern, sedimentation occurs at the inner bend while erosion takes place at the outer bend.

Alongshore transport also influences the availability of sediment in the river mouth. The main component of the alongshore current in the Colombian Caribbean coast is directed from east to west. This current predominates during north-eastern winds. River mouths along the coastline could limit the bypassing of sediment and can have a similar effect as a groyne. Sediment bypassing controls the migration of river mouths and the morphology of delta systems (Nienhuis et al., 2014). Sediment bypassing is also correlated with wave energy.

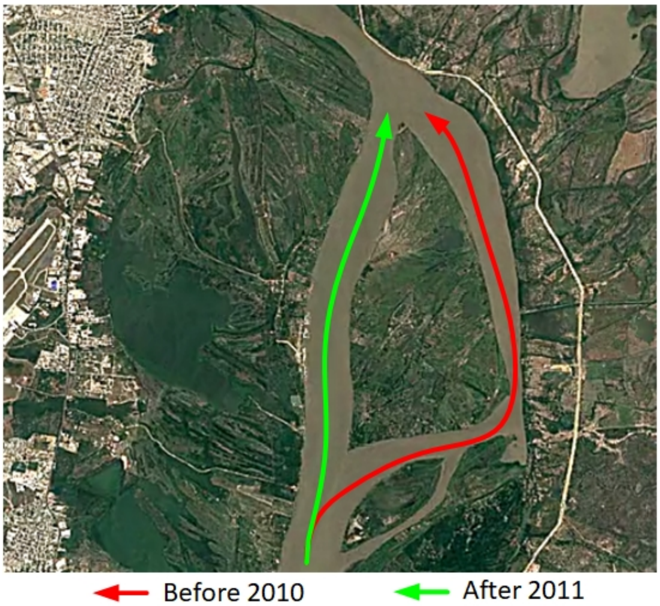


Figure 3.3: Change in the course of the main channel (K26-K34) (Manuel Alvarado Ortega, personal communication, 2 October, 2017; Earth Engine, 2017).

The occurrence of waves on the ebb shoal enhances the ability of the inlet to bypass sediments (Olabarrieta et al., 2014).

3.1.1. Secondary flow in river bends

Rivers exhibit meandering behaviour. River bends are inducing secondary flow, which is a cross-stream circulation (illustrated in Figure 3.4). This circulation is induced by a balance between the depth-varying centrifugal acceleration and a depth-invariant pressure term (de Vriend, 2008).

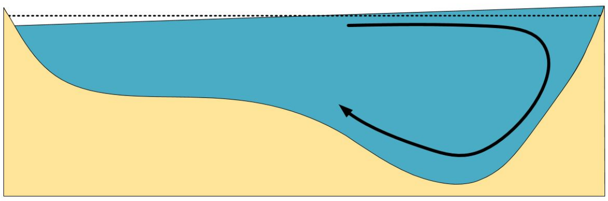


Figure 3.4: Direction of the curvature-induced secondary flow in the bend cross section.

For the purpose of this report, morphology in river bends is particularly interesting. The secondary flow results in a bed shear stress that is directed toward the inner bend. This encourages the tendency of the outer bend to erode and the inner bend to accrete. The balance between centrifugal force and pressure gradient results in (Ham, 2006):

$$\frac{u^2}{r} = g\frac{\delta\eta}{\delta r} \tag{3.1}$$

With:

$\delta\eta$	lateral water level difference [m]
u	velocity component tangential to a circular rotating flow at radius r [m/s]
δr	lateral change in radius [m]
g	gravitational acceleration $[\mathrm{m/s^2}]$
r	radius of curvature [m]

3.1.2. Salinity

In the mouth of the Magdalena river, Bocas de Ceniza, the fresh water meets the salty water of the Caribbean Sea. This creates a classic salt wedge that can propagate up to 20 km into the river during low flow (3000 m^3/s). Figure B.11 in Appendix B shows the salt intrusion in the access channel for a very low discharge (2200 m^3/s), as measured in January 2010.

Differences in salinity levels also influence the secondary circulation in the bend of the river at the mouth. The magnitude of the secondary circulation is larger due to the stratification, in which the lighter fresh water lies on top of the denser salt water from the Caribbean Sea. The result is upwelling of the more saline water at the inner bend and downwelling of fresh water at the outer bend (Lindhart et al., 2015). The river is fresh (0 ppt salinity) and the Caribbean Sea has an average salinity of 35 ppt near the coast of Colombia (Menzies, Robert James; Ogden, 2016).

3.2. Anthropogenic influences

The following anthropogenic influences are important in the processes related to erosion and sedimentation in the Magdalena river:

- **Deforestation:** Large scale changes regarding land use practices and exploitation of resources in the Magdalena river basin became evident in the 1970s and 1980s (Restrepo and Syvitski, 2006). These changes led to significant levels of deforestation, which is known to cause increased rates of soil erosion (Walling and Fang, 2003). Important drivers of deforestation are population growth and urbanisation (Geist and Lambin, 2001). The annual deforestation rate of 2.4%, based on measurements between 1990 and 1996 for the Magdalena basin is estimated to be among the highest of the world. (Sayer and Whitmore, 1991; CORMAGDALENA and IDEAM, 2001);
- **Agriculture:** Agriculture is a critical driver for the anthropogenic impact since it is important in the dynamics of landscape fragmentation (Tinker et al., 1996). Agriculture in tropical regions is responsible for 96% of the deforestation (Geist and Lambin, 2001);
- **Mining activities:** Mining may be less dominant than agriculture in terms of land-use changes, the participation of mining in Colombia's GDP has increased by 50% during the last 15 years (Restrepo et al., 2006a). Mining practices cause erosion and result in increased concentrations of suspended sediment;
- **Canal del Dique:** In 1650 the Spaniards wanted to make a connection from the Magdalena river to Cartagena. 93 km from the mouth they connected the existing lakes West of the Magdalena river with canals. The discharge in Canal del Dique is on average 550 m^3/s with extremes of 1100 m^3/s and 100 m^3/s. The sediment transport is estimated at $10 \cdot 10^{6}$ t/y. In the previous century and at the beginning of this century the channel had to be maintained by executing dredging works. Nowadays the channel needs $1.2 \cdot 10^{6}$ m^3/y of sediment (Ortega, 2008). Due to the extraction of water and sediment into Canal del Dique the sediment load and discharge in the Magdalena river decreased.

In the last century, humans have also intervened in the river itself, imposing major physical changes to the main discharge channel (Restrepo et al., 2015). To regulate the flow in the river, breakwaters and groynes have been built. A map of these human interventions in the river can be found in appendix C.

3.2.1. Breakwaters

The construction of breakwaters drastically changed the configuration of Bocas de Ceniza as can be seen in Figure A.1 in Appendix A. In 1936 both the western breakwater "Tajamar Occidental" ((1) in Figure C.1 and eastern breakwater "Tajamar Oriental" ((2) in Figure C.1 have been constructed. Due to the breakwaters, the main discharge channel of the river is isolated from the Ciénaga de Mallorquin. In 1949 and 1951, the breakwaters were expanded and extended to a total length of 7.4 km (Tajamar Occidental) and 1.4 km (Tajamar Oriental). The Tajamar structures are very controversial and sorted unexpected results. Furthermore, breakwaters deteriorate over time. It is essential to maintain and monitor the structures, otherwise these structure can fail suddenly. The lack of proper maintenance forms one of the reasons that the tip of the Tajamar Occidental collapsed in 1963 (Koopmans, 1971).

3.2.2. Groynes

Several groynes are constructed in order to obtain the desired cross-section alignment for navigation. An overview of the characteristics of these groynes can be found in Table 3.2.

Table 3.2: Overview of hydraulic structures at K0-K12 (1990-2010). The numbers between brackets correspond to the number in Appendix C.1. (Restrepo et al., 2015; Ortega, 2008; Visbal et al., 1995).

Sector	Name	Longitude [m]	Year of construction	Cost [USD]
Siape - Las Flores	Dique Direccional (9)	1200	1994	24,115,296
(Isla 1972)	Groyne 0 (8)	100	2006	1,962,403
	Groyne 1 (7)	207	2006	4,847,719
	Groyne 2 (6)	310	2007	5,797,607
	Groyne 3 (5)	265	2007	5,550,877
Exterior Curve (K4-K7)	Groyne 5 (-)	pending	pending	pending
	Groyne 7 (-)	pending	pending	pending
Bocas de Ceniza	Dique de Cierre (4)	670	2009	1,000,167
	Dique Guia	250	2009	13,037,538
	Groyne 6 (3)	230	2008	5,928,147

3.2.3. Bridge

In 1974, the Pumarejo bridge over the Magdalena river was built in Barranquilla. This bridge forms the connection N90 between Cartagena and Santa Marta. It is 1500 meter long and has a height of 16 meter. With the bridge located at the mouth of the river, this height is an obstruction for the navigation on the river (Otero, 2012). To improve the navigation, the new Pumarejo bridge is currently under construction and is expected to be finished in June 2018. This new bridge will have a span of 380 meters and a height of 45 meter (Pacheco and Magalhaes, 2015).

3.3. Sections of the Magdalena river

For reading convenience of this report, the river stretch under consideration is divided into five sections. Maps of the sections can be found in Appendix D. For each section, the main characteristics are indicated below.

- **Sector I: Bocas de Ceniza - Las Flores K0-8 (Figure D.2)**
  The first section is characterized by the river mouth and the surrounding breakwaters. Sediment bars occur at the entrance of the navigation channel.
- **Sector II: Las Flores - Dique Direccional K8-14 (Figure D.3)**
  In this section Isla 1972 can be found. After the construction of the Dique Direccional the configuration of Isla 1972 changed (Figure 3.5). Furthermore, discontinuities that are located between Groyne 0 and Groyne 1 hamper the navigation.

(a) 1988 (b) 1992 (c) 2016

Figure 3.5: Satellite images at K13 (1988-2016) (Earth Engine 2017).

- **Sector III: Dique Direccional - Puente Pumarejo K14-K22 (Figure D.4)**
  This area contains many port terminals. The section around the bridge deserves special attention.

Many stakeholders believe that the construction of the bridge enhances sedimentation in the access channel. This is also the sector where seagoing vessels are supposed to turn. What stands out in this section is the rapid development of Rondón Island (Figure A.4). This sector is the last river stretch that is accessible for marine vessels, cargo for the upstream area has to be transported by means of barges. Most ships turn in the area between K19 and K22, see Figure 3.6.

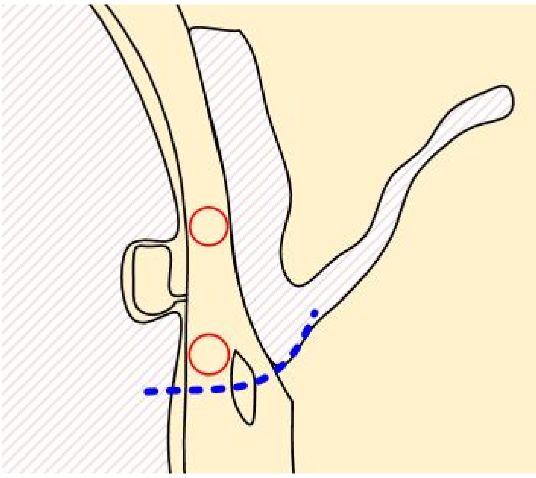


Figure 3.6: Areas where the majority of the ships turn, indicated with red circles. The blue dashed line indicates the location of the bridge.

- **Sector IV: Puente Pumarejo - Isla Cabica K22-K30 (Figure D.5)**
  The water depth in this section is lower than the previous sections. The development of this section is shown in Appendix A in Figure A.5. The navigation channel used to be in the eastern arm of the river. However, due to discharge distribution changes, the navigation channel moved to the western arm of the river.
- **Sector V: Isla Cabica - Pimsa K30-K38 (Figure D.6)**
  The last section that is analysed in this report ranges between Isla Cabica and Puerto Pimsa. In Pimsa, a station is located that regularly measures the water levels and discharges, which is one of the reasons why Puerto Pimsa is on the boundary of the area of interest.

3.4. Location of the problem areas

Based on bathymetry maps and conversations with local authorities and companies, 5 problem areas in the river are localised. The areas are listed below:

- K0 - Sand bar at the river mouth
- K7 - Sedimentation of the inner bend
- K11 - Sedimentation next to Isla 1972
- K14 - Sedimentation of inner bend, causing a small navigation channel
- K20 - Sedimentation at eastern side of the river, causing a small turning area

These locations are shown in more detailed maps in Appendix D and are further analysed in Chapter 8.

II

Stakeholders

4
Stakeholder analysis

A lot of different studies by many scholars have been conducted in which the importance of involvement of stakeholders in a project is argued. El-Gohary, Nora M.; Osman, Hesham; El-Diraby (2006) describe stakeholders as 'individuals or organisations that are either affected by or affect the development of the project'. Managing and involving these stakeholders is crucial for a successful project because when not managed carefully, conflicts can arise. By acknowledging the stakeholders and involving them when necessary, conflicts can be prevented (Olander and Landin, 2005; Bal et al., 2013). Therefore the stakeholders will be analysed in this chapter. First of all the stakeholders are identified and categorised whereafter the relations between the different stakeholders are illustrated in a network diagram. In section 4.2 the perception of the stakeholders with regard to the sedimentation problem in the port of Barranquilla is discussed. To conclude the stakeholders are categorised in a criticality table which will subsequently be used as input for the engagement plan in Chapter 10.

4.1. Introduction stakeholders

In this section the relevant stakeholders are identified. A more elaborate description of the stakeholders and stakeholder groups can be found in Appendix E. The information used to preform this stakeholder analysis is the result of both an elaborate literature study and interviews conducted with multiple stakeholders. More information about these interviews can also be found in Appendix E.

4.1.1. Stakeholder identification

In order to identify the most important stakeholders a complete list of all entities involved in the Magdalena river issue is given in Table 4.1. This table shows the general category to which stakeholders belong whereafter in the next column certain stakeholders are grouped. In the last column, the individual entities are mentioned. Some groups are not split up any further because this is unnecessary or impossible.

Table 4.1: Stakeholder identification and categorisation.

Category	Stakeholder group	Stakeholder specific
National Government	Ministry of Transport	ANI (National Infrastructure Agency)
		Invias (National Roads Institute)
	Ministry of Defence	Dimar (Harbour Master)
	Ministry of Environment and Sustainable Development	ANLA (National Environmental Licensing authority)(1)
	Cormagdalena	
	DNP (National Planning Department)	
Local/regional Government	Departments	Atlantico
		Magdalena
	Municipality of Barranquilla(2)	Baranquilla Verde(1) (Local Environmental Agency)
		Office of port affairs
	Other Municipalities(2)	Sitio Nuevo
		Palermo
NGO's	Asportuaria	
	Research Institutions	Observatory
Private companies	Dredging companies	
	Shipping companies	
	Private investors	
	Port Associations	Palermo Sociedad Portuaria S.A.
		Pizano S.A.
		Puerto Pimsa S.A.
		Sociedad Portuaria Bocas de Ceniza S.A.
		Sociedad Portuaria del Caribe S.A.
		Sociedad Portuaria del Norte
		Sociedad Portuaria Golfo de Morrosquillo S.A.
		Sociedad Portuaria Michellmar S.A.
		Sociedad Portuaria Monomeros Colombo Venezolanos S.A.
		Sociedad Portuaria Portmagdalena S.A.
		Sociedad Portuaria Riverport S.A.
		Sociedad Portuaria Siduport S.A.
		Sociedad Portuaria Sodintec
		Sociedad Portuaria Terminal de Mallorquin S.A.
		Sociedad Portuaria Terminal las Flores S.A.
		Vopak Colombia S.A.
Other	Citizens of Barranquilla	
	Users riverbank	Entities with concession riverbank
		Citizens illegally inhabiting riverbanks
	Nature preservationists	

(1) Combined in stakeholder group: Environmental Authorities.
(2) All municipalities are concerned as one stakeholder group due to their similar interests and perceptions.

4.1.2. Network diagram

When analysing stakeholders it is key to not only analyse the individual stakeholders and their relation to the problem owner, instead the whole network of stakeholders should be addressed. As argued by Rowley (1997), stakeholders interested in a particular problem are not only in a dyadic relationship with the problem owner, they operate in and are linked with other stakeholders as well through a social network. In order to illustrate such a stakeholder network, a network diagram is ideal. It shows the relevant relations between stakeholders, including what kind of relationships this pertains. Although most stakeholders are interconnected with the principal problem owner, other direct relations between the stakeholders are evident as well (Kivits, 2011). Note that not all stakeholders have to be directly connected to the problem owner.

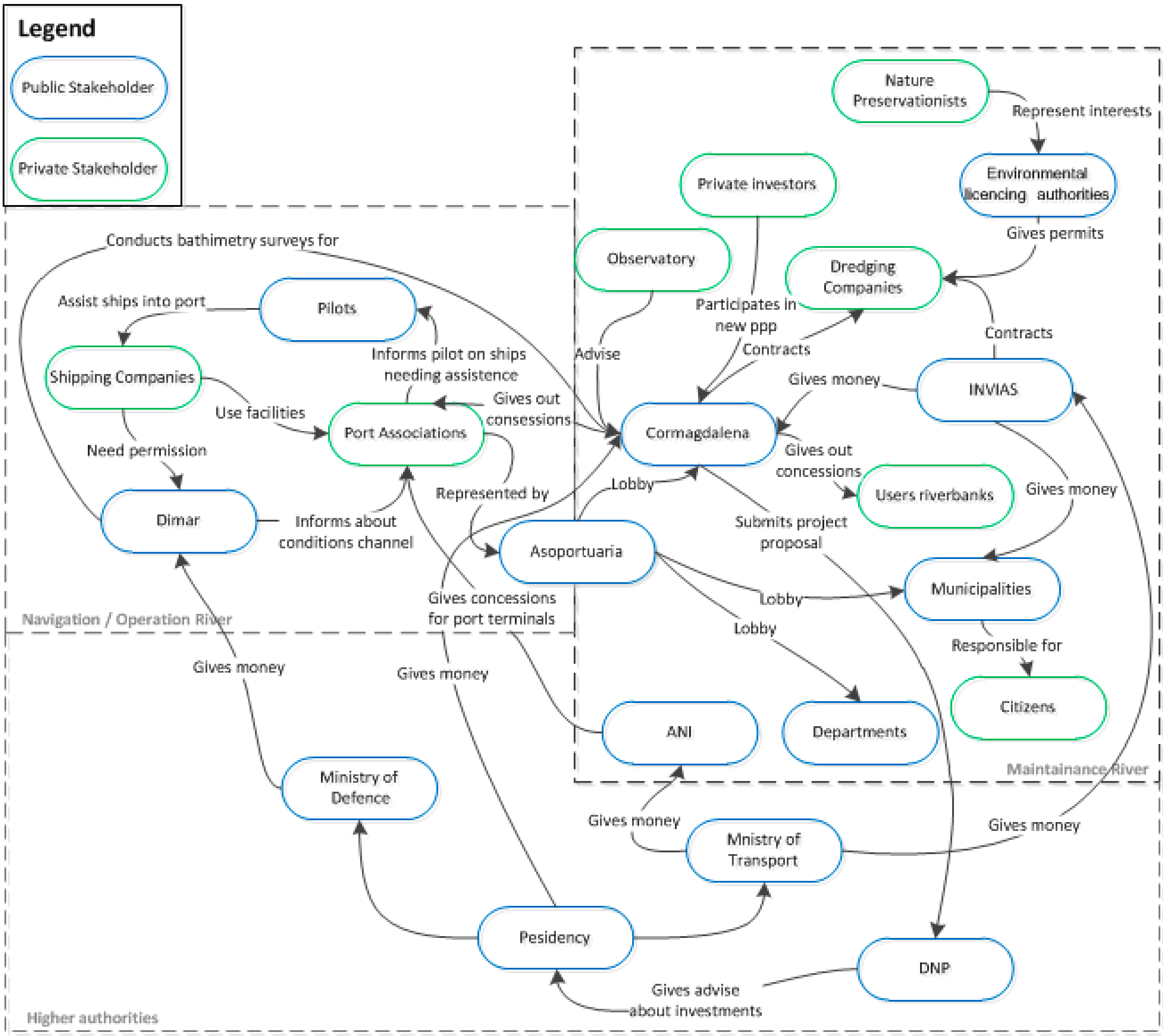


Figure 4.1: Network diagram.

As can be seen Figure 4.1, the network diagram is split into two subsections. One section concerns the maintenance of the river and the other is about the navigation on the river. Asoportuaria is situated in both sections because in representing the port associations it is both concerned with the navigation of the river and proper maintenance of the river. Therefore Asoportuaria can be seen as one of the important links between the different sections. Although the goal of this report is to advise the Observatory about the sedimentation problems the rest of this stakeholder analysis is conducted from the viewpoint of Asoportuaria. This is done because Observatorio del Río Magdalena does not have the means to involve different stakeholders while Asoportuaria is ideally located in the network to mediate between many different parties.

4.2. Problem perception of stakeholders

In the previous paragraph the stakeholders were introduced. Furthermore, their relations to each other were represented in a network diagram. In this paragraph, an analysis is conducted on the interests, perceptions and goals of the individual stakeholders with regard to the navigation problem in the port of Barranquilla. Additionally, an overview of the power and interests of the different stakeholders regarding this problem is given in a power-interest grid.

4.2.1. Interests, perceptions and goals

Table 4.2: Stakeholder interest, perception and goals.

Stakeholder	**Interest**	**Perception with regard to navigation issue**	**Goal in a future project**
ANI	Responsible for giving out concessions and working together with port associations to maintain the public port facilities. Also responsible for formulating and adapting infrastructure policies for roads, waterways and railways by working in public-private partnerships, however Magdalena River does not fall under their jurisdiction	If the Magdalena River would be more navigable this would be positive for the transportation infrastructure overall	Make the national transport infrastructure as attractive as possible including the navigability of waterways
Asoportuaria	Increase the prosperity of the port of Barranquilla in order to increase the overall economical activity by representing the port associations	The sedimentation problems threat the navigability of the port of Barranquilla for the larger vessels which is a problem for the competitiveness of the ports	Develop the port of Barranquilla to be the most competitive port in Colombia in collaboration with port associations, local and national government and other private parties
Citizens of Barranquilla	Live by the highest possible quality of life standards in which at least safety is guaranteed	Economical growth of the port will lead to more employment opportunities. On the other hand however the increase in industry might lead to a lower air quality and other negative external factors	Achieving economical growth of the port in a sustainable way without having to pay more taxes
Cormagdalena	The public authority in charge of: the recuperation of the river navigability and port activities, the sustainable management and protection of the environment of the Madgalena River	Currently Cormagdalena is struggling to maintain a certain depth of the entrance channel to the Barranquilla ports, this is a problem which needs to be fixed, preferably for a longer period	Reassure river navigation, transportation and port activity in Barranquilla and at the same time preserve the environment of the river and surrounding areas
Departments	Better infrastructure to facilitate productivity in industrial, agricultural and port sectors	Due to the navigation problem the port sector does not function optimally	Solve the sedimentation problems to create an environment for economic growth and make it possible to improve the quality of life of its inhabitants

Dimar	Regulates, authorises and controls activities related to the arrival, mooring, manoeuvring, anchoring, towing and departure of vessels and equipment into the port of Barranquilla and conducts bathymetry surveys	Large vessels are not able to enter the port, this is due to the depth of the river and the flow rate (including waves) of the water; action is required urgently in order to secure the possibility of vessels entering the ports	To strengthen the operational capabilities and to increase the satisfaction of the users of the river by solving the navigation problems
National Planning Department (DNP)	To give technical advise to the presidency and its other organs and prevent poor investments by the government	A possible project for the Magdalena River conducted by Cormagdalena has to be feasible and needs to be approved by the DNP in order to receive government funding	Only provide government funding if the project is realistic and feasible
Dredging companies	Dredging the port of Barranquilla is a source of income	The navigation depth issue creates demand for dredging, a possible solution for the problem might decrease this demand for dredging which is negative for the income of dredging companies	To still be involved in the dredging of the river where needed
Environmental licensing authorities	Provide the environmental permits needed for dredging or other river interventions	Permits for dredging and other activities will only be provided if environmental impacts are assessed and acceptable	Safeguarding the environmental friendliness and sustainability of the possible solution
Invias	To implement policies, strategies, plans, programs and infrastructure projects of the non-concessioned national transportation network including primary and tertiary roads, railways, inland waterways and other maritime infrastructure	The port of Barranquilla is not accessible for all vessels making the connection to other infrastructures not feasible	Join forces and coordinate necessary actions to develop a possible solution for the navigability issues of the access channel to the ports of Barranquilla
Municipalities	Develop the infrastructure in such a way that the accessibility and therefore the possibility for industry is maximised	The current navigation problem limits accessibility for larger vessels to the ports which reduces the industry in Barranquilla	Resolve the sedimentation problems so that the ports are better accessible
Nature preservationist	Ensuring the environment is not harmed by port activities and future developments of the ports	Extension of the industry should not have an effect on the environment, the national park Isla Salamanca should be protected, the noise and air pollution should not rise	Create awareness among important actors so no harm is done to the environment due to more industry in the port of Barranquilla

Observatory	Researching the Magdalena river in order to give insights into the technical characteristics, including the sedimentation transport	When more clarity into the transport of sediment is gained a possibly technical feasible solution might be found	Do useful research into sediment transport of the river in order to find a feasible solution for the sedimentation problem in the port of Barranquilla
Port associations	Creating income by providing logistics services to other companies	Due to the navigation problems income might be lost because larger vessels are not able to enter the channel to the ports	Work together with Asoportuaria to ensure navigability of the river and thereby ensuring profits
Private investors	Trying to make a profit by investing in projects wisely	The Magdalena river project might be an interesting project to invest in working together with the government	To invest in the project if it looks like a promising investment
Shipping companies	Prefer to go to the strategically most interesting port	Right now Barranquilla is lacking in competitiveness due to the limitations of depth, solving the depth problems will have a positive effect on competitiveness of the ports	make it possible to enter the port with large vessels
Users riverbanks	The riverbanks are important to their users and they want to preserve the current situation	Any changes regarding the river (constructions or displacement) might disrupt their business or homes	To protect the riverbanks in its current situation

4.2.2. Power and interest

Next to the interest, perception and goals of stakeholders on an issue, it is also important to consider the power stakeholders have. Therefore a power interest grid was constructed for the issue of the navigability of the port of Barranquilla. In a power versus interest grid, the different stakeholders are positioned on a two-by-two matrix. One dimension (horizontal axis) represents the interest of the stakeholder on the issue (low to high) and the other dimension (vertical axis) represents the power a stakeholder has to influence the issue (Bryson, 2004; Enserink et al., 2010).

The result of the power interest grid is that the stakeholders are divided into 4 groups: crowd, subjects, context setters and players. Each group should be dealt with in a specific way, if done successfully this will help to work to a solution for the issue at hand (Bryson, 2004). More information on how to deal with each group can be found in E.

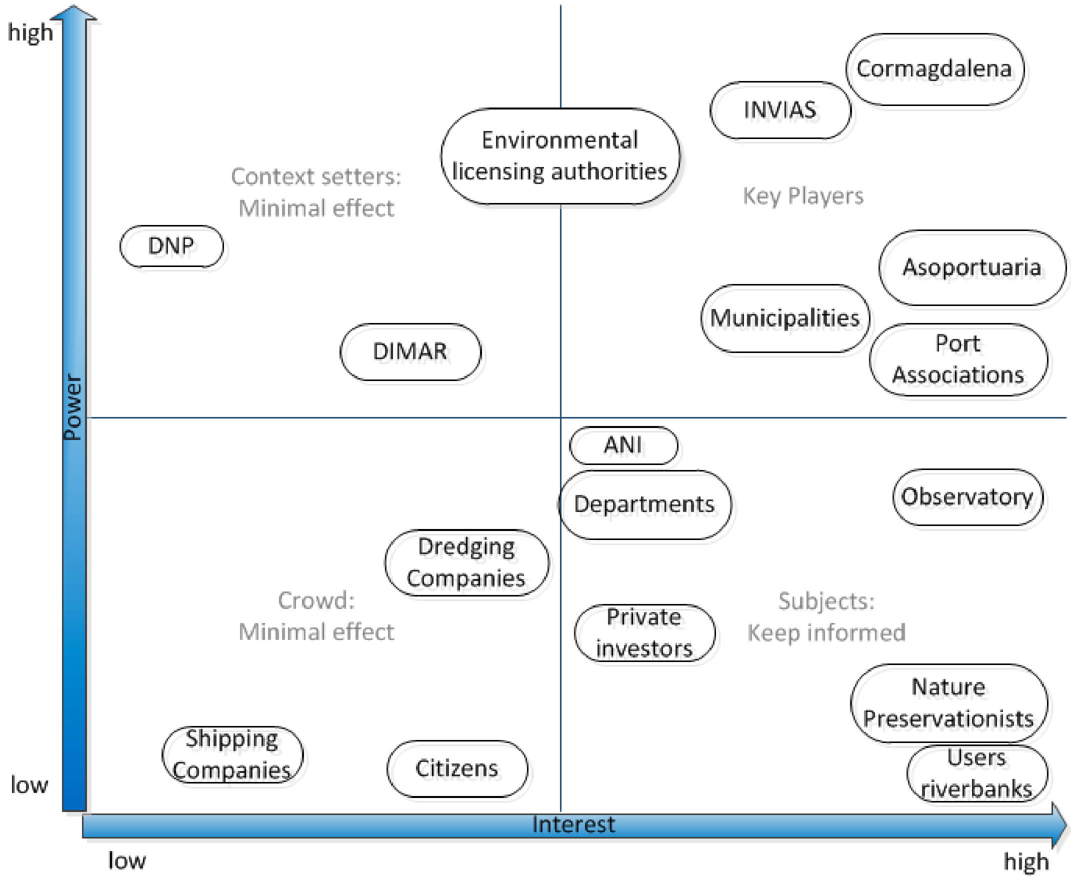


Figure 4.2: Power-interest grid.

4.3. Critical stakeholders

The aforementioned stakeholders all have an interest in the issue of the navigation of the port of Barranquilla. However, for the problem owner, Asoportuaria, it is not only important to know which stakeholders are interested in the problem, it is even more important to know whether these stakeholders are critical to solving the problem. A stakeholder can be identified as critical when they either dispose of a really important resource, they are non-replaceable or the overall dependency on this stakeholder is high (Enserink et al., 2010).
Besides the distinction between critical and non-critical stakeholders, Table 4.3 also categorises whether a stakeholder is dedicated to the problem or not. When a stakeholder is dedicated this means that they are willing to actively participate and where necessary use their resources in the project (Enserink et al., 2010). The other distinction which is made in Table 4.3 is whether stakeholders have comparable to or conflicting with interests and objectives from the point of view of Asoportuaria.

Table 4.3: Criticality table.

	Dedicated stakeholders		**Non-dedicated stakeholders**	
	Critical stakeholders	Non-critical stakeholders	Critical stakeholders	Non-critical stakeholders
Similar supportive interest and objectives	DIMAR Invias Port associations	ANI Municipalities Observatory Uninorte Private investors	DNP	Departments Shipping comp.
Conflicting interests and objectives	Cormagdalena Dredging comp. Users river banks	Citizens Nature preservationists	Environmental licensing authorities	

This table can be a very useful tool in assessing which stakeholders should be involved at what point in time. More information on the expected behaviour of different categories of stakeholders can be found in Appendix E.

4.4. Conclusion

The main conclusion which can be drawn from this chapter is that there are a lot of different parties involved in the navigability problem in the port of Barranquilla. This is partly due to the wide division of responsibilities. The most important stakeholders are taken out of the power interest grid in the upper right quadrant with the highest power and interest. Cormagdalena, INVIAS, Municipalities, Asoportuaria, Port Associations, Municipalities and the departments can be distinguished as the main stakeholders in the project. They all have a high degree of power and interest.
Furthermore, all stakeholders want to reach the same goal at the end; improve the navigability of the access channel of Barranquilla. Only the intentions in reaching this goal differ per stakeholder. That is also why attention has to paid to the dredging companies and the nature preservationists. The main interest of the dredging companies is to make money by dredging. If the solution won't have a dredging part in it, they might won't collaborate. Also, the interests and objectives of the nature preservationists are not similar to the interests of Asoportuaria. They want to preserve the nature. If the final solution will harm nature they will start lobbying by ANLA and Barranquilla Verde, the environmental licensing authorities, not to give the permits. This may give tensions between the stakeholders and results in an impaired implementation of a project.

5
Managing public-private partnerships

5.1. Public-Private Partnerships

Public private partnerships (hereafter abbreviated to PPP) have a long history, one commonly used example of a first form of PPP dates back to 1854 when the construction of the Suez Canal was concessioned (El-Gohary, Nora M.; Osman, Hesham; El-Diraby, 2006). The concession included the construction and operation of the Suez canal. Since then a lot of PPP projects have been executed, some being far more successful than others and the variation of forms being endless. When conducting a literature study on PPP's it can be concluded that the concept PPP is often not well defined causing confusion between the different forms of partnerships. Therefore a description about what a PPP is and which form is considered in this report will be given below.

Actors involved in a PPP

The basic idea of a PPP is already in its name. It is about a partnership between the public and private sector utilising the best of both sectors. The body presenting the public sector can originate from a wide variation of organisations reaching from national to local government or even autonomous public agencies. This representation depends on the scale of a project and the governmental settings of a country. In general however, the public entities involved in a PPP should safeguard the public interest. As for the representation of the private sector a wide variation exists as well, often these organisations are characterised by their market focus, creativity and efficiency. Next to these public and private parties some scholars have argued that a successful PPP should also include other stakeholders which can be labelled as 'civil society'. The civil society would consist of actors such as non-governmental organisations (NGO), community organisations and other nonprofit organisations (Bovaird, 2004; Mitchell-Weaver and Manning, 1991; Savas, 2000). In this report the involvement of these civil societies next to the public and private sector will be assumed.
Moreover PPP's could be introduced in networks of actors. An essential reason to establish a PPP in such a network would be when the interaction will result in a better and more efficient result then when conducted by a single actor (Kooiman, 1993). As to which specific actors in this network should be included, depends on both their criticality as discussed in 4 and early involvement in the process.

Setup of PPP

Over the past three decades large infrastructure projects have been characterised by a wide range of different PPP's arrangements. A few examples of the most common are: build-operate-transfer (BOT), build-transfer-operate (BTO), design-build-finance-operate (DBFO), design-build (DB) and design-build operate-maintain (DBOM) (Zhang and M. Kumaraswamy, 2001). The BOT and BTO concession projects are most commonly used in road projects followed by the DB/DBOM arrangements (Abdel Aziz, 2007). Although these contractual arrangements do tell a lot about the setup of a PPP what several PPP's fail to take into account is the partnership and cooperation necessary to make a PPP successful. Often the public organisation involved predefines the project design in such detail that the innovative and creative characteristics of the private parties and civil societies are not utilised. Subsequently resulting in the fact that the PPP's have a lot in common with normal contracting out, conducted by a public body (van Ham and Koppenjan, 2001). In order to truly capture the essence of a cooperational PPP, which many authors have described (El-Gohary, Nora M.; Osman, Hesham; El-Diraby, 2006; Mitchell-Weaver and Manning, 1991; Winpenny, 1987; Klijn and Teisman, 2005; van Ham and Koppenjan, 2001) , early stakeholder involvement is crucial. This early stakeholder involvement can be managed by the use of process management. As will be discussed in the next paragraph process management is one of the success factors in the formation process of a PPP.

5.2. Analysis of previous PPP

5.2.1. Description of the Navelena PPP

At the start of 2012, Cormagdalena expressed their interest to set up program they would call: the Magdalena River Navigability Recovery project (Zambrano, 2017). The objective of such a project would be to restore the Magdalena River as an important link in the multimodal inland transportation network. In May 2013, Cormagdalena initially pre-qualified three consortia (Watkins, 2014):

- Navegena Magdalena: Acciona, Jan de Nul and Castro Tcherassi;
- Desarollo Rio Magdalena: Iridium, Van Oord, RM Holding and Juneau Business;
- PSF Navelena: Odebrecht and Valorcon.

On 15th September 2013, the tender was officially awarded to PSF Navelena. A contract was signed describing a 13,5 year project in which the Magdalena River would be dredged 908 km between Puerto Salgar-La Dorada and Barranquilla to a Fminimum of 2 meters depth. This would enable the transport convoys of six barges. Furthermore the project would be structured as a PPP (Lagorio, 2014).
Originally, the project planning was to have a pre-construction phase in which the finance was finalised and designs were approved, followed by the start of construction. From June 2015 onward, Navelena had the legal permission to access the river to conduct bathymetric surveys and maintain the depth by dredging in especially the mouth of the river. While from March 2016 onward, the channelling and construction phase of the project would start. The positive vibe of the project came however to a sudden end when in March 2016 the corruption scandals of the Brazil construction firm Odebrecht, who had a 87% stake in the Navelena consortium, were revealed. Although not directly involved in the corruption scandals the impact on the Magdalena Navigability Recovery project were still significant. The financial closure which had to be delivered before June 2016 was never reached due to the bad light Odebrecht was in.
This was not only a huge setback for everyone involved in the project, it also brought some serious problems to the table. As the contract with Navelena was still legally binding no other company was allowed to dredge the entrance channel to the ports of Barranquilla. This led to accumulation of sediment, limiting the navigable depth greatly. Navelena received fines for this but since it was already in great trouble this did not help in solving the problem. It was only on March 24 that Cormagdalena decided to void the contract with Navelena after the various attempts of Navelena to come up with financial closure.
From that point on there have been several news updates that a new PPP would be tendered as soon as possible. However, currently (October 2017) still no final tender documents have been published by Cormagdalena. In order to deal with the serious sediment problems in the access channel of Barranquilla, a contract for the dredging till December 2017 was established.

A timeline of the aforementioned events is illustrated in Figure 5.1, based on articles from El Heraldo.

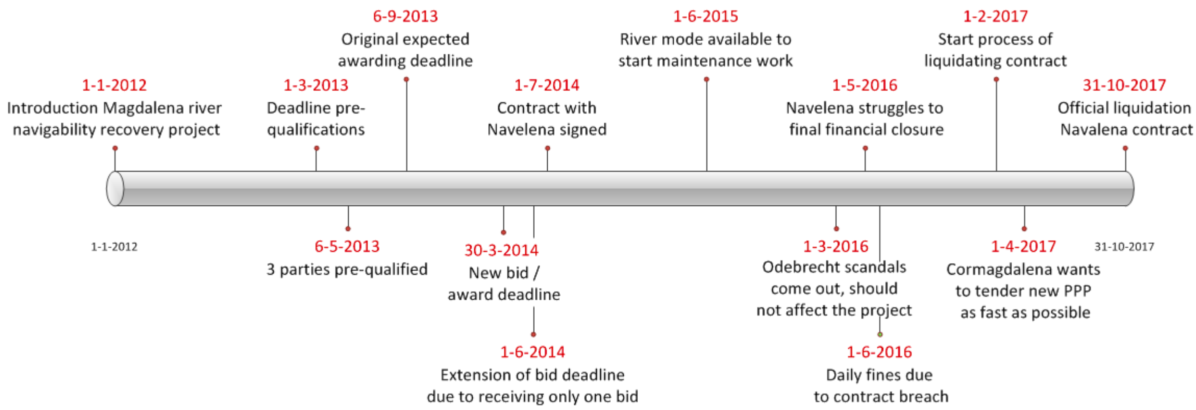


Figure 5.1: Timeline Navelena PPP.

5.2.2. Lessons learned from Navelena contract

Feasibility project

One of the main reasons why the other two consortia chose to withdraw the bid was because of the feasibility of the project. The risk due to the technical complexity of the works was too high compared to the benefits they would receive. The question is if Cormagdalena should really have pushed through the establishment of the PPP when the more experienced companies withdrew for this reason. Although Odebrecht is a big player in the construction industry, their experience in dredging was limited. Whereas the other consortia both included specialised dredging companies. It would have been better to look together with the dredging companies at the possibilities to make the project more feasible for all parties.

Political commitment

As the initiating partner, Cormagdalena was of course committed to the project. Since it is not an elected government body this commitment is a good start in the creation of trust. However, Cormagdalena is dependent on resources from other government entities such as the Invias, Ministry of Transport and directly from the Presidency.
Furthermore, the director of Cormagdalena shared his opinion about the fact that the previous PPP was focused to much on dredging and he wants to make sure that the next PPP will include sustainable structures which will limit the need for dredging (personal communication, 5 October 2017). Long-term vision is an important criterion in designing a large PPP like the river recovery one. However, not only long-term vision when designing a PPP is important, it is also important for the government to have a long-term integrated infrastructural strategy. As Roelofs (2013) argues; currently the governmental parties only assess private initiatives while not looking at the bigger picture for the entire infrastructure network. Especially in Colombia, where the power to establish large projects is divided among several public entities (for example ANI, Invias and Cormagdalena), this can lead to mismatches in projects. Ultimately a master plan should be established and on the basis of this master plan it should be assessed whether or not a project fits the long-term strategy of the country.

Opportunities in a project

The river recovery project could be seen as a very promising project. If the navigability of the river will be improved, the freight transportation over the river will increase as well. The seaports of Cartagena and Barranquilla can function as transshipment ports for further inland transportation. In this way the entire multimodal transportation sector of Colombia will be given a boost. Therefore, many stakeholders are interested in the project and are willing to participate and invest. So the available opportunities in the project was not one of the reasons the last project failed.

Intensive collaboration

The Navelena PPP was awarded in an classical hierarchical way through a tender procedure. Cormagdalena designed, with consultation of some of the stakeholders, the tender. The collaboration was not close in the designing of the contract. Which again illustrates the hierarchical character of the previous PPP.

Process management

As mentioned in the previous section no real collaboration was formed in the previous PPP. Hence, no process management was conducted.

Legal arrangements

In 2012 law 1508 was established in which the legal framework of 'APPs - Asociaciones Público Privadas' is presented. It states that when a public entity wants to establish a PPP, this should be justified on the following five subjects: strategic, economic, financial, commercial and managerial. When the PPP form of contracting is approved by the ministry of finance and the department of national planning (DNP), the public entity can either pre-qualify two to ten private parties or have an open bidding procedure. Another option is the initiation of a PPP by a private party, which entails more elaborate procedures. The legal arrangements established in the Navelena PPP were in accordance with this law for the public initiative of PPP's. This law is however focused on contracting a private party instead of including several stakeholders already in an early phase.

5.3. Cultural factors

The research of Koppenjan (2003) was conducted in The Netherlands, analysing nine different PPP projects. However, one can identify many cultural differences between the Netherlands and Colombia. In this paragraph firstly these cultural differences are discussed by using the 6-dimensions methodology created by Hofstede (Hofstede, 2011). Then, the implication of this differences on the application of the success factors (Koppenjan, 2003) is considered. These implications are derived through logic and theory and have not been verified by a study.

5.3.1. Cultural comparison: The Netherlands and Colombia

In this section, Colombia and The Netherlands will be compared on the six cultural dimensions by Hofstede (2011). The dimensions and the scores of the countries on these dimensions are shown in Figure 5.2. Hereafter an elaboration on the scores on these dimensions will be given.

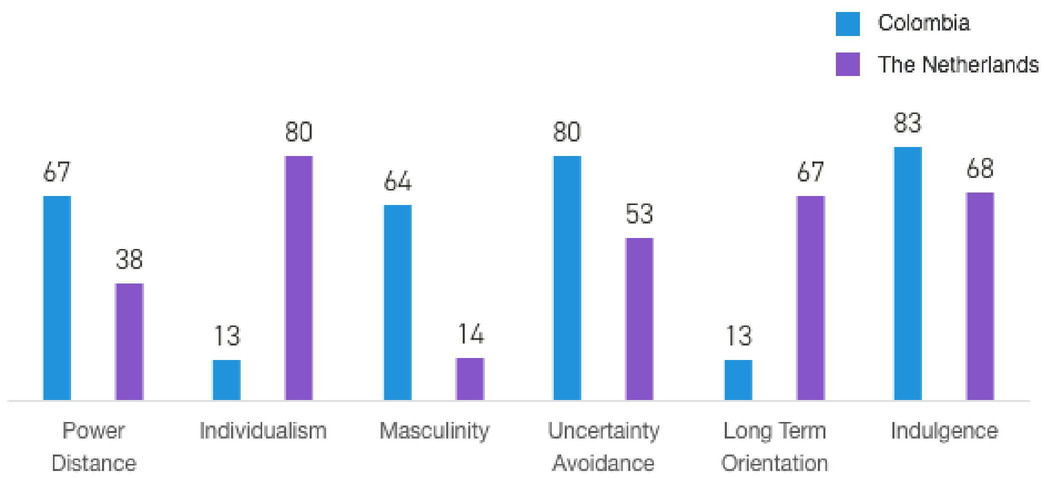


Figure 5.2: Cultural comparison on Hofstede's 6-dimensions.

Power distance

The dimension power distance relates to the level of acceptance of unequal division of power. As can be seen in Figure 5.2 Colombia scores 67 on the index from 0 to 100, whereas the Netherlands scores 38. It is important to note that this dimension not only represents the level of inequality in a country, it is also about the acceptance and expectation of this inequality. So whereas Colombia is much more accepting the inequality over all layers of the society, in the Netherlands they try to limit this inequality. Countries with a high power distance score are often also more sensitive to corruption and scandals are easier covered up.

Individualism vs collectivism

If the scores of individualism are compared, The Netherlands scores a lot higher namely 80 in comparison to 13 for Colombia. Colombia thus can be characterised as a collectivist society. If viewed globally Colombia is number 4 in most collectivist cultures. This means that people's self-image is largely defined in terms of 'We' instead of 'I'. People belong to in-groups that take care of them in exchange for unquestioned loyalty. In combination with a high score on aforementioned power distance, groups often have strong identities tied to class distinctions. In individualistic societies, people are more supposed to look after themselves and their direct family only. Also the employer-employee relationship is in The Netherlands a contract based on mutual advantage.

Masculinity vs femininity

The next dimension is the masculinity vs femininity index. A high score indicates a masculine society which will be driven by competition, achievement and success. This value system already starts in school and continues afterwards. Colombia with its index of 64 is a masculine society. This means highly success oriented and driven but in combination with the high score on collectivism, this competition is directed towards members of other groups. Also they often sacrifice leisure for work, but only if this is supported by their own group members and by people with power. A low rate, on the other hand, points towards a feminine society where caring for others and quality of life are important. The sign of success is equal to showing a high quality of life. This is also what is seen in the Netherlands, with a score of 14 on masculinity, it is important to keep the life/work balance and if there is a conflict, managers will negotiate to come to a compromise, this can lead to long discussions. Also people are valued equally, there is less hierarchy than in Colombia. In short the difference between masculinity and femininity can be summarised by what motivates people. If that is being the best, it indicates masculinity. Whereas it is more important that you like what you do in feminine societies.

Uncertainty avoidance
The score on uncertainty avoidance reflects the extent to which members of a culture feel threatened by ambiguous or unknown situations and till what extent they have created beliefs and institutions that try to avoid these situations. Colombia scores 80 on uncertainty avoidance. This is quite high meaning that as a nation Colombia attempts to find mechanisms to avoid ambiguity. There are rules for everything, but they are not necessarily followed. This depends on the position of the group. Whether or not rules are applicable to the members depends on the decision of the power holders. In combination with the earlier mentioned dimensions it is hard to change the status quo in Colombia. It is possible, but then a figure of authority has to stand up and lead a large group of people towards change. The Netherlands is less uncertainty avoiding with a score of 53. There are rules, but people are also open for negotiation. In those cultures there is an emotional need for rules, because time is money and people are mostly busy and work hard whereby precision and punctuality are the norm. Furthermore security an important element in individual motivation.

Long-term vs short-term orientation
Long-term orientation describes how societies maintain links with its own past while dealing with the challenges of the present and future. Normative societies, such as Colombia with a score of 13, show great respect for traditions and view social change with suspicion. In addition, they also have a relatively small propensity to save for the future, and their focus is on achieving quick results. This is relatively low in comparison to The Netherlands with a score of 67. Dutch people have a tendency to save and invest. Also for the achievement of results, agility and perseverance are attributes that are associated with more pragmatic societies (long-term oriented societies). They also encourage thrift and efforts in education as a way to prepare for the future.

Indulgence vs restraint
The last dimension mentioned by Hofstede is indulgence and is defined as 'the extent to which people try to control their desires and impulses'. If there is weak control of desires and impulses societies are called indulgence and a relatively strong control is called restraint. Both countries, Colombia with 83 and The Netherlands with 68, score relatively high on indulgence. This means both societies have a willingness to realise their impulses and desires and thus enjoying life and having fun. They also have a positive attitude and a tendency towards optimism. Although both countries share those characteristics for Colombia it is more evident because of the combination with a lower score on the long-term orientation dimension.

5.3.2. Implications for success factors of PPP's in Colombia

Corruption
Colombia is a high power distance country. This in combination with the high level of collectivism makes corruption more likely. Obliviously corruption is an important factor in the establishment of a PPP. It important that no stakeholders are excluded. However, in a collectivist society people tend to do business only with people belonging to the same in-group. During the interviews conducted in this research it was brought to the attention that several stakeholders (including governmental ones) do exhibit this kind of behaviour. Therefore it is very important that the process is very open and transparent.

Political stability
On the cultural dimension long-term orientation Colombia scores relatively low compared to the Netherlands. Therefore the success factor of political commitment might have a different influence on the formation process of a PPP than expected. Political commitment is in general a sensitive issue due to the turbulent political history of Colombia. Although currently they are trying really hard to abandon this image, especially for international companies this might still be an issue. Therefore it is even more important that the involved governmental entities demonstrate strong political commitment to making the project successful.

Openness for change
As the high score on uncertainty avoidance suggests generally the Colombian culture likes to avoid ambiguity. An important observation which was made during several interviews is that no one of the stakeholders really wants to, dares to or is able to take responsibility and do something about the problems in the river. This partly has to do with the many rules and regulations set up by the government. But also the party who will take responsibility stands for a big challenge and automatically also a lot of ambiguity will be involved.

5.4. Conclusion

In this chapter the PPP contract between Cormagdalena and the consortium Navelena is analysed. To do so the research by (Koppenjan, 2003) was used as a starting point. In this research Koppenjan identified six success factors for the set up of a PPP by analysing case studies in the Netherlands. Since the Navelena PPP was taking place in Colombia, a cultural comparison between the Netherlands and Colombia was conducted. This cultural comparison in combination with the empirical data about the PPP, gained through interviews with several stakeholders, let to a few important conclusions with regard to possible success factors in the formation process of a PPP in Colombia.

III

Model

6

Model set-up and calibration

An extensive data analysis preceded the model set-up and calibration. This analysis can be found in Appendix B.

6.1. Overview model methodology

To be able to investigate a wide range of scenarios, several Delft3D models are set-up, that differ in the type of vertical layering. For 3D models, two types of vertical grid layering are available in Delft3D, viz. Z-layers and σ-layers. In a σ-grid, the number of layers is constant over the entire horizontal domain and each layer covers a fixed percentage of the water depth, as defined by the user. Figure 6.2 shows the σ-grid that is used in this research. A drawback of this grid type is its poor performance for problems where stratified flow occurs in combination with steep topography. The estuarine area investigated in this research is exactly of this kind. Furthermore, it is expected that salt intrusion has a significant effect on sedimentation in the river mouth (Wright, 1977). Therefore, the σ-grid is not deemed to be suitable for scenarios in which salinity intrudes far into the river (see Section 3.1.2 and Section 6.5.2).

For these purposes, a Z-grid is more appropriate. This grid type uses a fixed thickness of each layer; the number of active layers varies with the depth. The grid has horizontal coordinate lines that are (nearly) parallel with density interfaces in regions with steep bottom slopes. This is important to reduce artificial mixing of scalar properties such as salinity and temperature (Deltares, 2014a). Figure 6.4 shows the Z-grid as constructed for this research. However, in the version of Delft3D that is used for this research (4.01.00), a Z-grid cannot be used in combination with morphology. Therefore, it is decided to set up both grid types, and use the most appropriate one for each specific scenario.

The model that uses the σ-grid includes waves, wind, tides and salinity in combination with sediment transport and thus covers all important processes. The model with Z-layers includes wind, tides and salinity, but not waves and sediment transport. This model is particularly of use to simulate the salt intrusion into the river. In order to predict the effect of the salt intrusion on the morphology, the Z-layer model is compared with a 2DH model that includes wind, tides, waves and sediment transport, but not salinity. By looking at the vertical velocity profiles as simulated with the Z-layer model and comparing them to critical velocities for sediment transport, that can be deduced from the 2DH model, the effect of salt intrusion on sedimentation can be predicted. An overview of the three models and the processes that are included is given in Table 6.1.

Table 6.1: Overview of models used in this research and the processes they include.

Process	2DH-model	Z-model	σ-model
Tides	✓	✓	✓
Wind	✓	✓	✓
Waves			✓
Salinity		✓	✓
Morphology	✓		✓

6.2. Set-up FLOW-module σ-layers

6.2.1. Grid

The horizontal grid as shown in Figure 6.1 is a curvilinear grid, covering the first 38 km of the river and an area of approximately 35×55 km of the ocean. The latter part is needed in order to be able to let wind and tides propagate into the domain from the boundaries. The grid is divided into 12,694 cells, having 447 cells in the m-direction (~N-S oriented) and 98 cells in the n-direction (~E-W oriented). The cell size varies from approximately 80×30 m at Bocas de Ceniza to 1.8×1.1 km at the ocean-side corners of the grid.

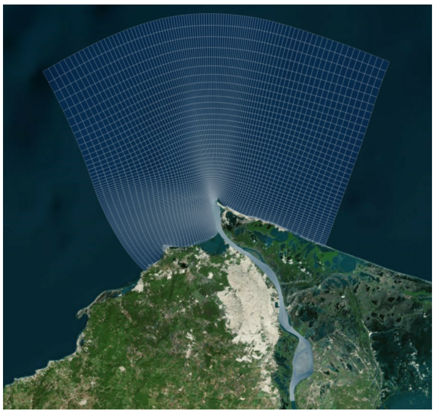


Figure 6.1: The flow grid imposed on a satellite image (Bing Aerial, 2017).

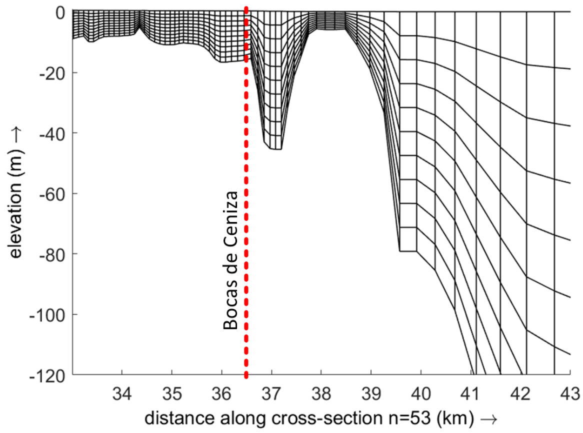


Figure 6.2: Vertical grid of the σ-model.

The vertical grid (Figure 6.2) consists of 10 equidistant layers.

6.2.2. Bed topography

The bed topography that is used in the FLOW-module is a combination from a bathymetric survey from April 2012 and linear water level interpolation between the mouth and Tebsa and Tebsa and Pimsa. The marine bathymetry is based on the GEBCO 08 dataset, as was explained in Section B.2. Using older data for the offshore part of the model is justified because the bar and the canyon in front of the mouth are included and the time scale on which these change is very large compared to changes in the river bed.

6.2.3. Boundary conditions

Boundary conditions are needed at the upstream river boundary and the downstream ocean boundaries. Both for the flow and the transport of salt and sediment, boundary conditions must be prescribed.

Flow conditions

At the upstream river boundary, the inflow of water is prescribed in terms of discharges. Discharge time series are determined according to the methodology described in Section B.1.1.
Water levels are prescribed relative to mean sea level (Spanish: msnm, metros sobre el nivel del mar). At the downstream ocean boundaries, water levels are set equal to mean sea level, with tidal variations superimposed. The tidal boundary conditions are taken directly from the research by Lindhart et al. (2015). For the method used to derive these boundary conditions, one is referred to the report by Lindhart.

Transport conditions

At the upstream boundary, a salinity of 0 ppt is prescribed, as there is inflow of fresh water. The salinity at the downstream boundary is set to 35 ppt (parts per thousand). At the downstream boundary, the sediment concentration is set to 0 kg/m^3. At the upstream boundary, use is made of the option in Delft3D-FLOW to specify the equilibrium sand concentration profile at inflow boundaries. The model calculates this profile on the basis of the characteristics of the prescribed sediment fractions and the local flow conditions. This means that the sediment load entering through the boundaries will be near-perfectly adapted to the local flow conditions, such that very little accretion or erosion should be experienced near the model boundaries (Deltares, 2014a).

6.2.4. Model parameters

- For sediment transport, the relation by Engelund-Hansen (Engelund and Hansen, 1967) is used with a calibration coefficient of $\alpha = 0.5$.
- The bottom roughness is defined by means of the Manning coefficient and is set to $n = 0.030$ $\left[\mathrm{s/m^{1/3}}\right]$.
- One sand fraction has been defined to schematise the sediment. The fraction has a specific density of $\rho_s = 2650$ kg/m^3 and a D_{50} of 200 μm, which is in accordance with the data described in Section B.6.
- To speed up the calculation, a morphological scale factor of 20 is used, which means that the speed of

morphological changes is multiplied with a factor 20. This is justified because morphological developments take place on a much larger time scale than typical flow changes (Deltares, 2014a).

- Wind is included in the simulation with a time series of wind speeds and directions at 3-hour intervals, see Section B.4.

Other physical parameters are specified in Table 6.2, whereas the numerical parameters are listed in Table 6.3.

Table 6.2: Physical parameters used in the FLOW-module of the σ-model.

Physical parameters	**value**	**unit**
Water density	1025	kg/m^3
Horizontal eddy viscosity	1	m^2/s
Horizontal eddy diffusivity	10	m^2/s
Model for 3D turbulence	k-ϵ	
Sediment & morphology		
Reference density for hindered settling	1600	kg/m^3
Dry bed density	1600	kg/m^3
Initial sediment layer thickness at bed	5	m
Spin-up interval before morphological changes	7200	min

Table 6.3: Numerical parameters used in the FLOW-module of the σ-model.

Numerical parameters	**value**	**unit**
Time step	0.5	min
Drying and flooding check at	Grid cell centres and faces	
Depth at grid cell faces	Mor	
Threshold depth	0.1	m
Marginal depth	-999	m
Smoothing time	60	min
Advection scheme for momentum	Cyclic	
Advection scheme for transport	Cyclic	
Forester filter (horizontal)	✓	
Forester filter (vertical)	✓	
Correction for σ-coordinates	✓	

6.3. Set-up WAVE-module

To simulate the evolution of waves travelling into the flow domain, the separate Delft3D-WAVE module was used. This module consists of the third-generation SWAN model. SWAN uses the wave action balance to calculate the evolution of the wave spectrum and is fully spectral (in all directions and frequencies) (Deltares, 2014b).

An online coupling between the WAVE and FLOW module was used, to account for both the effect of waves on current and the effect of flow on waves. The coupling interval was set to 480 minutes (every 8 hours). Both wave grids use the water level, wind and current results of the flow module, but these results are not extended outside the flow domain.

6.3.1. Grids

To correctly represent the propagation of deep water waves into the coastal zone, two wave grids were constructed (see Figure 6.3). The first grid covers an area of about 65×55 km of the Caribbean sea and has 144 cells in both M- and N-direction. The average cell size is about 500×300 m. The second grid is nested in the first grid and consists of a 13×13 km large part of the grid that is used in the FLOW module. The nested grid has 77 cells in M-direction and 63 cells in N-directions. Cell sizes are about 150×300 m, the smallest being approximately 80×30 m.

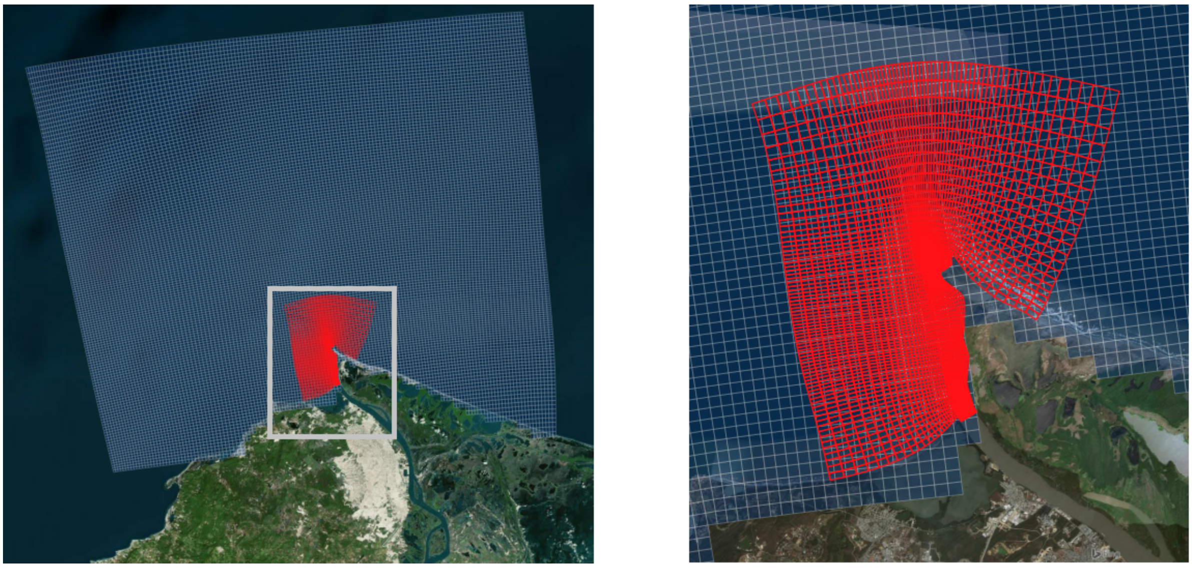


Figure 6.3: The wave grids imposed on a satellite image (Bing Aerial, 2017). The right figure shows the nested wave grid, marked by the grey frame in the left figure, in more detail.

6.3.2. Bed topography

The bed topography of the coarse wave grid is taken from a 2009 survey, whereas the nested grid uses the bed topography of April 2012. As the model simulations are carried out for the year 2012, the 2009 topography represents the situation less accurately. However, this does not introduce large errors in the results, as most of the coarse wave grid is situated in deep water. Wave transform mainly in the shallow coastal area, which is again correctly represented by the nested grid near the mouth. The bed features in the coastal zone outside the nested grid have changed to such a low degree between 2009 and 2012 that errors can be assumed insignificant.

6.3.3. Boundary conditions

Waves are imposed on the northern and eastern boundary of the coarse wave domain. The waves are uniform and specified with the parameters as indicated in Table 6.4. These parameters follow from the wave buoy data analysis as described in B.3.

Table 6.4: Wave boundary conditions.

Parameter	value	unit
Significant wave height H_{m0}	2.2	m
Peak period T_p	6.7	s
Direction (nautical)	60	deg
Directional spreading (cosine power)	4	-
Spectral shape	JONSWAP	-
Peak enhancement factor	3.3	-

6.3.4. Obstacles

Both breakwaters (Tajamar Occidental and Tajamar Oriental, see Section 3.2) are included as sheet type obstacles in the wave simulation. Wave reflections are defined as diffuse. The wave reflection coefficient was calculated according to the formula by Zanuttigh and van der Meer (2006), valid for rock impermeable slopes:

$$K_r = \tanh\left(0.14 \cdot \xi_0^{0.90}\right) \tag{6.1}$$

Where:

$$\xi_0 = \frac{\tan\alpha}{\sqrt{\left(2\pi H_{m0}\right) / \left(g T_{m-1,0}^2\right)}} \tag{6.2}$$

And, for single-peak spectra, as is the case here:

$$T_{m-1,0} = T_p/1.1 \tag{6.3}$$

With:

ξ_0	Iribarren parameter
α	slope angle
H_{m0}	significant wave height [m]
g	gravitational acceleration [m/s^2]
$T_{m-1,0}$	spectral wave period [s]
T_p	peak period [s]

Using the values for T_p and significant wave height H_{m0} as indicated in table 6.4 and a slope angle of 45°, results in ξ_0 = 5.13 and K_r = 0.54.

6.3.5. Model parameters

Table 6.5 and Table 6.6 give an overview of the other physical and numerical parameters used in the wave model. These are mostly the default values of the WAVE module. Wave diffraction was not included in the model, because SWAN can only solve this process accurately when a much finer grid (dx ≈ L/10, (Deltares, 2014b)) is applied. This is however not favourable in view of computational time.

Table 6.5: Physical parameters used in Delft3D-WAVE.

Physical parameters	**value**	**unit**
Water density	1025	kg/m^3
Minimum depth	0.05	m
Depth-induced breaking (B&J model)		
α	1	
γ	0.73	
Non-linear triad interactions (LTA)		
α	0.1	
β	2.2	
Bottom friction		
Type	JONSWAP	
Coefficient	0.067	m^2/s^3
Whitecapping		
Model	Komen et al.	

Table 6.6: Numerical parameters used in Delft3D-WAVE.

Numerical parameters	**value**
Directional space (CDD)	0.5
Frequency space (CSS)	0.5
Relative change	
$H_s - T_{m01}$	0.02
Relative change w.r.t. mean value	
H_s	0.02
T_{m01}	0.02
Percentage of wet grid points	98
Maximum number of iterations	15

6.4. Set-up FLOW-module Z-layers

This section describes the set-up of the Delft3D FLOW-module that is used to model hydrodynamics and salinity.

6.4.1. Grid

The horizontal grid of the Z-model is the same as the one used for the σ-model, see Figure 6.1. The vertical layer distribution is, with a total of 20 layers, chosen as follows (top to bottom in percentage of maximum depth): 12 layers of 1%, 1 layer of 2%, 2 layers of 5%, 1 layer of 6%, 2 layers of 10%, 1 layer of 20% and the lowest layer is 30%. This is done in order to have smaller grid layers in the river and very large layers at the sea part of the domain. In order to increase the amount of vertical layers in the river part, the maximum depth is set to 200 meters. At this depth the bottom will not yet influence the waves due to their wavelength.

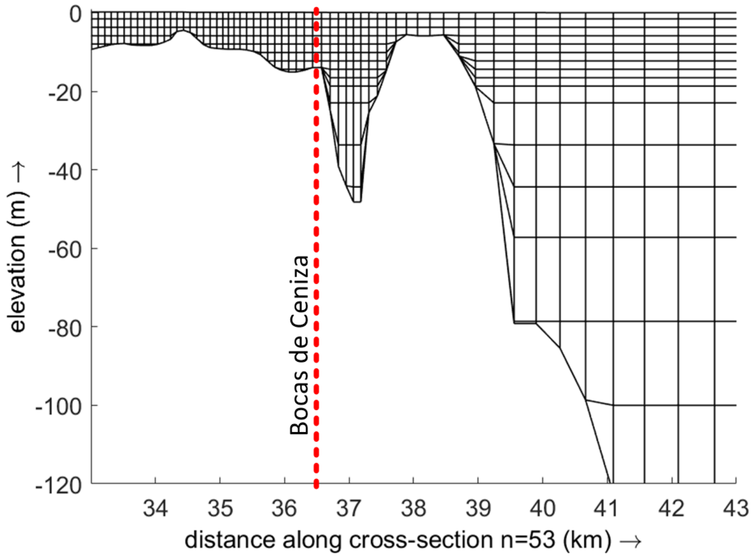


Figure 6.4: Vertical grid of the Z-model.

6.4.2. Bed topography

The bathymetries are the same as for the σ-model, see Section 6.2.2.

6.4.3. Boundary conditions

The boundary conditions need to be specified at the open boundaries of the grid. These are the offshore boundaries and the upstream river boundary.

Flow conditions

At the upstream river boundary a time series of discharges is prescribed in accordance with Section B.1.1. For the offshore boundaries a constant water level of 0 m is chosen for the salinity calibration, because the Z-model gives rise to spurious velocities at the offshore boundaries when the tidal boundaries from the σ-model are used.

Transport conditions

At the upstream river boundary the incoming salinity is 0 ppt. At the offshore boundaries the salinity is set to 35 ppt.

6.4.4. Model parameters

With regard to the model parameters, the difference with the σ-model lies only in a few numerical parameters: *Depth at grid cell faces* is automatically set to *Min* for all Z-models. The *Correction for σ-coordinates* is not available. In order to keep the model stable a time step of 0.4 minutes is chosen.

6.4.5. Morphology with 2DH-model

The 2DH morphology model is set up in the same way as the Z-model. However, it does not include salinity and waves and has no layers in the vertical. Secondary flow is activated with the physical parameters in the GUI. For the flow and transport conditions the same conditions apply as for the σ- and Z-model. Because the 2DH model has only one layer the velocities are depth averaged. This results in much quicker calculation time. Therefor the morphological factor is set to 1.

6.5. Calibration

Because several processes are taken into account, the model set-up is relatively complex and contains multiple calibration parameters. The model is therefore calibrated in several steps.

6.5.1. River flow calibration

In the first calibration step, only the river flow is taken into account. Tides, waves, salinity and morphology are not yet included. The only parameter used for calibration is the bottom roughness, which is defined by means of the Manning coefficient n. The model uses this coefficient to compute the Chézy friction coefficient as follows (Deltares, 2014a):

$$C = \frac{H^{1/6}}{n} \tag{6.4}$$

With:
H water depth [m]
n Manning coefficient [s/m$^{1/3}$]

Instead of defining a constant Chézy value throughout time and space, the bottom roughness is now made dependent on the water depth.

The calibration is performed using the bathymetry of April 2012 and the discharge time series of January - July 2012. With this time series, extreme discharges (both minima and maxima) are included in the simulation. Figure 6.5 shows the water level time series simulated for this period with Manning coefficients ranging between 0.020 and 0.035 s/m$^{1/3}$, compared to water levels calculated with a relation between the water level at Calamar and Pimsa, see Section B.1.1. The simulated water levels are consistently lower than the calculated ones. A Manning coefficient of $n = 0.035$ s/m$^{1/3}$ approaches the calculated water levels closest, and it can be expected that a higher value of n gives an even better result. However, to stay within the physically realistic range of Manning coefficients for large rivers, a value of $n = 0.030$ s/m$^{1/3}$ was selected for both the Z- and the σ-model (Chow, 1959). This gives a 20 to 35 % deviation from the calculated water levels at Pimsa.

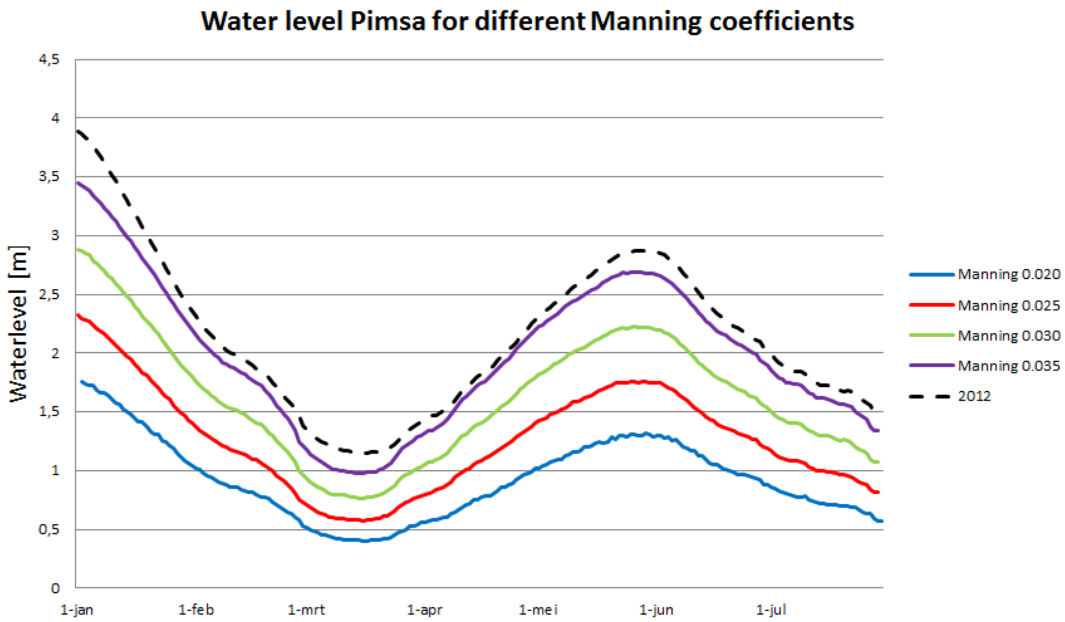


Figure 6.5: Comparison of results with different Manning coefficients and the discharge of 2012.

To compare these results, simulations in which the roughness is defined with a constant Chézy value are also carried out. Results of these simulations (see Figure 6.6) are similar to those with the Manning coefficient.

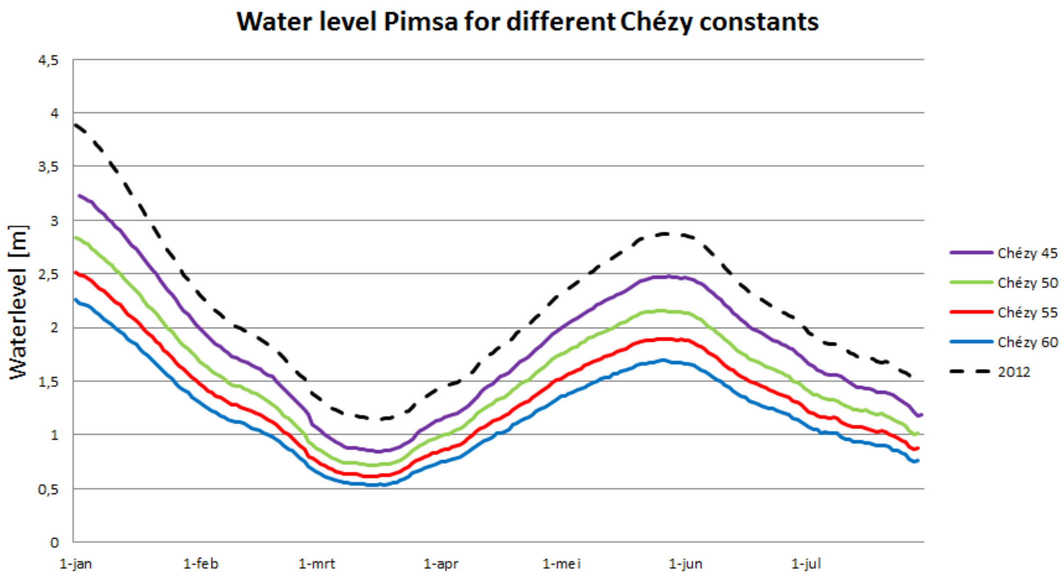


Figure 6.6: Comparison of results with different Chézy constants and the discharge of 2012.

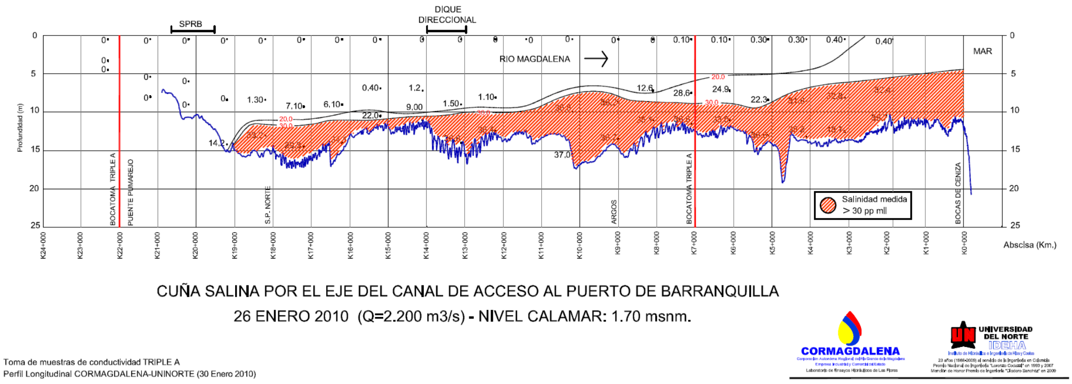
6.5.2. Salinity calibration

The only measurements that are available for the calibration of the salinity in both the Z- and σ-model are measurements done at the time of an extremely low discharge event in January 2010 (see Section 3.1.2). At this time a measurement campaign was set up to investigate the salinity intrusion because the intake of the drinking water for the city of Barranquilla was in danger of becoming saline. As no other measurements are available to us it is difficult to say something about the salinity distribution during conditions with a higher discharge. After the calibration, a comparison is made between the σ-model and the Z-model in order to determine which model captures the salt wedge more accurately. In both models, the parameters for viscosity and diffusivity are set to the values as presented in Table 6.7.

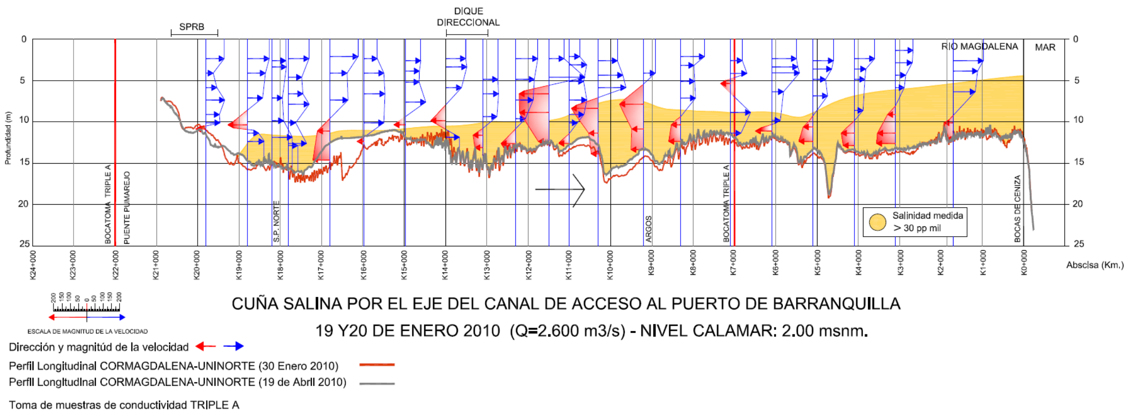
Table 6.7: Viscosity and diffusivity parameters for salinity calibration.

Parameter	value	unit
Horizontal eddy viscosity	1	m^2/s
Horizontal eddy diffusivity	10	m^2/s
Vertical eddy viscosity	10^{-6}	m^2/s
Vertical eddy diffusivity	10^{-6}	m^2/s
Ozmidov length scale	0	m
Model for 3D turbulence	k-ϵ	-

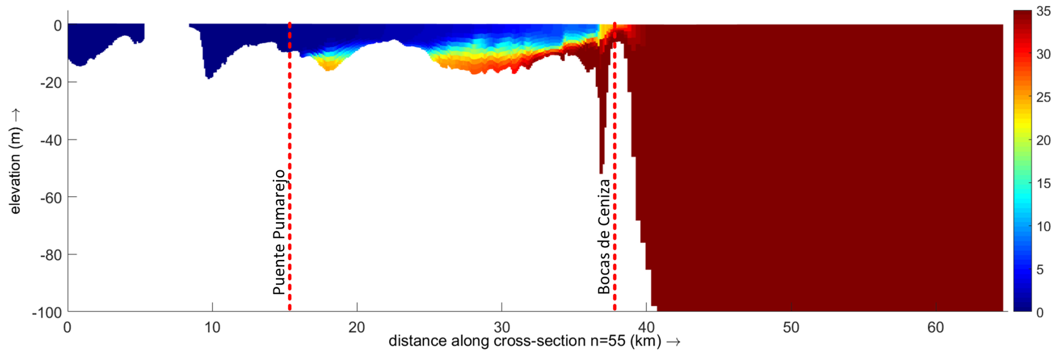
Figure 6.7a and 6.7b show the salinity measurements from the mouth until the Pumarejo bridge which is 22 km upstream. The calibration is done with the discharge as measured on the 26th of January (2200 m^3/s). The results are shown in Figure 6.7c and 6.7d.



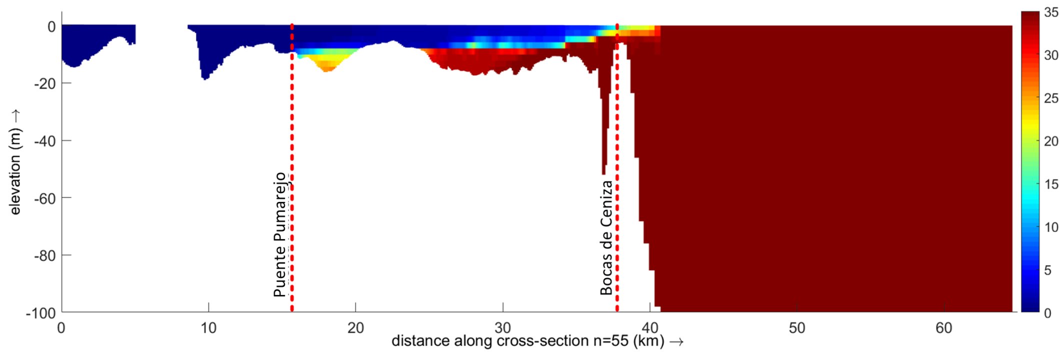
(a) Salinity in the access channel for a discharge of 2200 m^3/s, as measured in January 2010 (Cormagdalena & Universidad del Norte, 2010).



(b) Salinity in the access channel for a discharge of 2600 m^3/s, as measured in January 2010 (Cormagdalena & Universidad del Norte, 2010).



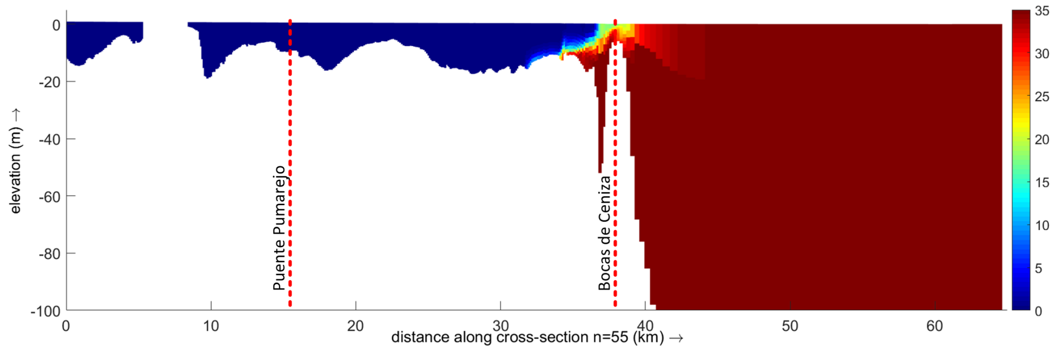
(c) Salinity as simulated with the σ-model, for a discharge of 2200 m^3/s.



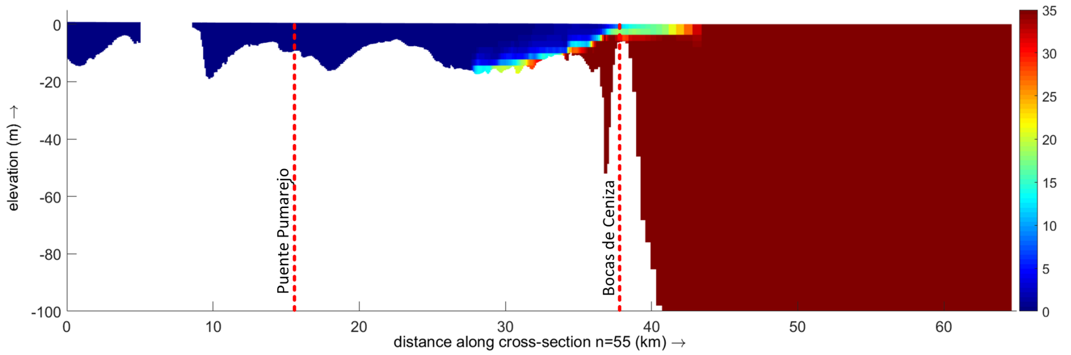
(d) Salinity as simulated with the Z-model, for a discharge of 2200 m^3/s.

Figure 6.7: Comparison of salinity as measured, as simulated with the σ-model and as simulated with the Z-model for a discharge of 2200 m^3/s.

It is clearly visible that the simulation with the σ-model leads to more diffusion and a smaller gradient over the vertical. In the Z-model simulation a more pronounced gradient is visible. This is in accordance with the measurements. Both of the models capture the salinity intrusion length accurately. However, due to the more diffuse salinity intrusion in the σ-model the salinity from approximately 10 km upstream to the end of the salt wedge (at 20 km upstream of the mouth) is closer to 20 ppt than the measured >30 ppt. From this it is concluded that the Z-model simulates the salinity better than the σ-model. Figure 6.8 shows the results of a further comparison between both models for different discharges. It can be seen that in the Z-model the salt wedge intrudes further. This can be explained with the behaviour of σ-models for steep bottom gradients. For a steep bottom topography, as is present in front of the mouth, the model creates artificial velocities that are directed down-slope. This leads to an overestimation of the velocity at the bottom and therefore increased mixing over the vertical.



(a) Salinity as simulated with the σ-model, for a discharge of 4520 m^3/s.



(b) Salinity as simulated with the Z-model, for a discharge of 4520 m^3/s.

Figure 6.8: Comparison of salinity simulated with the σ- and Z-model for a discharge of 4520 m^3/s.

6.5.3. Morphodynamic calibration

The morphodynamic behaviour is calibrated based on two bathymetric surveys, viz. from January and April 2012. The results of these surveys are used to construct two bed topographies. The bed topography of January 2012 is used as a starting point for a morphodynamic simulation of 3 months, whereas the topography resulting from this simulation is compared with the surveyed bathymetry of April 2012.

To model sediment transport, several sediment transport formulas are available in Delft3D. Some of these formulas calculate bed load and suspended load transport separately and some calculate the total sediment load. Because in this case, there is little information available to distinguish between the bed and suspended load fraction, it is decided to use a total sediment transport formula with one sediment fraction (see Section 6.2.4 and 6.4.4). For total transport, well-known formulas available in Delft3D are the ones by Engelund-Hansen and Meyer-Peter-Muller (Deltares, 2014a). The relation by Engelund-Hansen is often used for fine sediments, whereas the relation by Meyer-Peter-Muller is more appropriate for somewhat coarser sediment as it includes a threshold of motion. As we deal with relatively fine sediment, the relation by Engelund and Hansen (1967) is selected for this case:

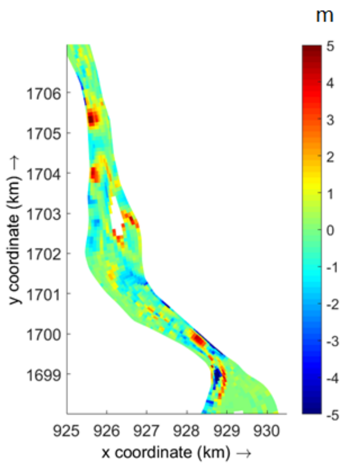
$$S = S_b + S_{s,eq} = \frac{0.05\alpha q^5}{\sqrt{g} C^3 \Delta^2 D_{50}} \tag{6.5}$$

With:

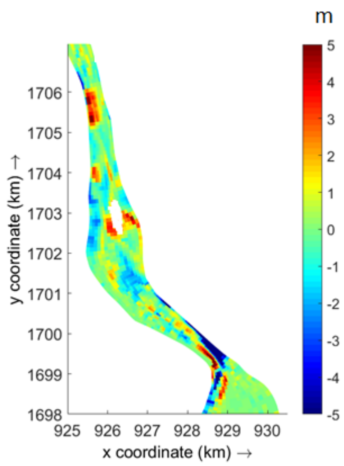
α	calibration coefficient (O(1))
q	magnitude of flow velocity [m/s]
C	Chézy friction coefficient [$m^{1/2}$/s]
Δ	relative density $(\rho_s - \rho_w)/\rho_w$
D_{50}	median grain diameter [m]

By varying the calibration coefficient α between 0.1 and 1.5, the best fit with the measured topography is sought. A value of $\alpha = 0.5$ turns out to give the best results. In Figure 6.9, these results are shown for the river section ranging from 18-29 km. For this section and further upstream, the models can give a qualitative prediction of the locations where sedimentation and erosion will occur. However, both the σ-model and, to a lesser extent, the 2D-model overestimate the rates of bed level change. Therefore, quantitative predictions are not possible with this model.

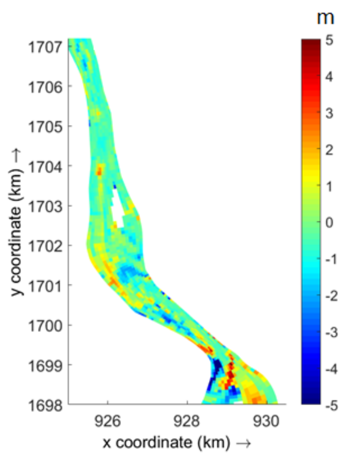
In the river mouth, both models are not able to predict morphological changes well. For the 2D-model, this is because salinity differences are not included in the model, such that no stratified flow can be modelled. This stratified flow is important for sediment transport in the river mouth. Waves, which are important for sedimentation in front of the mouth, are also not included in this model. In the σ-model, waves and salinity are included, but the model introduces artificial flows near the bed. This is a known problem for these types of models when they are applied in areas with salinity differences in combination with steep bed topographies (Deltares, 2014a). Due to these erroneous near-bed velocities, sediment transport is also ill-represented. Therefore, qualitative predictions in the area where salt intrudes (up to about 20 km upstream of the mouth) can only be made if results of the Z-model (including salinity differences) are combined with the results of the 2D-model (including morphology). This is done in Section 7.3.



(a) Modelled bed level change in the period January - April 2012 with the 2D model.



(b) Modelled bed level change in the period January - April 2012 with the σ-model.



(c) Measured bed level change in the period January - April 2012.

Figure 6.9: Modelled and measured bed level change in the period January - April 2012. Positive bed level change is sedimentation, negative bed level change is erosion.

7 Model results

This chapter only discusses the model results for several scenarios. A more elaborate description of the limitations of the model and a discussion of these results is given in Chapter 12. In this chapter first the morphodynamic responses for several discharge scenarios will be discussed. This is followed by the morphodynamic responses of the model with and without waves in Section 7.2. Lastly in Section 7.3 the influence of the salt intrusion is elaborated upon.

7.1. Morphodynamic response for several discharge scenarios

In this section four different discharge scenarios will be simulated with the 2DH model in order to model the morphological changes. These different scenarios are: low to high, high to low, constant low and constant high discharge levels. These scenarios are chosen because throughout the year all these different scenarios can be distinguished. Typically from September to January the discharge is high, then it becomes low before it increases again from March to July. Between July and September the discharge decreases slightly. In the simulations the goal is to investigate the level of sedimentation and erosion for the four scenarios. In the following section the discharge series that were used will be explained, after which the actual simulation results will be discussed.

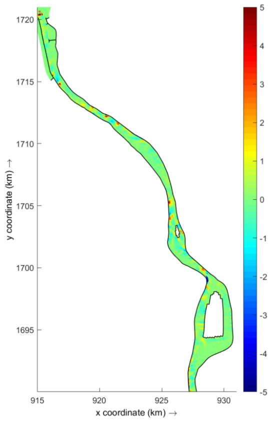
7.1.1. Discharge scenarios

The different discharge scenarios are chosen in such a way that the variability of the discharge as it can appear in reality is captured. In addition the scenarios also display what happens when the discharge is constant for some time.

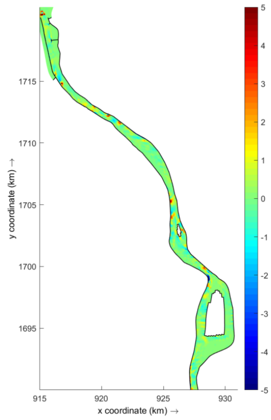
- Scenario 1: Low to high; the discharge increases from 2500 m^3/s to 11000 m^3/s in one month;
- Scenario 2: High to low; the discharge decreases from 11000 m^3/s to 2500 m^3/s in one month;
- Scenario 3: Constant low discharge of 4500 m^3/s for one month;
- Scenario 4: Constant high discharge of 9000 m^3/s for one month.

7.1.2. Results from scenarios

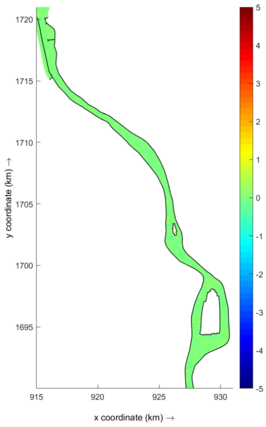
In these simulations it can be seen that with discharges higher than 5000 m^3/s erosion and sedimentation start to occur rapidly. The depth-averaged velocity is 0.9 m/s with a corresponding bed shear stress of 3.5 N/m^2. This results in a sediment transport of 10^{-4} $m^3/s/m$. These results can be seen in both the increasing and the decreasing discharge time series (scenario 1 and 2). First it appears as if the bed is stable until a certain critical velocity is reached after which the sedimentation and erosion rates increase. This subsequently leads to the movement of bed forms downstream. The difference between the bed level changes for the increasing and decreasing discharge time series is negligible. Both end up with nearly the same amounts of sedimentation and erosion along the length of the river.
Figure 8.1 shows the final bed level changes of the simulations. In the scenario in which a discharge of 4500 m^3/s is simulated for one month there is almost no sedimentation and erosion over the entire simulated reach. This supports the results from the first two scenarios which both showed very little sedimentation and erosion below 5000 m^3/s. Therefore it also results in very little bed level changes. On the other hand, when the discharge is constant at 9000 m^3/s the sedimentation and erosion rates are very high. This is seen in the large bed level changes (Figure 7.2). This means that bed forms are smoothed out and moved downstream. No net increase or decrease in the bed level appears to be happening. However around 6 to 8 km upstream of the mouth some net sedimentation can be seen. This is also the case for the left branch near the bridge at km 22. This is in line with the current maintenance since especially the location just before the bridge is known to be in need of dredging.



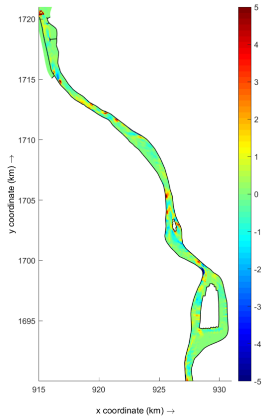
(a) Modelled bed level change with a discharge decreasing from 11000 to 2500 m^3/s.



(b) Modelled bed level change with a discharge increasing from 2500 to 11000 m^3/s.



(c) Modelled bed level change with a discharge of 4500 m^3/s.



(d) Modelled bed level change with a discharge of 9000 m^3/s.

Figure 7.1: Modelled bed level changes with the 2D-model with different discharge scenarios running for 1 month.

In the more narrow part at km 26 a lot of erosion is visible, which makes sense because the river becomes very narrow just after the confluence of the two branches. Just after the narrowing, when the river becomes gradually wider there is a lot of sedimentation.

At some locations along the banks a lot of erosion is visible in the simulations. This can however be caused by the smoothing of the bathymetry at the edges of the grid, since at these edges the measurements are not reaching to the actual bank. Therefore the modelled bottom gradient is different from the actual one.

In general the model does not show a lot of net sedimentation in any scenario but a lot of movement in the bed forms can be noticed when the discharge is high. Besides the downstream migration the bed forms get smoothed out at high discharges resulting in lower peaks and higher troughs.

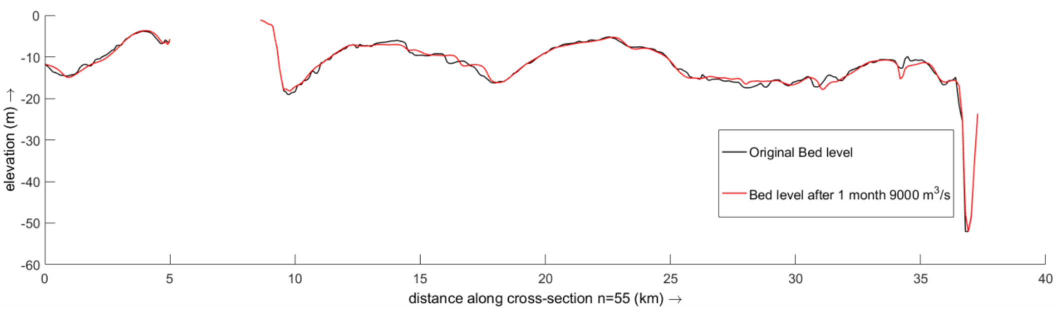


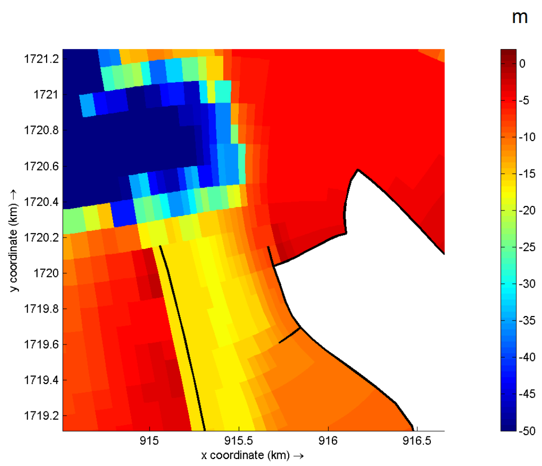
Figure 7.2: Bed level changes along longitudinal cross-section 55 after one month of 9000 m^3/s.

7.2. Morphodynamic response with and without waves

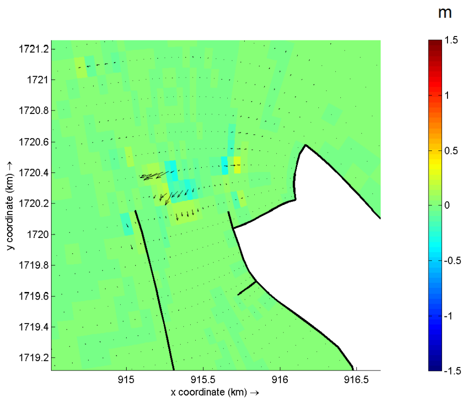
In order to investigate the influence of waves on sedimentation, two simulations are performed, one with and one without the presence of waves. These simulations are carried out with the σ-model, as this is the only model that includes waves (see Table 6.1). The simulation has a duration of 6.5 days with a morphological scale factor of 20 and a spin-up interval before morphological changes of 7200 min (5 days). The effective simulated morphological change thus covers a period of one month. The river discharge is kept constant at 3000 m^3/s throughout the simulation. The bottom topography at the start of the simulation is from January 2012. Other model parameters can be found in Section 6.2 and Section 6.3.

Figure 7.3 shows the outcome of these simulations. The results are shown in the mouth of the river only, because this is the only area where differences are visible. It can be seen that waves cause large sediment transports just in front of the river mouth. These transports occur where large topographic gradients exist, which can be caused by the presence of the canyon just offshore of the mouth. This results in deposition of sediments in the river mouth.

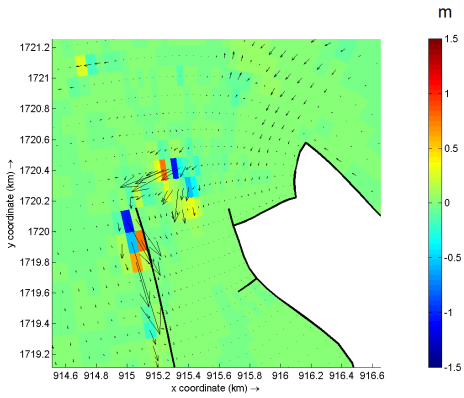
The large transports that are visible next to the breakwater are likely a result of the model schematisation of the breakwater, with a large topographic gradient on the west side of the Tajamar Occidental (see Figure 7.3a).



(a) Initial bed level in January 2012.



(b) Modelled bed level change after 1 month without waves. The black arrows indicate a representative sediment transport vector in each cell, for relative comparison between simulations.



(c) Modelled bed level change after 1 month with waves. The black arrows indicate a representative sediment transport vector in each cell, for relative comparison between simulations.

Figure 7.3: Modelled bed level change in 1 month at Bocas de Ceniza. The black solid lines indicate the Tajamares, groynes and land boundaries.

7.3. Influence of salt intrusion

In this section the results of the simulations that are done with the Z-model are presented. These simulations do not include morphodynamics due to limitations of Delft3D. After a spin-up time of 4 days the discharge was decreased from 11000 m^3/s to 3000 m^3/s. This was done in order to investigate the length of the salinity intrusion (Figure 7.4) and the resulting bed shear stress and flow velocities at the bottom and surface (Figure 7.5).

As seen in the measurements during low discharge (see Section 6.5) the Magdalena has a strongly stratified salinity intrusion. This means the fresh water flows on top of the denser salt water. For a very low discharge of 3000 m^3/s, as observed in January 2010, the salinity intrudes up to 20 km whereas at a discharge of 7000 m^3/s it only intrudes up to 1.5 km. So for decreasing discharge levels the salinity intrudes further into the river rapidly.

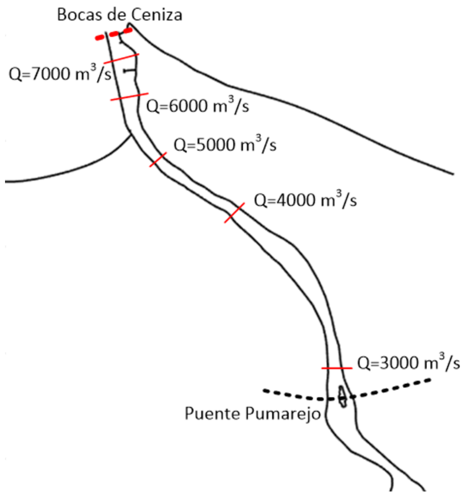
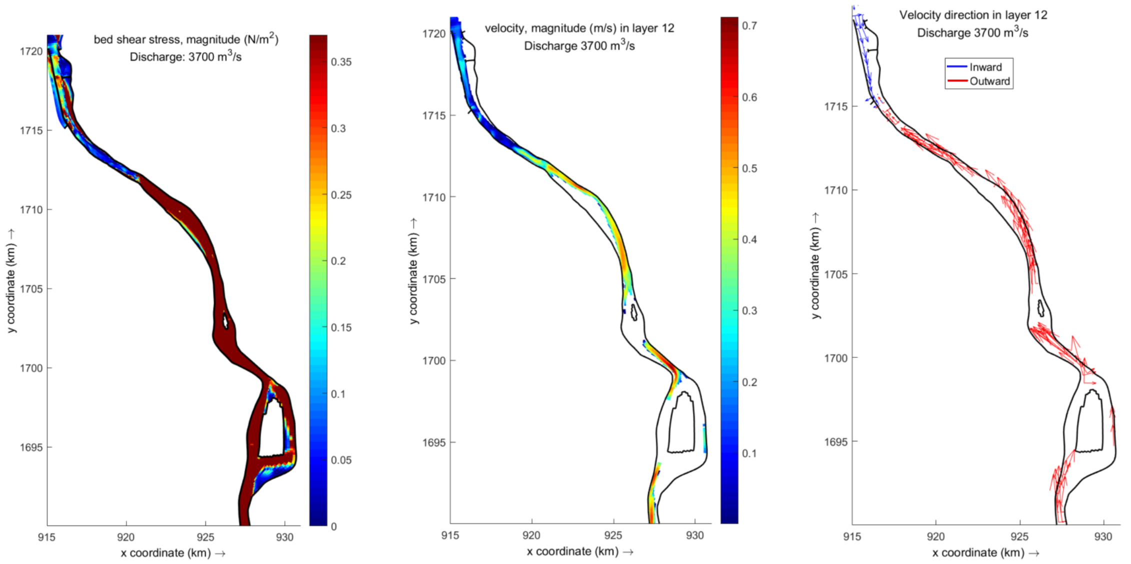


Figure 7.4: Salinity intrusion lengths for different discharges as simulated with Z-model.

From the simulations the flow velocities can be investigated in every layer in the vertical. The velocity at the bottom in the salt wedge is directed upstream due to the pressure gradient that follows from the difference in density between the fresh river discharge and the sea water. At the bottom the velocities are in the order of 0.1 m/s and bed shear stresses are in the order of 0.05 N/m^2. At the surface near the mouth the velocities strongly depend on the discharge. When the discharge is around 4000 m^3/s the velocity is 1.8 m/s at maximum, while further upstream the velocities are in the order of 1 m/s. When the discharge increases to 10000 m^3/s the velocities at the mouth can reach over 2.5 m/s and further upstream the velocities are in the order of 1.5 m/s.



(a) Bed shear stress at a discharge of 3700 m^3/s simulated with Z-model

(b) Velocity magnitude at the layer closest to the bottom

(c) Direction of the velocity at the layer closest to the bottom

Figure 7.5: Bed shear stress and near-bed velocities in the salt wedge. The bed shear stress shows a clear jump when outside the salt wedge. In the area where salinity influences the direction and magnitude of the velocity, the bed shear stress is below the critical value (Julien, 1998).

7.3.1. Influence on navigability

As the Z-model with with salinity is not able to model morphodynamics the influence on navigability has to be analysed indirectly. Because the bed shear stress near the bottom in the salt wedge is low and the velocity upstream directed, the area over which the salinity is located is susceptible to sedimentation. This is due to the fact that sediments that settle in the salt wedge will not be transported further downstream. Since there is always some intrusion, there is also always an area that is susceptible to sedimentation. The size of this area depends on the intrusion lengths, which in turn varies strongly with discharge. This means that the duration of a certain discharge determines the sedimentation level and its location. So for a low discharge the area of sedimentation is large whereas when the discharge is high the sedimentation will only occur at the mouth. Besides the sedimentation another problem for navigability is the very rapid surface flow velocity during high discharge. This can lead to difficulty in the navigation of large vessels that are entering the mouth with the assistance of tug boats.

IV

Interventions

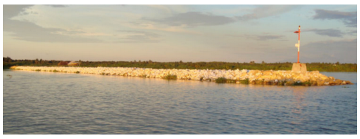
8
Measures

Effective sediment management strategies could reduce operational costs and significant adverse impacts on society and environment (UNESCO International Sediment Initiative, 2011). In this chapter, possible river training works are discussed. Next, some measures are proposed that deserve special attention and further research. A common distinction in interventions within the field of hydraulic engineering is the distinction between hard and soft measures. Hard measures involve the use of hydraulic structures, such as groynes and bank protection. Soft measures are solutions that do not include large infrastructure, but makes use of the powers of nature.

8.1. Hard measures

8.1.1. Groynes

Groynes are common structures in river engineering (Figure 8.1a). The primary function of river groynes is the protection of river banks in order to stabilise the river bed and fixate the flow of the river. Over the years, groynes became more important in maintaining a sufficient water depth for navigation. They narrow the cross-sectional area of the main channel, which results locally in larger flow velocities. This leads to deepening of the main river channel (Huthoff et al., 2013).



(a) Groyne 1 in the Magdalena river (Cañizares et al., 2007).

(b) Longitudinal dam in the river Waal (Buijse, 2015).

(c) Series of chevron dikes in the Mississippi river (United States Army Corps of Engineers, 2012).

Figure 8.1: Series of river training works.

8.1.2. Longitudinal dams

The essential difference between groynes and longitudinal dams (Figure 8.1b) is that longitudinal dams are not constructed perpendicular to the flow direction of the river, but parallel. They are used to concentrate the flow to the main part of the cross-section of the river, by dividing the river in a main channel and a bank channel. The velocity in the bank channel can be adjusted by varying the inlet crest height. This can prevent bank erosion. The following advantages of longitudinal dams compared to groynes can be identified (Huthoff, 2011):

- Longitudinal dams give less resistance to flow during high discharge events, which results in lower flood levels;
- Longitudinal dams allow for easy adjustments to in- and outlets in order to correct for morphodynamic effects. This can be done by regulating water and sediment distribution over the main and bank channel;
- An additional flow area can be created behind the dams, resulting in lower flood levels.

8.1.3. Chevron dikes

Chevrons are U-shaped dikes in which the closed end faces upstream. The United States Army Corps of Engineers (USACE) has used this type of structure extensively in parts of the Mississippi River to regulate the flow in the main channel (Figure 8.1c). These structures are usually not connected to the riverbanks, so water can flow freely around it. There are two types of chevrons: Blunt nose chevrons (Figure H.3b in Appendix H), which are mainly used to protect the head end of the island from erosion and chevron dikes (Figure H.3a in Appendix H) which are used to improve navigation conditions by guiding the flow in certain directions (United States Army Corps of Engineers, 2012).

8.1.4. Realignment

Changing the course of the river is a rigorous way of reaching the desired cross section. Channelisation, construction of bypasses and creating tributaries are examples of methods to change the course of the river. River cut-offs increase local river gradients. Since the upstream river will adjust to these changes, river cut-offs could have an influence on large river stretches. In the Mississippi River this resulted in numerous problems, such as unexpected erosion and rigorous changes in the development of the river course (Smith and Winkley, 1996). Hence, for the design of river alignments extensive research is needed.

8.1.5. Bank protection

In this section methods and techniques are discussed that protect river banks from collapsing or eroding. These are not direct measures to prevent sedimentation processes, but have an influence on the sediment load and the flow pattern of the river. There are many different applications to protect riverbanks. The use of vegetation as bank protection will be discussed in Section 8.2.2. Another possible protection is geotextile, that since its development around 1950 has been used in many applications. By applying a geotextile layer on top of the soil, the soil is prevented from washing out. If a stronger protection is required, an additional rock layer can be put on top of the geotextile to minimise wave impact. The application of bank protection prevents the river from eroding the banks, forcing it into an unnatural alignment.

8.1.6. Breakwaters

The main purpose of breakwaters is to dissipate wave energy. This allows a more convenient condition for the entrance of ships. Due to the reduction in energy, breakwaters could encourage sedimentation in the estuarine area. Furthermore, tides and waves in combination with longshore sediment transport may enhance sedimentation in the river mouth (Figure 8.2). Breakwaters in itself are not solutions for sedimentation, but an adjustment of existing breakwaters may solve sedimentation problems that are present.

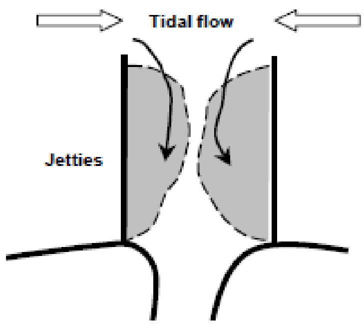


Figure 8.2: Sedimentation of inlets (van Rijn, 2005).

8.1.7. Fixed bottom layer

Construction of a fixed bottom layer consists of levelling of the deep navigation channel by dumping sand, followed by dumping of a top layer of rock. A fixed bottom layer decreases the cross-section in the bend. This leads to higher flow velocities which promote erosion. As the outer bend is protected by the fixed layer, only the elevated inner bend will erode. This leads to an increase of the navigable width.

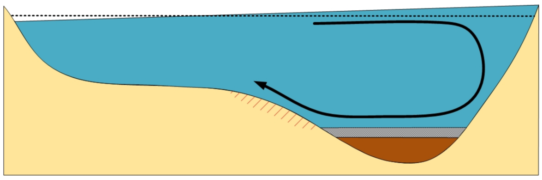


Figure 8.3: Sketch of a river cross-section with a fixed layer.

8.2. Soft measures

Soft measures are mostly based on benefits that the ecosystem can deliver, instead of relying on structural measures. Soft measures can have many benefits, for they can cut construction costs and reduce the production of CO2 (Boersma, 2014). Besides mitigating on erosion and sedimentation issues, soft measures are able to protect local habitats along the river and in the coastal area.

8.2.1. Dredging

Currently, dredging maintenance is carried out several times a year (see Table 2.2) for which different dredging techniques are available. This report is limited to the evaluation of the Trailer Suction Hopper Dredge (TSHD) and Water Injection Dredge (WID).

Trailer Suction Hopper Dredger

A TSHD is mainly used for maintenance projects of existing navigation channels. This is the most common technique and is currently applied for maintenance of the Magdalena River. Suction tubes transport the sediment from the river bed to the hopper. Subsequently, dredged material is moved to the dumping site by ship.

Water Injection Dredging

Water Injection Dredging (WID) is a relatively new approach in dredging, developed in the 1980's (Verhagen, 2000). The standard aforementioned dredging method requires a lot of transport. Since the majority of the dredged material is water, this not very efficient. Alternatively, WID makes use of the ability of nature to transport the sediment horizontally. First the sediment is fluidised by injecting large volumes of water at low pressure. In doing so, a density flow over the river bed is created. Among others, the following reasons make WID an attractive technique (Verhagen, 2000; IADC, 2013):

- There is no need for transporting or a pipeline;
- Water injecting requires less energy than pumping sediment;
- This form of horizontal transport is more environmentally friendly since only the affected layer remains just above the bed, instead of affecting the overlying water layers.

WID can not be used in every situation. There are several requirements which are important:

- The layer consists of mainly mud;
- The sediment of the layer has to be clean;
- The total length of the layer is limited to a few kilometres.

8.2.2. Vegetation

Vegetation can be used to reduce erosion rates. In the riparian zone, vegetation reduces flow velocities. Furthermore, vegetation directly reinforces riverbanks, which reduces the need for other stabilisation or maintenance measures. The impact of vegetation differs with the vegetation types. Therefore, it is essential to analyse erosion processes for selecting the proper type of vegetation.

8.2.3. Sand bypass

In many tidal entrances, sand bypasses are required nowadays. This is because entrances on littoral shores may form a barrier for longshore transport, which causes an updrift sediment accumulation and a downdrift erosion. This is also the case at the Magdalene river entrance. To prevent these phenomena, the sand has to be transported from the updrift side to the downdrift side, without causing problems for the navigation in the entrance. One of the ways to do this, is by dredging the sediment trap and dumping it downdrift of the entrance. This solution requires a permanent dredger. Another solution is a fixed bypassing plant, successfully used at the entrance of the Nerang River, Australia. Due to the bypassing plant, the depth in the entrance increased from 2 m to about 5 m (Bruun, 1996). A fixed bypassing plant pumps up the sediment in the sand trap using jet pumps (Figure H.6), after which the slurry is transported by pipelines to the other side of the entrance from where it can be picked up by the longshore current again.

8.2.4. Forestation

The deforestation in the inland of Colombia caused an increase in the sediment transport of the river in the last decades, with the result of more sedimentation in the lower reaches. In 2000, Cormagdalena signed a contract with the purpose of developing cultivation of forest trees in the Magdalena Basin (CORMAGDALENA, 2013). By regulating the deforestation and afforestation, the sediment load in the river might decrease. To determine the effects of such regulations, an additional study into this subject is required, this is beyond the scope of this project.

8.3. Summary interventions

All of these measures have different impacts on the river. In table 8.1 the impact on river functions is analysed. These functions are related to the morphological evolution and sediment continuity of the river. It is essential to realise that measures may have negative impact on those river functions. Hence, mitigating measures may be necessary.

Table 8.1: Potential direct impact of interventions on waterway functions (After Environmental Commission (2003)).

	Measures	Impact to function					
		Hydrodynamic character	Sedimentation processes	Surface water storage	Sediment character	Stream evolution	Energy processes
Hard	Groynes	▽	▽	○	▽	▽	▽
	Longitudinal dams	▽	▽	○	▽	▽	▽
	Chevrons	▽	▽	○	▽	▽	▽
	Realignment	▽	□	▽	▽	□	□
	Bank protection	○	□	○	▽	□	▽
	Breakwaters	▽	□	▽	▽	▽	□
	Bottom layer	▽	▽	▽	▽	□	□
Soft	Dredging (TSHD)	▽	□	▽	□	□	▽
	Dredging (WID)	▽	▽	▽	□	□	▽
	Vegetation	○	▽	○	▽	▽	▽
	Sediment bypassing	○	□	▽	□	□	▽
	Reducing deforestation	○	▽	○	▽	▽	▽

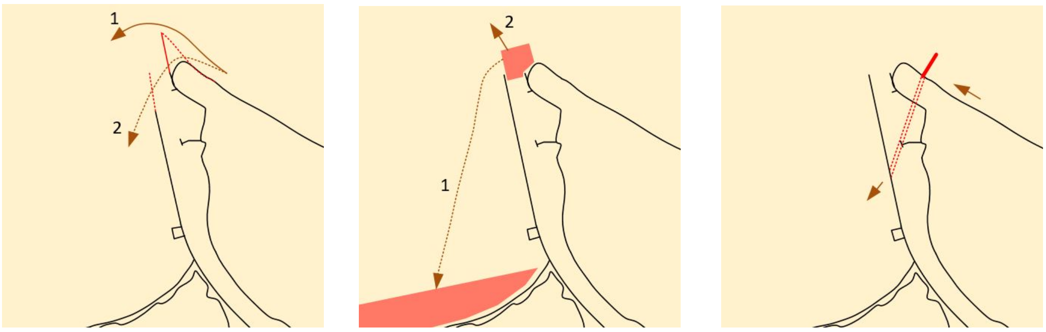
○ - No significant impact; ▽ - Potential minimized impacts;
□ - Impacts likely requiring mitigation measures.

8.4. Overview sectorization

In the design of interventions, the section division of paragraph 3.3 is used. A plan view of all and more detailed views of the different sectors can be found in Figure D.1 in Appendix D. For the alternatives, some of the sections are considered together.

8.5. Measures Section I

Section I considers the river mouth, ranging from K0 to K12. The critical part in this section is the sand bar forming at K0, between the tips of the Tajamares. The material forming the bar originates from river sediment transport and longshore sediment transport. Since the construction of the Tajamares in 1936 to fixate the river mouth, a lot has changed in the landscape around it. At the west side, the shore has eroded dozens of meters, where in the east the sedimentation has reached the tip of the Tajamar. The longshore current and waves from the north-east transport the sediment around the tip, where it contributes to the sand bar situated there (Manuel Alvarado Ortega, personal communication, 2 October 2017). The suggested solutions for dealing with this sand bar blocking part of the entrance, consist of hard and soft measures.



(a) Adjusting the length of Tajamares.

(b) Dredging the mouth.

(c) Sand bypass system.

Figure 8.4: Plan view of ideas for the river mouth (Section I).

8.5.1. Adjusting length Tajamares (Figure 8.4a)

In the current situation, both the eastern and western Tajamar extend equally far into the ocean. Sediment transported around the tip of the eastern Tajamar gets trapped in front of the western Tajamar, in the river mouth. Changing the length ratio between the Tajamares causes the sediment of the longshore transport to flow past the western Tajamar or disappear in the underwater canyon depending on which ratio is used.

Extending the eastern Tajamar

An extension of the eastern Tajamar until the edge of the canyon will cause the sediment of the longshore transport to flush into the canyon. In the first years after the extension, the sediment will accumulate at the eastern side of the Tajamar. After reaching the tip, it will flush around it where is will disappear in the canyon (Figure 8.4a [1]). The sediment is lost from the longshore transport system, which can cause erosion west of the mouth.

Shortening the western Tajamar

By shortening the western Tajamar, the sediment originated from the longshore transport no longer gets trapped in front of the breakwater, but is able to flush around it (Figure 8.4a [2]). Also the river sediment, that in the current situation partly disappears in the canyon, will bend westward and contribute to the longshore transport.

8.5.2. Water Injection Dredging (Figure 8.4b)

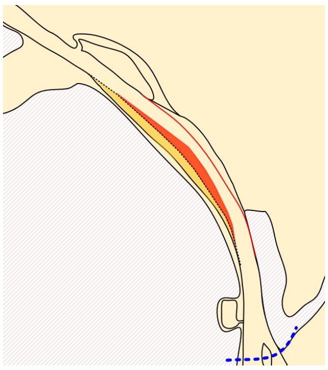
The layer that has to be removed in the first few kilometres of the access channel meets the requirements for WID mentioned in Section 8.2.1. Therefore, WID is a convenient option of dredging from both environmental and cost-effective point of view. The sediment is fluidised by water injection, subsequently picked up by the river current and transported into the canyon or along the coast. To prevent high costs for ad hoc dredging, a long term survey of the sand bar should be done, followed by a dredging plan. A disadvantage is the required continuous dredging.

8.5.3. Sediment bypass (Figure 8.4c)

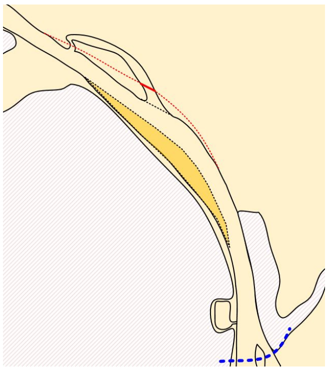
Since part of the sand bank in the mouth originates from the longshore transport, a sand bypass system is a possible solution. A jetty with jet pumps will be installed at the eastern side of the river mouth to trap the sediment. The obtained slurry will be transported by pipelines under the river, to the western side. From here, it will be picked up by the longshore current again. In this way, no sediment gets lost from the longshore transport system.

8.6. Measures Section II and III

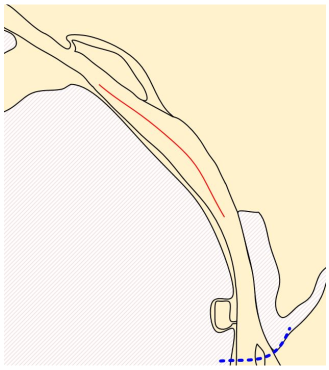
The critical parts in section II and III are close together, at K11 and K14. A solution for the problem at K14 will probably also have a large influence on the problem at K11. In this investigation, these two sections are considered together in order to find one integral solution for both critical parts. The problem at K11 is the insufficient depth over the whole width, at K14 the limited width of the navigation channel located in the outer bend and the limited depth in the inner bend are the problems. Several solutions are suggested to adjust the river bend between K13 and K15, to affect the problems in the bend and downstream.



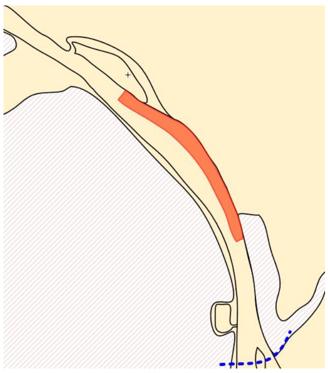
(a) Adjusting the bend radius.



(b) Relocation of Dique Direccional.



(c) Longitudinal dam at the curvature of K14.



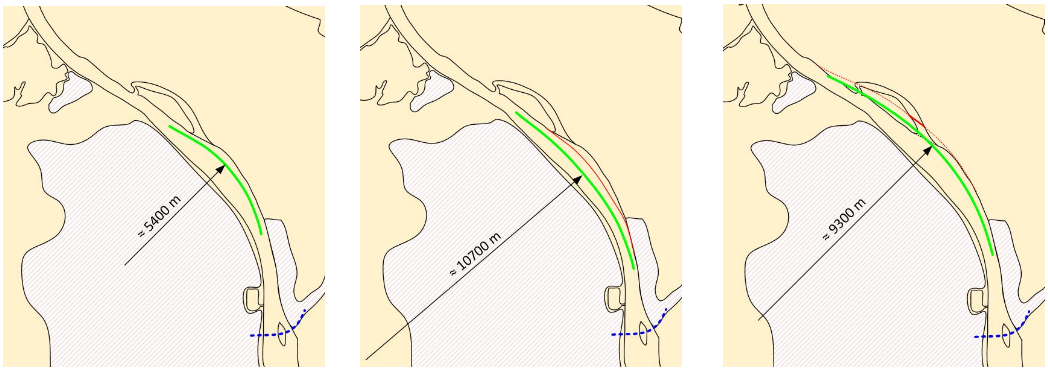
(d) Fixed layer in curvature K14

Figure 8.5: Plan view of ideas for section II and section III.

8.6.1. Adjusting the bend radius (Figure 8.5a)

Between K13 and K15, the main flow is in the outer bend of the river. Due to the relative small radius of the bend (Figure 8.6a), a secondary flow like discussed in Section 3.1.1 arises. This secondary flow causes erosion in the outer bend and accretion in the inner bend. The resulting cross-section of the river has a deep, narrow outer bend and a broad, shallow inner bend (see Section 3.4).
By relocating the outer bank more inwards, the radius of the river bend gets bigger (Figure 8.6b), resulting in a reduced secondary flow. To prevent erosion, the new bank requires a revetment or geotextile. However, due to the reduced width the flow velocity will increase, resulting in an increase of secondary flow. To maintain

the same cross-sectional area, part of the inner bend has to be dredged (red area in Figure 8.5a). Depending on the resulting flow velocity in the main channel, it can be decided to dump the dredged material in the inner bend (yellow area) or in the ocean.



(a) Original radius. (b) Relocation inwards. (c) Relocation outwards.

Figure 8.6: Adjusting the radius of the river bend between K13 and K15.

8.6.2. Relocation of the Dique Direccional (Figure 8.5b)

Another way to increase the radius of the bend is by replacing the Dique Direccional. The Dique Direccional is build to regulate the flow of the river. Therefore, the river is forced into an predefined course and is not allow the move freely, resulting in an relative sharp bend. By placing the Dique Direccional more to the north, the river will be able to follow its natural meandering pattern better, with an increased bend radius (Figure 8.6c). Due to the wider cross-section, probably some sedimentation in the inner bend will occur as a result of low flow velocities. As can be seen in Table 3.2 the construction cost of the Dique Direccional are high compared to other intervention, hence, it is likely that the costs of relocation will be relatively high as well.

8.6.3. Longitudinal dam (Figure 8.5c)

Constructing a longitudinal dam in the bend between K13 and K15 divides the river in an inner bend and an outer bend, directing the main flow to the outer bend and reducing the flow velocity in the inner bend. The main flow will have an increased flow velocity, due to the division in two sections. This will result in scour of the navigation channel, located in the outer bend. The difference with the previous mentioned solutions, is the blocked cross-section. With flow still possible over the whole width of the river, the blocked cross-section is small in case of a longitudinal dam.

8.6.4. Fixed bottom layer in river bend (Figure 8.5d)

In order the modify the distribution of secondary flow and sediment transport, a non-erodible layer can be constructed in the outer bend of the river. This layer can be constructed of sand and gravel, covered with a layer of rip-rap. Due to the lack of available sediment in the outer bend, the flow will start eroding the inner bend. In the long term, this will result in an increased width of the navigation channel. In the Netherlands this concept has been applied in the river Waal, with a positive result.

8.7. Measures Section IV and V

In section IV and V there are no critical zones like the first 3 sections, but these sections have a large influence on the sections downstream. The sections IV and V are therefore also considered together, to come to an integral solutions for flow regulation. To be able to control the flow pattern downstream, it is important to control the very dynamic character in these sections. Several solutions are suggested to adjust the flow pattern of the river, or prevent erosion and sedimentation in specific areas.

8.7.1. Blunt-nose chevron Rondón Island (Figure 8.7a)

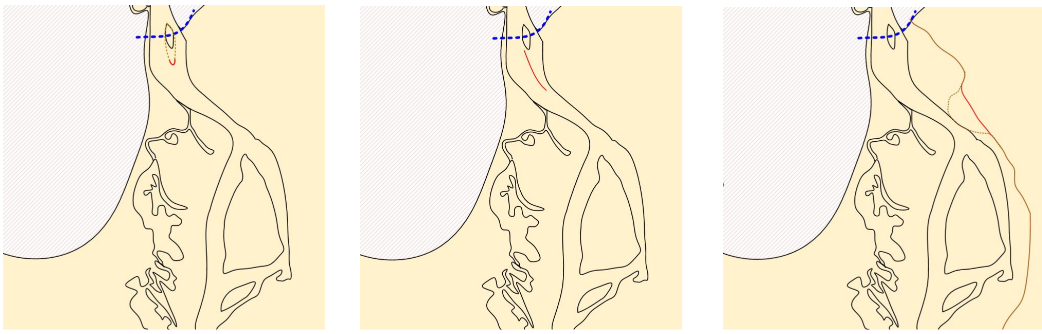
The area around K22 is very dynamic (Figure A.4). During the last years, the Rondón island is eroding rapidly. By implementing protection, erosion can be reduced and sedimentation at this specific location encouraged. The main purpose of blunt nose chevrons is to redirect the flow and reduce the flow velocities at the most upstream part of the island. Furthermore, an opportunity is created for sediment deposit at the open end of the chevron.

8.7.2. Longitudinal dam (Figure 8.7b)

Placing a longitudinal dam along Rondón Island will divide the flow in this branch in two sections, with the main flow on the western side. The flow velocity along the side of the island will be lower, reducing the ongoing erosion of the island and restricting the dynamic character.

8.7.3. Relocation of road (Figure 8.7c)

At K26 and K27 a river bend with a radius of 1,5 km is located. Due to the relatively small radius, high flow velocities occur in this area. Corresponding with this the area is very dynamic in terms of sedimentation and erosion. As described before (Figure 3.3) the course of the river has changed. This development in combination with the construction and protection of the road (Via 27) resulted in the sharp curvature of the Magdalena river. Relocation of the road will allow an increase of the radius of the curvature, which could reduce the flow velocities.



(a) Blunt nose chevron at Rondón Island.

(b) Alter division of flow using a longitudinal dam.

(c) Relocating the road (Vía 27).

Figure 8.7: Plan view of ideas for section IV and section V.

9 Evaluation of variants

Planning methods aim to solve problems by identifying solutions and establishing criteria to estimate their impact on various factors and functions in order to support decision-making (Walker, 2000; Lund, 2008). This chapter addresses the various factors and functions and judges the variants on the basis of these. This is done by performing a Multi-Criteria Analysis (MCA).

9.1. Multi-criteria analysis

In order to obtain insight in and analyse the different alternatives, an MCA is used. An MCA extends further than a cost-benefit analysis by addressing non-monetary criteria and assigning weights to different criteria. The implementation of this analysis can be considered as a complex and dynamic process which consists of one engineering and one managerial level (San Cristóbal, 2012). One of the main features of an MCA is that it improves the transparency in decision-making. The first step is to identify the evaluation criteria. The ideas for each sector are then evaluated by giving scores for each criterion. Subsequently, weights are assigned to the evaluation criteria. Eventually, the most promising idea for further research can be identified. An important objective is to minimise shipping risk. Shipping risk is defined as the summed probability of shipping delay times delay costs, including the total probability of water depth decrease times cargo capacity loss costs, integrated over all shipping movements (Rijcken et al., 2012).

9.1.1. Identifying evaluation criteria

The evaluation criteria are divided into 4 categories; hydraulic, financial, environmental and socio-economic aspects. Within the categories various criteria are defined.

Hydraulic Aspects

- Navigation conditions: The need for improvement of navigation conditions is the main reason for the construction of interventions. Therefore, within this criterion the expected draft improvement is evaluated. High flow velocities, especially in the mouth of the river, have a negative influence on the navigation conditions. Hence, flow velocities are considered as well.
- Adaptability: Hydraulic structures can be seen as long term interventions. Long term ideas are supposed to be effective for many years, so the structures must be able to keep up with the dynamics of the river. When the interventions can adjust to differences in river course, a high score will be assigned to this criterion.
- Ideas to improve one aspect invariably affect other aspects of the system. Hence, other river functions should be taken into account. When the expected impact on the river functions requires mitigation, a low score will be assigned. The score on this criterion is highly related to Table 8.1.

Financial Aspects

- Construction costs: For the purpose of this report the costs of each idea are estimated in relation to the other ideas. This does not result in specific values for the costs, but a ranking of the cost estimates. This ranking can be used to assign a score ranging between 1-5. A score of 5 represents a relatively cheap idea, a score of 1 is an expensive idea in relation to other ideas.
- Maintenance costs: In comparing different ideas, it is essential to take the entire lifetime of the structure into account. In this perspective, maintenance costs play an important role. Again, a score of 5 represents low maintenance costs.

Environmental Aspects

- Sustainability: The river has many more functions besides providing room for shipping. Mono-functional ideas that are designed without taking into account the surrounding system are not preferred. Therefore, interventions that serve more than one goal are assigned a higher score. Another important criterion for sustainability is the connectivity of the river. Ecology is enhanced when the river can interact in lateral (e.g. floodplain interaction) and vertical direction (e.g. nutrient cycling).
- Impact on national parks: the condition of the national parks is under pressure. The potential impact of an intervention on the national parks is evaluated. Obviously, an intervention that has a positive impact on the condition of the national parks is preferred and therefore assigned a high score.

Socio-economic Aspects

- Downtime: as the Magdalena river is used for transport, the availability of the navigation channel and port facilities is important. Downtime indicates to what extent the availability is preserved.
- Construction time: besides looking into the final navigation conditions, the construction time is considered. There is a need for better navigation conditions right now, which means that construction time is critical for economic development.
- Possibility for industry: Eventually, the navigation conditions should lead to higher competitiveness of the industry in Barranquilla. Furthermore, when it becomes cheaper to ship goods to Barranquilla, inland transport is stimulated as well.

9.2. Assigning scores

First, the scores for the different ideas are assigned. The score of 1 and 5 represent a negative and positive impact on the situation respectively. The motivation behind the scores can be found in Appendix I.

Table 9.1: Multi-criteria analysis of 4 selected variants without weights.

Criteria	*Current section I*	Adjusting Tajamares	Water Injection Dredging	Sediment bypass	*Current section II+III*	Adjusting bend radius	Relocation Dique Direccional	Longitudinal dam	Fixed bottom layer	*Current section IV+V*	Blunt nose chevron	Longitudinal dam	Relocation Via 27
Hydraulic													
Navigation conditions	2	3	5	4	3	4	4	4	4	3	3	3	4
Adaptability	3	2	4	2	3	2	2	2	2	3	2	2	4
Impact on river functions	3	3	3	3	3	2	2	3	4	3	3	3	4
Financial													
Construction costs	5	3	5	1	5	1	1	2	4	5	3	2	1
Maintenance costs	1	4	2	2	3	3	3	4	4	3	4	3	4
Environmental													
Sustainability	2	3	3	4	3	2	2	3	4	3	4	4	2
Impact on national parks	3	3	3	2	3	4	1	3	3	3	3	3	2
Socio-economic													
Downtime	2	4	4	3	3	4	4	4	4	3	4	3	3
Construction time	5	3	5	2	5	1	1	2	3	5	3	2	2
Possibility for industry	3	3	4	4	2	4	3	3	4	2	2	2	3

9.3. Assigning criteria weights

As mentioned before, MCA makes use of the weights for various criteria, that are derived from values held by different stakeholders. These weights can be assessed by using scorecards and utility functions (Rijcken et al., 2012). In this report, the scores are approximated based on conversations with stakeholders. This means that the weights contain some degree of subjectivity.

9.4. Results MCA

In Table 9.2 the complete result of the scores and weights is presented. For each section a ranking of measures is derived.

Table 9.2: Multi-criteria analysis of 4 selected variants with weights.

Criteria	Weight	*Current section I*	Adjusting Tajamares	Water Injection Dredging	Sediment bypass	*Current section II+III*	Adjusting bend radius	Relocation Dique Direccional	Longitudinal dam	Fixed bottom layer	*Current section IV+V*	Blunt nose chevron	Longitudinal dam	Relocation Via 27
Hydraulic	**0,3**													
Navigation conditions	0,2	2	3	5	4	3	4	4	4	4	3	3	3	4
Adaptability	0,05	3	2	4	2	3	2	2	2	2	3	2	2	4
Impact river functions	0,05	3	3	3	3	3	2	2	3	4	3	3	3	4
Financial	**0,35**													
Construction costs	0,15	5	3	5	1	5	1	1	2	4	5	3	2	1
Maintenance costs	0,2	1	4	2	2	3	3	3	4	4	3	4	3	4
Environmental	**0,1**													
Sustainability	0,05	2	3	3	4	3	2	2	3	4	3	4	4	2
Impact national parks	0,05	3	3	3	2	3	4	1	3	3	3	3	3	2
Socio-economic	**0,25**													
Downtime	0,1	2	4	4	3	3	4	4	4	4	3	4	3	3
Construction time	0,05	5	3	5	2	5	1	1	2	3	5	3	2	2
Possibility for industry	0,1	3	3	4	4	2	4	3	3	4	2	2	2	3
Total score	**1,0**	**2,65**	**3,25**	**3,85**	**2,7**	**3,3**	**2,9**	**2,65**	**3,25**	**3,8**	**3,3**	**3,2**	**2,7**	**3,05**
Ranking		3	2	1	4	2	4	5	3	1	1	2	4	3

Several conclusions can be drawn from the result of the MCA. These results are discussed per section in the remainder of this chapter.

9.4.1. Result Section I

The most promising measure for section I is the implementation of Water Injection Dredging (WID). This is mainly due to the improved navigation conditions, the adaptability and the decreasing downtime. Furthermore, the difference between the total score of the current situation and the total score of WID is large. This is an indication that it is highly favourable to change the current situation for section I. This is in agreement with our system analysis and numerical model, since the navigation issues in the very first kilometres upstream of the river mouth are the most urgent.

9.4.2. Result Section II+III

For section II+III, the most promising measure is the implementation of the fixed bottom layer. This measure scores high on maintenance costs, downtime and possibility for industry. Furthermore, it is striking that the current situation is ranked second. This indicates that the need for river training works in this particular section is limited. Measures such as relocation of the Dique Direccional are not attractive due to the high construction costs. Furthermore, it is hard to predict and quantify the improvement on criteria such as navigation conditions and impact on river functions.

9.4.3. Result Section IV+V

The most striking result for this river stretch is that the current situation has the highest score. Although the difference between the scores is fairly small, this illustrates that river training measures are not obvious for this particular section of the access channel. This section is currently not important for seagoing vessels since the Pumarejo bridge does not allow large vessels to enter this stretch. However, when the new bridge is operational and the old bridge demolished, this section gains importance in the port area of Barranquilla. Therefore it is valuable to bear the analysis of measures for this river stretch in mind.

10 Engagement Plan

The environment in which the sedimentation problems of the port of Barranquilla occur is complex. Therefore when a process approach is used to design a project the use of different process rounds can be very useful. In each round, different substantive subjects will play a role. In this engagement plan, three different process rounds have been identified: an environmental, port development and feasibility round. In each round several stakeholders are involved, whereas stakeholders can be involved in multiple rounds. Whether or not a stakeholder is involved depends on their power and interest on the subject of the specific round. If limited power and interest are identified the stakeholders are not included in that round. However, they should still be informed if important decisions are established during the round. For each round an engagement plan is constructed and illustrated with the use of Power interest grids and engagement tables. More information on the engagement tables can be found in Appendix J.

As previously mentioned in Chapter 4 about the stakeholders, the Observatory is not ideally located in the network of stakeholders to mediate between the different parties. Therefore this engagement plan is aimed at Asoportuaria as they are the ideal entity to act as process manager. This paragraph will firstly discuss the result of the SWOT/TOWS analysis conducted for a future project to solve the sedimentation problems in the port of Barranquilla. Subsequently the engagement plan is presented for each round. This is structured in such a way that first the substance of the round will be explained followed by the interest grids for the current situation and the desired situation after engagement. To conclude the engagement plan of a round the engagement table is presented.

10.1. SWOT analysis / TOWS matrix

In this paragraph the SWOT/TOWS analysis is discussed. SWOT/TOWS can be used to connect both the internal and external factors of a problem to stimulate new strategies for a future project. A table is constructed containing an overview of the strengths, weaknesses, opportunities and threats concerning a future project for the problems in the Magdalena River. The strengths and weaknesses are internal factors, meaning that they can directly be influenced by the problem owner. The weaknesses and opportunities are external factors which cannot directly be influenced.
The four quadrants in the middle define different strategies which are important to keep in mind when designing a future project. The strategies take advantage of strengths on the one hand and minimise the weaknesses on the other hand. By maximising the strengths and minimising the weaknesses subsequently opportunities can be seized and threats can be avoided.
The SWOT/TOWS matrix of the Magdalena River problem is shown in 10.1. The analysis includes only the most predominate factors and strategies and there is the possibility to go further and complement the matrix with more factors and strategies this is however outside the scope of this report.

	Strength:	**Weakness:**
	- Ports of Barranquilla have strategically favorable geographical location - Most stakeholders have same perception on the wish to solve the issue - A project will help the developement of entire development of transport network in Colombia - There is a budget available to conduct a project	- Current political system is still vulnerable for corruption - No local ownership of dredging hopper - Old bridge restricts passage height of larger vessels more upstream - No clear overview of technical data - Unattractictive for international companies to operate in Colombia due to many laws and regulations
Opportunity:	**Strategies that use strengths to maximize opportunities**	**Strategies that minimize weaknesses by taking advantage of opportunities**
- More employement opportunities with increase of industry and port activity - Attracting other business to the city of Barranquilla - Chance to prove the citizens and other countries Colombia is capable to excecute a large infrastructure project succesfully - Many newly educated engineers get chance to work on a large project	- Develope a intregral plan to make multi-modal freight transportation in Colombia cheaper - Make optimal use of the strategic location of the port of Barranquilla to attract investors and other businesses - Involve all the important actors in the process to reach the shared goal	- A new project with newly educated engineers is a chance to make a clear overview of and use all the available technical data - Assess the feasibility of buying a dredge - Lobby to make the legislation on PPPs and dredging more flexible in order to attract more international companies
Threat:	**Strategies that use strengths to minimize threats**	**Strategies that minimize weaknesses and avoid threats**
- Political upheaval due to presidential elections in 2018 - Change in behaviour insurgent groups - Environmental issues due to more industry - Floodings due to unexpected results of the technical solution - Not engough industry due to growth of competing ports (Cartagena and Santa Marta)	- The project should have an elaborate environmental impact study to limit damage to the environment - Allocate sufficient budget to limit environmental damages - Technical solution should be evaluated carefully and all risks (including flooding) should be assessed and mitigated where possible	- Change the focus of Barranquilla as a city to the service industry instead of industrial industry - Invest in buying a dredge and continue to oparte in the same manner - Make sure (international) specialised companies are involved in a future project to minimise possible mistakes - Make sure the process is transparent and fair for every stakeholder to avoid corruption

Figure 10.1: SWOT/TOWS future river project.

10.2. Environmental process round

10.2.1. Substance of the process round

In the environmental process round the substance to be discussed is the environmental implementations of a future river project. Many of the in chapter 4 identified stakeholders are concerned with the environment. Preferably the environment is as less impacted by a future project as possible. However, this might be impossible and in order to come to some consensus on this subject both stakeholders with technical knowledge, the observatory and (international) dredging companies, should be involved. Furthermore, the stakeholders concerned with the environment are involved: citizens, environmental licensing authorities, nature preservationists and users of the riverbanks. Lastly, also Cormagdalena is important in this and every other process round since they will be the party responsible for a future project.

10.2.2. Engagement of different stakeholders

Citizens

Citizens are concerned that a future project might influence their living area. They are however not specifically interested in how the project is shaped as long as their interest are being taken into account. Since there are nature preservationists who actively fight for the protection of the environment, the interest of the citizens is already represented. Therefore the citizens will only be informed and not furthermore involved in the process. Whenever important milestones of decision-making have been reached this will be shared with the public through newspapers.

Cormagdalena

As mentioned before Cormagdalena is the entity legally responsible for the river and its maintenance. With regard to the environment, Cormagdalena does not demonstrate a particularly large interest whereas there power is quite high. In order to make sure Cormagdalena does not use its power to initiate a project without taking the environment into account, it is important to engage them in this process round. Having an open dialogue with the other involved stakeholders can show the threats, as identified in the previous paragraph, of not taking the environment into account. By coming up with solid strategies to prevent this environmental harm multiple parties will be satisfied.

Environmental licensing authorities:

Obviously, the environmental licensing authorities have legally speaking a lot of power with regard to the environmental criteria to approve a project. They are the entities who give out permits. In the past however, there have been incidents that projects already started the construction phase without having the necessary permits in place. This is not the proper way to operate of course. Therefore, by involving the environmental licensing authorities in this round, they can already indicate the minimum criteria a future project needs to achieve and in this way no surprises of permits not being given will occur later on. Since the power and interest of the authorities are already high they do not have to be engaged. During the round it is important to collaborate, thus involve them on the highest level, due to their ultimate power of giving out the permits.

Nature preservationists

Nature preservationists are a group of people who are highly concerned with the environment. Their goal is to limit the environmental damage happening to the world as much as possible. A future project will undoubtedly have an impact on the environment, possibly in multiple ways. Two examples are that a change of the river course course might impact nature on the riverbanks and that an increase in vessels and corresponding industrial activity will increase air pollution. The goal is to disengage this stakeholder by involving them in the initiation and design phase of the project. In this way they can share their concerns and they feel like they are being heard. It is important to consider their opinions seriously and include them in the project when reasonably possible. If this is done in the right way, any resistance of this stakeholder might be prevented during the implementation phase.

Observatory

The observatory is not specifically concerned with the environment, their goal is to provide the necessary knowledge with regard to technical operation of the river. However, they are the party who can assess whether or not a solution will have major impacts on the environment. Therefore, it is important to engage the observatory. This can be done by consulting with them on a regular basis to make sure whatever future solution is chosen also has minimal environmental impact.

Users riverbanks

The users of the riverbanks do not want their living/industrial area to be influenced by a future project. Furthermore, Cormagdalena has contracts with (most) of the users and depending on the specifics of this contract the users have some power to demand the compliance of this contract. By including the users of the riverbanks early on in the process (during initiation and design) they feel appreciated and might be more willing to disengage if the right compensation is offered to them.

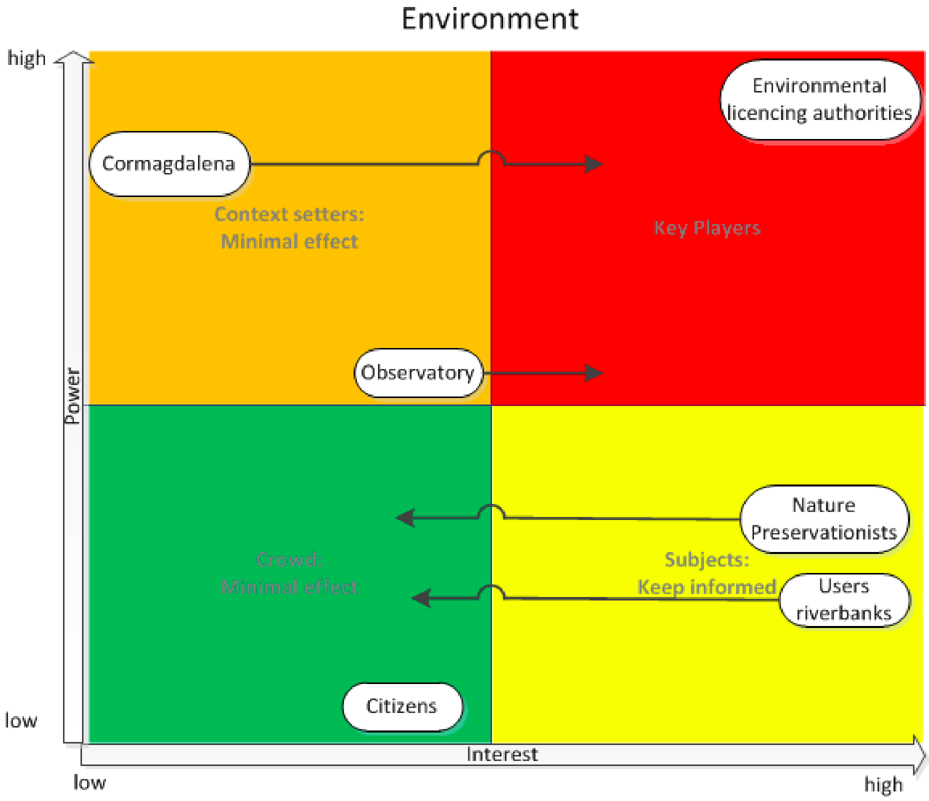


Figure 10.2: Power interest grid for environmental process round.

Stakeholder	Power interest-group: Current	Power interest-group: Engaged	(Dis)engage	Project phase	Engagement level	Frequency	Communication
Citizens			Do nothing	All	Inform	Occasional	After major decision-making
Cormagdalena			Engage	All	Collaborate	Very frequent	Continuously
Environmental licensing authorities			Do nothing	All	Collaborate	Very frequent	Continuously
Nature preserva-tionist			Disengage	Initiation & Design	Involve	Occasionally	During joint stakeholder meetings only
Observatory			Engage	Initiation & Design	Consult	Frequent	During meetings and when needed
Users riverbanks			Disengage	Initiation & Design	Involve	Occasionally	During joint stakeholder meetings only

Figure 10.3: Engagement table for environmental process round.

10.3. Port development process round

10.3.1. Substance of the process round

Currently, Barranquilla is a medium-sized port. However, as some of the stakeholders mentioned during the interviews, several stakeholders (especially port authorities) would be interested in expanding. A key element in doing so is the navigability depth of the channel to the ports. This will allow larger sea-going vessels to navigate the access channel and would therefore improve the competitiveness in relation to Cartagena. An ongoing research conducted by INVIAS is already investigating the technical and financial feasibility of such a project. However, by including this subject as a substantive part of the process, stakeholders can find out in which way they might benefit from future cooperations. Ideally, different issues can be coupled in such a way that multiple stakeholders are satisfied. It is important to consider this long-term development because if many stakeholders have the ambition to develop the port into a main competitor of Cartagena, it is not feasible to do so after several measures have been taken already.

10.3.2. Engagement of different stakeholders

ANI

Since the expansion of the port area would cost a lot of money, it is valuable to take into account which parties will play a role in financing. The financial feasibility is now researched by INVIAS. ANI is one of those important parties in this process of expansion because they are one of the parties who will provide funds for the project. Therefore, it is important to keep them involved in the whole process so they know what is going on. This can best be done already from the beginning.

Cormagdalena

Obviously, Cormagdalena is an important stakeholder in the future development of the port area. The concessions for port operation and land is given out by Cormagdalena and they are the party responsible for making the entry channel accessible for ships. In the current situation however Cormagdalena is not engaged yet to further deepen the entry channel in Barranquilla. They are focused on maintaining the current situation as it has been for several years, accessible for medium-sized sea-going vessels. The goal of this process round is however to look into the possibilities for future port development. This includes attracting the large sea-going vessels. Cormagdalena's perception towards such a development is currently not positive, they regard Cartagena as the main port on the Caribbean coast. Therefore Cormagdalena will have to be engaged during the process round port development.

DIMAR

DIMAR is also an important stakeholder in the future development of the port area. They advise the National Government on all topics related to international maritime instruments and regarding to the sedimentation problem in the Magdalena river this also includes the authorisation and operation of dredgers which is of great importance in expanding the current port area. They posses a lot of knwoledge of the river mouth, this knowledge can be of great use. Therefore, this party should be consulted on occasional basis and more in the planning and construction phase of the whole project.

Invias

INVIAS is as ANI one of the parties who will provide funds for the project. Therefore their power is high. By involving them more frequently their interest can be increased because they will have more opportunities to share their opinion about the substance of the expansion of the current port area. They will only provide the funds if they agree upon what is decided so it is important to engage them.

Observatory

The role of the observatory in this round is limited. As in every other process round they have fairly high power because of the technical knowledge no other stakeholder possesses. However their interest is medium because they are not specifically interested in the further development of the port. Therefore the observatory will not be engaged in this round, they will be consulted whenever more technical knowledge is required during the process.

Office of port affairs
The office of port affairs has high interest but less power. They are interested and curious about the effects of building a new superport outside the mouth of the river for the ports who are already operating now. To get support from them it is important to involve them frequently, also in the beginning of the project. They already have a lot of experience with keeping a port running.

Port associations
The port associations have a high interest in the future development of the port of Barranquilla. A development of the port would mean an opportunity for growth of their operations which in turn translates itself into an opportunity to make more revenue. The power they have to accomplish the development by themselves is however quite limited. By working together with the other stakeholders and sharing their wishes and interests they are engaged to be key players in this round.

Shipping companies
The shipping companies initially do not have any interest or power. However, it can be valuable to engage them during this round. By gaining their attention and interest a discussion can be posed whether or not they see the need or possibility for the port of Barranquilla to compete with Cartagena. They possess a lot of knowledge on the market situation which could be very useful in this process round.

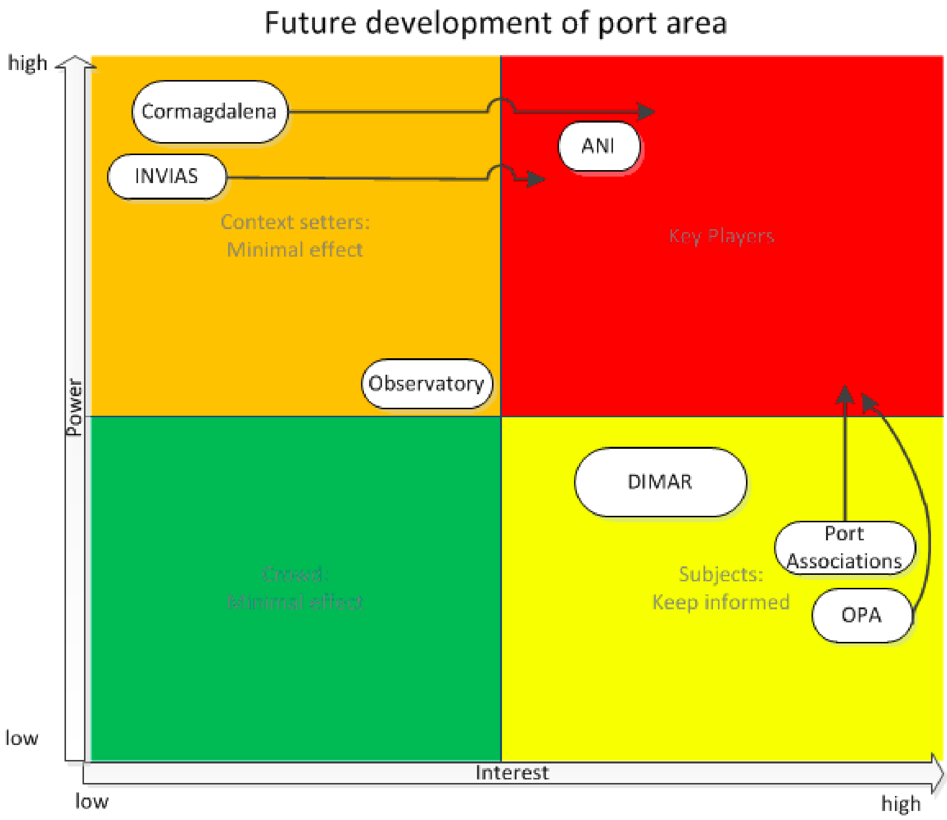


Figure 10.4: Power interest grid for future port development process round.

Stakeholder	Power interest-group		(Dis)engage	Project phase	Engagement level	Frequency	Communication
	Current	Engaged					
ANI			Do nothing	Initiation & Design	Involve	Frequent	During meetings and when needed
Cormagdalena			Engage	All	Collaborate	Very frequent	Continuously
DIMAR			Do nothing	Planning & Construction	Consult	Occasional	Approach when knowledge needed
INVIAS			Engage	Initiation & Design	Involve	Frequent	During meetings and when needed
Observatory			Do nothing	Initiation & Design	Consult	Occasionally	Approach when knowledge needed
Office of Port Affairs			Engage	All	Involve	Frequent	During meetings and when needed
Port associations			Engage	All	Involve	Frequent	During meetings and when needed
Shipping companies			Engage	Initiation & Design	Consult	Occasional	During joint stakeholder meetings only

Figure 10.5: Engagement table for port development process round.

10.4. Feasibility process round

10.4.1. Substance of the process round:

After some important decisions have been made in the two previous rounds it is important to consider the feasibility of different proposed solutions. A solution should be both technically and financially feasible. Financial feasibility is especially critical when the support of private investors is needed. By discussing these issues with the most interested and powerful stakeholders, misunderstandings about a future project can be prevented. The stakeholders involved in this round are therefore: ANI, Cormagdalena, National Planing Department, (international) Dredging Companies, Invias, Observatory and private investors.

10.4.2. Engagement of different stakeholders

ANI

ANI is one of the parties who will provide funds for the project. Their interest is therefore high. They are however not involved in the design of the project since Cormagdalena has this authority. Involving ANI and thereby increasing their power will create the opportunity to share their opinion about the substance of a future project. Including how they think money could be best spent.

Cormagdalena

Cormagdalena can be regarded as a key player during the feasibility process round because they will play a very important role during the implementation of a future project. Together with the process manager, they should take the lead in this round by involving the other stakeholders. An open conversation about the ideas on how to realise a future project in a feasible way of those stakeholders should be the goal of this process round. The knowledge and resources of those stakeholders are essential to a feasible project.

Dredging companies

Dredging companies are important in this round due to their technical knowledge on dredging work. Whatever solutions are chosen, the plan will most likely include dredging practices to secure sufficient depth in the access channel of Barranquilla. How this can be done in a efficient and feasible way can be discussed with the dredging companies. This knowledge can be gained through consultation and their is no need for further engagement of the dredging companies.

DNP

The national planning department is an important stakeholder because the power they have comes from the power to disapprove the plans which ultimately will result in the project not getting sufficient governmental funding. By involving the DNP they can share their thoughts on how the project should be set up and what their criteria are for testing and evaluating a project plan.

Invias

For Invias the same reason on why they should be involved applies as to ANI; they provide funds for a future project and will only do so when they agree upon the project terms set up by Cormagdalena.

Observatory

The observatory is again important because they have the technical knowledge of what will work as a solution and what won't. By consulting them information about the suitability, sustainability and feasibility of a project idea will be gained.

Private investors

The private investors are next to the government important resources for funding of the project. By involving them in this round they can share there thoughts and interest in a future project. When these thoughts are taken into account when designing the project the chances of the project having sufficient funding are higher.

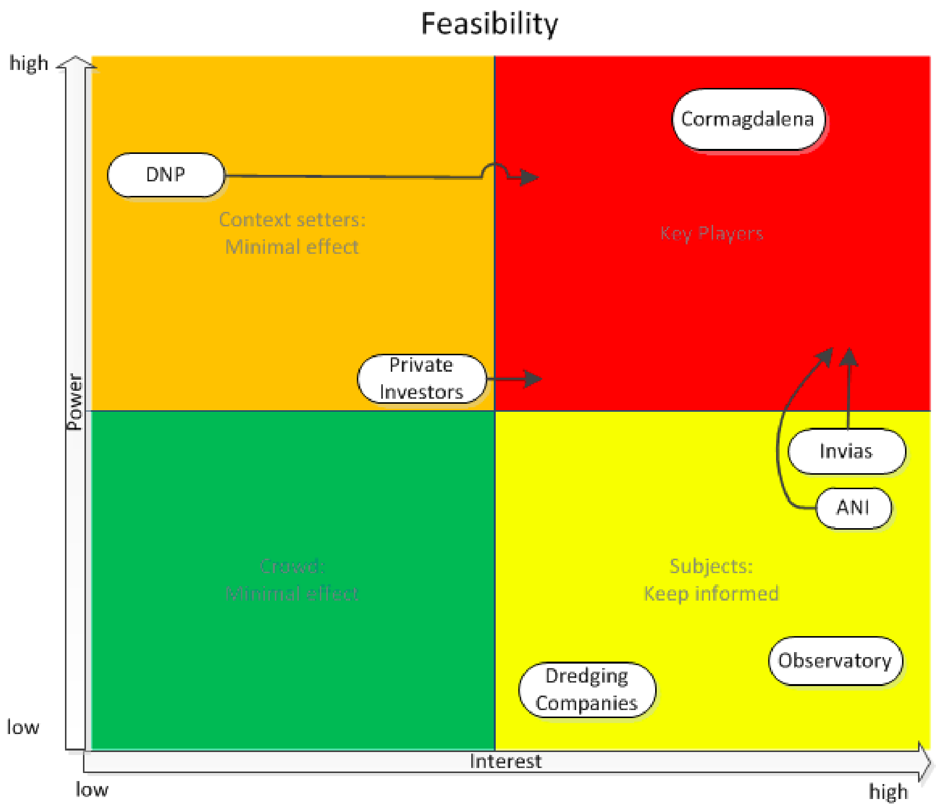


Figure 10.6: Power interest grid for the feasibility process round.

Stakeholder	Power interest-group		(Dis)engage	Project phase	Engagement level	Frequency	Communication
	Current	Engaged					
ANI			Engage	Initiation & Design	Involve	Frequent	During meetings and when needed
Cormagdalena			Do nothing	All	Collaborate	Very frequent	Continuously
Dredging companies			Do nothing	All	Consult	Occasional	Approach when knowledge needed
DNP			Engage	Initiation & Design	Consult	Occasional	During stakeholders meetings only
INVIAS			Engage	Initiation & Design	Involve	Frequent	During meetings and when needed
Observatory			Do nothing	Initiation & Design	Consult	Occasional	Approach when knowledge needed
Private investors			Engage	All	Involve	Frequent	During meetings and when needed

Figure 10.7: Engagement table for feasibility process round.

10.5. Conclusion engagement of stakeholders

The most powerful party in the environmental process round are the environmental licensing authorities. If they don't provide the license, the whole project will be delayed or even cancelled. Therefore, there has to be continuous communication and collaboration with them. If the focus shifts more to the port development process round the involvement of the environmental licensing authorities is not that necessary anymore. The parties Cormagdalena and ANI have a lot of power because they give permits and money. They can use this to put pressure on decision making. To avoid such an event it is important to involve and collaborate with those parties. The last round, the feasibility process round, describes both the technical and financial feasibility. Both sides should be taken into account to bring the whole project to a success. So using the knowledge of the involved parties in combination with taking the budget into account what can be spent. What can be said overall is that Cormagdalena plays a role in every round. This is because they give out the permits in the port area. Also the Observatory should be consulted in every round since they have a lot of technical knowledge no other stakeholder possesses. If parties feel they are heard, they won't demonstrate that quickly, which contributes to a smooth running of the project.

V

Conclusion, discussion and recommendations

11 Conclusions

In this project, sedimentation in the mouth of the Magdalena river has been studied from a multidisciplinary perspective. Processes influencing sedimentation in the river mouth have been identified. Subsequently, these processes were further investigated with a Delft3D model. The socio-economic context of the research area has been analysed in order to find out how a future project to improve navigability in the mouth of the Magdalena river should be managed. Furthermore, several river training works have been proposed that can be implemented to improve navigability. These ideas have been evaluated on the basis of a Multi-Criteria Analysis, such that the most promising ideas for further research could be identified.

11.1. Processes influencing sedimentation

Both natural and anthropogenic influences play an important role in the sedimentation in the mouth of the Magdalena river.

11.1.1. Natural influences

The most important natural influences are high discharge variability, stratification and wave action. The high variability in discharges is, next to seasonal influences, mainly caused by the El Niño-Southern Oscillation (ENSO). During El Niño periods, decreasing precipitation leads to low flows in the Magdalena river (5500 m^3/s on average), whereas discharges are high (8750 m^3/s on average) in La Niña periods, when there is a large amount of rainfall (Restrepo and Kjerfve, 2000). A high variability in discharge will lead to patterns of sedimentation and erosion.

Stratification is caused by the interaction between salt and fresh water. Dense sea water intrudes in the river mouth along the bed, whereas the river discharge flows towards the sea on top of this. During low river discharges (3000 m^3/s), the salt wedge can intrude as far as 20 km into the mouth. This leads to low flow velocities near the bed that are directed upstream, making the reach over which salt intrudes susceptible to sedimentation.

The wave environment at the project location is characterised by swell waves with a significant wave height of 2.2 m. The breaking of these waves induces an alongshore sediment transport, that is directed from east to west along the Caribbean coast of Colombia. In front of the river mouth, the water is locally deeper, leading to a decrease in sediment transport and the formation of bars in front of the entrance.

11.1.2. Anthropogenic influences

The main anthropogenic influences on the river system are direct interference in the form of river training works and changes in land use in the basin of the Magdalena river. With the construction of two breakwaters (Tajamar Occidental and Tajamar Oriental) in 1936, the mouth of the Magdalena river was fixed in its current position, whereas its natural tendency is to move continuously along the coast. This has led to lateral shifting of the main channel upstream of the mouth. Furthermore, several groynes have been constructed along the first 20 km of the river, with the intention to fix and deepen the flow-carrying section and thus improve navigability. Dredging activities are carried out several times a year. By dumping the dredged material in the canyon just offshore of the mouth, sediment is permanently taken out of the system. Deforestation and the development of agricultural and mining activities have led to in increase in the sediment load of the Magdalena river over the past decades.

11.2. Socio-economic project control

In this report several analyses have been conducted to gain insight into the non-physical characteristics of a future river project. One of these analyses was a stakeholder analysis in which the most important stakeholders have been identified. In a future project, from an early stage onward, it is important that the critical stakeholders are managed closely. It can be concluded that in the overall project the following stakeholders are critical to a successful project: DIMAR, Invias, port associations, Cormagdalena and dredging companies. This does however not mean that the other stakeholders should not be taken into account. A more elaborate engagement plan was constructed. In this plan a crucial role is set for Asoportuaria, since this is the ideal party to manage the stakeholders during the process of setting up a project.

Another important socio-economic aspect is how a future project is set up. By analysing the previous failed public private partnership (PPP) in combination with interviews with important stakeholders, it was possible to list several success factors for setting up a PPP. The hypothesis which followed from the research is that corruption, political stability and openness for change might influence the success of setting up a PPP. In a country like Colombia, having a difficult history regarding corruption, it is deemed extremely important that the process of setting up a PPP contract is as open and transparent as possible. The same applies to political stability, since a PPP is based on a partnership between public and private parties a strong government with a clear vision might help in making the PPP successful. Or the other way around, a very unstable government will result in an unsuccessful PPP contract. Lastly, the openness to change is a difficult aspect. In order to change the status quo a strong party needs to take the lead, whereas in the case of the maintenance and operation of the Magdalena river the responsibilities are extremely divided over many parties, making it hard for one party to take the lead.

11.3. Promising ideas

From the physical analysis it can be concluded that the Magdalena river system is highly dynamic. Inevitably, one should be critical about the implementation of river training works. If interventions are considered necessary, the following two ideas are the most promising. The ideas are developed for each section of the river stretch (Section 3.3).

11.3.1. Water Injection Dredging (Section I)

The most urgent issue of sedimentation occurs in the mouth of the river. The conclusion can be drawn that the most promising idea for implementation in the river mouth is Water Injection Dredging. This idea excels in the multi-criteria analysis on the improvement of navigation conditions, construction costs and adaptability. Since dredging is a short-term solution, a significant drawback is the cost of maintenance.

11.3.2. Fixed-bottom layer (Section II+III)

The purpose of the fixed-bottom layer is to increase the width with sufficient depth in the river bend (K14). This idea is the most promising because it directly decreases the cross-sectional area and fixes the bed in the outer bend so the inner bend will erode due to the increased velocities. Leading to a wider navigable reach. The fixed-bottom layer has limited construction costs and is not expected to affect other river functions in a rigorous way.

11.3.3. No river training works (Section IV+V)

For these sections river training works are for several reasons not obvious. The limited depth and the puente Pumarejo prevent seagoing vessels from reaching this stretch. This stretch will gain interest when the new bridge is operational and the old bridge removed. However, these sections can be improved to facilitate the barges that are navigating upstream. Furthermore, since the sedimentation processes do not stick to the sectorisation made in this report, intervening in this part will result in changes to other stretches. Nonetheless, the conclusion can be drawn that other sections are far more interesting for river training works.

When further investigating these ideas, it is important to bear in mind the various process rounds, discussed in Chapter 10. These process rounds propose which stakeholders should be included in which phase of the project. As stressed throughout the whole report, it is essential to carefully manage stakeholders in complex environments. Otherwise, it is hard to determine the feasibility of the project and the values of the stakeholders might not be represented in the design.

12
Discussion

This chapter describes the limitations and sources of error and uncertainty of the conducted research. The elements of the research are each discussed separately, in the sequence in which they appear in this report.

12.1. Data

Not only is the input of the Delft3D model largely based on measurements and observations, also its output is judged and calibrated by comparison with observations. Therefore, errors, uncertainties and gaps in the data directly lead to a decreasing model performance. It is expected that a large part of the disagreement between model and observations is due to this effect, although this contribution is difficult to estimate.
Measurements never represent reality exactly, but some data have larger uncertainties than others. From all the different data sources (see Appendix B for an overview) the measurements of discharges and water levels is estimated to introduce the largest errors, followed by sediment characteristics, bed topography and salinity measurements.

Discharges and water levels
Discharge measurements at the Calamar gauging station were used for the hydrodynamic calibration (Section 6.5.1) in combination with water level measurements at Pimsa, which is located at the upstream boundary of the model. Thus it is implicitly assumed that the discharge at Pimsa is equal to the discharge at Calamar, although these stations are almost 80 km apart.
Furthermore, a relation between discharge measurements at Pimsa and water level measurements at Calamar was used to generate daily discharge time series at Pimsa as input for the model. Thus, the discharge input is not based on direct measurements, which introduces errors in the input.
Yet another relation, this time between the water levels at Calamar and Pimsa, was used to generate water level records at Pimsa in order to calibrate the water levels simulated with Delft3D. Besides the fact that also this calibration is not based on direct measurements, the data on which this relation is based is not available to us. Therefore the agreement of this relation with measurements is unknown, which introduces uncertainty in the calibration.
As each data source has its own errors, using these different sources combined can lead to error accumulation.

Sediment characteristics
There is not much recent data available concerning sediment characteristics in the river mouth. On top of that, the available data shows a lot of scatter. The morphodynamic calibration is performed by changing the D_{50} of the sediment fraction, which is model input. These values are based on measurements of the D_{50}. Therefore scatter in these measurements introduces model uncertainties.

Bed topography
Several recent bed topography surveys are available, but most of these surveys only cover the navigation channel. Thus, other data sources had to be used in order to obtain a bathymetry covering the complete model grid, including the offshore part. As these data originate from different years, the complete bathymetry does not represent reality at one moment in time. Furthermore, within surveyed areas the data resolution is often smaller than the model grid resolution. To obtain complete coverage averaging procedures had to be carried out. Large gradients and local unevennesses are therefore not represented well by the model.

Salinity
Only two salinity measurements are available and these are carried out during an extremely low discharge

event. Therefore, no salinity data for average conditions is available. Therefore, the salinity calibration had to be carried out on an extreme event, which introduces uncertainty in the model performance for average salinity conditions.

12.2. Stakeholder and PPP analysis

Many interviews have been conducted, with the most important stakeholders. However, the length and depth of these interviews varied and therefore a distorted picture of some stakeholders might have been drawn. This was partly due to a language barrier. Also not all stakeholders have been interviewed because of language barriers again and the limited time available. Nevertheless the interviews conducted were very useful, full of information and indicated the clear differences between certain stakeholders.
The methods which have been used to conduct the stakeholder analysis are not the only methods available. There are many other ways to conduct a stakeholder analysis, however the used methods are widely used and are established as good ways to explore the stakeholder environment.
Furthermore the analysis of the previous PPP was done with limited information, since none of the stakeholders interviewed seemed very interested to talk about the past too much. They were more focused on how to solve current problems. Also other parties who were involved before the contract was given to Odebrecht were, other than indicating it was too risky, not eager to go into further detail with regard to the whole process.

12.3. Model

Because of the limitation of the Delft3D model with respect to the modelling of morphodynamics in a Z-model, the choice was made to run a 2D simulation with morphology and a separate 3D simulation with salinity. The 2D model cannot reproduce the velocities and bed shear stresses correctly over the area in which the salinity would intrude. This means that the results of the 2D model will only be valid upstream of the furthest point of salinity intrusion at a certain discharge. So only a relative analysis between the simulated discharge scenarios is possible.
Besides this fundamental limitation to the model there are also uncertainties and limits to the parameters used. For the σ and 2D model a median grain size of 200 μm is chosen to represent the whole bottom of the model. This is an assumption which is based on the measurements in the mouth (Ortega, 2008). In order to model the longshore transport and influence of waves on sediment transport in the mouth, a more detailed modelling of the sediments along the beach is necessary. With the σ-model the velocities along steep bottom gradients are distorted (Deltares, 2017). The flow velocities are directed downstream a steep gradient due to numerical artefacts. This can lead to an overestimation of the sediment transport and as mentioned in 6.5.2 to more mixing of salt and fresh water. But also in the river the accuracy of sedimentation and erosion simulations can be improved by investigating the bed composition of the Magdalena river in more detail and dividing it into multiple sediment fractions in the model.
The banks of the river in the model are not erodible. This means that in reality banks can erode but in the model only sediments are picked up at the bottom. Especially in the narrow bend at km 26.5 the bottom erosion is overestimated in the 2D model. Furthermore, there has been no calibration on the cross-sectional steepness and spiral flow. Also the island at the location of the puente Pumarejo is eroding rapidly. This is not modelled in the Delft3D simulations. As a result from this the sediment input consists only of the equilibrium input at the upstream boundary and the locally picked up sediment from the bottom. Bottom erosion can therefore be overestimated, because in reality sediment can be supplied from bank erosion.
Although the groynes are modelled in the form of thin dams at grid cells their location and exact geometry are different from reality. This means that steep bottom gradients can lead to large bed level changes in the model, while the actual bed level changes are smaller.

Finally, no sensitivity analysis or validation of the model was carried out. This poses large uncertainties regarding the performance of the model for different conditions.

12.4. MCA

The MCA provides insight in the considerations of the implementation of river training works. It should be noted that the current MCA serves as an indicator of promising measures for further research. In this stage of the project the MCA can not be used as a tool for direct decision-making since the input is fairly limited. In this discussion the following steps of the MCA deserve special attention:

- **Assigning scores**: The score for each criterion is based on the performance of the measure. In this stage of the project, approximations of the performance are used. When the modelling becomes more sophisticated, the expected performance will change. Therefore, it is valuable to reassess the scores when more information becomes available;
- **Assigning weights**: The weights form the backbone of the MCA. One should realize that altering of the weights highly affects the total score of the MCA. As explained in section 9.3 the weights represent the values that are held by the stakeholders. The weights can be defined more accurately by using systematic methods. In this report the weights are only based on conversation with some key stakeholders. This input is limited, therefore the MCA can be strengthened by approaching more stakeholders;
- **Sensitivity analysis**: In order to strengthen and improve the robustness of the results of the MCA a sensitivity analysis should be carried out. Systematic varying of the scores and the weights might indicate weak links in the MCA. This report does not contain a sensitivity analysis, which means that the robustness can not be guaranteed.

In this report, the solutions are evaluated separately. When more interventions are considered necessary, the interaction between those solutions becomes an essential component that should be taken into account.

12.5. Engagement plan

It is important to keep in mind that the engagement plan is a guideline and no absolute truth or the only way to conduct efficient process and stakeholder management. Ultimately stakeholders might act differently than anticipated and therefore the engagement plan might be less successful than expected. Another limitation of the engagement plan is that it is based on current points of view of stakeholders. It is important to realise that those views might change over time. Besides this, new stakeholders might arise in the future, that are currently not taken into account.

Furthermore it should be noted that the choice was made to use a 2-dimensional power-interest grid. This neglects the fact that interests toward a future project can be both positive or negative. However, the decision not to add this extra dimension was made for reasons of clarity. In the explanation on how to deal with the stakeholders themselves (Chapter 10) it is discussed what the likely behaviour and view of the stakeholders is.

13 Recommendations

In this chapter recommendations for further research and stakeholder collaboration are given. Recommendations are categorised as general, related to stakeholders and model recommendations.

13.1. General

In this section general recommendations are discussed. These recommendations are more oriented to further improve the coordination in river management. The following general recommendations can be made:

- **Long-term plan**: Currently, plans for dredging maintenance are made ad hoc. In river engineering it is important to develop a long-term plan. By doing so, it would be easier to improve the current situation based on financial, ecological and navigation criteria. Incorporation of a long term perspective will result in different design choices. For example, on the long term it may be cost effective for involved parties to purchase a dredging vessel instead of hiring other companies.
- **Dynamic system**: As the Magdalena river is very dynamic, both in terms of river course and sediment processes, it is important to consider the Magdalena River from a dynamic perspective. This means that every analysis and solution should be evaluated with a complete range of possible scenarios, including the effects of climate change. Monitoring the river system helps to develop understanding of the river system. Especially, monitoring can help in assessing the performance of river training works and other anthropogenic consequences.
- **Analyse other limitations**: In the current situation draft forms the principal limitation on navigation. When the draft is increased, other limitations will enter the spectrum. To prevent undesired surprises, it is recommended to look into other limitations as soon as possible. Subjects that deserve special attention are; the instability of hydraulic structures (e.g. quay walls, groynes, breakwaters) and the turning area for ships.
- **Monitoring infrastructure**: Over time, several hydraulic structures have been built in the river. It is very important to keep track of the status of those structures. Ad hoc maintenance or replacement of infrastructure is unnecessarily expensive. Therefore, monitoring provides essential input in the development of a long-term sustainable river management plan.

13.2. Delft3D model

The model performance can easily be enhanced by improving the data used for input and calibration. In order to do so, it is worthwhile to set up campaigns to frequently measure discharges and water levels at Pimsa, which is located at the upstream boundary of the model. Improved measurements of sediment characteristics, bottom topography and salinity would also benefit model performance.

The model set-up can be improved by looking into a more accurate representation of the bed material by making multiple sediment fractions. This will lead to a more accurate sedimentation and erosion simulation. Also a different numerical model might be considered that can capture both the sedimentation and salinity intrusion together. When the aim is to capture more of the dynamics of the banks and islands in the river the grid should be extended and the erosion resistance of the banks should be included.

In order to get a quantitative analysis of dredging works the model should capture an accurate representation of both the sediment at the bottom and the salinity intrusion and wave influences at the mouth.

In order to understand more about the sedimentation processes in the mouth it would be useful to also calibrate the alongshore sediment transport due to waves. Currently this is just done qualitatively by using a wave climate and a single grain size.

A sensitivity analysis and a model validation should be carried out in order to assess the model performance for different conditions.

13.3. Related to stakeholders and management

The research of Koppenjan (2003) in combination with the cultural dimensions theory by Hofstede (2011) played a very large input for the hypotheses about possible success factors for setting up a PPP in Colombia. It would be very valuable to first test these hypotheses in several PPPs in Colombia, both successful and unsuccessful ones, in order to see if the hypotheses can be accepted. This falls however outside the scope of this research and would therefore be a good input for future research on the management of PPPs. Another point that came forward was the degree of corruption and how this contributed to the decision making in the whole situation. This is a topic which is also good input for future research and what can be valuable input for engagement plans in the future.

13.4. Further research on river training works

During this research it became clear that the Magdalena river is a very dynamic system which is difficult to comprehend in a model. Additionally, flow and structure interaction is hard to predict. This combination increases the need for further research on the performance of river training works in the access channel of the Magdalena river. Since many stakeholders are involved in the development of the Magdalena river, the exchange of information and further research should be facilitated. This task could be performed by Observatorio del Río Magdalena.

13.5. Recommendations for collaboration

During the performed research a lot of parties have been interviewed. However, these interviews were conducted separately from each other. What can be useful in order to pursue an integral approach is to invite all stakeholders around the table referring to the process rounds. New stands might thus emerge or solutions might be presented that had not previously been considered. Performing the engagement plan will contribute a lot to finding out how to collaborate with all the parties and to finding a solution that is supported by the majority. In order to do so parties will have to make compromises. It is important that these compromises are made fairly.

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A

Physical aspects Magdalena river

A.1. Major physical changes in Magdalena River mouth

Changes in a river are constantly happening, this is also the case for th Magdalena river for the last 5 million years. Figure A.1 presents the major changes in the river delta that happened during this period. In the early days, the river followed the course of the Ranchería and Cesar river, resulting in the river mouth being located at Riohacha [1], more eastward of the current position. Due to tectonic movement and the rise of the Sierra Nevada near Santa Marta, the river migrated west to Ciénaga at the western side of the mountains [2]. It continued migrating west to Galerazamba, through the channels of the swamps of Totumo, Tocagua, Luruaco and the reservoir of El Guájaro [3]. Although it has not been proven, it is assumed that over the last 700,000 years, the river varied between Galerazamba [3], the bay of Barbacos [4] and Barranquilla [5-6], until the mouth was fixed at its current position [6] (Ortega, 2008).

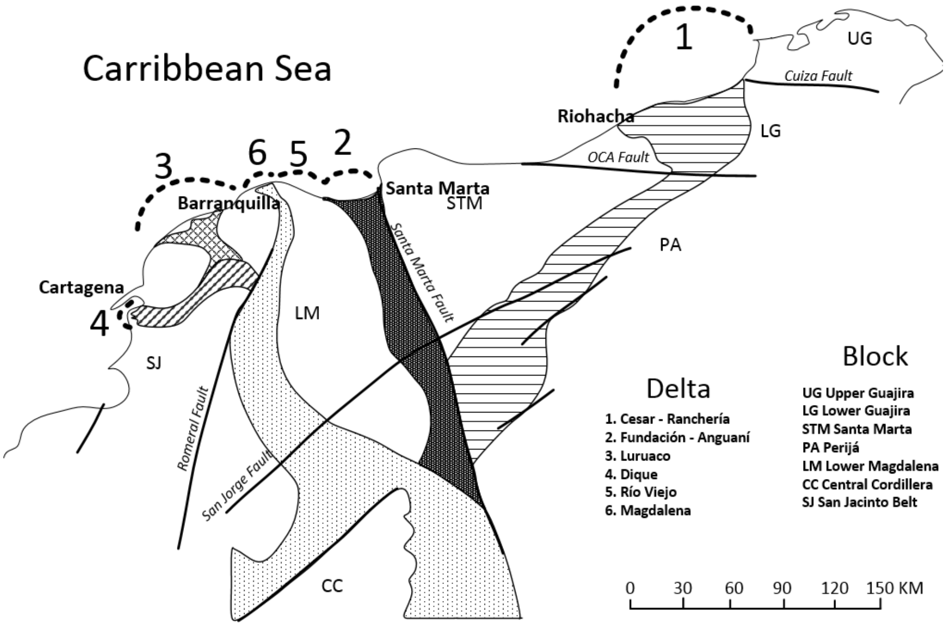


Figure A.1: Shifting of the Magdalena river delta over the past 5 million years (after Llinás et al. (1983)).

At the location of Ciénaga [2], where in previous days the river flowed into the ocean, the Ciénaga Grande de Santa Marta has formed as a part of the river delta. This ecological system with a great biodiversity, consisting of large lakes and mangrove forests, is a Ramsar Site (Ramsar Sites Information Service, 1998) and a national park (PNN, Parque Nacional Natural). To survive, mangrove forests are dependent on the combination of salt water intrusion from the ocean and fresh water supply. In earlier days, the Magdalena river provided this fresh water, but at present day the fresh water discharge into the Ciénaga has dropped to only 200 m^3/s. As a result of this lack of fresh water, parts of the forests are in bad condition and trees are dying. An additional problem occurs during El Niño years. In these years, the discharge in the river drops, with a resulting drop in the groundwater table in the adjacent Ciénaga. This makes it even harder for the trees to reach the fresh water, having tree mortality as a result.

For millions of years, the Magdalena river has provided sediment to the river delta from Riohacha to Cartagena due to the changing position of the river mouth. The sediment was picked up by the longshore current and transported westward along the coast. In 1936, 2 breakwaters were built at the coast in Barranquilla to fix the river mouth and stabilise the access channel to the port of Barranquilla, see also Figure C.1. By fixing the river mouth, a problem arose at the coastlines east and west of it. The river sediment is now transported to the mouth at Barranquilla, where a large part of it disappears in the underwater canyon in front of the coast, see Figure A.2 The canyon has a depth of over 100 meters, so all of the sediment disappears in it. Just a small part in picked up by the longshore current in westward direction along the coast. The lack of sediment at both sides of the mouth causes an erosion of the coastline at the Ciénaga Grande (east) and Ciénaga Mallorquin (west) due to the alongshore current. The retreat of the coastline varies between dozens and several hundreds of meters and causes erosion problems along the Ruta Nacional 90 (RN90), the highway between Barranquilla and Santa Marta (Randazzo et al., 2015).

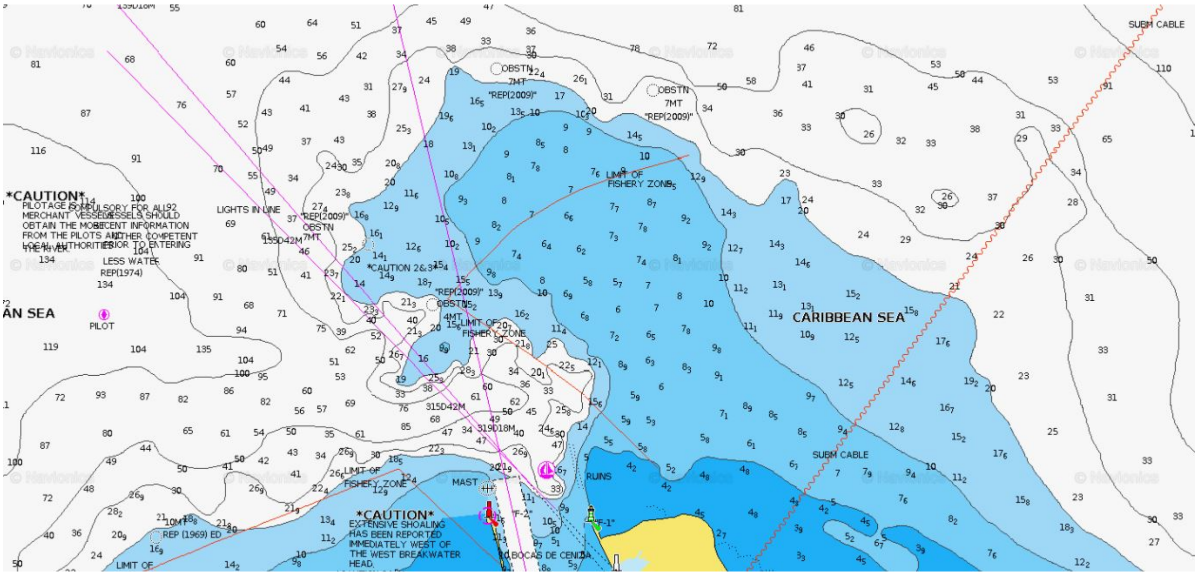


Figure A.2: Canyon (in white) just offshore of Bocas de Ceniza (Navionics, 2017).

Figure A.2 shows the sand spit in front of the mouth, formed by the longshore transport from the east. Due to the limited water depth at the location of the spit, navigation into the Magdalena river is limited to the approach channel in north-west direction.

A.2. Resistance to erosion

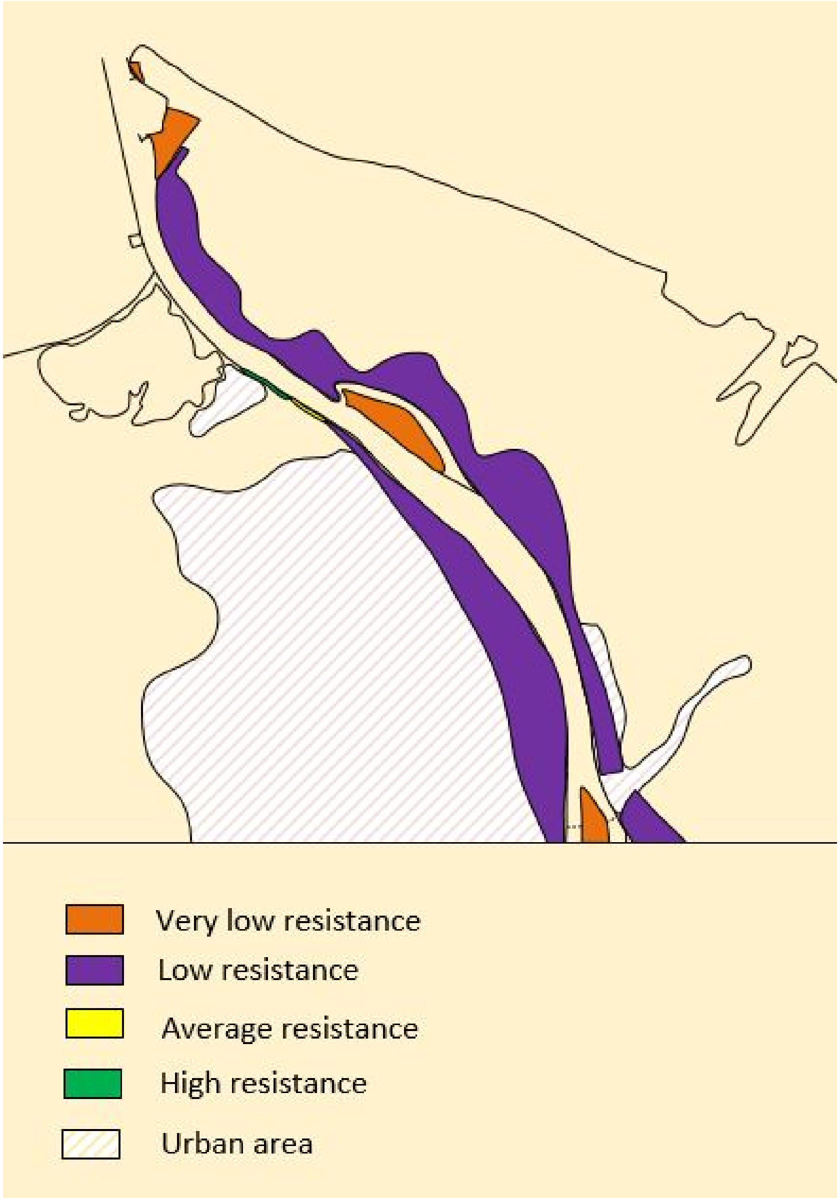


Figure A.3: Map of sediment resistance to erosion (K0-K22) (after Ortega(2008)).

A.3. Changes in river configuration section K22-K30

Every year, a satellite image is made of the Magdalena river. With the software Earth Engine is it possible to observe the changes in the river configuration during the period of 1984 till now. The sections K22 and K30 underwent important changes during some years of this period. The figures presented here show the change from 2000 till 2016 for K22 and the change from 2004 till 2016 for K30.

(a) Satellite image K22 2000

(b) Satellite image K22 2008

(c) Satellite image K22 2016

Figure A.4: Satellite images K22 (2000-2016) (Earth Engine 2017).

(a) Satellite image K30 2004

(b) Satellite image K30 2008

(c) Satellite image K30 2012

(d) Satellite image K30 2016

Figure A.5: Satellite images K30 (2004-2016) (Earth Engine 2017).

B
Data description

In this report, different kinds and sources of data are used. This appendix describes the parameters and their values that are used throughout the technical report. Furthermore, the processing of the data is discussed. The output of this chapter serves as the input for the numerical modelling, which is discussed in Part III.

B.1. Discharges and water levels

The discharge, and with that also the water levels, of the Magdalena River are highly variable. To measure this, several measurement stations are located along the Magdalena river. For this project, the stations located in Puerto Pimsa and Calamar (Figure B.1) are important. These stations are located at 38 km and 115 km upstream of Bocas de Ceniza respectively.

Figure B.1: Location of the gauging stations Calamar and Pimsa (Google Earth, 2015).

B.1.1. Data for model set-up and calibration

From 2006 to 2012, discharge measurements at Calamar were taken on the same days as water level measurements at Pimsa. Plotting these two against each other results in Figure B.2. These measurement series are used for the hydrodynamic calibration (see Section 6.5.1).
On the basis of discharge measurements at Pimsa and water level measurements at Calamar, that were taken about twice a month between 2006 and 2014, a relationship between these two variables can be established (Figure B.3). Because there are only a few discharge measurements at Pimsa, but daily water level measurements at Calamar from 1967-2015, this relationship was used to create daily discharge time series at Pimsa. These generated time series are used as input in the Delft3D models, see Chapter 6. Since the bathymetries used in the model are from 2012 (see Section B.2), especially the generated discharge time series of 2012 following the relationship mentioned above, is important. This time series is shown in Figure B.4.
Using yet another relationship between the water level at Calamar and the water level at Pimsa, the water levels simulated with Delft3D can be calibrated, as shown in Figure 6.5 and 6.6 in Section 6.5.1.

B.1.2. Discharge variability

On the basis of the water level measurements at Calamar (1967-2015), several daily discharge exceedance levels were calculated (Figure B.5). The spreading of these levels clearly shows the high variability of the river discharge over the years.

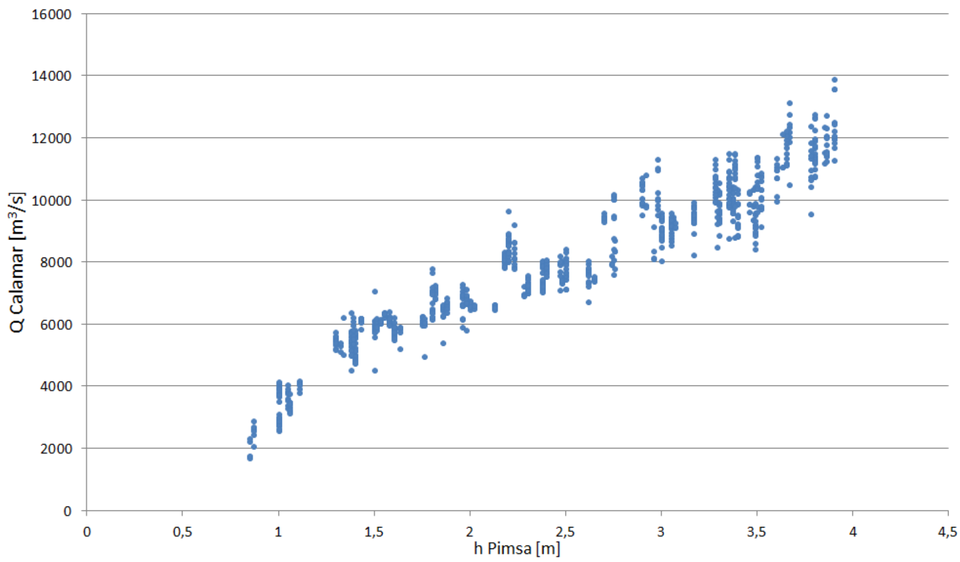


Figure B.2: Discharge measurements at Calamar versus water level measurements at Pimsa (2006-2012).

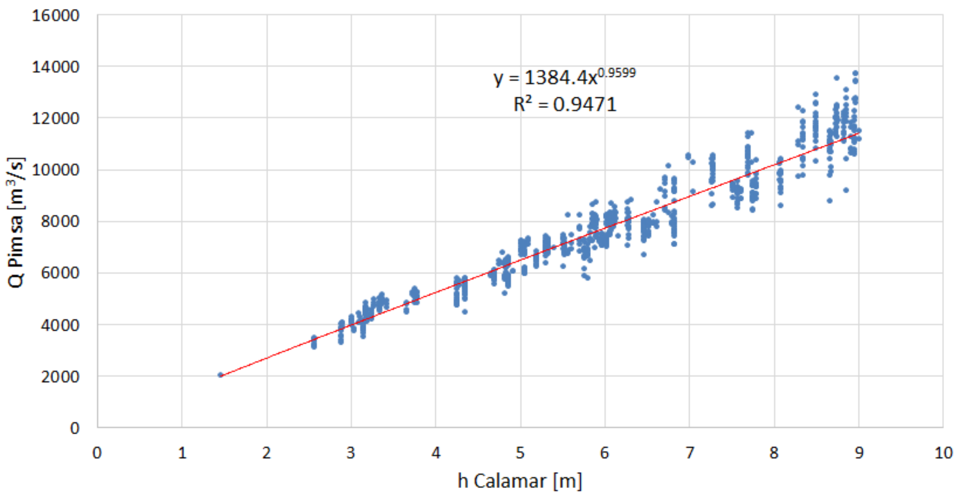


Figure B.3: Relation between the water level at Calamar and the discharge at Pimsa, based on data from 2006 to 2014.

B.2. Bed topography

Bed topography data is essential for the set-up and calibration of the model. Bathymetric surveys of the studied river section are available for January, April, June and July of 2012 and August 2014. The water level measurements of these months were subtracted from the bathymetric data to obtain bed topographies. However, the measurements do not cover the entire model grid, as often only the depth in the navigation channel was measured. Furthermore, the model also contains an offshore part that was not included in the measurements. The resulting topographies were therefore combined with the bed topography that was included in the model of Mathilde Lindhart (Lindhart, 2015), which is based on measurements from June 2012 for the river and the GEBCO 08 dataset for the offshore part of the model.

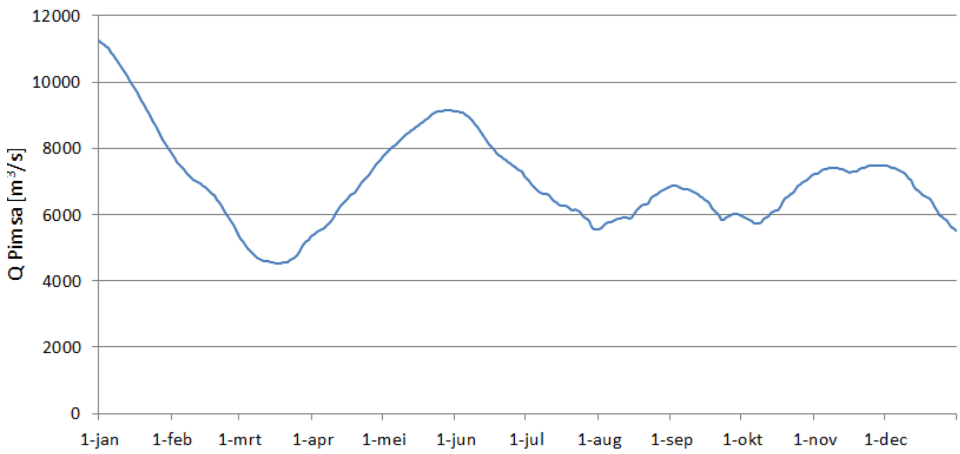


Figure B.4: Hydrograph at Pimsa (2012).

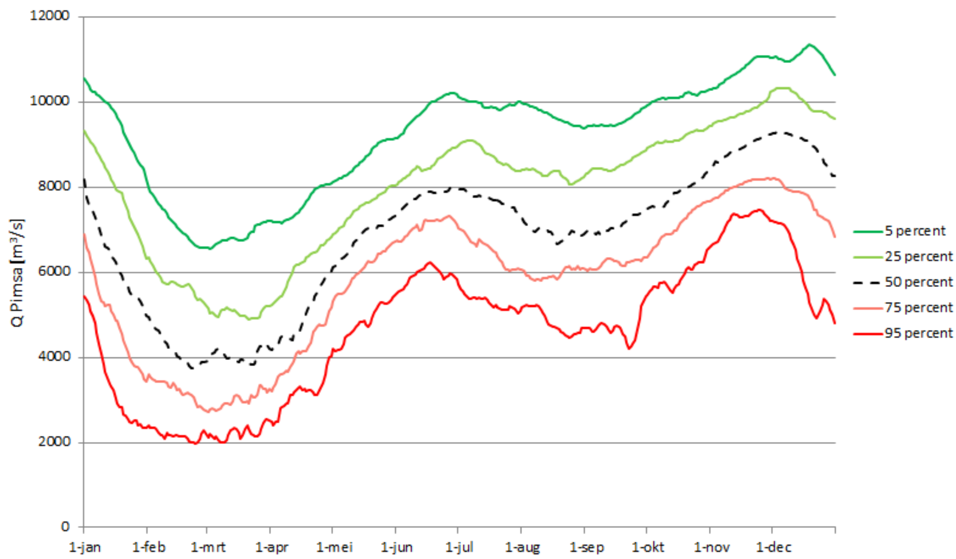


Figure B.5: Hydrograph at Pimsa for different levels of exceedance (1967-2015).

B.3. Waves

Waves are important for sediment transport, especially in estuarine environments (Hoefel, 2003). In an area with a radius of about 100 km from the river mouth, four wave buoys are stationed at the locations as indicated in Figure B.6. These buoys measure every 3 hours the wind and wave data and process this into relevant parameters (such as H_s and T_p). This data is available for the period 1979-2014. To get an idea of the wave climate present in the system, the data of the buoy North of the mouth (11.5N, 75.0W) is analyzed and presented in a number of relevant figures. Figure B.7 and B.8 show histograms of H_s and T_p. Figure B.7 shows a main significant wave height of about 2.2 m, meaning a high-energy wave environment. The peak period amounts to about 7 s. These values agree with literature (Ortiz-Royero et al. (2013)). According to this, the significant wave height (H_s) of the delta wave system is equal to 2.2 ± 1.1 m and the peak period (T_p) is equal to 6.7 ± 2.3 s.
Figure B.9 shows the wave rose following from the same data set, from which it can be seen that the main wave direction is 60° (nautical convention). Figure B.9 and B.8 show that the wave spectrum is narrow in both frequency and direction, which is typical for swell. The wave climate at the project location can therefore be defined as a swell dominated.

Figure B.6: Location of wave buoys (Google Earth, 2016).

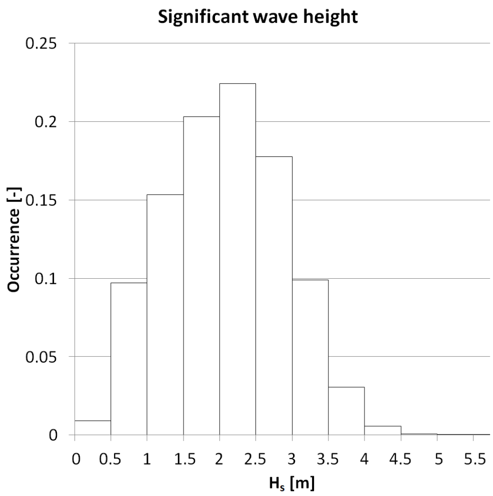


Figure B.7: Histogram presenting the significant wave height for the years 1979-2014 of buoy 11.5N, 75.0W of Figure B.6, divided in bins of ΔH_s = 0.5 m. The measurements indicate a high-energy wave environment.

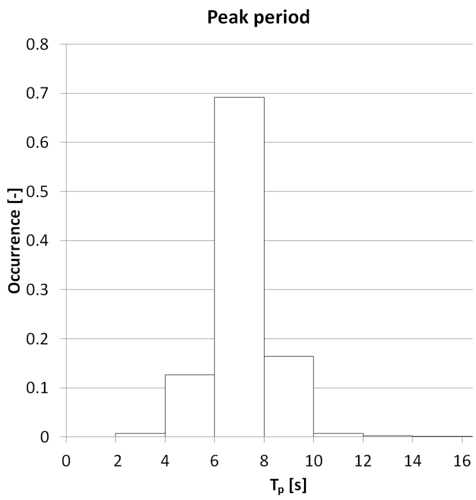


Figure B.8: Histogram presenting the peak period for the years 1979-2014 of buoy 11.5N, 75.0W of Figure B.6, divided in bins of ΔT_p = 2 s. The narrow frequency spectrum is typical for swell.

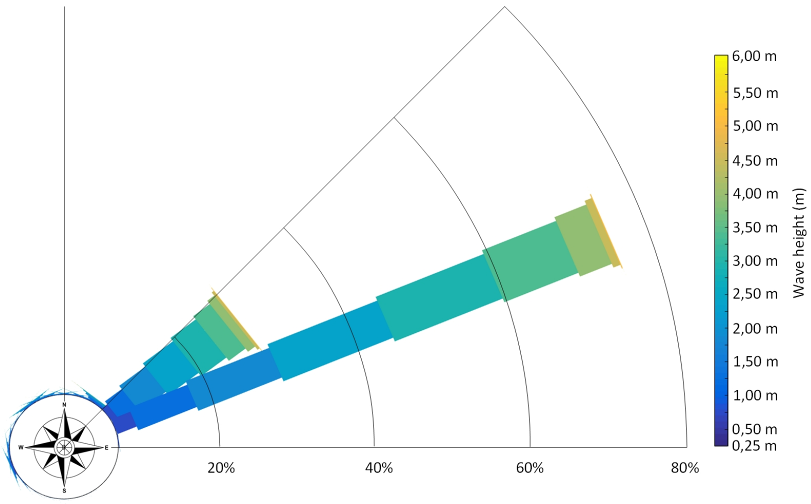


Figure B.9: Wave rose for buoy 11.5N, 75.0W. The uni-directional spectrum is typical for swell.

B.4. Wind

Wind has an influence on both waves and currents in estuarine environments (Whitney and Garvine, 2005). Data about the wind has been collected together with the wave data, by the buoys as described in Section B.3. Figure B.10 presents the wind rose for buoy 11.5N, 75.0W. It shows that the main wind direction is 60° (nautical convention), whereas the predominant wind speed is approximately 11 m/s. The wind direction is fairly constant, typical for tropical trade winds.

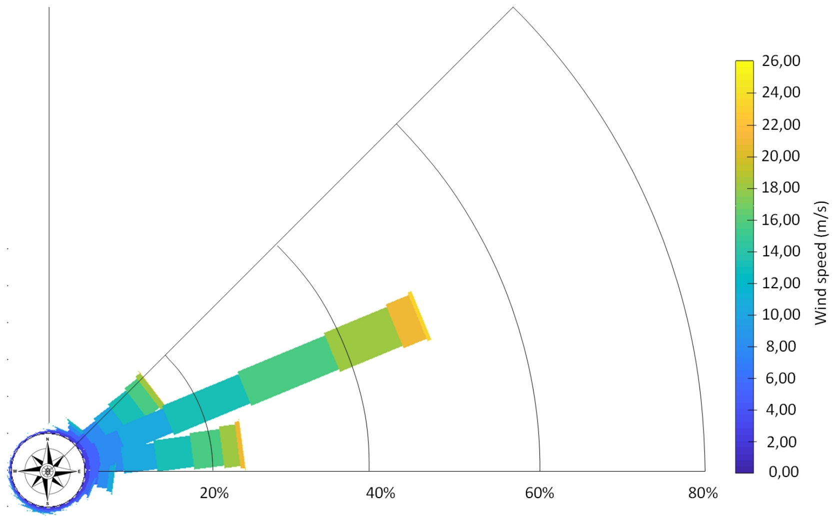


Figure B.10: Wind rose for buoy 11.5N, 75.0W.

B.5. Tides

The Magdalena river delta experiences a micro-tidal regime with a mixed type, predominantly diurnal character (form factor $F = 1.81$). The tidal range varies between 0.64 m (spring tide) and 0.48 m (neap tide), with a mean of 0.62 m (Restrepo and López, 2008).

B.6. Sediment characteristics

Table B.1 shows results of measurements of suspended sediment characteristics. The measurements, that were performed at Pimsa in the period 1989-2002, show a D_{50} ranging between 50 and 382 μm. In March 2005, measurements of the bed load were taken in several sections of the river. The results of these measurements are shown below (Table B.2) and indicate a D_{50} range of 195-418 μm.

Table B.1: Measurements of suspended sediment characteristics at Pimsa (Ortega, 2008).

Date	D16 [μm]	D50 [μm]	D84 [μm]	D90 [μm]	C (kg/m^3)
06/12/1989	165	220	290	305	0,45
16/03/1989	-	50	300	335	0,283
21/06/1990	100	220	350	470	0,775
14/12/1990	205	279	354	385	-
17/03/1991	120	174	242	269	0,638
31/05/1991	96	130	178	198	0,712
06/12/1991	151	200	223	258	0,824
16/05/1992	111	172	230	211	0,535
29/06/2000	270	323	454	489	0,865
04/10/2000	271	382	511	588	0,685
05/04/2002	-	202	-	249	0,86
23/12/2002	-	242	-	392	0.932

Table B.2: Measurements of sediment characteristics of the river bed (Ortega, 2008).

Location (Distance from Bocas de Ceniza)	D10 [µm]	D50 [µm]	D90 [µm]
S1 (K21+400)	150	203	247
S2 (K20+200)	177	376	680
S3 (K19+100)	140	215	370
S4 (K18+250)	138	201	308
S5 (K17+200)	210	360	480
S6 (K16+200)	125	300	430
S7 (K15+300)	250	418	725
S8 (K13+900)	260	410	750
S9 (K12+250)	147	240	303
S10 (K11+800)	134	261	390
S11 (K10+900)	143	250	367
S12 (K10+100)	151	238	305
S13 (K9+500)	152	238	300
S14 (K8+700)	125	200	286
S15 (K6+900)	136	195	280
S19 (K1+100)	268	410	760

B.7. Salinity

Stratification, due to a gradient in sediment concentration or salinity, can have a significant impact on sediment transport in estuarine environments. It can affect the flow pattern in such a way that flow velocities near the bed are opposite from the mean flow direction, inducing a sediment transport in the upstream direction near the bed (Wright, 1977).

In January 2010, salinity measurements have been carried out in the first 21 kilometres of the river, by Cormagdalena and Universidad del Norte jointly. In this period, river discharges were exceptionally low, such that the salt wedge intruded far into the river. Figure B.11 and B.12 show the results of these measurements in a longitudinal profile of the river mouth. It can be seen that for both a discharge of 2200 m^3/s and 2600 m^3/s, salt concentrations of more than 30 ppt (parts per thousand) are measured up to 19 km upstream of the river mouth. Figure B.12 also shows the opposite flow velocity near the bed.

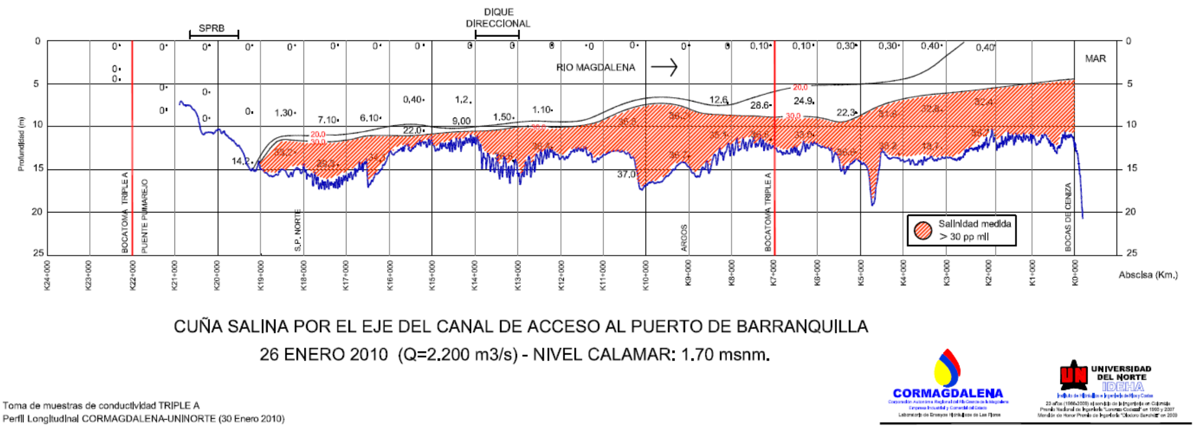


Figure B.11: Salinity in the access channel for a discharge of 2200 m^3/s, as measured in January 2010 (Cormagdalena & Universidad del Norte, 2010).

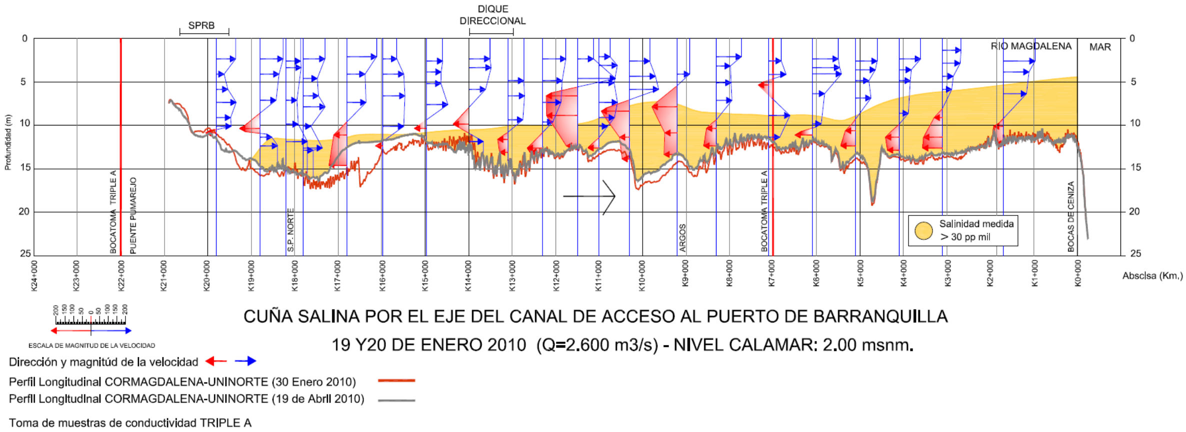


Figure B.12: Salinity in the access channel for a discharge of 2600 m^3/s, as measured in January 2010 (Cormagdalena & Universidad del Norte, 2010).

C
History of human interventions

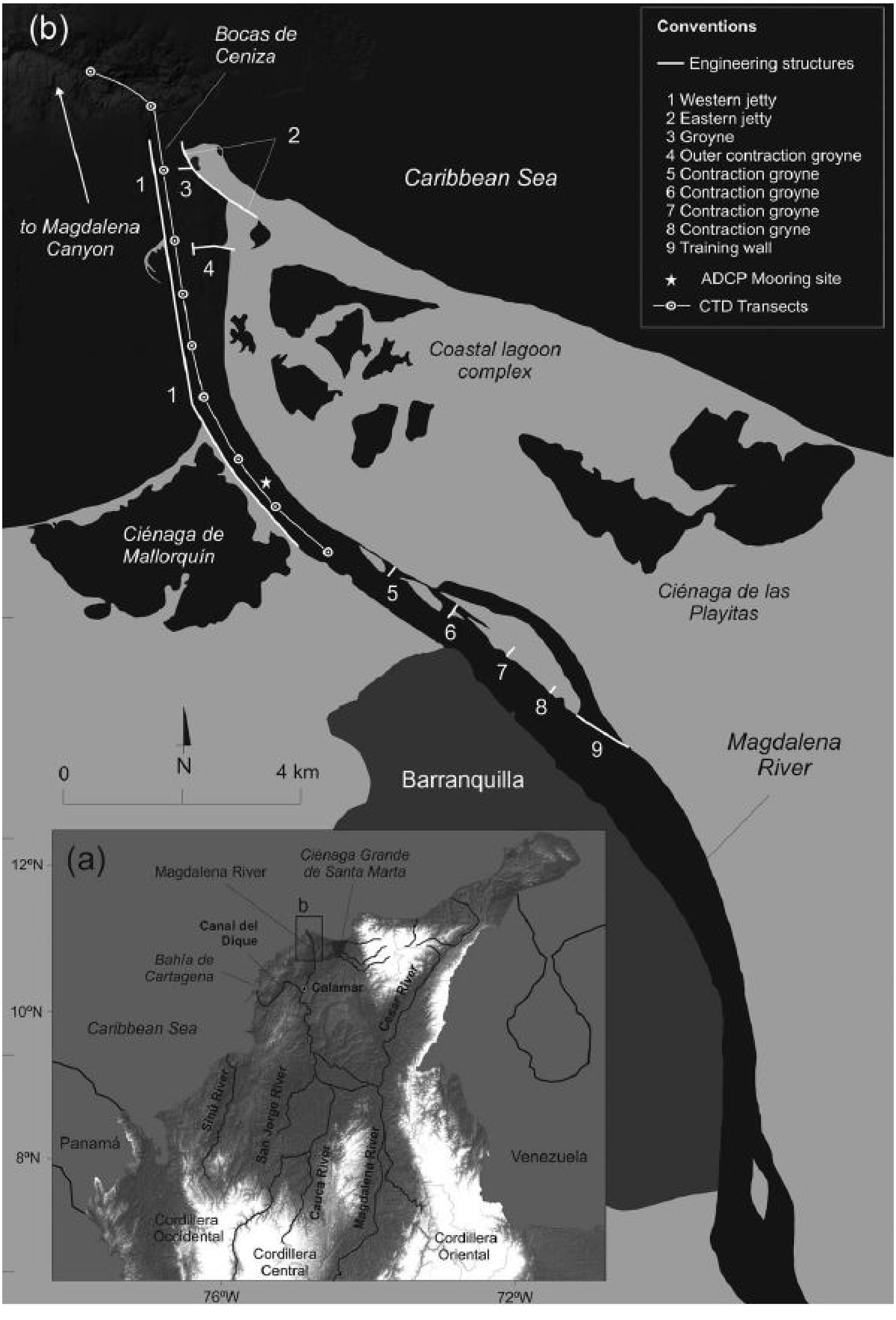


Figure C.1: Human interventions (1990-2010) (Restrepo et al., 2015).

D

Sections and critical locations Magdalena river

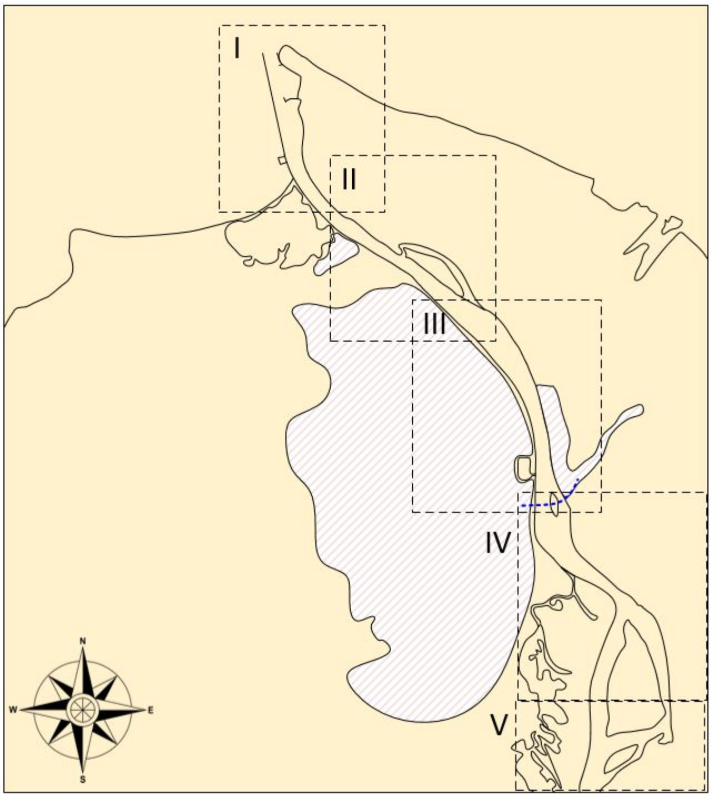


Figure D.1: Overview of sections of the Magdalena river.

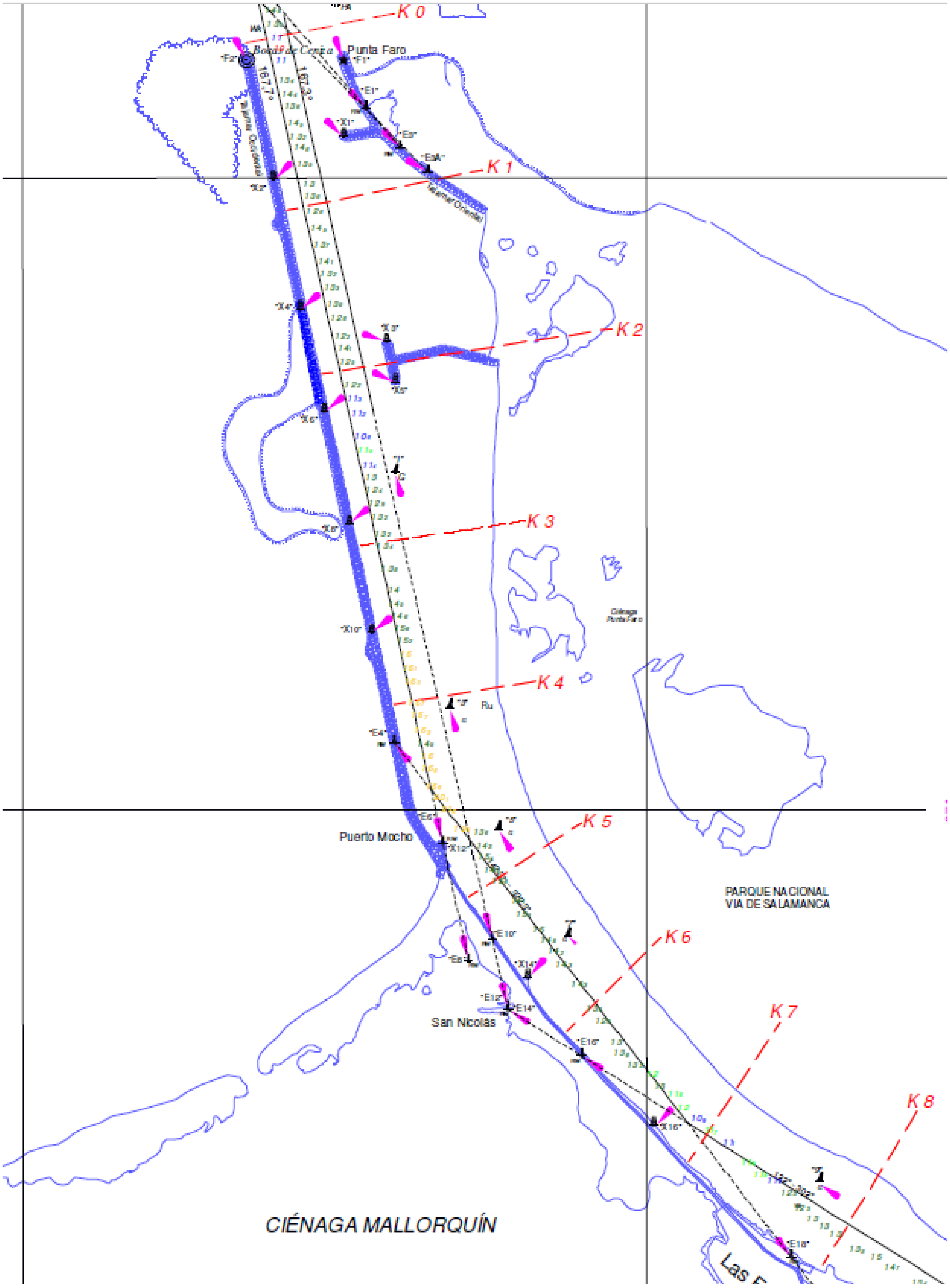


Figure D.2: Section I: Bocas de Ceniza - Las Flores K0-8 (DIMAR, 2017)

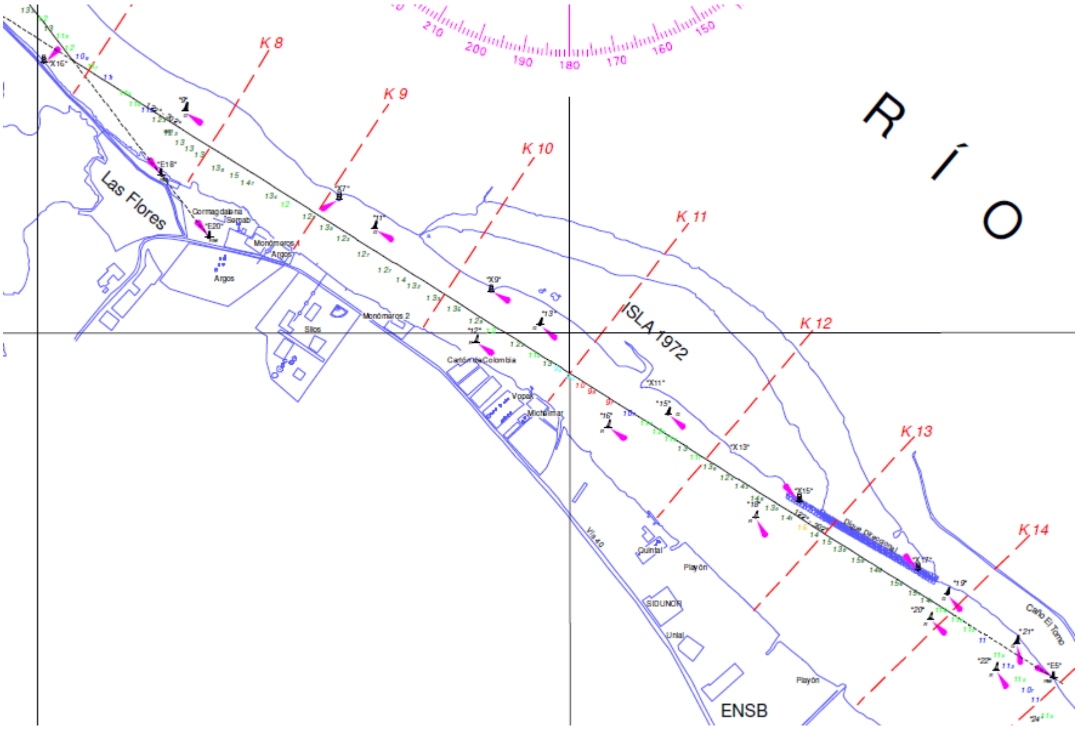


Figure D.3: Section II: Las Flores - Dique Direccional K8-14 (DIMAR, 2017)

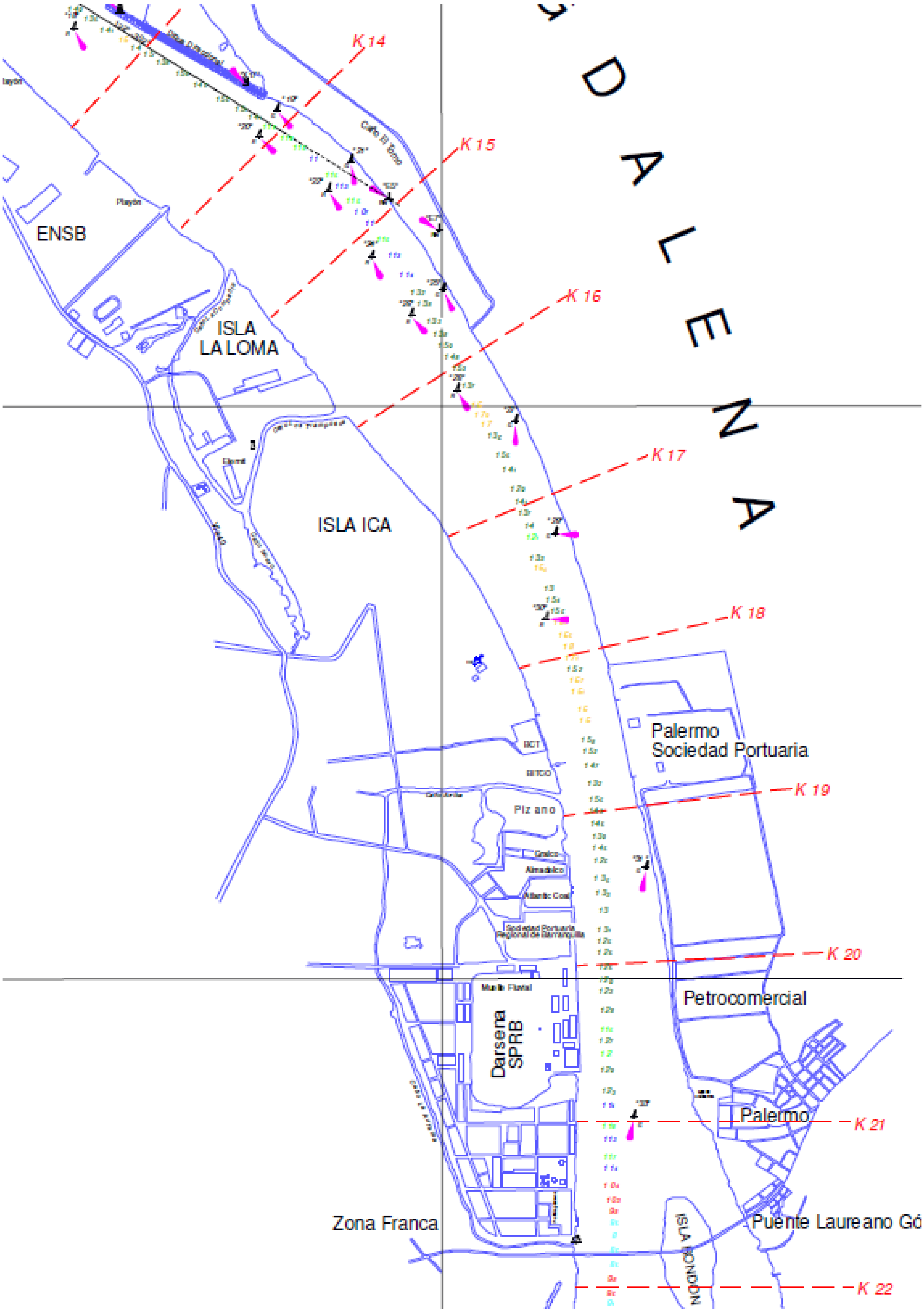


Figure D.4: Section III: Dique Direccional - Puente Pumarejo K14-K22 (DIMAR, 2017)

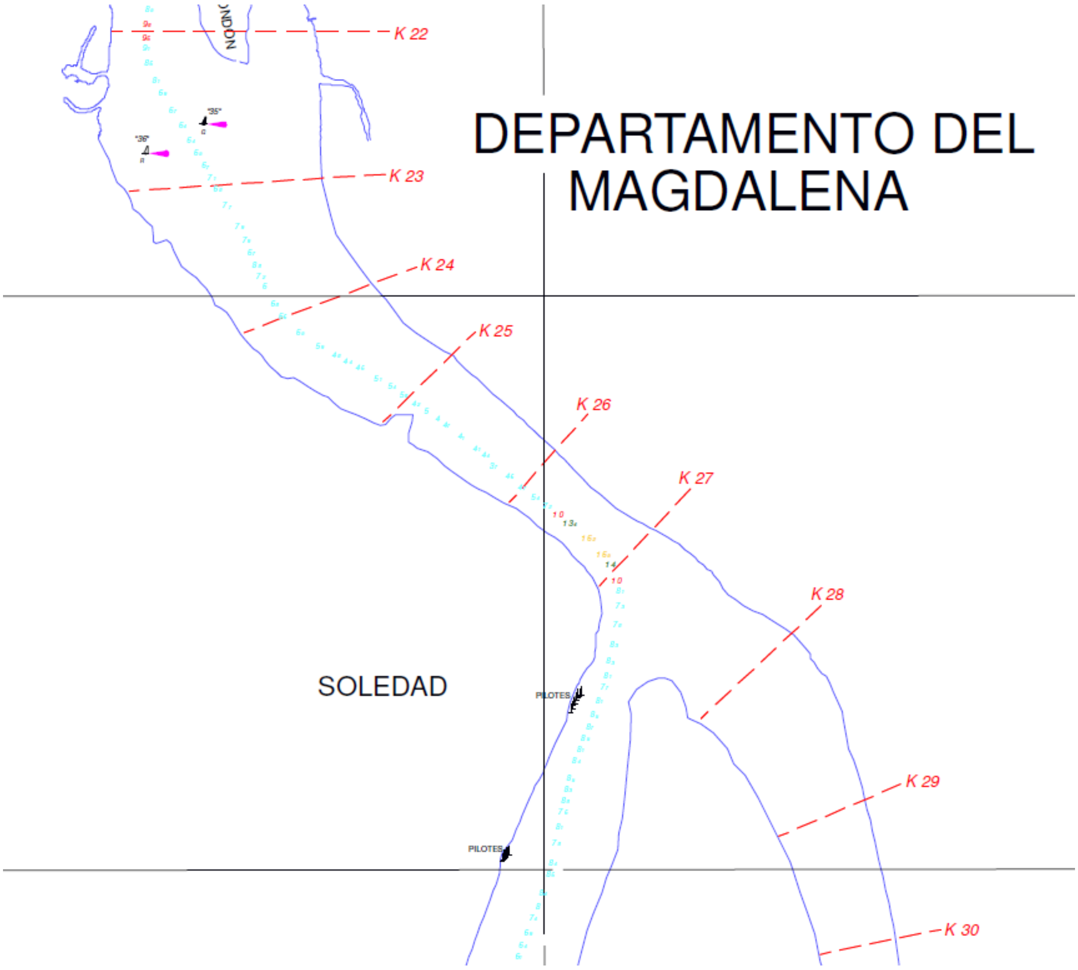


Figure D.5: Section IV: Puente Pumarejo - Isla Cabica K22-K30 (DIMAR, 2017)

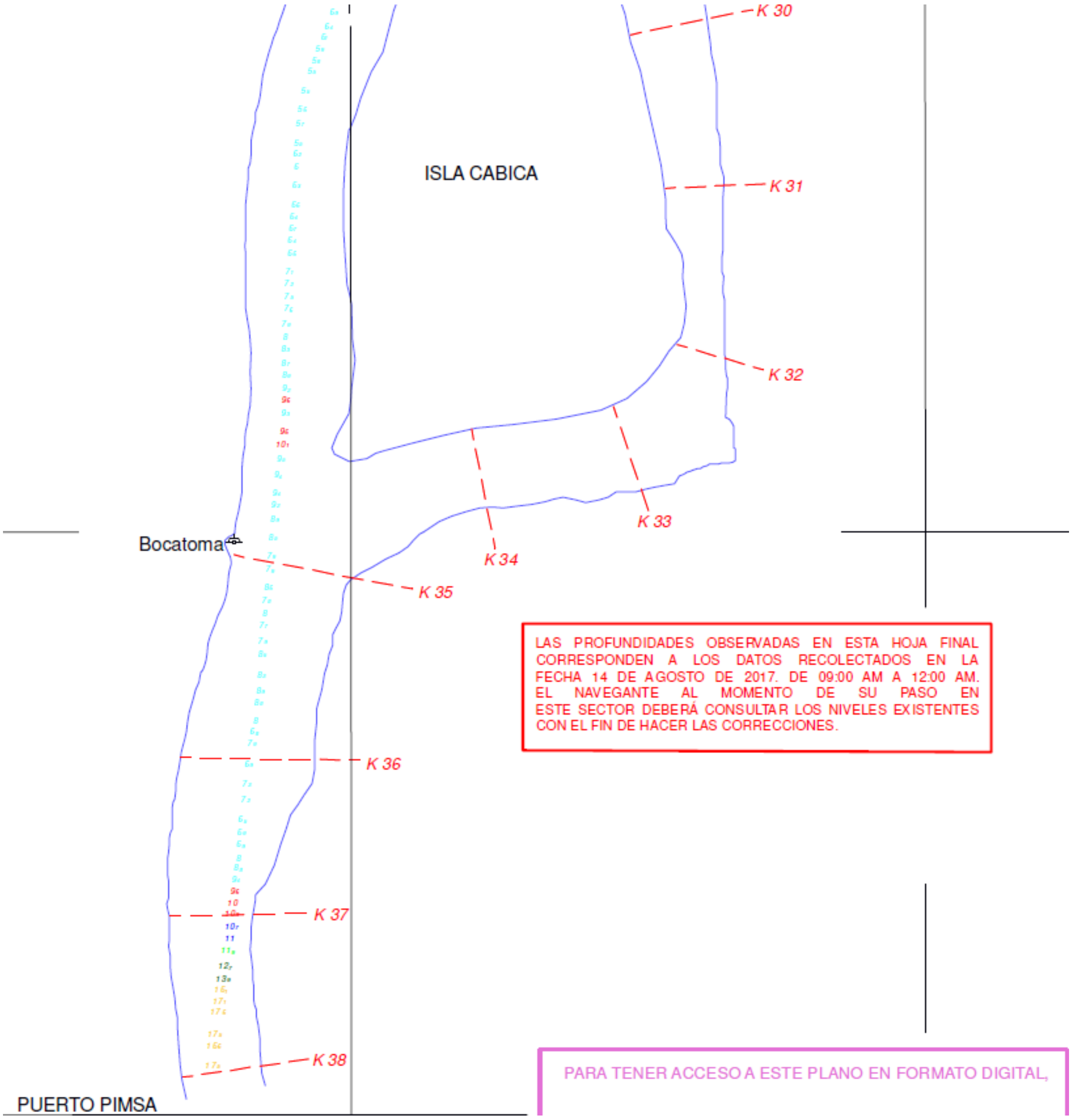


Figure D.6: Section V: Isla Cabica - Pimsa K30-K38 (DIMAR, 2017)

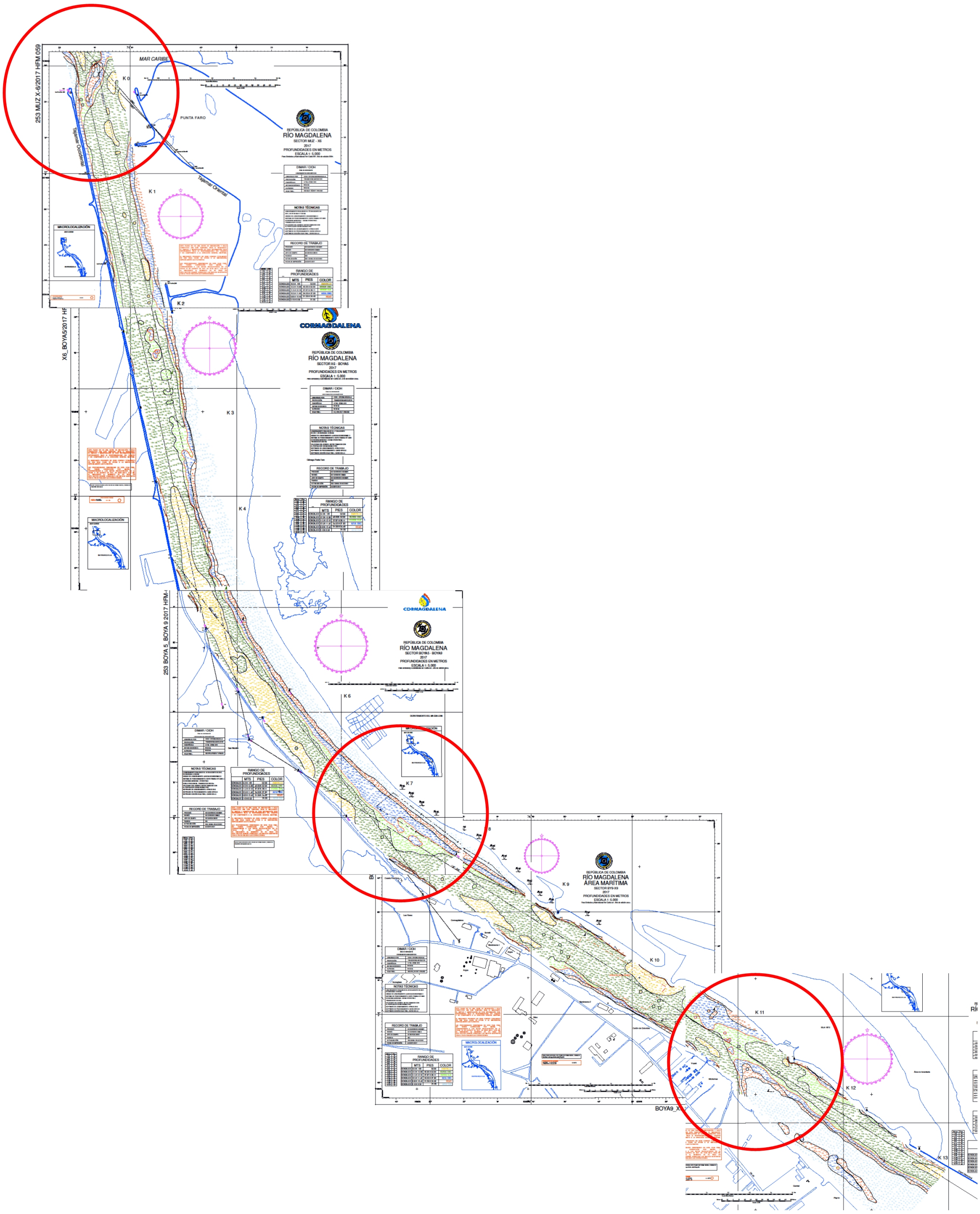


Figure D.7: Location of critical sections (K0-K13).

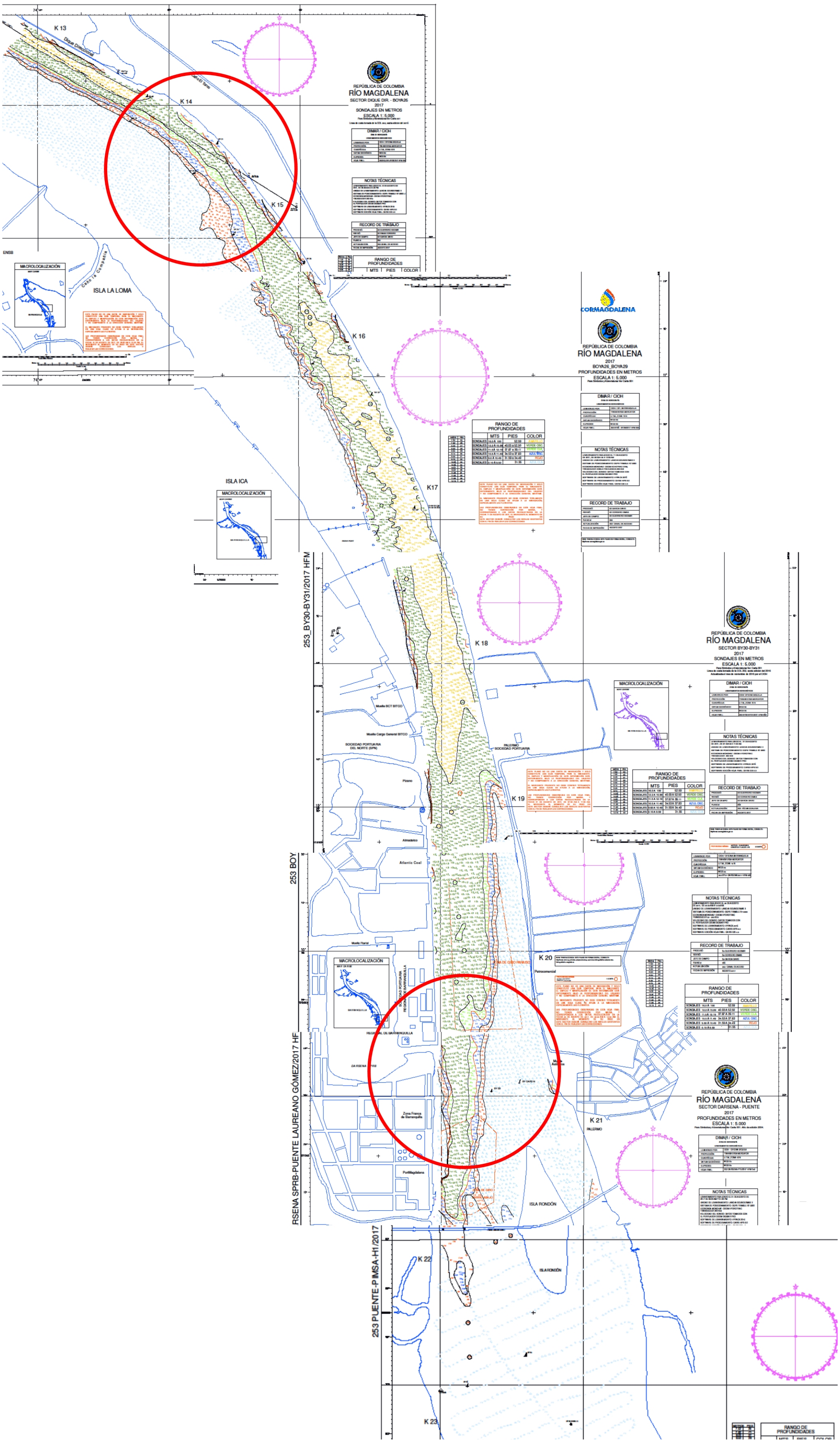


Figure D.8: Location of critical sections (K13-K25).

E

Stakeholder Analysis

E.1. Description Stakeholders

ANI - National Infrastructure Agency:
ANI is the National Infrastructure Agency, founded in 2011. They belong to the Ministry of Transport and have their own legal personality. They also have their own assets and administrative, financial and technical autonomy. Due to this, they provide Cormagdalena with money to contract dredging companies and keep the port of Barranquilla navigable (ANI, 2017). They facilitate projects of concessions and are in charge of public private partnerships. Those projects are all related to the development of public infrastructure of transport and related services (Watkins, 2014).

Asoportuaria
Asoportuaria is the port association of Barranquilla, founded in 1994 as an initiative to stimulate the Colombian economy. By merging the interests of the 16 ports Asoportuaria represents, their position during negotiations is much stronger. The largest type of cargo transported in the ports of Barranquilla are hydrocarbons and coal. Also, a lot of transshipment takes place (Oxford Business Group, 2014). Plans to increase the navigability of internal waterways will enhance multimodal transport.
The overall interest is to increase the international trade, expansion and restructuring of all the ports. Their main focus is on offering facilities for foreign trade and to expand the navigation on the Rio Magdalena. Thereby the challenge is to support the companies and activities that must guarantee the depth of the river so the larger vessels are also able to enter the port of Barranquilla.
Another focus point of Asoportuaria is on transferring information between several parties: their members, public entities, national and foreign entities and also trade unions who are interested in the development of the Caribbean Region. By guaranteeing the accessibility of the port, it makes it more interesting for foreign companies to do business in the area of Barranquilla (Asoportuaria, 2011).

Citizens of Barranquilla
The citizens living around the port of Barranquilla are not directly affected by deepening the river, but they will be influenced by the indirect effects. If larger vessels get access to the port, more cargo will be shipped and the economy will increase. More economic activity also means that the employment opportunities will increase which will improve the living standards of the people living in the surroundings of Barranquilla. More cargo will be shipped, so more people are needed to assists the ships entering the harbour, transferring the goods etc. Also, the price of oil will decrease. A lot of the profit margin goes to shipping the oil distracted in Colombia itself. Another option for oil transport would be pipelines, but these are vulnerable to oil theft and attacks from rebel groups (Stratfor, 2013). This effect will also be noticed in a wider area than only Barranquilla.
On the other side the air pollution will probably rise by increasing the amount of factories. Another downside resulting from more vessels in the port is that the connection from the port to the public roads must be good, otherwise the traffic will get stuck, which has negative influences on economic development. If the citizens do not agree with a solution made by a higher authority, they have the opportunity to protest against the proposed solution.

Cormagdalena
Cormagdalena is short for: 'La Corporación Autónoma Regional del Río Grande de la Magdalena'. The goal of this so-called CAR (Corporación Autónoma Regional) is to integrally recover the navigability and port activity in the Rio Magdalena which should result in an efficient means of transportation and life (CORMAGDALENA, 2016). Colombia first created a CAR beginning 1950s as an experiment to more decentralised governance. It

turned out to be a successful way of governing therefore more CARs were created. In 1991 Cormagdalena was established in order to effectively manage the river thereby transcending the departmental borders (Griggs, 2010).

Next to managing and maintaining the Rio Magdalena, Cormagdalena also has responsibilities regarding sustainable development and environment sustainability, laid down in Law 99 (Rodriguez Becerra, 2009). The resources to do so partly come from the National Royalty Fund (NRF). The fund receives royalties from the exploitation of non-renewable natural resources (Rodríguez Becerra and Ponce De León, 1999). Subsequently, the money is divided among municipalities, ports and other regional corporations in such a way that it is being used effectively to protect the environment (Rodríguez Becerra and Ponce De León, 1999; Vega, 2009).

The internal structure of Cormagdalena is set up in such a way that various organisations are represented in the board of directors. In Figure E.1 the structure is illustrated. By using a structure like this it might be hard to find a suitable director on which the majority of the board of directors can agree. The board of directors consists of:

- Delegate of the President as president (currently the Director of Invias);
- Ministers or vice ministers of: Transport, Environment, Mines and Energy, Commerce and Agriculture;
- President of Ecopetrol;
- 3 governors of the departments river dwellers, one of each of the geographical sections of the river (high, medium and low Magdalena);
- 6 mayors of the municipalities rivers dwellers, two of each geographical sections of the river (high, medium and low Magdalena);
- A representative of the guilds of the river navigation.

Each of the representatives will be appointed by the President for a period of three years (Colombian law 161, 1994).

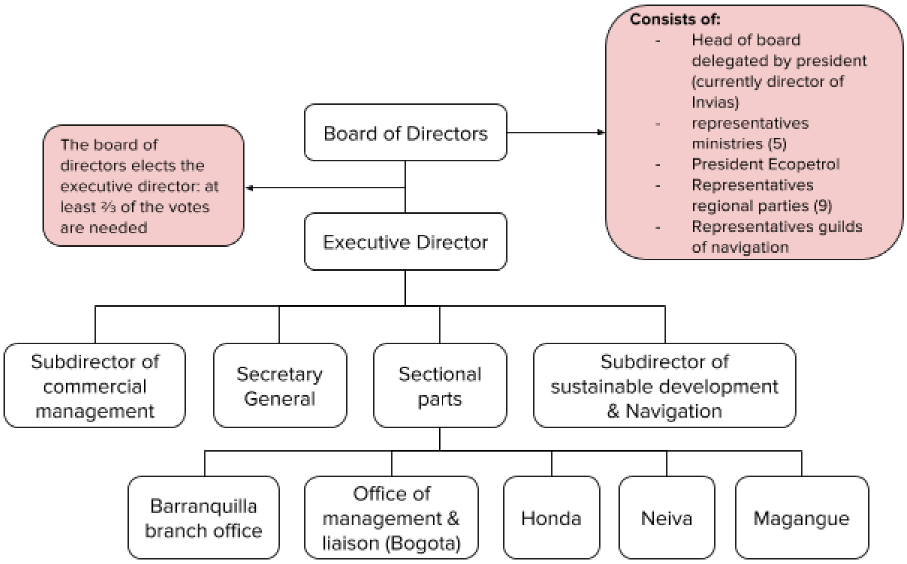


Figure E.1: Organogram Cormagdalena.

Departments (Atlántico; Magdalena)

In the past Colombia consisted of 3 departments, later this increased to 5 and it currently consists of 32 departments. The heads of the departments, the governors, were pointed by the president, but now they are chosen by elections for four years. Every district controls its own finances and administration, within the limits set by the constitution. For the sedimentation problem in the port of Barranquilla two departments are involved, namely Atlántico on the West side of the river and Magdalena on the East side. Those districts are further subdivided into different municipalities which will be described later in this Appendix.

DIMAR
DIMAR, the maritime authority, is part of the Ministry of national Defence. They advise the National Government on all topics related to international maritime instruments. The first law referring to maritime transport dates from 1931. After that some additions were made and DIMAR was formed in 1972. The overall responsibility of DIMAR consists of controlling the maritime, fluvial and coastal activities with integral safety. If we zoom in from the responsibilities of DIMAR for whole Colombia to DIMAR as a stakeholder in the sedimentation problem in the Rio Magdalena, their responsibility, together with the Navy, can be described as to exercise the administrative, operative and legal control of all the foreign vessels which want to enter or leave the port. This also includes the authorisation and operation of dredgers. They are the party who knows everything about the ocean mouth but this is not the only thing they do in the area of Barranquilla. They also install and maintain the service navigation aids, make hydrographic surveys and produce national nautical cartography. Important to consider is the fact that DIMAR authorises and controls the dredging, filling and other ocean engineering practices in their area. This is the part from K0 into the ocean, but if companies want to dump sediment in the ocean, they have to talk with DIMAR before they can do that. Also for building another port outside the river, for transferring cargo from naval crafts to smaller vessels, DIMAR is an important party in the decision making process (DIMAR, 2016; Ministerie van Economische Zaken, 2015).

National Planning Department
The National Planning Department, also shortened as DNP, is an administrative department which belongs to the Government and reports directly to the President of the Republic. If looked into their position in the whole governmental structure, they can be placed in the same category as the ministries, but without legislative initiative. Their functions consist of directing, coordinating, serving and giving the government the right information for decision-making. This is done by designing, preparing and evaluating public policy on social, economic and environmental issues as well. They also allocate and manage investments in public works what is based on plans, programs and projects.

Dredging companies
The dredging companies involved in this problem can roughly be divided into two groups, namely the big international companies such as: Jan de Nul and Van Oord, on the other hand the smaller more local dredging companies play a role. In this research contact was established with Van Oord and a local dredging company called: SDC Servicios de Dragados y Construccior es S.A.
Currently the access channel to the ports of Barranquilla is being dredged by EDC Sucursal Colombia, the local subsidiary of the Belgian Jan de Nul. After the disaster with the Navalena PPP contract a new contract up until December 2017 for the port of Barranquilla only was awarded. This contract only deals with the access channel in order to ensure sufficient depth for vessels to enter the ports (Gracia, 2017).

Environmental licensing authorities
In this analysis two important environmental licensing authorities were identified. Firstly, there is the National Environmental Licensing Authority (ANLA). They operate on a national level and are concerned with the overall condition of the Colombian environment. Secondly, Barranquilla Verde is an important player on the local level. Barranquilla Verde is specifically concerned with the environment of Barranquilla and has higher ambitions with regard to the environmental conditions.

INVIAS
Invias is the National Road Institute and is responsible for managing the national highway plan of Colombia. This includes the construction, rehabilitation and maintenance of the roads which are not operated under concessions (Samad et al., 2012).

Municipalities
Before 1990s local governments, including municipalities had very limited power. However since the new constitution in 1991 and the establishment of several other laws, local governments now have more resources, responsibilities and decision-making power. This includes; responsibility to provide services in education, health, water, sanitation, roads and agricultural extension (Fiszbein, 1997). The municipalities are now independent and democratically elected lower level authorities.
Another recent change in the responsibilities of the municipalities is the obligation to organise direct citizen participation in the planning of municipal land use (Colombian urban reform law: 388, 1997). However, a

case study on the implementation of this citizen participation in Barranquilla by Koch and Sanchez Steiner (2017) concluded that since the citizens are excluded from the circles of power the possibility to influence the decision-making regarding the land use of the city is non-existing. They identify three reasons why the participation failed in the case of Barranquilla. Firstly the economic and political power is coinciding because both powers often belong to the same circles of friends and families. Closed-door negotiations about the plans are conducted within those circles, thus there is no reason to discuss the plans in a more public setting. The second reason why the participation failed is that civilians still fear to participate in politics due to the sometimes violent character. Finally overall the confidence in politics and institutions are very low causing people to be reluctant towards the participation.

Nature preservationists
Nature preservationists can consist of more smaller parties who have a lot of knowledge regarding to the surrounding nature areas. This can be of great value if an analysis of the area is needed. They also can oppose if a measure is proposed which damages nature. Therefore this party has to be taken into account.

Observatory
In August 2017 a newly founded organisation was set up: 'Observatorio del río Magdalena'. Their goal is to research and monitor the river. They aim to gain technical knowledge about the erosion and sedimentation processes in order to support institutions responsible for the navigability of the river. The newly found observatory is the successor of the in 2015 dissolved 'Laboratorio de Ensayos Hidráulicos de Las Flores'. An organisation comparable to the observatory.

Port associations
The port of Barranquilla consists of several private port associations. As mentioned before Asoportuaria is the body which connects these associations. In total there are 16 ports who operate in the first 38 km of the Rio Magdalena. The largest port association operating in Barranquilla is 'Puerto de Barranquilla' and belongs to the Sociedad Portuaria Regional de Barranquilla S.A.. This is a joint-stock company established in 1992, with the purpose to manage the Sea and River Terminal of Barranquilla and to provide any type of port operation services (Port of Barranquilla Corporate Group, Port of Barranquilla). These services include handling all sorts of cargo: containers, refrigerated and frozen cargo, general cargo, bulk cargo, liquid bulk cargo and coke.

Private investors
Private investors can play a significant role in making the project financially feasible. With the Nevalena project the financing part was one of the reasons why the project failed. They can not only help with the financing, but also help to run the project efficiently.

Shipping companies
In the transportation of goods, either import, export or domestic transport of products, shipping companies play a very important role. The strategic position of Barranquilla could make its port the perfect hub between import/export originating from the Caribbean sea and further domestic transport over the river. Moreover currently inland shipping on the Rio Magdalena is only possible up until .... when much smaller tugboats are used. As for the larger vessels these have to be unloaded in the port of Barranquilla. Examples of large shipping companies currently operating in the Barranquilla ports are Mearsk, Orange freight and Clipper.

Users riverbanks
Within the jurisdiction of Cormagdalena does not only include the river itself, it also includes its riverbank. Meaning that all the land 30 meters from the riverbanks is owned by Cormagdalena. This land is never sold to any entities however there is the possibility to obtain a concessions for a certain amount of years against certain costs. This concession makes it legal to use the concessioned land. There are however also riverbanks which are legally not given out by any concessions but are still used by people. This illegal habitation of the banks happens quite often and although it is illegal some people consider this their homes.

E.2. Hierarchical structure

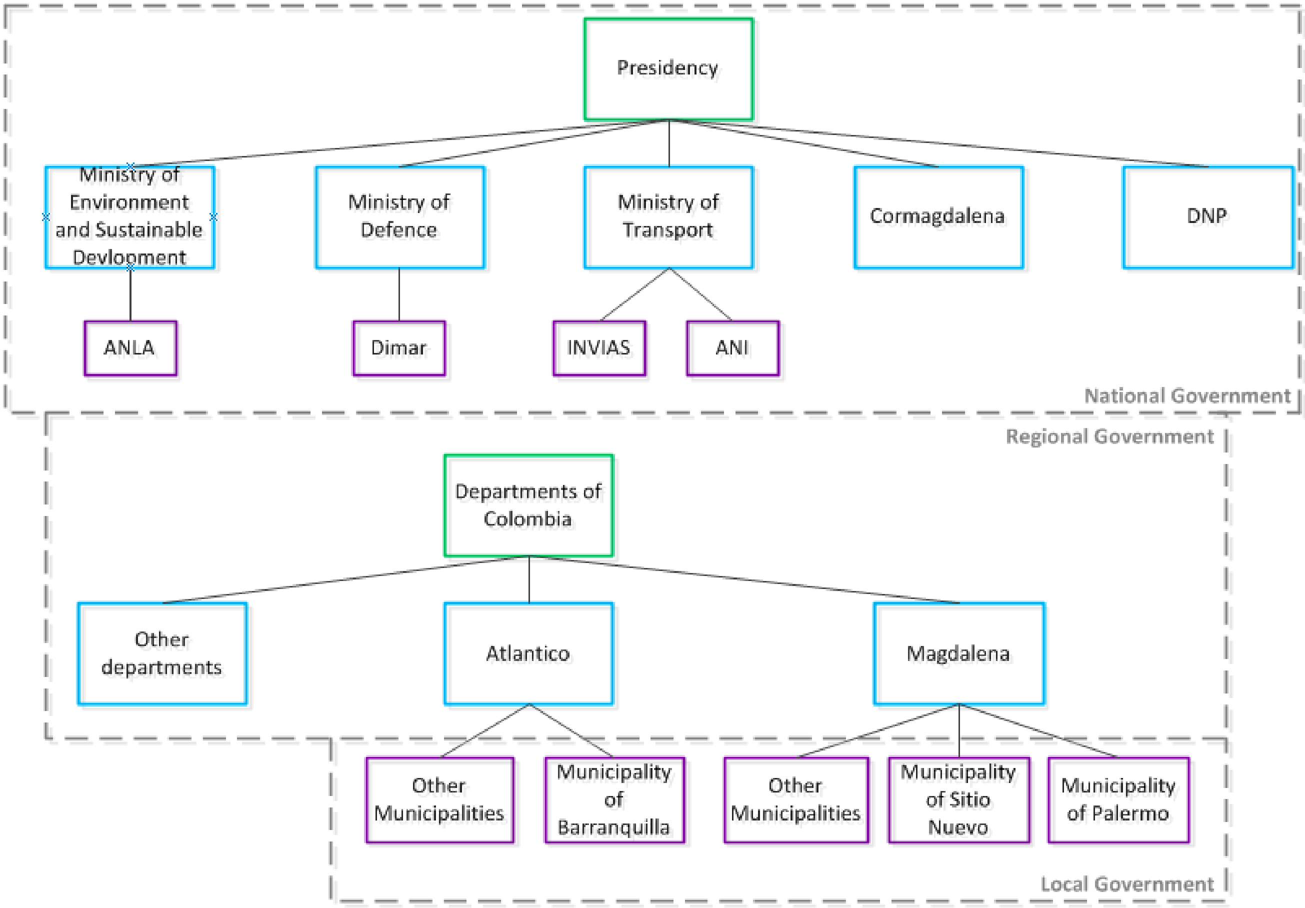


Figure E.2: Hierarchical overview.

E.3. Power interest groups

By studying the sedimentation problem in the Magdalena river several stakeholders are involved. Each of them with their own interests and power. To come to a solution which is accepted by everyone it is important to take their position in the power interest grid into account. Sometimes it is important to activate stakeholders who have less interest but more power. They can arrange things, but if there is nothing that concerns their interest, they won't become active. The diagram shown in Figure E.3 shows the power interest grid.

The two by two matrix shows on one dimension the interest of the stakeholders from low to high. The other dimension shows the degree of power the stakeholders have, to influence the problem. The matrix can be divided into four quadrants, each with its own characteristics. The first and easiest group is the crowd. They have minimal effect and can be seen as potential rather than actual stakeholders. Their interest and power are both low. This could be raised, but mostly they have other concerns than the problem owner so their power and interest are low. The next group are the context setters. To make the process as smooth as possible, you want to convert them into key players. This can be done by raising awareness and develop positive interest. The context setters can influence the future overall context because of their high power, but they have little direct interest. The subjects on the other hand don't have that much power, but they do have a significant interest in comparison to the context setters. The best way to deal with this group is to initially keep them informed. It is also possible to encourage coalitions due management to increase the power of the positive subject stakeholders and convert them to players or neutralise the negative subject stakeholders. The key players are located in the last quadrant. Those actors are significant stakeholders who deserve sustained attention. This is because they have high power and high interest (Bryson, 2004).

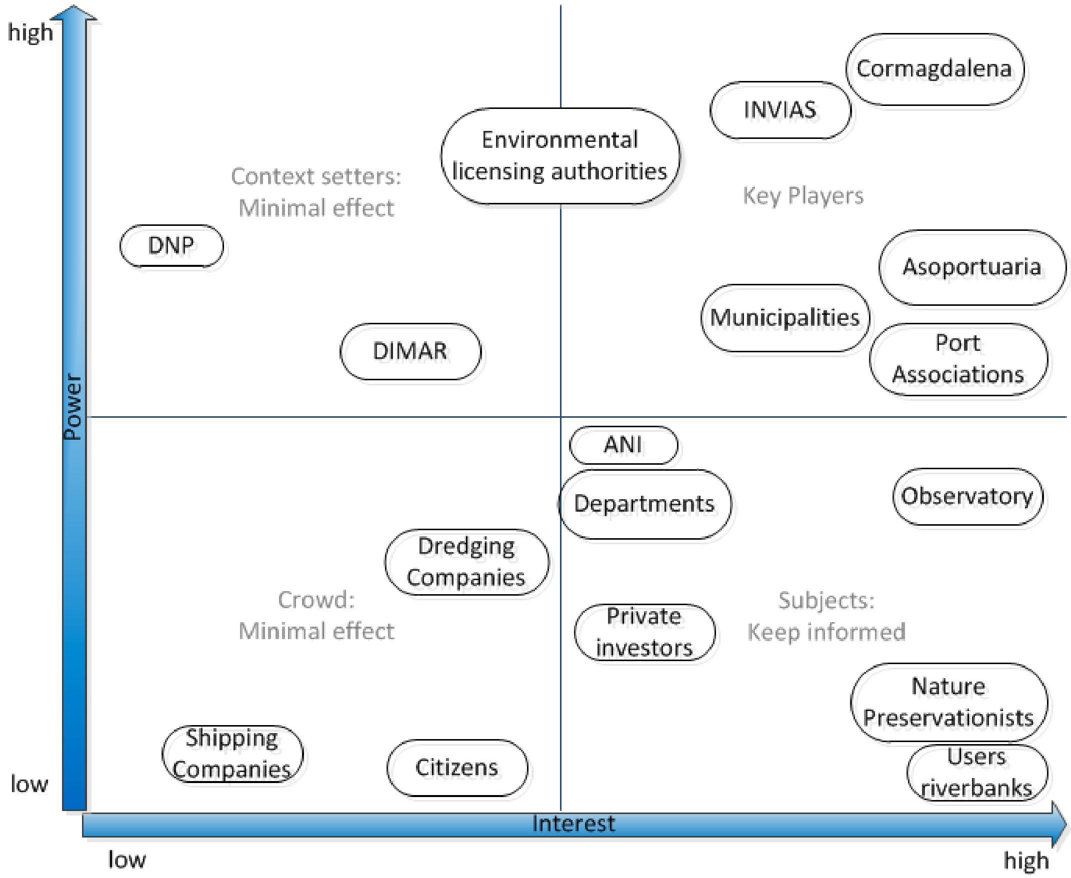


Figure E.3: Power-interest grid.

Crowd
The part in the lower left corner, the crowd included stakeholders who have less interest and less power. For this analysis, the shipping companies are placed there. If the Magdalena River is not navigable for those companies they can move to the neighbouring harbours Santa Marta or Cartagena. Their interest is to make business and it is not important for them if they do that in Barranquilla or in the cities approximately 150 kilometres away in the same country. However, there are a lot of possibilities to make Barranquilla more attractive as a port. With the Magdalena river reaching till 900 km land inwards this could be a good transfer point for the navy crafts to load the cargo on vessels suitable for the river. That is why the interest of the shipping companies is not placed at zero. The power on the other hand only consist of pressure and threatening to go to another port city. They don't have measures themselves. The other party in this quadrant are the dredging companies. Their interest is to keep dredging. If the solution to keep the river navigable includes a part with dredging, they will be content. Until that point, the interest of the dredging companies and the problem owner are the same. But for the problem owner it is not necessary the final solution has a dredging part in it. The citizens also belong to the crowd. During chatting sessions hold with citizens in Barranquilla, it became clear that there was not a lot of awareness of the problem under the citizens. People knew that there was something with the sedimentation, but that was it.

Subjects
The quadrant on the left side of the crowd is called 'subjects'. The best tactic that can be used with this group of stakeholders is, as earlier said, to keep them informed. The first group placed in this quadrant are the nature preservationists. Their interest is very high. They want to prevent nature of any harm. What is seen now is that parts of parc Ilsa de Salamanca are burnt down. Including the living area of specific birds and other animals. People do this because when the nature is gone, people can use that piece of land for other purposes. This is contrast with the goals of the nature preservationist. If parties harm the environment they will start complaining to the environmental licensing authorities. To avoid extra delays and troubles it is impor-

tant to inform the nature preservationists about what is going on and which decisions are made concerning the direction of the solution. The other party placed in this quadrant is ANI. The power they have is giving or not giving money to Cormagdalena. However, Cormagdalena has multiple lenders, so they are not really dependent on ANI. This is why ANI is placed in the quadrant with less power. Their interest, on the other hand, is bigger because it is their responsibility to adapt infrastructure policies for roads, waterways and railways and if the Magdalena river is better navigable, this would have a positive effect on the transportation infrastructure overall. It can be concluded that ANI has to be kept informed about the things that are going on regarding to the navigability of the Magdalena river. The last party in this quadrant are the citizens.Their interest is medium high because it concerns changes in the area they work and live. This does not apply to everyone to the same extend. The power they have is minimal. They can go demonstrate against ideas or decisions, but usually, this has little effect. Furthermore, corruption plays a role as with the other stakeholder groups. The best way to deal with this stakeholder group is to keep them informed. As a result, they feel less quickly closed outside and the resistance will be less.

Context setters

The context setters in this problem are DIMAR and the environmental licensing authorities. The last party also plays a role in the key players part. This is due to the degree of interest they have. They care about the environment and everything related to that. The power they have is giving permits or not. What is seen often is that projects in Colombia already start without having a permit. The resulting consequences are less significant than in The Netherlands. That is also why it happens more often. This is also the reason why this party is not placed at the highest point on the arrow which indicates the degree of power. DIMAR has less interest and less power than the environmental licensing authorities because their main focus is to authorise the operation of ships in Colombian water. For them it does not really matter whether they carry out their activities in the port of Barranquilla, Cartagena or another area. But their power should not be underestimated. They decide if vessels can enter the port. It would be best if the interest of both parties increases till they are in the quadrant of the key players. For DIMAR this can be done by raising awareness, that if there is nothing done about the sedimentation problem, this will influence the whole transportation on the Magdalena river and not only the first part.

Key players

The other parties, INVIAS, Cormagdalena, Municipalities, Departments, Asoportuaria and the Port Associations are the key players. This group deserves sustained attention because they have high power and high interest which they can use to influence the process and the outcome of the problem. What exactly their perception and interest are can be seen in the stakeholder description in the paragraph above.

E.4. Criticality table background

Besides the power interest grid. the criticality table can be helpful by giving Asoportuaria, as the problem owner, an impression of the possible reactions of the involved stakeholders. Table A.2 shows the different categories with their characteristics into which the stakeholders can be divided. The first distinction made is between dedicated and non-dedicated stakeholders. Dedicated means that the involved stakeholder is willing to actively participate and use their resources if necessary. The other distinction refers to the interest of the stakeholder (Enserink et al., 2010). Table A.3 shows the table filled with the involved stakeholders for the sedimentation problem of the Magdalena river. What can be seen is that there are no non-dedicated stakeholders with conflicting interests and objectives. The parties with conflicting interests and objectives are the dredging companies and the nature preservationists. The main interest of the dredging companies is to continue their business and thus to continue dredging. If the final solution to keep the Magdalena river more navigable does not contain a dredging part, they will not be satisfied. At the moment they dredge the river quite often, if this is not necessary anymore they will lose a large part of their current activities and thus income. For the nature preservationists it is not their main concern to make the river more navigable. They want to protect the nature from any harm, so also the nature around the Magdalena river. They will do everything to prevent parts of Parque Isla de Salamanca are burnt down or other measures that harm the environment. They will express their criticisms on those measures and they will try to stop it by lobbying by the environmental licensing authorities not to give permits. They do not really have the power to block the process or solution so that is why they are not placed in the critical actor category. The environmental licensing authorities are classified as 'non-dedicated critical stakeholder' because they will be critical on giving permits which are needed to successfully execute a future project. They will follow the procedure and if parts of the solution do not comply the permits will not be given which blocks the process. That's why their interests might be conflicting.

Table E.1: Classification criticality table (Enserink et al., 2010).

	Dedicated stakeholders		**Non-dedicated stakeholders**	
	Critical stakeholders	Non-critical stakeholders	Critical stakeholders	Non-critical stakeholders
Similar supportive interest and objectives	Actors that will probably participate and are potentially strong allies	Actors that will probably participate and are potentially weak allies	Indispensable potential allies that are hard to activate	Actors that do not have to be involved initially
Conflicting interests and objectives	Potential blockers of certain changes (biting dogs)	Potential critics of certain changes (barking dogs)	Potential blockers that will not act immediately (sleeping dogs)	Actors that need little attention initially (stray dogs)

All the other parties have a similar interest, they also want to keep the river better navigable by solving the sedimentation problem. The difference between the critical and non-critical dedicated actors lies in the fact that they are potentially strong or potentially weak allies with the problem owner. Asoportuaria has a strong connection with the Port associations because Asoportuaria represents them. Also the relation with DIMAR is strong. This is because if Asoportuaria wants to fulfil the wishes of the ports, they have to keep close contact with DIMAR to guarantee the ships can enter the port area and thus also the ports. The Observatory will also actively participate to solve the sedimentation problem. Therefore they will use their research skills. With this information, they can advise Asoportuaria what the consequences will be from the different solutions. The other parties which are critical and dedicated are ANI, Invias, the Municipalities and the Departments. Asoportuaria had a direct lobby to the Departments and Municipalities so they can be classified as potentially strong allies. Also, the relation with ANI is strong. If they want to build, operate or maintain, they need permission from ANI, so it is better to keep a good relation with this party and also to actively involve them in the process. Invias provides Cormagdalena and the Municipalities with money. They also contract the dredging companies. They don't really have a direct relation with Asoportuaria, but for keeping the river navigable at the moment, dredging is important. Invias has a wider scope than just the port area of Barranquilla, so they will not immediately do everything they can to solve the problem, but they are willing to work together. Therefore this party is classified as a non-critical dedicated stakeholder. Cormagdalena on the other hand has also the same interest, but for them it doesn't really matter if the vessels reach the inland via the port of Cartagena or Barranquilla. They keep track on the whole river stretch. The non-critical non-dedicated stakeholders are the shipping companies and the citizens. As seen earlier they have less power. They do have the similar interest as Asoportuaria, but their main objectives are different.

F Interviews

In order to gain more insights into the problem, several interviews with the most important stakeholders have been conducted. In this appendix a short summary containing the most important information resulting from the interviews will be reported.

F.1. Interview Asoportuaria

Date: 7^{th} of September 2017
Stakeholder: Asoportuaria
Interviewee: Alfredo Carbonell
Function of interviewee: Director

First of all Mr. Carbonell explained the status of the current situation of the port of Barranquilla. At the moment, a contract is in place till December with Jan the Null (Belgium dredging company). They will dredge till sufficient depth is reached in the entry channel: a draft of 10 meters and a depth of 12 meters. Currently navigation is restricted for 50 days a year, which is quite a lot and has a big influence on the economy and ports.

Next he explained a little bit more about Asoportuaria as an organisation. Asoportuaria is a guild which represents the interest of the port users; 15 different port associations are represented from the mouth to Cesar department. They work closely together with the local government (municipality) and national government (Cormagdalena, Invias, Ministery of Transportation). It is important to attain good public relations and to make sure that new regulations (made up by the government) do not have any unwanted effects for the port associations.

Cormagdalena is the party which gives out the concessions to install port infrastructures in the river. But as for everything else the government has to provide to the port associations, Asoportuaria tries to guarantee and smoothen this process. Furthermore they lobbying to show the importance of the river to as many parties as possible. For example, they organised a feedback session with international entities (shared best practices) and many other stakeholders last August.

When asked about the roles of some of the stakeholders he gave the following answer:
The role of Invias: their core job is to make the national road network, but besides this they have a budget to dredge different ocean ports. In Barranquilla this is the area from 0 to -3 kilometers into the ocean at the Bocas de Ceniza. The role of DIMAR: they are in charge of operating the navigation channel and therefore give authorisation to enter the port and make a program of which ships can come in and when. Furthermore they measure the depth of the channel.

The system of stakeholder he defines as 'unorganised', which makes it hard to work together. But even so, they try to work together with as much interested stakeholders as possible (private industry, academic sector).

Currently also a study on the economical impact of the ports on the entire local economy is being conducted. This is done to create a better understanding by the local people. They think only a few people profit from the ports but this is probably not true.

When asked about the previous and future PPP the following things where mentioned. He has great expectations for the new PPP to have more inland shipping possibilities. As for the problems with the previous PPP: the good thing was that there was always a dredge available when needed, but the issues with Odebrecht caused the contract to be litigated.

He thinks the superport is an interesting idea, however a new road is necessary in order to develop and operate the superport. Current research on how to do this without harming the environment too much is being conducted. A master plan for the superport will include a inner port (containers and general cargo) and outer port (coal). As for the future of the current ports a deepening study on the hydraulic situation of the river is being conducted by Invias. It will investigate the influence of the new bridge and the maximum possible depth of the channel till 38 km, including a cost and benefit analysis.

In the new contract, only dredging the river until the bridge is taken into account. But then the new high bridge is useless in relation to navigation, so Asoportuaria tries to pressure to deepen the river for a longer stretch. However, currently there is also no budget to demolish the old bridge. As long as the old bridge stands, the new one will be useless in relation to the navigation problem. This is one of the many an examples of bad plan forming because it is not functional.

Asoportuaria believes the infrastructure (multi-purpose terminals and specialising on the users) is able to double the current capacity. But to exploit this capacity, a greater depth is required. The river is the limiting factor to transport more in the ports of Barranquilla.

The port associations pay tax to the government to build the infrastructures to connect the ports. Asoportuaria has to check that this money is really invested in structures that benefit the port associations. Also the municipality opened a new port office, so more institutions are concerned with the river whereas in the past no-one of the municipality was concerned with the river. This is also a sign that things are changing.

The following answer was given to the question how do you see the future:
'Afraid, because of the new elections are coming up. The new contract (10 year) ideally has to materialise before the elections, otherwise a it will take a long time. The tendering of the new contract is delayed because the old contract has still not been terminated (legal issues). Also, changing something is hard because of the many stakeholders; nobody wants to take responsibility. An example of this is the width of the channel. This is just the same as defined in the old contract but it could be much more.'

F.2. Interview Cormagdalena

Date: 5th of October 2017
Stakeholder: Cormagdalena
Interviewee: Alfredo Varela de la Rosa
Function of interviewee: Director

The main objectives of Cormagdalena: recovery of the productivity and navigation of the river and conserving land around the river for agricultural purposes. Furthermore they are interested in sustainability projects including hydro-power, but that's a more future goal. Another goal is to guarantee and preserve the environment, including the ecosystem and fishing activities.
The answer to the question if the navigability was better in the past was as follows:
'In the past the river was the only method of transport of goods and people but this suddenly stopped due to bad maintenance. The goal is to recover the in-land navigation, because the highway system is not sufficient. The river is a natural highway so we should utilise this in a better way. The location of the river, in the centre of the country, is also very attractive for transportation. A multi-modal network, not competing with the road but supplementing it, integrating the different means of transportation should be the goal.'

Some general information they shared:

- The river goes through 18 department, 129 towns and 900 km of navigable river up to Honda.
- All the ports are required to have authorisation of Cormagdalena to operate on and around the river. The ports need to show their plans including the feasibility and sustainability they foresee.
- Annually fees have to be paid to operate the ports and to make use of the banks of the river. Cormagdalena owns 30 meter of the banks on each side of the river and concessions are necessary to use this land.

An important thing which was mentioned is that oil and gas related products are transported from Barrancabermeja to Cartagena mostly, because the possibility for the bigger vessels to enter the port Cartagena is preferred. Barrancabermeja is the main port for Eco-Petrol, a Colombian oil company who moves a lot of its products by water.

When questions where asked about the previous PPP with Navelena the following was said: 'Navelena did some good work but than the scandal happened and they could not find enough investors to financially support the project. It is important that something happens again in order to keep the river navigable. The first 20 km of Barranquilla is considered as maritime area due to the sea going vessels entering, this part needs sufficient depth so that sea going vessels can enter.'

As for the new contract: in the new contract (PPP) better goals are set up compared to the previous contract. Rre-work was already finished as the first two years of the original PPP had already been executed by Navelena. Therefore the new contract will be for 10 years with the goal to make it navigable from Barranquilla to Honda. Cormagdalena does not want all the money to be invested in dredging only, but prefers structures. Maybe a part of the river will even be moved to construct an alternative channel, however the environmental permits necessary are important. The total budget of the project will be 800 million. There are already many interested (international) parties for the new contract, which will be tendered as soon as the Navelena contract is legally liquidated. The party which receives the new contract will have to take care of the permits.

Next the focus was changed more to the issues in Barranquilla. They think the river activity is mainly directed to Cartagena by Canal del Dique. In Barranquilla there is less activity, so only the necessary dredging for maintenance will be continued in the new contract, no structures will be included in this part of the river. However, the tajamares are old and they want to make them entirely new because of their bad state. Some studies about the reconstruction of the tajamares are already being conducted by Invias. The sedimentation in Barranquilla is probably not only resulting from the river but also from the sea, therefore the reconstruction of the tajamares is important.

He gave the following answer to the question if other parties where/are involved in setting up the contract: They talked with some parties (including Asoportuaria, Universidad del Norte, Dimar) and the input of these parties was used to adjust make adjustments for the new contract. Furthermore they would like to start a research department within Cormagdalena to conduct research on the river, because he Observatory Universidad del Norte is more to indicate where the problems are in the river and they do no research on how to solve it. Invias is also investigating if it is possible to deepen the entrance channel in Barranquilla. Another idea for the development of Barranquilla is the superport. They like the idea but the money is a problem. However, they think it is the only way to compete (on containers and oil) with Cartagena.

F.3. Interview Dimar

Date: 3th of October 2017
Stakeholder: DIMAR
Interviewee: Germán Augusto Escobar Olaya
Function of interviewee: Capitán de Puerto de Barranquilla

Mr. Escobar spoke limited English, therefore the interview was conducted in Spanish with the help of someone who spoke both English and Spanish. The most important point the captain made was that there are two problems if you look at the Magdalena river. The first problem is in the the port of Barranquilla, which results from everything going on upstream. The second problem in the first 38 kilometres (until Pimsa) is the salt wedge intrusion.

As for the role of Dimar, they make sure the river is operated in the correct way. They give authorisation on who can enter the river or not and at which times. Sometimes they have to make the decision to close the entry channel due to bad conditions (either not enough depth or storm making it hard to enter through the Bocas). As for the funds they receive money from Cormagdalena to conduct measurements on the status of the river. This an continuously ongoing process; when they have measured till 38 kilometres they start at 0 again.

Regarding the stakeholders in this problem, Mr. Escobar mentioned that a lot of stakeholders are commercial and they are only concerned with money. This causes problems, because they all want to make as much money as possible without keeping the public interest in mind.

F.4. Interview Municipality - Office of Port Affairs

Date: 27th of September 2017
Stakeholder: Municipality - Office of Port Affairs
Interviewee: Rafael Castillo and Pablo Morillo
Function of interviewee: Director and Advisor respectively

This secretary was first situated with the secretary of economic development. In this secretary, there are 3 areas: port, marine and river.

The office of port affairs started 6 months ago, in February 2017 and is in the middle of the private and public sector working for the city. They have to bring different parties together and therefore they started a process of engagement to give confidence to the people in general. The parties which are already in the engagement plan: Uni Norte, Uni Tonoma, Asoportuaria, Cormagdalena, port owners. There are a lot of port owners who have concessions. The main goal of the OPA now is to get everybody together to get an overall plan. They really want to give results to the city, to the country and to the world. They are aware of their privileged location they have with the city. This year (2017) it is all about management and engagement. Next year the office will have money and then they will be able to do more. The idea is to create a document that stipulates what the university can offer them and vice versa. The university has a research center, the Observatory, with which the municipality can work together with. There are a lot of problems in the river. The Observatory can provide the municipality with data and answers to a lot of questions. They can make it real.

The river is too shallow. To solve this, a dredger is a common solution. As public sector, they can talk to the government and mention the materials they need to keep the river accessible, with all the consequences. The Observatory can not really talk to the President or Ministry, but the municipality is in a position to do that.

The mentioned superport is a really long term plan. The required investments are huge. There are several concessions already made for the benefits from the superport. The municipality wants to work on it, together with a lot of different other parties.

They lobby with Cormagdalena, who give out the port concessions and gets the money. ANI structures it afterwards. But at the moment, no one is supervising this. The municipality is interested in doing this supervision. In that way, the municipality will also earn more money which can be used to do more.

Several parties receive money from the national government for maintenance of the river. The heads are Cormagdalena, Ani, Invias and Dimar. They are the big heads in the problem, they are the principles. Dimar doesn't give money, but they give the permissions. Ani is the one who gives money to Cormagdalena. The problem is that those four parties have the same interest, but with different responsibilities. Everyone looks at the problem from his own vision and with its own solutions. In the public sector, there is a lot of bureaucracy. This makes it difficult to execute stuff, because there are a lot of people involved. In the private sector, it's way easier to execute things. The goal of the municipality is also to make it easier in the public sector by, for example, taking away all the unnecessary regulations.

Dimar depends on the ministry of defence. The people of the municipality are in good relationship with the director of Cormagdalena, Asoportuaria and Dimar. This makes it easier to work together with them.

About the previous PPP with Navelena, there is not much known by the municipality. In the vision of the municipality there is one big problem, and that are the activities related to the dredging. If there was a dredging machine available all time, there wouldn't be a problem. 60-70 percent of the big ships that want to come to Barranquilla cannot enter the port and have to go to Cartagena. This means a loss for the economy of Barranquilla. The big cruisers with approximately 5000 people go to Santa Marta and Cartagena and spend their money there. Barranquilla doesn't have those benefits. Right now, Barranquilla receives 9 million tons of corridor. If there is a dredging machine available all time, this amount can grow up to 15-20 million tons per year.

The municipality has developed a new plan for the use of the land next to the river. The plan is to make the city more attractive, by turning the face of the city to the river. In order to do this, lots of industry next to the river have to be moved. The municipality wants to do this by giving those parties discount on taxes for the coming 10 – 15 years. The industries which should move are not from the port sector. It are other companies, which have nothing to do with the ports. This relocation is not related to the sedimentation problem, but to the problem that Barranquilla is built with it's back to the river. Right now they try to change that, they want to face the river and integrate in into the city. The family of the current president and major is one of the most powerful families in Colombia. Over the last ten years a lot has changed in a good way, there are positive results and less corruption. So it's not such a big problem the government functions are fulfilled by a select group of persons, it has also positive sides.

Nowadays the office of port affairs is the only OPA office in Colombia, but this doesn't withhold them of consulting other municipalities.

F.5. Interview Observatory

Date: Constant contact
Stakeholder: Observatorio del Río Magdalena de la Universidad del Norte
Interviewee: Humberto Avila
Function of interviewee: Director

The Observatorio del Rio Magdalena de la Universidad del Norte, hereafter observatory, was recently established (2017) in order to gain more knowledge on the status of the river. It followed in the footsteps of another institution from Universidad del Norte named: 'Laboratorio de Ensayos Hidráulicos de Las Flores' which consisted from 1986 till 2005 and pertained a similar goal as the observatory.

Mr. Avila, as a hydraulic engineer and inhabitant of Barranquilla, has a great amount of knowledge about the behaviour of the Magdalena river. Since he was also our supervisor during our research he shared a lot of valuable information, mostly technical, on which the model is based. He also represented the Observatory and shared some information on the role of the Observatory, however since their existence was only established recently this role is still changing and growing.

With the main goal of investigating the river, implicitly they want to advise Cormagdalena and other organisations about how the future of the river can be guaranteed. Therefore they do not only do research, but they also monitor and try to share their knowledge as much as possible. They look at how to maintain the river in order to guarantee the navigability, prevent floods and droughts and try to understand the erosion/sedimentation processes.

F.6. Interview Puerto de Barranquilla

Date: 29^{th} of September 2017
Stakeholder: Puerto de Barranquilla
Interviewee: René Puche and William Elliott V.
Function of interviewee: President and Vice President of Operations respectively

There are several issues which should be taken into consideration. The first is INVIAS with the route national. It should be conducting an analysis on the access channel and the behaviour of the access channel. Results should be whether it is possible to further deepen the access channel or not. But I'm not sure if this is part of your studies. The study of INVIAS should be finished in December this year, but there is not much belief this deadline will be made.

At the moment they don't know what is going on, as all research takes very long. The experience they have now with the instability of the access channel is never seen before. The director or Puerto de Barranquilla believes it has to do with the building of the new bridge or the small Island over there. It is the only thing new since then. They just started dredging again in the river mouth, but they lost three meters one week later.

The flow velocity of the river today was 5 till 6 knots, its discharge 6000 or 7000 m3 per second. If you look at the river before it passes the bridge, it is very wide. Then the width decreases from 800 meters to 400 meters. That makes it difficult, because often if you want to deepen the river, it means narrowing it. That might also cause even larger flow velocities, making the situation also quite complex.

The question rose if we considered the different terminals in our research. One is for grain and the other is for coal. They are both deeper upwards of the river. This is not included in our model. We did include the large groins like the dique Nacional and the Tajamares. The causes of the problems are also more upstream, partly due to changes in land use. This caused that over the years more and more sediment has been found in the river.

René Puche advised we should speak with Aldo Rossi, from the company called Travo Petrolio because he has been involved in the process for a really long period. He unfortunately seemed to be out of the country at the moment.

The involvement of Puerto de Barranquilla is more from the user point of view. They only make pressure towards the public entities, such as the state. This to make sure the terminal can stay competitive also in the future. It works, but every time there needs something to be done they start dredging. They haven't been able to find a sustainable solution yet. This year the terminal has had a loss of 350 thousand tons of products due to lack of sufficient depth of the river. It is also very difficult because there are too many entities involved.

When we showed the network-diagram, he was impressed. It is important to get everyone around. Rene already tried to do that. From the networkdiagram you can see how complex the situation is, and also how bureaucratic.

The construction of the new bridge started without having done all the previous studies, like an impact study. They did not have an environmental license, and still do not. Authorisation to cross the bridge was also not given at that time. The construction of the bridge started in September 2016. By the end of that year still none of the documentation was fixed. So Puerto de Barranquilla put a lot of pressure on the government and asked for all the prior documentation. There the conversation ended. Afterwards Puerto de Barranquilla went to Invias and asked for an analysis. Currently, they are conducting the hydraulic impact analysis. Puerto de Barranquilla would like to know if it's possible to deepen the river to 15 meters and to widen it 150 to 300 meters. The construction of the bridge is still going on, and by Puerto de Barranquilla they believe that this is causing the problems with the access channel. The investigation was supposed to tell whether terminals were also ready for 15 meters. If you get 15 meters, you will get bigger vessels and the problem then would be the turning of the vessel. The river is quite narrow.

Are you also interested in deepening the river more upstream so that you have the possibility to get the cargo into smaller barges and bring them inland or is it only trucks? The plan from the government is to bring seagoing vessels up to here and then discharge it into barges. The barges then go upriver all the way to Barranca and from there to Bogota. It will be more the European style. The situation now is that Colombia has the highest transportation costs of whole Latin America, which reduces their competitiveness. 80 percent goes by truck nowadays and that is too high. Puerto de Barranquilla doesn't expect the terminal to become very large. 5 or 6 million tons per year, maybe 7 million. There is a mutual dependency between the ports and Barranquilla.

About the previous contract with Navalena, the director of Puerto de Barranquilla was not sure they did a good job. The contract was divided in 4 phases. One was from Bocas the Ceniza up to the bridge. Then from the bridge to Puerto Sancar the depth was about 7 feet and they had to do maintenance dredging. Problem is that there are some areas where the river can become one kilometer wide, so they need to narrow it to increase the water level. They started too soon with all that. For the terminals it became an opportunity, the fact that the contract was awarded. In the beginning the contract did not include the access channel. They managed to include it at the last minute and the only thing they were able to do was to keep the depth of the access channel at 11.43m. It was good they managed the last 22 km in the contract, because that allowed Navalena to bring in a dredge every time needed. Otherwise they were required to go to a public tender and the state would hire one. When the people from Puerto de Barranquilla looked deeper into the contract and reviewed it, they realised that many things that were needed were not included. The problem in Colombia is, that once you give a concession no one else can touch, in this case, the river. Even at the time between December and April, the river had to be dredged. Navalena was not going to do it because they were under investigation. But due to the concession, nobody else could do it, even if another party had the money to hire a dredge. The government also couldn't do it, which resulted in a complete mess. That was when Puerto de Barranquilla started pressing to get the contract avoided and then with the contract voided maintenance of the river was possible again. In Colombia, there is a misinterpretation of a PPP at all. It is just a contract, not a PPP. As a private person, the director of Puerto de Barranquilla would rather just have a contract instead of a PPP. It is really hard to have a PPP with the state, it is not the same as in the Netherlands. Compared to the second Maasvlakte in Rotterdam, there is a port authority, and the state owns the land and they do the development and then they rent it out to someone. The basic infrastructure belongs to the state. That's not the case here in Colombia. We should, in Colombia, start with having a port authority. The problem is that nowadays you go to the government and say: 'I want that piece of land concessioned', and they give it to you. You do have to present your 20 years business plan on a piece of paper. If you haven't done anything 10 years later the government doesn't know. At the end, the government should have a much bigger role in the process. In the sense that if I present a business plan it should agree with what the government is looking for. I cannot do whatever I want. Here in Colombia, everyone can do anything. 60 percent of the ports here in Colombia are multipurpose. We do a little bit of everything, which is the worst scenario, very inefficient. If we get together as terminals and say: you do this and I do this, the authority comes and says: 'hey you're forming a cartel or what?'.

The responsibilities are also very widespread. With so many authorities, is it still clear what everyone's task is? If they bundle their strengths it would be better, but why this is not happening already, no one knows. We all see it doesn't work, but nobody does something because that has to come from the government. The corruption does also play a role in this. Another point is also that it takes very long before things are done, or decisions are made. Research from INVIAS has to be finished in December, but there is not much believe this is also going to happen. The Navalena contract is also too complex to evaluate.

The superport makes sense if you look at it in comparison to Rotterdam, but Rene Puche thinks the people are not mentally prepared to do that. If you build the superport to compete with the current ports, they will all die and the superport will never be a success, because it is an one billion dollar investment. You need easily 20 till 25 tons of cargo to make it happen and if you take the volume we move through our terminals today, it is about 11 million tons, which is not enough cargo. If you put the superport to compete with the smaller ports, they will off-course take customers away and volume away, but they will not take 100 percent. But if the current ports move less, they will not survive. So, there has to be at least an increase in volume. As a result, you will also be competing with Cartagena, Panama, Kingston, Cuba, Costa Rica and so on. The smaller ones in the mouth of Barranquilla could become small terminals for logistic support. What might work, but only if we are mentally prepared for it, and Rene Puche doesn't think so. Rene and William are interested in playing a part in the superport idea. If it happens, they will take their port and move it to the superport. But then everyone wants that. It will cost a lot of money and the port infrastructure has already grown too much. If you take the install capacity from different terminals in Colombia, the volume can be doubled, without having huge investments. It is just a mess right now, because it is not organised. In Buena Ventura, one of the ports in the mouth of the Magdalena river, they went from one container terminal to three. Another point mentioned is that it will be hard to find an operator, who is willing to invest in the superport.

F.7. Interview Servicios de Dragodos & Construcciones S.A.

Date: 5th of September 2017
Stakeholder: Local dredging company - Servicios de Dragados & Construcciones S.A. and Damen Shipyards
Interviewee: Andrew Williams and Pieter Becker
Function of interviewee: financial manager of the dredging company and sales manager Latin America respectively.

Tug operations are concessions which are made. You can see that the transport of the amount of goods and thus also the port calls declines. This is not only for Barranquilla but for the whole of Colombia. Still there are harbours which are or have plans for expanding, but they must keep dredging there or else they will lose customers.

It is more interesting to look at the shipping in the whole Magdalena River. Because it is not deep enough, you've to keep dredging. The interesting thing is to look what the origin of all the sediment is, which is the core of the problem. Transport to the inland nowadays goes with small vessels in a crapy way.

Cormagdalena, a governmental institution, structures the process of maintenance. They receive money from the ministry. The whole maintenance consists of three big projects: dredging of the port, maintenance of the port and dredging of the river. The Cienaga de Santa Marta is a national park, but there is some industry inside and also a port, on the other side of the bridge facing the river. They have a lot of problems with trash. Nowadays 60 concessions are issued by Cormagdalena, but half of them don't do anything. They are scattered along the river banks.

The island by the bridge didn't exist before. It has formed when the bridge was built. All the ports in Barranquilla are grouped in an association, named Asoportuaria. This party looks after the interest from the ports. The river was dredged three times in two months, which is a lot and economically not feasible. Each time the costs were about 50 million dollars. The dredge operations lasted approximately two weeks. Having your own dredge would save a lot of money. Barranquilla is losing clients to Cartagena because big ships cannot enter Barranquilla.

The width is in most places not such a big problem, as you can turn with the help of tug boats.

The river is too shallow for the big ships, that's why the transport further upstream goes with smaller barges. For example, the company Huseco does transport of cements and coal. They are upstream and want to transport it to the Caribbean. They want to do it one time with a big vessel, but that is not possible yet.

There are four to five dredging companies in Colombia, but the problem is that the size of those companies and their equipment is not sufficient enough to do the huge projects. The work in Bocas de Ceniza has to be done with bigger material then they have. There are 3 categories dredges:

- Really big ships: Jan de Nul, Van Oord, Boscalis, Damen
- Middle area: small hopper dredgers: that's what you need here in Barranquilla.
- Small equipment: current scale of Colombian equipment

The required middle area is not really an existing market. The equipment is too small for the big companies, but too big for the smaller companies. The work in the Bocas de Ceniza has to be done by an international company with a big vessel, or a consortium of local companies that buy a bigger dredge than currently available.

You cannot leave the dredged sediment everywhere. You have to know what kind of sediment you're dredging. The location of the dumping site is decided by Cormagdalena, they have the jurisdiction of the Magdalena river. They use sediment for coastal reinforcement, if it's not polluted. The Magdalena river is basically a sewage pipe for lots of people. They are dug canals where people dump all the sewage water, which all this ends in the Magdalena river causing pollution of the sediment.

Figure F.1: Interview DIMAR.

Figure F.2: Interview Puerto de Barranquilla.

Figure F.3: Interview Asoportuaria.

G Comparison project and process management

Project and process management are both essential for successfully accomplishing a project. Process management is a newer form of handling a project. It emerged mainly in the last thirty years and is focused more on dealing with inter dependencies and dynamics in network situations than project management. Project management on the other hand is already in use for a longer period. In 1969 the Project Management Institute was founded to give this branch more professionalism and to let this sector grow faster (Meredith, J.R.; Mantel Jr, 2011). A project can roughly be divided into project preparation and project realisation. It is argued that the most effective management is conducted when process management is applied both in the preparation phase and in the project realisation phase. It is important not to use the techniques strictly separated but instead let them complement each other and use them in parallel when needed.

G.1. Project management

Project management can best be used when the project is clearly delineated with clear goals and requirements, thus in the project realisation phase after the initiative has taken place. Project management focuses on the content of the project with its framework defined before the start of a project. This means that controlling on budget, time schedules, information flows and quality are commonly used strategies in project management. To apply these strategies a wide range of tools is available. For this it is important that the project has a 'frozen' context, the environment has to be stable and static. The main problem in project management is that a project entails only the implementation of a predefined solution to a problem and therefore it is often insufficiently accepted by the involved actors. This can mostly be avoided by organising stakeholder participation meetings and conducting process management (Edelenbos and Teisman, 2008; Heurter, 2007).

G.2. Process management

Where project management focuses on the content of the project, process management on the other hand can best be used in uncertain situations, to initiate or develop a project or to realign it to changed conditions. Those uncertain situations are partly caused by unknown stakeholders and mostly goals are not clear yet. It mainly focuses on gaining support and acceptance for a plan or process. Therefore, it is less strict in time in comparison to project management. The process is more important than the objectives defined before. It is about gaining support by making compromises, mostly done in rounds with different subjects. This is to make sure only the parties who have an interest in the subject which will be discussed on the table are involved. Process management is applied in dynamic situations. Those dynamics are not always caused by internal situation. External projects can also influence the project. By the navigability of the Magdalena river for example, the realisation of the Malecón project on the river side has to be taken into account by designing the process of making the port area more navigable. By designing the engagement plan this can be used to come to compromises between different parties and to gain support for the plan. Also if the port gets better accessible more parties will become interested in doing business, all with their own interests, views and interaction with the current stakeholders.

G.3. Comparison

A quick overview of the differences between project and process management is given in table B.1.

Table G.1: Difference project and process management based on: (Heurter, 2007; De Wit, 2010; Edelenbos and Teisman, 2008).

	Project Management	**Process Management**
Goals	Known	Unknown
Actors and Stakeholders	Known	A lot, but partly known
Occurs in which phase	After initiative	All phases, including the idea
General support	Control, course and result are known in advance	Goal-seeking, flexibility and coping with complexity
Decision-making	Operational	Strategic
Context	Static, 'frozen' context	Dynamic, interwoven, erratic context
Focus	Content of the project is leading. Focuses on a sound, well- substantiated project proposal.	Smoothly running the process. Focuses on the most important parties (their interests and views) and how to bring and keep them together.
Main problem	Result is not sufficiently accepted by the involved actors.	Creating acceptance via process and process rules takes time.

G.4. Process management in PPP's

PPP's are mostly adapted in projects which are highly complex and where many different interest play a role. In these kinds of projects it is where the government needs the help of the private sector to utilise their expertise, resources and innovative power to make the project successful. However, to utilise these strengths it is important that the private parties are involved as early on as possible. Meaning that the partnership should not only function as a framework during the construction and exploitation phase but it should already be established during the planning phase (van Ham and Koppenjan, 2001). One crucial criteria in the development of such a truly cooperational PPP is the trust which needs to be earned between the participants. The partnership should not only be fixated on the contractual arrangements but much more on commitment to the project and the other stakeholders (Bovaird, 2004). This is where process management can play an important role.

The use of process management in PPPs is a fairly new principal but has proven to be successful various times already. For example in the A2 passageway Maastricht infrastructure project PPP process management was used. This Dutch national highway used to form an east-west barrier in the city of Maastricht. Due to the many traffic problems from the 1980s onward several attempts had been undertaken to solve this problem. However these attempts failed mainly because of inadequate financial resources and lack of political support. In 2001 a more successful attempt was made to address the problem. This time different than before because governmental actors started cooperating and the scope of the project was broadened to include issues such as liveability and safety to come to a solution accepted by all stakeholders. These issues were discussed in several process rounds, in order to engage the stakeholders. As for the financial problems, negotiations were restarted between the national and regional government resulting in an administrative agreement (Verweij, 2012).

H
Alternatives

In this appendix an elaboration on the possible measures is given, including the design considerations.

H.1. Groynes

Figure H.1: Groyne 1 in the Magdalena river (Cañizares et al., 2007).

Design considerations
The following considerations are important in the design of Groynes (Kraus et al., 1994):

- Length: the longitude of groynes depends upon the configuration of the river channel. If groynes are too long, they are liable for damage due to settlement differences in easy erodible rivers. In this perspective it is valuable to determine a so called free river zone in which you don't allow any enclosement;
- Spacing between groynes: very often instead of one groyne a series of groynes is used. Each groyne can protect only a specific river stretch. When the spacing is too far, bank erosion between the groynes is possible. If the spacing is too close, deposition areas will not develop. Hence, an essential factor for groyne spacing is the length of the groyne. A spacing of 2 to 2.5 times the longitude of the groynes is a value that is commonly used (Kharagpur, 2013);
- Elevation: elevation of the groynes governs the over topping of the groynes. During high discharge conditions, groynes obstruct the flow which can lead to higher water levels and possible flooding. In these cases, overflow of the groynes may be desirable. A disadvantage of river flow over topping the groyne is the development of scour holes downstream of the structure;
- Orientation of the groynes: the angle of the groyne to the river bank can be varied;
- Porosity: porosity determines the behaviour of the structure in the flow. This is important for erosion and sedimentation around the structure and for the stability of the structure itself;
- Shape: shape is mainly controlled by the slope of the groyne;
- Construction materials: the material that is used influences several factors, such as the flow properties, deterioration rate of the structure and construction costs.

H.2. Longitudinal dams

Figure H.2: Longitudinal dam in the river Waal (Buijse, 2015).

The following design considerations have to be taken into account:

- Length: the length governs the area that is affected by the longitudinal dams. Longitudinal dams can induce erosion at the downstream end of the dams, therefore the location of where the dam ends deserves special attention;
- Elevation: mainly important for the opportunity of overflow;
- Openings: longitudinal dams can be constructed with gaps. In this case the behaviour of the dams may be different.

H.3. Chevron dikes

(a) Series of chevron dikes in the Mississippi river.

(b) Blunt nose chevrons in the Mississippi river.

Figure H.3: Blunt nose chevrons and chevron dikes in the Mississippi river (United States Army Corps of Engineers, 2012).

The following considerations have to be taken into account in the design of chevrons:

- Configuration: chevrons can vary in their configuration. Depending on the river system, the radius of curvature of the closed end and the distance between the downstream ends can be changed;
- Length: the total length of the chevron is defined as the chevron leg (Singh and Sharma, 2014). The chevron leg controls the area that is influenced by the chevrons. In interaction with the configuration, the total length along the perimeter of the chevron and the length of the downstream ends can be changed;
- Location: chevrons are commonly used at the location of bifurcations in the river to guide the flow in the main channel without completely locking off the side channel. Depending on the width of the

bifurcation one or multiple chevrons are situated in a line, as illustrated in Figure H.3(b). Also at the upstream end of an island chevrons are used to protect it from erosion;
- Spacing between chevrons: series of chevrons tend to work better (United States Army Corps of Engineers, 2012);
- Elevation: like groynes, chevrons form an obstruction in the flow of the river. During periods of high discharge, this can cause flooding problems. In the Mississippi project at St. Louis, a height of 4.6m above bed level was used, which is half of the flood level at that location (9m) (Khanal, 2012);
- Porosity: the porosity of the structure influences the flow patterns around it and the resulting erosion or sedimentation;
- Construction materials: the construction material influences the porosity and possibility of erosion of the structure.

H.4. Breakwaters

The following considerations have to be taken into account in the design of breakwaters:

- Length: in the current situation both the eastern and western Tajamar extend to the same level seaward. Adjusting the length of one or both of the Tajamares, influences both the river flow and the longshore transport;
- Orientation: the angle between the Tajamares and shore can be changed. The current orientation of the Tajamares causes a curve in the river. By changing the orientation, the mouth of the river can be straightened which has influence on both the river flow and longshore transport;
- Elevation: submerged or emerged;
- Porosity: the porosity of the structure influences the flow patterns around it and the resulting erosion or sedimentation;
- Extra protection: in order to mitigate for scour or sedimentation areas extra protection can be used. This could done by means of toe protection or rip rap revetments among others.

H.5. Soft measures

H.5.1. Dredging

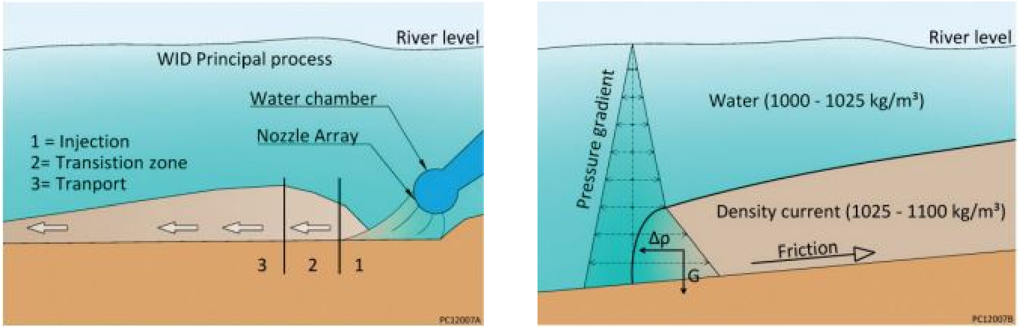
The technique of Water Injection Dredging (WID) is based on the principles of hydrostatic pressure difference and gravity force. With low pressure pumps a large volume of water is injected into the soil through the nozzles of a horizontal bar above the bottom (Figure H.4a). By adding enough water into the soil, the distance between the soil particles is increased until the effective cohesion of the soil is overcome and a mixture of sediment and water is developed. Since water injection is done with low pressure pumps and because of gravity, a density current is formed in the lowest 1 to 3 m above the bed.

The density current than flows under the influence of natural forces. Due to the different densities of water and the density current, a pressure difference develops (Figure H.4b) which is the driving force. The resisting forces are the friction between the current and the bottom layer and internal friction. As long as the driving force of the pressure difference is bigger than the friction, the layer will keep moving.

The success of WID depends on the boundary conditions of the application site ((PIANC, 2013)):

- Soil characteristics
- Bathymetry and geometry
- Hydrodynamics
- Geographic location
- Contamination type and level

For the WID to be able to liquefy the soil particles, the soil has to meet specific conditions. A too high undrained shear strength will result in clay lumps quickly settling at the bottom, without the possibility of transport. In case of granular material, a too high average grain size will result also in quick settling of the particles. The highest production rates for WID are achieved with median grain sizes of 0.05-0.06 mm. An increase in grain size will result in a decrease of transported distance.



(a) Principal process (b) Driving forces of density current

Figure H.4: Principals of WID technique (PIANC, 2013).

Application of WID

A well known application of WID is for maintenance in an access channel of a port. These channels are often protected against waves by man-made structures, like breakwaters. A negative effect is the sheltered zone, where sediment settles. WID can stir up the sediment in this zone, bringing it back into the natural transport system.

Figure H.5: Water injection dredging (Verhagen, 2000).

H.5.2. Sediment bypassing

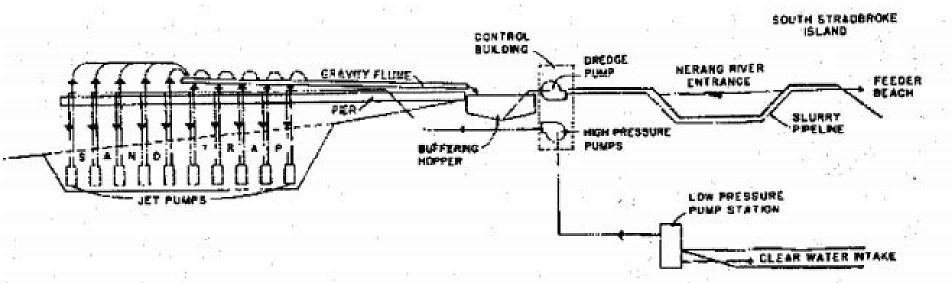


Figure H.6: Elevation view of Nerang river bypass.

I

Motivation scores MCA

In this appendix a short motivation for the scores is given. The consequences of the river training works are discussed for each criterion.

I.1. Section I

I.1.1. Current situation Section I

Navigation conditions (Score: 2)
Currently, during the year the navigation conditions are most of the time not sufficient. In order to improve the navigation conditions, an alternative plan is required. Current infrastructure has improved the navigation conditions in some reaches, but it remains difficult to guarantee the required depth for the full stretch of the access channel, particular in the river mouth.

Adaptability (Score: 3)
The current strategy in the first sector consists of the use of dredging vessels and river training works. The current strategy cannot cope with the sand bar in the mouth, which results in long periods of downtime. A positive characteristic of the use of dredging vessels is that they can be used in different reaches of the access channel. Hence, dredging vessels can be used when the river changes course.

Impact on river functions (Score: 3)
The current strategy of dredging the river mouth has no significant positive or negative influence on the functioning of the river. A neutral score is assigned.

Construction costs (Score: 5)
There are no construction costs when the current situation is maintained.

Maintenance costs (Score: 1)
Maintenance costs are relatively high because there is need for dredging. Dredging vessels carry out maintenance several times a year. Furthermore, involved parties do not possess a dredging vessel. Other (international) dredging companies are hired to fulfil the dredging practices, which results in additional costs.

Sustainability (Score: 2)
In the current situation, the Magdalena river is seen in a mono-functional way. This means that possibilities to improve other river functions besides navigation remain unused.

Impact on national parks (Score: 3)
The current situation does not have a significant positive or negative impact. Therefore the assigned score is equal to 3.

Downtime (Score: 2)
When the required depth is not reached, downtime occurs. Due to the absence of a effective dredging plan, the river is dredged only until the required depth. This means that the navigation conditions are immediately affected when sedimentation occurs.

Construction time (Score: 5)
When the current situation remains, there is no construction time which results in a high score.

Possibility for industry (Score: 3)
As ships are able to navigate the Magdalena river, there are many possibilities for industry. However, since the navigation conditions are far from optimal, the costs of goods are relatively high. This contributes to the tendency of companies and industry to settle in another region.

I.1.2. Adjusting length Tajamares (Figure 8.4a)

Navigation conditions (Score: 3)
By adjusting the length of the Tajamares the effect described in Section 8.1.6 is reduced. This will result in a short-term response. Since other effects remain unchanged, the navigation conditions are expected to improve slightly. The long-term effect of this application is difficult to predict. This depends mainly on the development of the longshore sediment transport.

Adaptability (Score: 2)
It is hard to adjust the influence of breakwaters. Due to the bathymetry and dynamics of the river mouth, it can be hard to extend the breakwaters. Furthermore, the adjustment of infrastructure takes a long time, especially when the infrastructure is located in a high-energy environment.

Impact on river functions (Score: 3)
The readjustment of the Tajameres will affect the various processes in the river and therefore the river functions. At this stage it is not possible to indicate which functions will change and how large this change will be. Therefore, a neutral score is assigned.

Construction costs (Score: 3)
Without a detailed design it is hard to make an accurate cost estimation. The costs for the breakwater depend on the quantities and the unit rates of the components. Based on Table 3.2 the costs of the adjustments of the Tajamares are expected to be considerable but not very high compared to the other presented ideas.

Maintenance costs (Score: 4)
The adjustment will reduce the sedimentation of the river mouth which will reduce the costs for maintenance dredging. This reduction is counteracted by the costs for maintenance of the infrastructure. Since this solution is about a relatively small adjustment of the current infrastructure, the additional maintenance costs will make a minor difference. Therefore the assigned score is higher than the score for the current situation.

Sustainability (Score: 3)
The adjustment of the Tajamares does not change the mono-functional approach of the Magdalena river. This results in an unchanged score of 3.

Impact on national parks (Score: 3)
Because the Tajamares extend into the ocean, changing the length will have no or very little effect on the national park east of it. A neutral score is assigned.

Downtime (Score: 4)
Since the sediment volume to be dredged is reduced, the downtime related to the dredging practices is reduced as well. Other contributions to downtime will remain unchanged, which results in an slightly improved situation.

Construction time (Score: 3)
The construction time is expected to be significant, but since it is an adjustment of existing infrastructure the duration of construction will be limited.

Possibility for industry (Score: 3)
Due to the adjustment of the breakwaters, less dredging is required. This will result in less downtime and more certainty for navigation depth.

I.1.3. Water Injection Dredging (Figure 8.4b)

Navigation conditions (Score: 5)
WID can improve the navigation conditions considerably, especially when a proper dredging plan is developed. Water Injection Dredging is expected to be faster than the current method, since there is no transportation of dredged material needed.

Adaptability (Score: 4)
Generally, dredging is a very flexible method. However, Water Injection Dredging needs additional conditions to be effective. This will reduce the flexibility and therefore the adaptability. Furthermore, not every dredging company possesses a Water Injection Dredger, this requires additional attention when a dredging plan is developed.

Impact on river functions (Score: 3)
WID has a slightly more positive impact that TSHD dredging 8.1. However, this impact is assumed to be very limited, therefore the same score is assigned as in the current situation.

Construction costs (Score: 5)
This method does not require additional infrastructure. Hence, there are no construction costs.

Maintenance costs (Score: 2)
WID can be seen as maintenance dredging for the access channel. Therefore the maintenance costs will be relatively high. Since WID is expected to be cheaper than TSHD dredging, the score is higher than the score for the current situation.

Sustainability (Score: 3)
In the current situation, the sediment that is dredged is dumped in the offshore canyon. When WID is used, the dredged material is suspended in the river, which means that the sediment is transported seaward through the mouth of the river. This mechanism will supply sediment for alongshore transport. Therefore the idea scores slightly higher than the current situation on the sustainability criterion.

Impact on national parks (Score: 3)
This solution does not have a positive nor negative impact on the national parks along the river. Therefore the score on this criterion remains the same.

Downtime (Score: 4)
The downtime will be reduced significantly. This is mainly due to two factors: the transportation time is reduced, which means that the cycle time is reduced with respect to the current situation. Secondly, when Water Injection Dredging is used there is an opportunity to develop a proper dredging plan.

Construction time (Score: 5)
Again, this method does not require additional infrastructure. Hence, there is no construction time.

Possibility for industry (Score: 4)
The reduced downtime and the improved navigation conditions result in increased opportunities for industry. Furthermore, when a proper dredging plan is implemented, the required depth can be guaranteed for an longer period.

I.1.4. Sediment bypass (Figure 8.4c)

Navigation conditions (Score: 4)
In the mouth, the navigation conditions are mainly limited by the sandbar in the entrance. Alongshore transport has a large share in the development of this sandbar. With the implementation of the sediment bypass, the alongshore sediment transport is reduced. Consequently, the contribution of the alongshore transport to the sandbar development is reduced, which improves the navigation conditions.

Adaptability (Score: 2)
A sediment bypass is a rigid construction. This means that it is hard to adapt the bypass when the alongshore transport is changing. However, the intake of the sediment bypass can be adjusted to the sediment supply.

Impact on river functions (Score: 3)
Sediment bypass does not have an impact on the river functions. Therefore the score remains unchanged.

Construction costs (Score: 1)
Sediment bypass is known as a costly idea. This is due to the construction of the jetty and the pipes for the transportation of sediment. Furthermore, an expensive pump is needed to generate the pressure for transportation of water and sediment.

Maintenance costs (Score: 2)
The maintenance costs for dredging will be reduced since the alongshore sediment transport is limited. However, the sediment bypass needs maintenance as well, therefore the maintenance costs are slightly lower than the current situation.

Sustainability (Score: 4)
The sediment bypass supplies sediment for longshore transport in western direction. This means that the use of the sediment bypass is not mono-functional, which results in a higher score for the sustainability criterion.

Impact on national parks (Score: 2)
For the construction of the sediment bypass a road is needed through the national parks. This will affect the national park in a negative way.

Downtime (Score: 3)
The downtime will be reduced since the volume that needs to be dredged is decreased. However, during the construction of pipes of the sediment bypass the navigation channel needs to be closed partly, which will compensate the reduction of the downtime. Therefore a slightly higher score is assigned to the downtime criterion.

Construction time (Score: 2)
The complexity of the sediment bypass results in a long construction time. Furthermore, the sediment bypass needs to be tailored to this specific situation, this results is a long stage of research and development.

Possibility for industry (Score: 4)
The sediment bypass will serve as a long term solution which reduces the need for dredging. Therefore the downtime will be reduced and this will increase the possibility for industry.

I.2. Section II+III

I.2.1. Current situation Section II+III

Navigation conditions (Score: 3)
At present, the navigation channel in this section has sufficient depth to accommodate large vessels, but the limited width causes problems. An increased width of the channel could increase the score on this criterion.

Adaptability (Score: 3)
The current situation has been maintained by dredging and the building of the Dique Direccional. Dredging can easily be adapted to a change of the river course, but the location of the Dique Direccional is fixated and can not follow changes in the river course.

Impact on river functions (Score: 3)
The river bend is fixated in its current location due to the building of the Dique Direccional. By maintaining the current situation, the impact on the river will not change but remain as it is. A neutral score is assigned.

Construction costs (Score: 5)
There are no construction costs when the current situation is maintained.

Maintenance costs (Score: 3)
Due to the need for occasional dredging during the year, the maintenance costs in the current situation are relatively high. Also the Dique Direccional requires some maintenance, but at present this is not carried out frequently.

Sustainability (Score: 3)
In the current situation, the Magdalena river is seen in a mono-functional way. This means that possibilities to improve other river functions besides navigation remain unused.

Impact on national parks (Score: 3)
The current situation does not have a significant positive or negative impact. Therefore a neutral score is assigned.

Downtime (Score: 3)
Dredging activities in the river bend might lead to (partial) blockage of the navigation channel, due to its limited width. Also the sedimentation itself can cause problems for navigation.

Construction time (Score: 5)
When the current situation remains, there is no construction time which results in a high score.

Possibility for industry (Score: 2)
The navigation channel is located in the outer bend, opposite to the city which is located in the inner bend. The companies located in the shallow inner bend do not have sufficient depth in front of their quay walls, which forces them to use jetties.

I.2.2. Adjusting bend radius (Figure 8.5a)

Navigation conditions (Score: 4)
Increasing the radius of the river bend will result in a reduced secondary flow. In the long term, this will result in a somewhat less deep, but wider navigation channel. This will give more possibilities for navigation.

Adaptability (Score: 2)
Once the radius is changed, the river bend will be fixated by means of a bank protection. If the river changes upstream or downstream, the bend will not be able to follow these changes.

Impact on river functions (Score: 2)
Changing the radius of the bend will have major impact on the river functions. The river will have to find its new equilibrium depending on the radius, resulting in a different morphology.

Construction costs (Score: 1)
The outer bank will be relocated inwards, to the location of the current navigation channel. This has to be done over a distance of several kilometres, resulting in high construction costs. For this stretch, a bank protection has to be applied as well to prevent erosion of the outer bank.

Maintenance costs (Score: 3)
Once the construction project is finished, only small maintenance and dredging activities have to be done.

Sustainability (Score: 2)
When adjusting the bend radius the river banks have to be strengthened. This means that the lateral connectivity in this stretch of the river is affected, this results in a lower score on this criterion than the original situation.

Impact on national parks (Score: 4)
During construction time the national park might experience some damage, but when the project is finished an area will be added to the park.

Downtime (Score: 4)
Once the construction project is finished, only some small maintenance and dredging activities will take place. With the increased width of the navigation channel, this will not cause many problems for navigation.

Construction time (Score: 1)
During construction, (part of) the navigation channel will be blocked due to construction works in the channel. Also, the increase of the width after increasing the river bend radius is a natural process, which will take time.

Possibility for industry (Score: 4)
After completion of the project and the natural erosion of the inner bend, the navigation channel will be wider and located more inwards. This will increase the possibilities for navigation and for port companies in the inner bend.

I.2.3. Relocation of Dique Direccional (Figure 8.5b)

Navigation conditions (Score: 4)
Relocating the Dique Direccional outwards will result in an increased river bend radius. Increasing the radius of the river bend will result in a reduced secondary flow. In the long term, this will result in a somewhat less deep, but wider navigation channel. This will give more possibilities for navigation.

Adaptability (Score: 2)
Once the Dique Direccional is relocated and the radius is changed, the river bend will be fixated by this structure and the use of bank protection. If the river changes upstream or downstream, the bend will not be able to follow these changes.

Impact on river functions (Score: 2)
Changing the radius of the bend will have major impact on the river functions. The river will have to find its new equilibrium depending on the radius, resulting in a different morphology.

Construction costs (Score: 1)
The current Dique Direccional has to be demolished and be built up again more outwards. On top of that, the river bank has to be excavated for several kilometres and later reinforced with bank protection.

Maintenance costs (Score: 3)
Once the construction project is finished, only small maintenance and dredging activities have to be done.

Sustainability (Score: 2)
The relocation of the Dique Direccional is a drastic measure. This involves many construction practices which are not beneficial for ecology. Furthermore, the Dique Direccional was built in order to close a secondary branch of the Magdalena river. This reduced the lateral connectivity of the river, which affects the sustainablitity in a negative way. By relocating this infrastructure, this impact is not expected to change. Therefore, a lower score on sustainability is assigned than the current situation.

Impact on national parks (Score: 1)
The area next to the Dique Direccional is a national park. By relocating the dique further outwards, a part of this park will get lost.

Downtime (Score: 4)
Once the construction project is finished, only some small maintenance and dredging activities will take place. With the increased width of the navigation channel, this will not cause many problems for navigation.

Construction time (Score: 1)
During construction, (part of) the navigation channel will be blocked due to construction works in the channel. Also, the adaptation of the cross section after increasing the river bend radius is a natural process, which will take time.

Possibility for industry (Score: 3)
After completion of the project the navigation channel will be wider, but more outwards. This will increase the possibilities for navigation, but reduce possibilities for port companies in the inner bend.

I.2.4. Longitudinal dam (Figure 8.5c)

Navigation conditions (Score: 4)
The longitudinal dam will divide the river in two channels. Due to different flow velocities, the inner bend will accrete, while the outer bend will erode. This will result in some increase of the navigation channel width.

Adaptability (Score: 2)
Once the dam has been built, it is difficult and costly to adapt it to changes in the river course due its fixated location.

Impact on river functions (Score: 3)
Due to its limited cross section in flow direction, the dam will have a low impact on the river functions. Locally at the sides of the dam the flow will increase or decrease, resulting in local erosion or accretion. Turbulence will occur around the structure, but is not expected to be significant because the cross-sectional obstruction is limited. Hence, a neutral score is assigned.

Construction costs (Score: 2)
The construction costs of a longitudinal dam depend on the configuration of the dam. But construction will take place in the middle of the river and for several kilometres, resulting in relatively high construction costs.

Maintenance costs (Score: 4)
Once the dam has been built, it requires only regular small maintenance. Due to the erosion of the navigation channel, less dredging is required which results in reduced maintenance costs.

Sustainability (Score: 3)
The construction of the longitudinal dam will create a zone where low flow velocities occur, this could be beneficial for various fish and plant species. However, construction will be stressful for ecology. Therefore a neutral score is assigned.

Impact on national parks (Score: 3)
The dam will be built in the middle of the river and will have no impact on the national park on the river bank. Therefore a neutral score is assigned.

Downtime (Score: 4)
Once the dam has been built, the required dredging in the navigation channel will be reduced due to erosion. Downtime due to blockage of the channel will be reduced in comparison with the current situation.

Construction time (Score: 2)
Construction will take place in the middle of the river, (partly) blocking the navigation channel. The location also makes construction difficult, resulting in a relatively long construction time.

Possibility for industry (Score: 3)
Erosion of the channel in the outer bend increases the channel width, increasing the possibilities for navigation. However, the construction of a longitudinal dam in front of port companies in the inner bend reduces possibilities for these companies. A neither positive nor negative value is assigned.

I.2.5. Fixed bottom layer (Figure 8.5d)

Navigation conditions (Score: 4)
In the long term, a fixed bottom layer will result in an erosion of the inner bend. This will increase the width of the navigation channel, giving possibilities for navigation upstream.

Adaptability (Score: 2)
Once the layer has been placed, it is fixed at its location. If the course of the river changes, it is possible to extend the layer, but replacing the layer is difficult.

Impact on river functions (Score: 4)
The placement of a fixed bottom layer will have a low impact on the river functions, for it will only induce a local change in cross section. In the long term, the cross-sectional area will remain the same.

Construction costs (Score: 4)
The fixed layer consists of sand fill-up to make the river bed horizontal, with a rock layer on top of it. This is mainly dumping material in the river and levelling it. In comparison with building a structure, this is relatively cheap.

Maintenance costs (Score: 4)
Once the layer has been placed, only monitoring and small maintenance has to be done, resulting in low maintenance costs. Also required dredging might decrease.

Sustainability (Score: 4)
A fixed bottom layer scores slightly better on sustainability than the current situation, because maintenance dredging is no longer needed. This means that the sediment stays in the river system that transports it downstream, instead of it being dumped in the canyon.

Impact on national parks (Score: 3)
The layer will be placed on the bottom of the river and the secondary flow will mainly erode the inner bend, resulting in no harm for the national park.

Downtime (Score: 4)
In the long term, the width of the navigation channel will increase and the depth will still be sufficient. If some maintenance dredging is still needed, navigation can continue during dredging due to the increased width. This will decrease the downtime of this section.

Construction time (Score: 3)
The construction consists mostly of dumping and levelling material at the bottom, which is a relatively fast construction method. However, construction will take place in the navigation channel, blocking this during construction. Therefore a neutral score is assigned.

Possibility for industry (Score: 4)
Once the layer is placed and the inner bend has eroded until its equilibrium, the width of the navigation channel will have increased. This will increase the possibilities for navigation upstream. Also companies in the inner bend will benefit from the navigation channel being closer to the inner bank.

I.3. Section IV+V

I.3.1. Current situation Section IV+V

Navigation conditions (Score: 3)
Upstream of the Puente Pumarejo (K22), the depth is not sufficient for seagoing vessels. Furthermore, the height of the current bridge does not allow seagoing vessels to pass. Currently, this stretch of the river is navigable by barges. The relatively sharp bend at K28 results in high flow velocities and difficulty for shipping.

Adaptability (Score: 3)
This stretch of the river does not contain river training works. Maintenance of the navigation channel is performed by dredging vessels. Therefore, the adaptability of the current strategy is assigned with a score of 3.

Impact on river functions (Score: 3)
The impact on the river functions is limited because there is no infrastructure in the river. The impact of dredging is not severe, therefore a score of 3 is assigned.

Construction costs (Score: 5)
There are no construction costs when the current situation is maintained.

Maintenance costs (Score: 3)
Regular dredging of the navigation channel is needed to provide sufficient depth for barges. This results in costs for maintenance.

Sustainability (Score: 3)
On the one hand sustainability is not that much affected by dredging, on the other hand there are no attempts to improve other functions of the river besides shipping. Dredged material is dumped in the canyon, which means that it is not preserved in the river system.

Impact on national parks (Score: 3)
The current situation does not have a significant positive or negative impact. Therefore the assigned score is equal to 3.

Downtime (Score: 3)
Because of the current navigation conditions and the absence of proper signage and buoys, it is hardly possible to navigate the river during the night. In combination with dredging maintenance, this results in a significant downtime which is assigned with a score of 3.

Construction time (Score: 5)
When the current situation remains, there is no construction time which results in a high score.

Possibility for industry (Score: 2)
Currently, this stretch of the river cannot be reached by seagoing vessels. When the depth of this stretch is increased, port facilities that are able to harbour seagoing vessels can be realised. To allow seagoing vessels in this river stretch, the currently operational Pumarejo bridge needs to be demolished. Currently, there is no contract or agreement stating which party will demolish the old Pumarejo bridge.

I.3.2. Blunt nose chevron (Figure 8.7a)

Navigation conditions (Score: 3)
Implementation of a blunt nose chevron is expected to result in higher flow velocities in the western branch of Rondón Island. Since the depth is sufficient in this branch the navigation conditions are not likely to improve in this stretch. However, the blunt nose chevron will prevent further erosion of Rondón Island and induce sedimentation directly behind the chevron.

Adaptability (Score: 2)
Chevrons are structures that are not easy to adjust. This means that the adaptability to changes in the course of the river is constrained.

Impact on river functions (Score: 3)
On the one hand chevrons improve several river functions, such as the habitat for fish species. On the other hand, the flow velocity is expected to increase, which will limit sedimentation in this range, but is not beneficial for shipping. Therefore, a neutral score of 3 points is assigned.

Construction costs (Score: 3)
Chevrons are relatively small structures, which means that the price for construction is not high. Furthermore, in this case the choice is made to construct one chevron instead of a series of chevrons, which is expected to be cheaper.

Maintenance costs (Score: 4)
The main purpose of the chevron is to prevent erosion of Rondón Island and trap sediment. Therefore, less maintenance dredging than in the current situation is needed, which results in a positive score for maintenance.

Sustainability (Score: 4)
Chevrons create a zone where flow velocities are reduced. This creates protected zones from which vegetation and river life can benefit. Thus, besides the shipping function, the habitat function of the river is enhanced.

Impact on national parks (Score: 3)
The national parks are not affected by this solution, therefore a score of 3 is assigned.

Downtime (Score: 4)
The downtime caused by the structure is limited, since the construction is not located within the navigation channel. Furthermore, the chevron is expected to trap sediment that is coming from upstream. Hence, less dredging practices are required, which will reduce the downtime.

Construction time (Score: 3)
Chevrons are not difficult to construct and since this plan concerns one single chevron, construction time can be approximated with reasonable accuracy.

Possibility for industry (Score: 2)
The chevron will not improve or reduce the possibility for industry. This results in the same score for this criterion as the current situation.

I.3.3. Longitudinal dam (Figure 8.7b)

Navigation conditions (Score: 3)
The longitudinal dam will redirect the flow to the main channel (western branch of Rondón Island). Due to higher flow velocities, sedimentation will be prevented in this stretch. The reason that the score is neutral for this solution is that in this particular stretch, increased flow velocities are inconvenient for the mooring of ships.

Adaptability (Score: 2)
A longitudinal dam is a very rigid construction, this means that there is a chance that the construction loses effectiveness due to the dynamics of the river system.

Impact on river functions (Score: 3
Longitudinal dams are known to reduce to impact on the river function in respect to groynes. The river flow is redirected, but not very much affected.

Construction costs (Score: 2)
Construction of the longitudinal dam will be expensive since it concerns a long construction. Therefore, a large volume of construction material is needed.

Maintenance costs (Score: 4)
Maintenance costs are expected to be reduced because sediment is trapped in the eastern branch of Rondón Island. This means that the availability of sediment in the navigation channel is reduced. Therefore sedimentation of the navigation channel is likely to be constrained as well.

Sustainability (Score: 4)
Longitudinal dams create a zone of low flow velocities. Low velocities are favourable for certain fish and vegetation species.

Impact on national parks (Score: 3)
This measure does not affect the functions of the national parks along the Magdalena river. Therefore, a neutral score is assigned.

Downtime (Score: 3)
Construction of the longitudinal dam will not take place within the navigation channel. Hence, shipping is not significantly affected. Again, this measure is expected to reduce the need for dredging.

Construction time (Score: 2)
Since it concerns a large structure, the construction will take more time than is the case for the other proposed measures.

Possibility for industry (Score: 2)
Relative to the current situation, the longitudinal dam is not expected to have a direct impact on possibilities for industry.

I.3.4. Relocation Via 27 (Figure 8.7c)

Navigation conditions (Score: 4)
Relocation of the road will give the river the possibility to follow a more natural course with an increased bend radius. An increased radius will have a positive effect on navigability, making it easier for ships to manoeuvre through the bend. In the current situation, the bend in the river is almost 90 degrees. However, seagoing vessels are still not able to reach this river section due to the restricted height of the Pumarejo bridge.

Adaptability (Score: 4)
In the new situation, the river will be able to determine its own course to a certain degree. The surrounding area is able to follow these changes, until the river reaches the location of the new road. If this happens, bank protection has to be applied in order to fixate the river in its new course.

Impact on river functions (Score: 4)
Removal of the current constriction in the bend will have a positive impact on the river functions, giving the river more room to follow its own course.

Construction costs (Score: 1)
In order to build the new road section, the area North-East of the current road has to be made suitable for construction. This area consists of soft wetland, so groundwork has to be done in order to construct a good foundation. Also the old road section has to be removed.

Maintenance costs (Score: 4)
In the current situation, a lot of sedimentation takes place in the inner bend of this section. By increasing the bend radius, this erosion will decrease, resulting in less costs for maintenance dredging. Maintenance costs of the road will stay approximately the same in comparison with the current situation.

Sustainability (Score: 2)
The relocation of the road is only focused on the course of the river, neglecting the influence on the surrounding area.

Impact on national parks (Score: 2)
By relocating the road, an area of land will be given to the river to erode. This means a loss of natural area next to the river, resulting in a low score.

Downtime (Score: 3)
Due to the dynamic character of the river in this section, it will still be hard to predict the location of the sand banks in the river. Dredging is still required, resulting in downtime for this river section.

Construction time (Score: 2)
During construction, traffic will still be able to use the old road. In order to minimise hindrance, demolition of the old section will start when the new section is finished. It will take time for the river to develop its new course, so positive effects for navigation will also take time.

Possibility for industry (Score: 3)
Due to the Pumarejo bridge, seagoing vessels are not able to reach this part of the river. In the new situation this is still the case, making it unattractive for companies to start a business in this river section.

J
Engagement table

A table is used to describe several aspects of the engagement of the stakeholders. This gives a clear overview on how the different stakeholders will be involved in the different rounds. The following aspects are illustrated in these tables:

- Stakeholder;
- Power-interest group;
  - In the current situation;
  - After (dis)engagement;
- Project phase;
- Engagement level;
- Frequency of contact;
- Tools for engagement.

Hereafter the aforementioned aspects will be discussed in more detail.

Power-interest group:
The column of the power-interest in the engagement table illustrates the power-interest of the stakeholder's in the specific round in the current situation and after (dis)engagement. It is illustrated with the colors of the power-interest grid meaning: green = crowd, yellow = subjects, orange = contest setters and red = key player. It can be the case that a stakeholder is neither being engaged or dis-engaged and is considered to be already in the right position. Often they can still be consulted without really engaging them.

Project phase:
The following four project phases are distinguished: initiation, design, planning and construction phase. Often stakeholders are involved in several phases, sometimes even all phases. This is for example the case with Cormagdalena as a stakeholder with legal power over the Magdalena river.

Engagement level:
The level of engagement is determined by the perceived power and interest of a stakeholder with regard to a subject. The scale which is used for this aspect is as follows:

- Inform: oneway information stream to stakeholder, no further participation;
- Consult: stakeholders are consulted at a certain point in time, they can share their opinion however their opinion will not necessarily be used in decision-making;
- Involve: stakeholders are involved as much as possible into the process, input can be shared when they feel fit there is however still no guarantee that consensus will be reached;
- Collaborate: when stakeholders are in a collaboration the parties try to reach consensus, their input is used as much as possible but ultimately when no consensus can be reached they do not have any decision-making power;
- Empower: full empowerment of stakeholders mean that they will have the full decision-making power.

As can be concluded from the aforementioned information the level of engagement reaches from zero engagement with the inform option to full transfer of decision-making power with empower. Both these levels are considered extreme when a solution suitable for all stakeholders is the goal. Therefore these two are rarely used if stakeholders are invited into the process round.

Frequency of contact:
The following scale is used for the frequency of the contact with the stakeholder:

- Very frequent;
- Frequent;
- Occasional;
- Never.

Communication during process:
The communication during the process is highly linked to the engagement level. The following scale is used:

- Continuously;
- During stakeholder meetings and whenever urgently necessary;
- During stakeholder meetings only;
- Approach when knowledge needed;
- Only after major decision-making has taken place.

K
Fieldtrip

Figure K.1: Tajamar Occidental on 02-10-2017 (Universidad del Norte, 2017).

Figure K.2: Map of the fieldtrip (September 20, 2017

Figure K.3: Current Pumarejo bridge and construction of new Pumarejo bridge (September 20, 2017).

Figure K.4: Shipping and fishing in the Magdalena river (September 20, 2017).

Figure K.5: Nueva Venecia de Santa Marta, village in the Ciénaga Grande (September 20, 2017).

Figure K.6: Dredging practices in one of the channels in the Ciénaga Grande (September 20, 2017).

Figure K.7: Impression of the port area of Barranquilla (September 20, 2017).