Possible integrated coastal interventions in Playa Unión and Puerto Rawson

An area prone to coastal erosion

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TU Delft

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Possible integrated coastal interventions in Playa Unión and Puerto Rawson

An area prone to coastal erosion

by

MP341

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Summary

Playa Unión and Puerto Rawson are facing severe coastal erosion and increasingly the negative effects. Since the first half of the 20th century there have been signs of erosion, but also of sedimentation. However, the coastline in the project area is retreating over the years. The situation has recently been declared an emergency. Furthermore, there are several expansion plans for the port consisting of new quay walls and dredging. It is unsure if these plans will influence the erosion. In this report, the following research question is formed: "What are valued, preferably nature-based, interventions that can mitigate the coastal erosion in Playa Unión and Puerto Rawson considering the planned expansion of the port?"

Due to the limited information and data available, assumptions have been made during the research. A site analysis and a CoastSat analysis are conducted to research the morphology of the coastline and its drivers. The coast has been shaped into a steep upper section of coarse granular material and a gentle lower slope with finer material. The main driver of longshore sediment transport in the area are swell waves, with predominant directions SSE and E. This transport is directed from south to north, resulting in the inflow and outflow of sediments. Furthermore, there is a sediment flow from the Chubut river. Due to the construction of the port's breakwaters, the longshore sediment transport is interrupted, which causes an imbalance in the sediment flow in the system. More sediment flows out of the system than enters, causing coastal erosion.
The development of the port contains public as well as private expansion plans and maintenance dredging. The expansion plans will have little effect on its surroundings. The private plan include a parallel breakwater, which alters the natural balance in the area and dredging works, for which the stability of the existing breakwaters has to be figured out.
A stakeholder analysis was done to get insights in the opinions and visions of the stakeholders. This was done by interviewing stakeholders and by doing a questionnaire, resulting in a power-interest grid and overview of interests and attitudes. The boundary conditions for the interventions and criteria for the multi-criteria analysis are partly formulated as a result of the stakeholder analysis.

The following interventions were considered in this report:

- Permeable pile groynes and low crested groynes
- Opening the northern breakwater: opening and reshaping with a curve, constructing tunnels underneath the breakwater and a sediment bypass
- Port expansion and a sediment bypass with power supply southern of the port
- Dredging and moving sediment
- Sediment trap
- Plant vegetation with beach nourishment
- Gravel engine
- Temporary longitudinal flood barrier as a short term intervention.

A conceptual multi-criteria analysis in combination with a nature-based assessment has been conducted to distinguish the most promising interventions in the conceptual design phase. The criteria formulated were effectiveness, easiness of implementation, maintenance, environmental impact and the benefits for recreation. From this, it can be concluded that the gravel engine and the plant vegetation with beach nourishment score the best.

Preface

This report documents a multi-disciplinary project of a group of six students from the TU Delft. It is intended for anyone with an interest in different interventions for challenges with coastal erosion and port expansion.

As part of the second year of our masters, we had the opportunity to set up a project abroad. This project combines our different fields of expertise, which are: Civil Engineering (Structural Engineering, Hydraulic Engineering, Hydraulic and Offshore Structures) and Transport, Infrastructure and Logistics. This specific project is in collaboration with the Facultad de Ingeneria Universidad de Buenos Aires - Escuela de Graduados en Ingeneria Portuaria (FIUBA -EGIP), La Universidad Nacional de la Patagonia San Juan Bosco (UNPSJB) and Industrias BASS.

We got into contact with Pablo Arecco and Sebastian Iglesias, who enthusiastically invited us to work on a challenging project in Argentina. After a long period of preparations, the project in this distant country could finally start. Three months, two cities and lots of mate cups later, this is the final result of our research there. We would like to thank everyone who contributed to our project.

We would like to give a special thanks to the following people involved. Firstly, we would like to thank our four supervisors Hayo Hendrikse, José Antolinez, Pablo Arecco and Sebastian Iglesias for their supervision, advice, patience and time to meet us at the most challenging hours during the day due to all the different time zones. We would like to thank Martin Castillo, Alfonso Pinzon, Pablo Rojas and Giuliana Mangini for working together and providing information, flight tickets and an apartment in Trelew. Furthermore, we would like to thank Pablo Bereciartua for providing an office at the Argentine Center of Engineers and Gabriel Kaless for providing his office in Trelew and for feedback on the project. We would like to thank Rodrigo Bastia, Jonathan, Marcos de Vincenzi and Leandro Foletto for the guided tours and feedback. We would also like to thank the people from the Labievi for providing their lab for our grain size analysis. We would have been nowhere near without the translating help of Claudia Bracco, Max Howells and Laura Bellido, thank you very much.

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Buenos Aires, November 2023

Disclaimer

This report is written by Civil Engineering master students from the Delft University of Technology as part of their studies. Since it is a case study, it is solely intended for academic and informational purposes. The authors of this report and the involved universities bear no responsibility for any decisions or actions taken based on the contents of this document.

Contents

Summary ii

Preface iii

Disclaimer iv

Definitions and acronyms xiii

1 Introduction 1

2 Methodology 4
- 2.1 Background study 4
- 2.2 Nature-based solution framework 5
- 2.3 Interviews 6
- 2.4 Questionnaire 6
- 2.5 Stakeholder analysis 6
- 2.6 Design brainstorm 7
- 2.7 Multi-criteria analysis 7

3 Site study 9
- 3.1 Geology of the area 9
- 3.2 The port and hydraulic structures 11
  - 3.2.1 History of the port 11
  - 3.2.2 History of hydraulic structures 12
  - 3.2.3 Fishing industry 13
  - 3.2.4 Political context of fishing and port 14
- 3.3 The history of the coast 15
- 3.4 Ecosystem 16

4 Morphological development and drivers 19
- 4.1 Sea state 19
  - 4.1.1 Wave climate 19
  - 4.1.2 Wind climate 20
  - 4.1.3 Tidal currents 21
  - 4.1.4 Climate impact and sea level rise 22
- 4.2 Morphological analysis of the coastline 22
  - 4.2.1 Morphological characteristics 22
  - 4.2.2 River sediment 24
  - 4.2.3 Sediment between the northern breakwaters 24
- 4.3 Bathymetry analysis 25
- 4.4 CoastSat analysis 27
- 4.5 Comparison of erosion rates 28
- 4.6 Conclusion on sediment fluxes 29

5 Development of the port 31
- 5.1 Public expansion plans 31
- 5.2 Private expansion plans 31
- 5.3 Maintenance dredging project 32

5.4 Impact on the coast and port . . . 33
5.4.1 Public plans . . . 33
5.4.2 Private plans . . . 33
5.4.3 Maintenance dredging . . . 34

6 Stakeholder analysis 36
6.1 Results questionnaire inhabitants . . . 36
6.2 Description of stakeholders . . . 40
6.3 Power interest grid . . . 43
6.4 Conclusion . . . 43

7 Boundary conditions 45

8 Possible interventions 46
8.1 Groynes . . . 46
8.1.1 Permeable pile groynes (PPG) . . . 49
8.1.2 Low crested groynes . . . 50
8.2 Dredging considering the port expansion . . . 50
8.3 Opening northern breakwater . . . 51
8.3.1 Opening the northern breakwater with curve . . . 51
8.3.2 Tunnel . . . 52
8.3.3 Sediment bypass . . . 52
8.4 Port expansion and sediment bypass in the south . . . 53
8.4.1 Bathymetry analysis . . . 54
8.4.2 Types of ships to be accommodated in the new port . . . 54
8.4.3 Conceptual design of breakwater . . . 54
8.4.4 Sediment bypass . . . 56
8.5 Creating a sediment trap . . . 59
8.6 Temporary longitudinal flood barrier . . . 60
8.7 Plant vegetation with beach nourishment . . . 61
8.8 Gravel engine . . . 62
8.8.1 Conceptual design . . . 63

9 Evaluation of proposed interventions 65
9.1 Nature-based evaluation . . . 65
9.2 Multi-criteria analysis . . . 67
9.3 Sensitivity analysis . . . 68

10 Conclusion 69

11 Discussion 71

12 Recommendations 73

References 76

A Extreme value analysis of the wave climate 81

B Grain size analysis 83

C Bathymetry 87

D Coastsat analysis 91
D.1 Erosion calculation . . . 92
D.2 Further research with this method . . . 95

E Interview script 96

F Interview Summaries **97**
F.1 Rytec . . . 98
F.2 Municipality of Rawson . . . 101
F.3 Direction of Port Infrastructure . . . 102
F.4 Ministry of Infrastructure, Energy and Planning from the province of Chubut . . 104
F.5 Instituto del agua Chubut . . . 107
F.6 Industrias BASS . . . 109
F.7 Mercedes Bagalciaga, the Geologist . . . 111
F.8 Claudia Bracco . . . 112
F.9 Eugenio Krämer . . . 114
F.10 Servimagnus S.A. . . . 115

G Online questionnaire **117**
G.1 Form in Spanish . . . 118
G.2 Form in English . . . 125

H Brainstorm possible interventions **127**
H.1 Groynes . . . 127
H.2 Dredging . . . 127
H.3 Parallel breakwaters . . . 127
H.4 Redesign current breakwaters . . . 128
H.5 Energy interventions . . . 128
H.6 All interventions . . . 128

I Calculations Groynes **130**
I.1 General design . . . 130
I.1.1 Low crested groyne . . . 132

J Port expansion and sediment bypass in the south **134**
J.1 Draft of the new port for different types of ships . . . 134
J.2 Design of the breakwater . . . 134
J.2.1 Goda's wave propagation . . . 135
J.2.2 Free-board calculations . . . 137
J.3 Possible nature-based breakwater for the port expansion . . . 138
J.4 The Sand bypass system on the Gold Coast . . . 138
J.5 Sand-windmill . . . 139

K Temporary longitudinal flood barrier **140**

L Plant vegetation with beach nourishment **143**

M Sand/Gravel engine **149**
M.1 Bathymetry . . . 149
M.2 Design conditions . . . 149
M.2.1 Waves . . . 149
M.2.2 Wind . . . 150
M.2.3 Tide . . . 151
M.3 Sediment . . . 152
M.4 Physical surroundings . . . 152

N Multi-criteria analysis **153**
N.1 Scoring . . . 153
N.2 Argumentation scores given to criteria . . . 153
N.2.1 Scoring by externals . . . 158
N.3 Results MCA . . . 158

N.3.1 MCA without weights 158
N.3.2 MCA with weights 159
N.4 Sensitivity analysis 161

O Monitoring techniques 162
O.1 Wave data 162
O.2 Wind data 162
O.3 Bathymetry 162
O.4 River flow data 163
O.5 Sediment data 163
O.5.1 River sediment 163
O.5.2 Marine sediment 163

List of Figures

1.1 Map Chubut Province (Adapted from OpenStreetMap contributors (2017)) . . . 1
1.2 Project area (Adapted from Google Earth 2023) 2

2.1 Structure of the methodology 4

3.1 Indication of cliffs, beach and meseta (adapted from Google Earth, 2023) based on (Schillizzi et al., 2014) 9
3.2 Old riverbeds north of the Chubut river (Adapted from Google Earth 2023) . . . 11
3.3 Ground layers (left) and tuff stone (right) (Serman y Asociados s.a., 2019) . . . 11
3.4 Historic images port of Rawson (Patricia Lorenzo Harris, el Museo 1923) . . . 12
3.5 Lay-out of the access channel (del Vecchio, 2018) and Top view current situation port (A. Lazzari, 2022) 12
3.6 Overview of the hard structures in the area (Adapted from (Hugo Juan Donini, 2021)) 13
3.7 Boats yellow fleet in the public port and red fleet in the private port 14
3.8 Total landing of shrimps per month (del Vecchio, 2018) 14
3.9 Timeline starting from 1850 16
3.10 Native plants at Playa Unión 16
3.11 Animals living in and next to the sea 17
3.12 Predominant fauna in the area west of Puerto Rawson and Playa Unión 18

4.1 Comparison of the locations of the data acquisition of (Savioli et al., 2011) and (Universidad Nacional de Córdoba, 2022). 20
4.2 Different wind roses required from available data 21
4.3 High and Low Tide Levels 21
4.4 Tides $4^{th} - 11^{th}$ of October 2023 (“Tides Chart”, 2023) 21
4.5 Regional sea level change at 2100 for different scenarios (Fox-Kemper et al., 2021) 22
4.6 Erosion north of the short breakwater at two different dates 23
4.7 Site analysis, 14/09/2023 (Adapted from Google Earth 2023) 24
4.8 Location of the nine samples (adapted from Google Earth 2023) 25
4.9 Results grain size analysis 25
4.10 Place of the cross sections of the bathymetry data adapted Google Earth, 2023 26
4.11 Close-up of the S and M cross of the bathymetry analysis of the bathymetry data provided by Savioli et al. (2011) 27
4.12 Seasonally averaged and long term trend of coastline change in six cross sections 28
4.13 Overview of the sediment fluxes in the study area (Adapted from Google earth 2023) 30

5.1 Overview of the port and development plans (Adapted from Google Earth 2023) 31
5.2 Location of the new docks and conceptual design for the new port 32
5.3 Some remaining material in the pipe used to dispose the dredged sediment (De Vincenzi, 2023) 33
5.4 Damage to the old southern breakwater and accumulation of cobbled sediment 35

6.1 Age and residence location of respondents 36
6.2 Beach division into three zones and beach use of respondents 37
6.3 What are the positive aspects of the beach that the respondent experiences? . 37
6.4 What are the negative aspects of the beach that the respondent experiences? 38
6.5 How many effects do the respondents experience? 38
6.6 What effects of coastal erosion does the respondent experience? 39
6.7 Difference watercolour, before and during dredging (taken on 19/09/2023, Playa Unión) 40
6.8 Relevant stakeholders 40
6.9 Power interest grid port expansion 43
6.10 Power interest grid coastal erosion interventions 43

8.1 The eight proposed intervention types that will be elaborated in this report . . . 47
8.2 Example of permeable pile groynes (Bosboom & Stive, 2023) 49
8.3 New design of opening up the northern breakwater 52
8.4 Schematizing of the tunnels underneath the breakwater 52
8.5 Schematizing of the sediment bypass using pumps on the northern breakwater, adapted from Van der Meer et al. (2018) 53
8.6 Area of interest southern port expansion 53
8.7 Analysis of the bathymetry data south of the southern breakwater 54
8.8 Cross section of the design of the new breakwater, adapted from Van der Meer et al. (2018) 56
8.9 Principle sand by-pass system (van de Graaff, 2022) 56
8.10 Layout new port with sediment bypass 59
8.11 Lay-out of the sediment pass pumping system 60
8.12 The Sand Engine in 2020 (Rijkswaterstaat, 2020) 63

9.1 MCA without weights 68

12.1 Road map recommendations 73
12.2 Engagement of the stakeholders 74

B.1 Conducting the grain size analysis 84
B.2 Plots of the grain size analysis 85
B.3 Results Grain size analysis 86

C.1 Playa Unión, 13 December 2011 (Google Earth) 87
C.2 Playa Unión, 5 January 2023 (Google Earth) 87
C.3 Analysis of the bathymetry data 88
C.4 Close-up of the analysis of the bathymetry data of (Savioli et al., 2011) 89
C.5 Particle size according €2 coin, 14/09/2023 (Adapted from Google Earth 2023) 90

D.1 Examples of detected shorelines for the different satellites 92
D.2 Overview of the six cross sections used 92
D.3 Overview of the twelve cross sections used as shown on the map 93
D.4 First calculation of the erosion rate 93
D.5 Seasonally averaged time series with long term trend of coastline evolution, in twelve cross sections 94
D.6 Detailed calculation of the erosion rate and erosion during the coastal retreat in the winter of 2022 94

F.1 Overview of the interviewees 97

F.2 Form of small breakwater Playa Unión 104
F.3 Possible locations for port expansions 105
F.4 Origin of sediments 106

I.1 Summer swell waves 130
I.2 Wave calculations with return period of 10 years 131
I.3 Groyne design S-cross section 132
I.4 Groyne design M-cross section 133
I.5 Low crested groyne 133

J.1 Different types of breakwaters acquired from De Graauw (2022) 135
J.2 Formulas for wave propagation by Goda acquired from Bruining (1994) 135
J.3 Python script with the Goda's formulas 136
J.4 Maple sheet with the calculation of the free-board height 137
J.5 Sandbar casestudy aquired from Spek et al. (2020) 138
J.6 Sandwindmill (adapted from Rutteman (2021)) 139

K.1 Geobags used in practice (Maccaferri (2023)) 140
K.2 Non self inflating temporary flood defences filled with water 141
K.3 Water-gate flood barrier (Flood protection solutions (2023)) 141
K.4 Floodwalls 142

L.1 Side-by-side comparison of images 143
L.2 Plants considered in the analysis 146

M.1 Bathymetry at the Zandmotor and Playa Unión 149
M.2 Comparison of wave heights between the Netherlands and Playa Unión 150
M.3 Windroses at the Zandmotor and Playa Unión 151
M.4 Comparison of average wind velocities between Hoek van Holland and Playa Unión 151

N.1 Pairwise comparison of the criteria 159
N.2 MCA without weights 160
N.3 MCA with weights 160
N.4 Sensitivity analysis MCA 161

List of Tables

1 Definitions . . . xiii
2 Acronyms . . . xiv

4.1 Wave data 2022, point 2, waves to westward direction. Weibull distribution . . 20
4.2 Wave data 2011, waves to westward direction. Generalized Pareto distribution 20
4.3 Slope of the lower and upper profile for the different cross sections . . . 26
4.4 Erosion rates, from different sources compared to the coastsat analysis . . . 29

6.1 Conclusion stakeholder analysis . . . 44

8.1 Average cross section slopes for design . . . 48
8.2 Groyne results . . . 48
8.3 Evaluation of types of pumps for bypass system . . . 58
8.4 Data comparison Playa Unión and Hoek van Holland . . . 63

9.1 Nature-based evaluation . . . 66

A.1 Waves from 130-145 degree range . . . 82
A.2 Waves from 25-190 degree range . . . 82
A.3 Wind from 130-145 degree range . . . 82
A.4 Wind from 25-190 degree range . . . 82
A.5 Waves from 130-145 degree range (168 hours) . . . 82
A.6 Waves from 25-190 degree range (168 hours) . . . 82
A.7 Wind from 130-145 degree range (168 hours) . . . 82
A.8 Wind from 25-190 degree range (168 hours) . . . 82

B.1 Coordinates of the nine sediment samples . . . 83

C.1 Slope of the lower and upper profile for the different cross sections . . . 90

F.1 Timeline actions Rytec . . . 99
F.2 Timeline of the dredging project . . . 116

L.1 Plants comparison . . . 147

M.1 Average wind velocities . . . 151

Definitions and acronyms

The terms and other relevant indications (Table 1) and the acronyms (Table 2) used in this report are bundled in this chapter.

Table 1: Definitions

Term	Definition
Seasons	
Winter	June, July, August
Spring	September, October, November
Summer	December, January, February
Autumn	March, April, May
Water levels	
SHN	Water level system of the Naval Hydrographic Service
MOP	Water level system of the Ministry of Public Works, 0,00m SHN is equal to -1,88m MOP
NMM	Mean seawater level system, 0,00m SHN is equal to 2,75m NMM
IGM	National Vertical Reference System, 0,00m SHN is equal to 2,436m IGM
Project area	Puerto Rawson and Playa Unión, including the port and beach
The beach of Playa Unión	The part of the beach at Playa Unión and Puerto Rawson, the stretch of 3,3 km subjected to erosion within the the project area
Number notation	Thousands are with a dot and decimals with a comma

Table 2: Acronyms

Abbreviation	Definition
BwN	Building with Nature
DPI	Direction of Port Infrastructure, Dirección de Infraestructura Portuaria
DWL	Design water level
EFPU	Estación de Fotobiología Playa Unión
EVA	Extreme value analysis
GROW	Global Ocean Wave Reanalysis project
IDA	Instituto del Agua
LCG	Low crested groyne
MCA	Multi-criteria analysis
MIEP	Ministry of Infrastructure, Energy and Planning
NBS	Nature-based solutions
Odesys	Open Design Systems
PPG	Permeable pile groynes
SLS	Service limit state
UBA	University of Buenos Aires
UNPSJB	Universidad Nacional de la Patagonia San Juan Bosco

1
Introduction

Since the founding of the towns of Puerto Rawson and Playa Unión, there has been disharmony between living safely along the coast, recreation on the beach, the sea with unpredictable behaviour and an upcoming fishing industry in the port. Breakwaters have been built to improve fishing port operating conditions starting from 1960, which have disturbed the coastal balance there previously was. This could have resulted in the observed significant increase in erosion of the coastline. In the coming years, the port expansion continues. There are plans for new quay walls and dredging works, executed by the main stakeholder of this study: construction company Industrias BASS.

However, if nothing is done, the erosion effects may even become bigger, which is also realised by the Rawson City Council. They declared the situation a 'coastal emergency' and demanded help from the national government (Política Chubut, 2023), expressing the urgency of the situation.

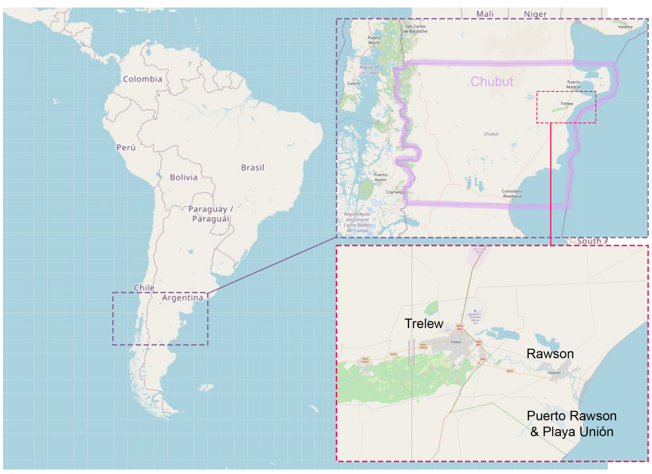


Figure 1.1: Map Chubut Province (Adapted from OpenStreetMap contributors (2017))

The specific location of the research project is Playa Unión and Puerto Rawson, in Chubut Province in Patagonia, as can be seen in Figure 1.1. This is a fishing port located at the mouth of the Chubut River to the Atlantic Ocean. The port is home to a number of trawlers and other fishing vessels. North of the mouth of the Chubut River, the beachside village of Playa Unión is situated. The town of Rawson, the capital of Chubut Province, is located seven kilometres upstream from the river mouth. Rawson has a population of over 30.000 inhabitants. Twenty kilometres further upstream is the city of Trelew, with about 100.000 inhabitants the largest city in the lower Chubut Valley.

These towns were created by Welsh settlers, who agreed to immigrate to the unconquered Patagonia in exchange for land along the river. First, in 1865, Porth Madryn (now Puerto Madryn) was founded. However, the climate was semi-desert and the people from a second ship travelled southwards to the valley of the Chubut River, where they founded Rawson in the same year. A year later, Trelew was established as a beginning point for a railway line in the area. Playa Unión was founded in 1923 and named after ”L'Unión”, the name of a ship that was wrecked near the beach in 1890.

There have been a number of studies about this area in recent years, looking into the morphodynamic characterisation of Playa Unión (del Vecchio, 2018), the coastal erosion processes (Hugo Juan Donini, 2021) and impact from the port on the coastal area (Brágoli & Donini, n.d.). These however have not led to any long-term solutions regarding coastal erosion. The problems are still very relevant and urgent. There are various stakeholders that are involved in different ways in this area and affected by the developments of the coastal zone and/or the expansion of the port. Some separate research about the river, the coast, and the sediment has been done so far. However, there is no centralized agency that coordinates the information and communicates between these stakeholders, which has led to some misunderstandings in the past. An example of a recent conflict is a forced interruption of dredging works of the port, after demonstrations of citizens (Portal Portuario, 2023). So, the situation could benefit from an integral approach, combining information from both literature and stakeholders. Together with knowledge gained from TU Delft, this project strives to add value to the future situation of the towns.

The research focuses on the coastal erosion affecting Puerto Rawson and Playa Unión. The project area can be seen in Figure 1.2: it spans from the accumulation of coarse sediment south of the breakwaters as a southern boundary to almost the end of the residential area at the beach, located 3,5 kilometres to the north of the port. This is the area which suffers from coastal erosion. Furthermore, three sediment inputs are considered. Namely, the sediment transport from up the Chubut river, the marine sediment transport from the south and the marine sediment transport from the north. Climate influence is also considered.

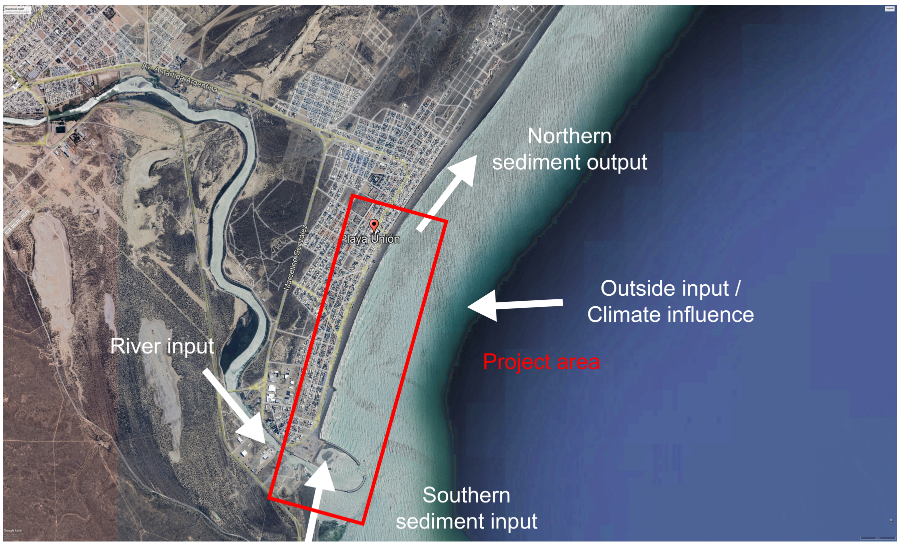


Figure 1.2: Project area (Adapted from Google Earth 2023)

The time horizon in this project is limited to the coming 50 years due to the economic lifespan of hydraulic structures. The recent history taken into account is since 1923, when Playa Unión is founded. Please be aware that the public and private port expansion plans, as outlined in Chapter 5, are taken as an assumptions of this case study.

Taking into account the demarcations, this study focuses on the following research question:

What are valued, preferably nature-based, interventions that can mitigate the coastal erosion in Playa Unión and Puerto Rawson considering the planned expansion of the port?

Nature-based is, according to the guidelines from the United Nations, defined as "Nature-based Solutions are actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits" (United Nations Environment Programme 2022). Nature-based solutions (NBS) have both advantages and disadvantages over "grey" solutions: traditional engineering solutions such as dikes and other hard infrastructures. The advantage of grey solutions is that they often solve the problem right away with high visibility, thus it shows clear results. NBS often need less capital for building and maintaining, and there is less disruption or degradation in the ecosystem (Huthoff et al., 2018). However, some grey solutions are still also considered.

The following six sub-questions are defined in order to arrive at an answer for the research question:

- What is the geology, ecosystem and history of Puerto Rawson and the coastline of Playa Unión up to 2023?
- What is the morphology of the coastline of Playa Unión and what are its drivers?
- How will the planned developments of the port area influence the direct area of Puerto Rawson and Playa Unión?
- Who are the relevant stakeholders and what are their interests?
- What are possible, preferably nature-based, interventions to protect Playa Unión against coastal erosion?
- What are the relevant criteria to evaluate the proposed intervention?

The methodologies applied in order to answer the research questions are explained in the chapter 2. The next chapter, chapter 3, will provide the reader with information on the geological and ecology history of the project area. Chapter 4, will cover the sea state, morphological development. Thereafter, chapter 5, will cover the development plans of the port. In the next chapter, chapter 6, all the involved stakeholders and their involvement, needs and wishes are identified. Chapter 7, portray the boundary conditions for the possible interventions. All the possible interventions are elaborated in chapter 8. Chapter 9, contains the evaluation of the interventions, this is done by a nature-based evaluation and a multi-criteria analysis. A conclusion is then drawn, chapter 10, and a discussion, chapter 11, is provided. Lastly, valuable advice is given in the recommendations chapter, chapter 12, about how to proceed and what further research is required.

2 Methodology

A schematic structure of the research steps and methods used in this research is shown in Figure 2.1.

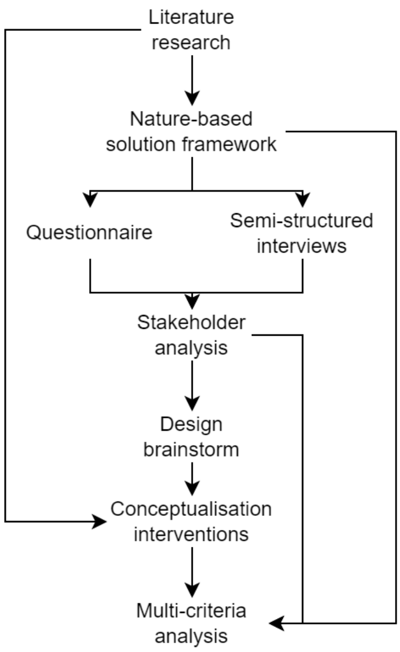


Figure 2.1: Structure of the methodology

2.1. Background study

First, a background study was done regarding the geology, history and morphological developments of the project area. This was mainly done by means of literature research and partly by interviewing researchers. The Coast-Sat analysis and the bathymetry analysis are conducted with existing data. Literature research in combination with using prior knowledge is done to forecast the effects of the port expansion plans on the morphological development of the coastal area. Furthermore, site visits have been done, to give insight into the current state of the project area. Pictures taken at specific locations are used to evaluate changes in the site over time, compared with literature and to support the text written in this document.

2.2. Nature-based solution framework

Because finding nature-based alternatives is part of the research, a framework was needed to specify the meaning of the nature-based alternatives and their valuation. The nature-based solution framework was based on several literature sources and these were combined into a practical framework specific for this project.

The framework was composed of two parts. The principles of Building with Nature (BwN) were combined with a specific framework for assessing the NBS. The BwN principles were used throughout the whole project. The second part of the framework was specifically used for assessing the alternatives.

BwN is a design approach for developing NBS for water-related infrastructure. BwN tries to work with nature, instead of against it. Furthermore, interaction with relevant stakeholders is a very important part of BwN for successful implementation (Ecoshape, 2023). NBS uses natural processes and materials and provides economic, societal and environmental benefits. This research followed partly the BwN guidelines developed by the BwN innovation programme. These guidelines are the following (De Vriend & Van Koningsveld, 2012):

1. Understand the system (including ecosystem services, values and interests);
2. Identify realistic alternatives that use and/or provide ecosystem services;
3. Evaluate the qualities of each alternative and preselect an integral solution;
4. Fine-tune the selected solution (practical restrictions and the governance context);
5. Prepare the solution for implementation in the next project phase.

The first step was done with a background study, interviews and stakeholder analysis. The alternatives were identified with a brainstorming session and the number of alternatives was narrowed down afterwards to a number of feasible alternatives. The alternatives were then worked out and evaluated. The last two steps are not part of this research, but follow-up steps were advised.

Valuing the benefits of NBS compared to or over grey infrastructure was quite a challenge. NBS often have other benefits than only solving the main problem, such as opportunities for recreation and tourism and strengthening biodiversity (Van Zanten et al., 2023). The *Assessing the Benefits and Costs of Nature-Based Solutions for Climate Resilience book* proposed a six steps framework to assess the benefits and costs of NBS for climate resilience (Van Zanten et al., 2023):

1. Scoping benefits
2. Defining the decision support framework
3. Hazard and risk assessment
4. Risk reduction benefits valuation
5. Other benefits valuation
6. Cost valuation

This framework has been used as a guideline for assessing the proposed interventions. Stakeholders were consulted and literature has been used to identify the key benefits of the project. A multi-criteria analysis was chosen as the decision support framework, which is further elaborated in section 2.7. The risk reduction benefits, thus the decline in coastal erosion and risk of flooding, were boundaries with which the alternatives must comply. Other benefits, for example, opportunities for tourism and no horizon vision pollution, were taken into the multi-criteria analysis. A cost valuation is done only roughly within the MCA, due to the limited time.

2.3. Interviews

To get a clear insight into the opinions and visions of the stakeholders, a number of interviews were conducted. Also, some interviews were done with researchers to gather background information about the geology and future port expansion plans.
The interviews were conducted in the form of semi-structured interviews. For this type of interview, a general interview script was used, but deviation from it was possible. This allowed for a pleasant atmosphere during the interview where the interviewee could talk openly, and the interviewer could go deeper into interesting subjects (Dingemanse, 2015). For these interviews, a general script was used which was adapted to the stakeholder, see appendix E. The general script was used as a guideline during the interviews. With each interview, it was tried to get an answer to these three main questions:

- What is your occupation?
- What are the challenges you see in relation to the port and the coast?
- What are the opportunities you see in relation to the port and the coast?

The summaries of the interviews, which were approved by the interviewees, can be found in Appendix F.

2.4. Questionnaire

To get insights into the opinions and visions of the inhabitants and touristic companies of Playa Unión, Puerto Rawson, Rawson and the surroundings, an online questionnaire was made. An online questionnaire was chosen because it was an easy way to reach a large group of respondents in a short time. Another benefit was that people answered honestly because it was anonymous. A disadvantage was that it was hard to ensure external validity, so to which extent it is possible to generalise the results to the population (Benders, 2023). Although complete external validity has not been reached, the results of the questionnaire in combination with the interview with a local inhabitant gave an insight into the opinions of the inhabitants.

The questionnaire was designed to collect mainly qualitative information regarding the positive and negative aspects of the beach and the port. A combination of close-ended and open-ended questions was used. The close-ended questions were in the form of multiple-choice questions and Likert scale questions. The open-ended questions were in the form of short-answer question to ask the reasoning for the closed-ended questions. The questionnaire was distributed via the University of Trelew and some acquaintances who have shared it with people in their surroundings. The aim was to reach a respondent group of 30 to 50 respondents. In total 85 persons have filled in the questionnaire.

In appendix G, the questionnaire and a summary of the responses can be found.

2.5. Stakeholder analysis

The coastal erosion of Playa Unión and Puerto Rawson and the expansions of the port involve several stakeholders. The information gathered via the interviews and the questionnaire was used to do a stakeholder analysis.

To visualize the stakeholders, two power-interest grids were made: one focused on the port expansion and the other on the coastal erosion. The stakeholders were placed in this grid based on their power and interest.

Additionally, an overview was made of the stakeholders including their attitude towards the port expansion and coastal erosion. This provides insight into whether a stakeholder is likely to cooperate or work against it. A combination of high influence, high interest and a positive attitude is a stakeholder which can be very helpful. Stakeholders with high interest and influence but a negative attitude do have high blocking power and thus can obstruct the project.

Stakeholders with high influence and interest should be managed closely. It is important to keep the stakeholders with a high interest but low influence informed. In the recommendations, it is advised how to keep the stakeholders engaged.

2.6. Design brainstorm

To find possible interventions, the double diamond design thinking theory was applied. The double diamond is a visual representation of the design and innovation process. Two key aspects of the method are divergent thinking and convergent thinking.

The design thinking process consists of four steps: discover, define, develop and deliver (Elmansy, 2021). The third and fourth step are done in the brainstorm:

- *Develop*: Is the first step in finding the solution. People are encouraged to give different solutions to the problem by seeking inspiration from elsewhere and by co-designing with people of different disciplines.
- *Deliver*: The last step is about testing different solutions at small scale and rejecting the ones that will not work and go into more detail in the ones that will work.

In the development step, possible interventions were developed. by carrying out a brainstorm, including the double diamond technique. In the first diverging step a mind map about the found problem statement was made. Here there were no limitations set, so creative thinking was stimulated. Thereafter, the first converging step was made. By grouping the brainstorming ideas to eleven corresponding locations in the area. In the second diverging step, the combination of the ideas per location was further elaborated, specifically on how those ideas would influence the eleven determined sectors of the project area. Lastly, the second converging step was made. The ideas were selected based on the following categories: capital investment, nature-based, construction time and maintenance. This selection results in the eight interventions that are further elaborated into a conceptual design in chapter 8. In appendix H a short overview of the mentioned interventions in the first step of the brainstorm that did not end up in the report can be found.

2.7. Multi-criteria analysis

To value the interventions proposed for countering the coastal erosion, a multi-criteria analysis (MCA) has been done. A MCA is a qualitative method which can be used to score and compare different interventions by assessing their performance. There are several reasons why a MCA was chosen:

- There is a lack of available data (for example data regarding waves and tides), so it is difficult to evaluate interventions more precisely. The report *Assessing the Benefits and Costs of Nature-Based Solutions for Climate Resilience book* also advises a MCA, because of the limited amount of time, data and resources.
- It is possible to consider the input of the stakeholders. A MCA analysis gives the opportunity to rate interventions from different perspectives.
- Different decision variables can be integrated without assigning a monetary value to these decision variables.

Other analysis that were considered were the cost-benefit analysis and the Odesys Methodology. However, it is very hard to perform a cost-benefit analysis because there is little data available regarding costs. Using the costs of the Netherlands as a reference is not realistic, due to the economic differences. For example, ground in the Netherlands is very expensive because there is little available. In Argentina, it is the opposite. Labour is also cheaper in Argentina, the salaries are much lower compared to the Netherlands. Furthermore, the Odesys (Open Design Systems) methodology has been considered for implementation in this project due to large quantities of stakeholder preferences. ”This method aims to advance the application of civil infrastructure through a socio-technical approach” (Wolfert, 2023). However, due to a lack of data and time that is available for this project, the optimization stage will not be reached. Therefore, the decision is made to not use this methodology.

For the MCA, first, the criteria were identified. It was chosen to limit the number of criteria to keep it comprehensive. Furthermore, the interventions have been elaborated on a conceptual level, thus a very detailed analysis was not possible. Two MCAs were conducted, one without weights, thus all criteria have the same importance, and one with weights. Both are methods that minimise biases. Especially the first one completely erases biases. For the second MCA, the weights were determined by pairwise comparison. By pairwise comparison, the criteria in pairs are judged on which of each criterion is more important. The interventions with the highest scores were recommended for further research and could perhaps be implemented.

3 Site study

This chapter will answer the first sub-question: What is the geology, ecosystem and history of Puerto Rawson and the coastline of Playa Unión up to 2023?" The first section looks at the geology of the area, starting from about 2.6 million years ago. Next, the history of the port, the hydraulic structures and the coast is discussed, starting from 1916 and considering developments up until 2023. Lastly, the ecology of the area is described.

3.1. Geology of the area

This section will describe the geology of the area. This gives insight into the development of the Chubut River, and its effect on the composition of the ground in this area. An overview of the surroundings is shown in Figure 3.1.

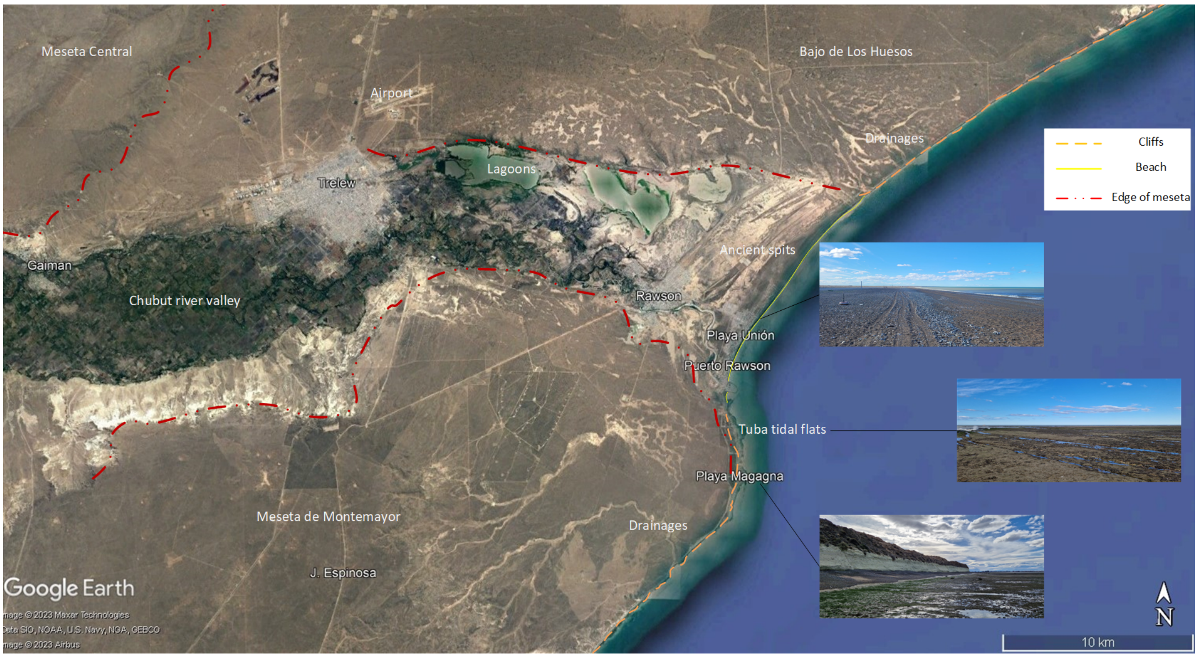


Figure 3.1: Indication of cliffs, beach and meseta (adapted from Google Earth, 2023) based on (Schillizzi et al., 2014)

In this area, the exposed surface layers date from both the Quaternary period, the last 2.6 million years. The sediments visible are gravels, sands, shells and pelites, fine-grained mudrocks. Underneath, there are sediments from the Tertiary period, the period before the Quaternary.

The solid bedrock foundation is made up of rocks from the Jurassic period, which are volcanic in nature (del Vecchio, 2018) .

The area is strongly influenced by the river and the sea. The are four types of deposits present; coastal deposits influenced by both rivers and the sea, beach deposits located along the shoreline, shallow deposits consisting of clays and silts brought by surface runoff and winds, and aeolian deposits created by wind action and consisting of fine to medium sand (del Vecchio, 2018). The shallow deposits can still be seen when it rains. Then, the colour of the river changes due to the higher quantity of sediments taken from the land (M. Bagalciaga, personal communication, 20 September 2023).

There are three types of erosion that have shaped the area: Fluvial, wind and marine erosion. The river generates valleys and drainage channels are cut by run-off after rain events. Wind erosion generates small dunes of fine sand as a result of the strong winds in the area. Marine erosion has a daily activity as a modeller of the coast, generating not only erosion but also sedimentation (del Vecchio, 2018).

According to (del Vecchio, 2018), there are different geo-morphological areas that can be differentiated.

1. **Mesetiformes areas** are elevated coastal plains. They are located to the north and the south of the Chubut River's mouth. The terrain is gently sloping and extends to the coast, where cliffs are formed. The sharp edges of these plateaus are marked with a red dotted line in 3.1.
2. A **Floodplain** forms the floor of the valley. Both the Chubut River and the sea played a role in shaping this area through erosion and deposition. In Figure 3.2, this floodplain can be seen, marked in green. Due to the abundance of vegetation compared to the surrounding landscapes, it can be easily distinguished (M. Bagalciaga, personal communication, 20 September 2023).
3. **Terraced areas** are primarily located in the lower reaches of the Chubut River valley. Terraces are flat or gently sloping surfaces, and they are a result of the river's historical actions. Over time, the river has deposited sediments at different levels, creating these terraced features. Signs of this effect can still be seen by the curls north of the purple marked area in Figure 3.2. These curls mark where an old riverbed was (M. Bagalciaga, personal communication, 20 September 2023).
4. **Coastal areas** have a variety of land forms. There are cliffs, like in Magagna Beach (south of Puerto Rawson), marked with an orange dotted line in Figure 3.1. They are sculpted by marine processes and shaped by the constant interaction between waves and the coastline. The cliffs are interrupted by a few bays and the estuary of the Chubut river, marked with a yellow line in the same figure. There are sandy marine deposits of varying grain sizes and gravel up to five centimetres in diameter make up the shoreline. This is a dynamic and changing environment, influenced by wave action, sedimentation, and coastal erosion.

Figure 3.2: Old riverbeds north of the Chubut river (Adapted from Google Earth 2023)

Along large parts of the Patagonian coast, there are tidal flats in front of the cliffs. This can be seen south of the breakwaters of the port. These tidal flats are called restinga. The flats are formed due to erosion that exposes a harder ground layer, which can also be found at certain depth in the surrounding towns. The material of the restinga is tuffaceous consolidated clay, It contains volcanic materials (Ardolino et al., 2003). A granulometry test conducted in the port of Puerto Rawson show that this layer is located at 2,40 metres depth there. The first 2,40 metres is easily penetrated during the test, because it consists of gravels and clay sands. Below that, the tuff stone is located, which showed great resistance against the test machine (Serman y Asociados s.a., 2021). Tuff stone can be seen in the right picture of Figure 3.3. The left figure shows the different layers of the ground.

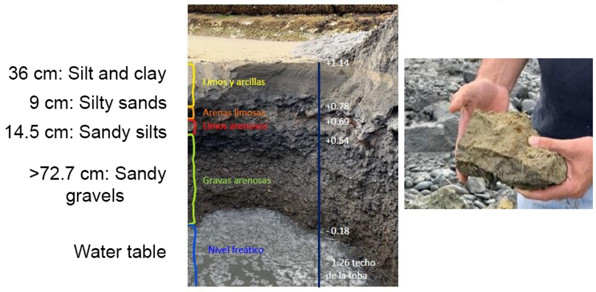


Figure 3.3: Ground layers (left) and tuff stone (right) (Serman y Asociados s.a., 2019)

More on the morphological history can be found in Appendix F.7.

3.2. The port and hydraulic structures

In this section, the history of the port and breakwaters up until 2023 is presented. Furthermore, some context is given about the fishing industry and political regulations.

3.2.1. History of the port

The port of Rawson is located along the last kilometres of the river. It has been in operation since the settlers founded Playa Unión (1923), with the first dock made of wood (Hugo Juan Donini, 2021). The oldest pier was renovated in 1981, resulting in the opening of the Murray Thomas Quay on the northern bank of the river. On the southern side of the Chubut River, the first private dock (Agropez-Conarpesa Dock) is constructed around 2003, by construction company Industrias BASS.

There is dredging done in 2003 as part of a project on remodelling Puerto Rawson. It was done to improve the operating conditions and give larger vessels access. The planned widths and depths of different parts of the channel can be seen on the left in Figure 3.5. However, it is not confirmed if this goal was reached, nor what the state of the depths currently is. The dredged sludge is deposited north of the northern breakwater (Brágoli & Donini, n.d.).

A second public quay wall is built in 2010, called the Muelle Nuevo or new quay. In 2016 a fishing vessel capsized and sank in the river close to the Elsa bridge. Due to legal issues, it has not been removed from the river (L. Faletto, personal communication, 19 September 2023).

From 2018, Industrias BASS started expanding on the southern shore of the river. These plans are still under development and will be further discussed in section 5.2. The latest public development in the port is the extension of the Murray Thomas Quay in 2022.

A top view of part of the public port (bottom of the figure) and private port (top of the picture) can be seen in Figure 3.5.

Figure 3.4: Historic images port of Rawson (Patricia Lorenzo Harris, el Museo 1923)

Figure 3.5: Lay-out of the access channel (del Vecchio, 2018) and Top view current situation port (A. Lazzari, 2022)

3.2.2. History of hydraulic structures

The first relevant hydraulic structure in this area is located 60 kilometres downstream of the Chubut river. This dam, named 'la Boca Toma', was built in 1919 and regulates the water in the irrigation channels in the lower Chubut valley. In 1943, the construction of the Florentino Ameghino dam began and twenty years later in 1963 it was completed. This dam is 225 metres long and 113 metres high.

In order for the ships to be able to come into port safely, different types of breakwaters have been built. The first one in the north was already built in 1960, now referred to as the old northern breakwater. Then, a southern breakwater was constructed in 1974, the old southern breakwater. In 2002, the southern breakwater was extended by 265 metres, resulting in a total of 800 metres. A year later, in 2003, the northern breakwater was completed with a length of 544 metres, it has an asymmetrical section (Hernán et al., 2019). In 2005, a short breakwater is constructed on the beach of Playa Unión, about half a kilometre above the northern breakwater.

An overview of the Spanish and English names of the structures can be found in Figure3.6.

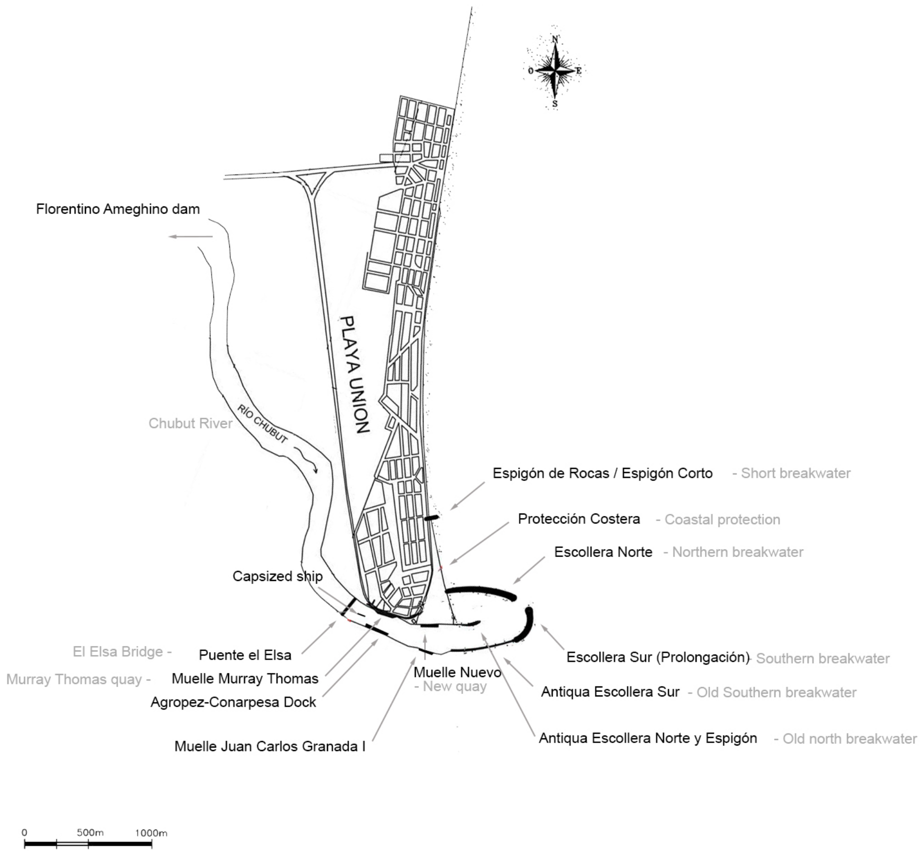


Figure 3.6: Overview of the hard structures in the area (Adapted from (Hugo Juan Donini, 2021))

The length of the southern breakwater is 800 metres. It is built with a rock core and a 2 m³ accropode shells. The foot has a diameter of 43 metres. The northern breakwater is 540 metres long and its section is asymmetrical (del Vecchio, 2018). On the crest, there is a path with a metal railing, so pedestrians can walk on top.

Different designs of both breakwaters were considered, as is demonstrated by Brágoli and Donini (n.d.). The northern breakwater is designed based on physical and mathematical modelling, as can be read more about in a paper by del Valle et al. (n.d.).

3.2.3. Fishing industry

The fishing industry is one of the main industries that are taking place in the Province of Chubut. Other economic activities are hydrocarbon and oil extraction, aluminium manufacturing, livestock like sheep breeding, agriculture and tourism. In 2016, almost a quarter of the marine catches of Argentina were done in the province of Chubut (del Vecchio, 2018).

Looking at the amount of tons of fishery products, Puerto Madryn is the most important port within the province. Puerto Rawson comes in the second place. Other ports are Puerto Comodoro Rivadavia and Puerto Camarones.

The ships that are active in the public and private port of Puerto Rawson are from the yellow fleet, including only small-size vessels with lengths between 10-21 metres. Since 2003, there has been an artisanal fleet with lengths less then 10 metres. They catch mainly shrimp, hake and squid. In the private port, the red fleet also docks. Figure 3.7 shows a picture taken on the field trip where both fleets on both sides of the river are visible.

Figure 3.7: Boats yellow fleet in the public port and red fleet in the private port

The fishing season starts in October and ends between March and April (del Vecchio, 2018). The monthly total landings of shrimps can be seen in Figure 3.8 for the years 2000-2016.

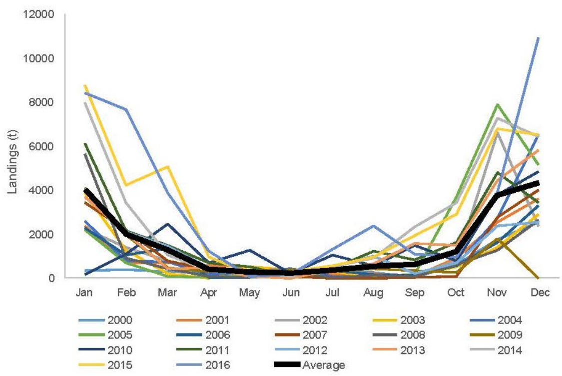


Figure 3.8: Total landing of shrimps per month (del Vecchio, 2018)

3.2.4. Political context of fishing and port

In the period of 1943-1991, the National State had ownership of all the ports in Argentina, as well as their administration, control and operation. This was done through the General Administration of Ports (la Administración General de puertos, AGP). However, the law was reformed in 1989 and henceforth the province controls the authority of the ports. Since then, the port of Rawson has been regulated by provincial laws (del Vecchio, 2018). The enforcing authority is the governor of the province together with the ministries like the Ministry of Infrastructure, Energy and Planning (MIEP) and the Ministry of Environment. The Direction of Port Infrastructure (DPI) controls the everyday business of the port and is responsible for the maintenance of the public side of the port together with the Secretary of Fishing (L. Faletto, personal communication, 19 September 2023).

Since 2009, there have been guidelines for the Federal Fisheries Law stating maximum allowable catches of any given species. This has been a result of reports written in 1990 that indicate the consequences of over-exploitation of the Argentine sea. Therefore, each vessel has a fishing permit, which indicates the Maximum Allowable Catch of certain species. This amount is reevaluated yearly by the Federal Fishing Council (del Vecchio, 2018).

Other political instances involved with the port and building in the river and along the coast, like the Water Institute, are further elaborated on in Chapter 6, since they are relevant stakeholders in the project.

3.3. The history of the coast

The erosion of the coastline has marked some significant developments, through the years, as can be found in literature. This section gives an overview of these developments and places them in the context of the previously mentioned history of the port and hydraulic structures. The first signs of erosion were in 1930 before any of the hydraulic structures were constructed. In 1942 the first row of houses at Playa Unión was destroyed by the sea. Nowadays the first row of houses was the second row back then (Hugo Juan Donini, 2021). After that, the hydraulic structures were constructed. In the report of Hugo Juan Donini (2021) some erosion phenomena are mentioned. For example, the retreat of 70 metres of the coastline, between 1976 and 1996. Due to a storm in 2002 there was a substantial retreat of the coastline at Playa Unión.

Between 2012 and 2016, due to the construction of the short breakwater, there is an accumulation of material between the short and the northern breakwater. However, north of the short breakwater, there is a lot of erosion. In the same report, the coastal profile is divided in certain layers. The upper layer of the profile, around the point of wave impact, is prone to erosion during high tidal flow and by high waves breaking on the coast, storms and swells. However, after these events, the profile will partially recover. The lower layer, -7 to -9 metres MOP, is affected during storm surges at low tides and lower wave heights, this will not recover. As a result, the coastline is slowly retreating over the years (Hugo Juan Donini, 2021).

An overview of all the events regarding coastal erosion and sedimentation and the construction of hydraulic structures over the years is given in Figure 3.9.

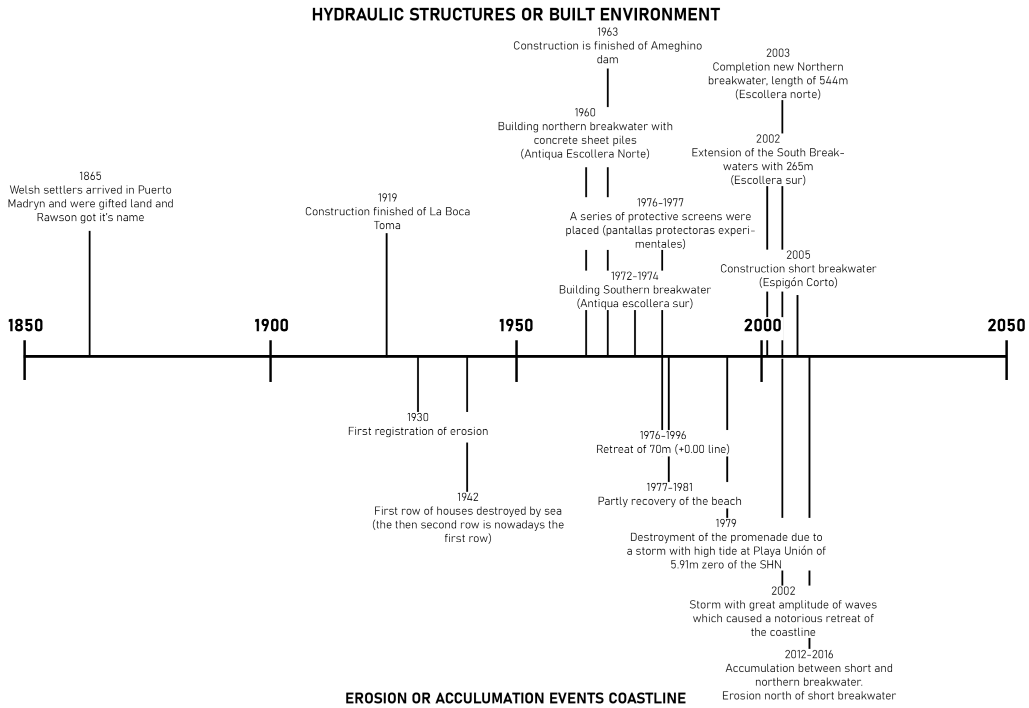


Figure 3.9: Timeline starting from 1850

3.4. Ecosystem

In this section, a short description of the ecology in the area will be given. Both, the flora and the fauna will be discussed. In Figure 3.10 the vegetation found around the project area is shown.

Figure 3.10: Native plants at Playa Unión

Puerto Rawson has a mid-latitude steppe climate. According to Stanley (n.d.) a steppe climate is a dry, grassy plain with cold winters and warm summers, due to seasonal temperature changes, and semi-arid. Because of the small amount of rain, short grasses can grow but trees and tall grasses cannot. In general, the vegetation on the Patagonian steppe is, therefore, small and thorny. The coastal landscape in the area around the project area is called a shrub-steppe, with dominant vegetation shrubs like Chuquiraga avellanedae, Atriplex lampa, Larrea divaricata, Schinus johnstonii, and Grindelia chiloensis (del Vecchio, 2018).

Animals that live at the coastline of Playa Unión include for example birds, like furnarius, and colonies of sea lions, see Figure 3.11. The sea lions live in the port next to the docks inside the harbour and are sometimes seen on the beaches of Puerto Rawson and Playa Unión. Next to the sea lions, the Commerson's dolphin is the most remarkable mammal living in the sea (Tolosano et al., 2022). Next to that, there are shrimps, camarones, but it is thought that those shrimps disappeared when the harbour shelters were built. The other type of shrimp, the larger one called langostinos, does not approach the coast at all (Lic. L. Oviedo, personal communication, 12 October 2023).

Figure 3.11: Animals living in and next to the sea

The biodiversity of the area south of the Chubut River between Playa Unión and Rawson is investigated. In this article, some characteristics of the area are mentioned resulting in the current biodiversity (Tolosano et al., 2022):

- Average rainfall: 150-200 millimetres per year
- Wind direction: Western wind
- Average annual wind speed: 30 kilometres per hour
- Average annual temperature: 12° and 13° C.

From this, the largest available flora can be determined as (Tolosano et al., 2022):

- Botanical species: eudicots (68,33%)
- identified habitats: herb (41,67%) and shrub (38,33%)
- Botanical families: Asteraceae (20%) and Poaceae (20%)

The predominant fauna in the area can be seen in Figure 3.12 and consists of: mammals, southern mountain cavy, grey fox, red fox, puma, guanaco, several species of rodents, Patagonian canastero, ringed warbling finch, cinnamon warbling finch, Patagonian mockingbird, Lesser shrike-tyrant, Burrowing parrot and birds of prey, such as Black-chested buzzard-eagle and the Peregrine falcon (Tolosano et al., 2022). However, those plants and animals are spotted not directly at the coastline but more to the west as mentioned above. It is therefore likely that a lot will be similar to the coastal region, but there will not be a complete resemblance.

Figure 3.12: Predominant fauna in the area west of Puerto Rawson and Playa Unión

To conclude, there is a steppe climate, resulting in the growth of small and thorny vegetation. The animals that live in the harbour and at the beach are different types of birds, sea lions, rodents and some other mammals.

4 Morphological development and drivers

This chapter finds an answer to the sub-question: "what is the morphology of the coastline of Playa Unión and what are its drivers?" This is done by first researching the sea state, conducting a morphological analysis of the coastline and a CoastSat analysis. Furthermore, erosion rates from different literature sources are compared and lastly, an overview of the sediment fluxes is made.

4.1. Sea state

In this section, the sea state is discussed. The wave climate, wind climate, tides and possible effects of climate change are investigated. Due to the lack of data, some assumptions have to be made. The possible interventions are designed using the conditions determined in this chapter.

4.1.1. Wave climate

To acquire a better understanding about the wave climate, a comparison between the report "Estudio de la dinámica costera de Playa Unión y propuesta de protección para la costanera, Provincia de Chubut" from Universidad Nacional de Córdoba (2022) and the report "Estudio de Protección de Costas Playa Unión Informe final" from Savioli et al. (2011) is made. The measurement locations of both studies are different, as can be seen in Figure 4.1. In order to make a comparison between the data sets, it is assumed that the wave climate at both points is the same. This is a big assumption, but due to the lack of available data in the region, this was deemed to be necessary to make a comparison between both data sets.

The study by Savioli et al. (2011) uses data from 1990 to July 2010 acquired via Oceanweathers Global Ocean Wave Reanalysis project (GROW). This is a global hind cast model that uses global wind fields to generate the waves (oceanweather inc, 2007). The wave data is for an offshore location that corresponds to Point 11369 of the GROW project grid, 175 kilometres south-east of Puerto Rawson. In that study, the full wave climate is used for the numerical modelling of sediment transport. The wave data from the report from Universidad Nacional de Córdoba (2022) was obtained from the Copernicus Climate Change Service database. The resulting wave data from the report can be seen in Table 4.1. To validate the wave climate described by Universidad Nacional de Córdoba (2022), a comparison is made with the data obtained by Savioli et al. (2011). In order to compare the datasets with each other the data of Savioli et al. (2011) is subjected to an extreme value analysis (EVA). The EVA of the data is

Figure 4.1: Comparison of the locations of the data acquisition of (Savioli et al., 2011) and (Universidad Nacional de Córdoba, 2022).

described in Appendix A. The results of the analysis can be found in Table 4.2.

Table 4.1: Wave data 2022, point 2, waves to westward direction. Weibull distribution

Return period (Years)	Green point Figure 4.1		
	Hs (m)	Tp (sec)	Windspeed (m/s)
5	5,60		18,1
10	6,29	9,4	19,2
25	7,05	9,8	20,7
50	7,61	10,2	21,8

Table 4.2: Wave data 2011, waves to westward direction. Generalized Pareto distribution

Return period (Years)	Yellow point Figure 4.1		
	Hs (m)	Tp (sec)	Windspeed (m/s)
5	6,71	10,3	19,98
10	7,00	12,2	20,47
25	7,34	14,4	20,97
50	7,55	16,0	21,26

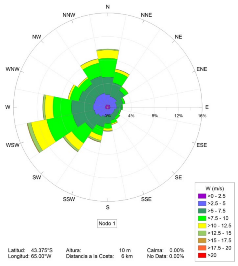
When comparing the values found by Savioli et al. (2011) and stated by Universidad Nacional de Córdoba (2022) it can be seen that the values matches each other in terms of significant wave height (H_s) and wind speed for the corresponding return periods. However, the peak periods (T_p) differ. This difference suggests that in the data retrieved from the study by Savioli et al. (2011) swell waves (ocean surface waves) are the governing waves in the wave climate. However, the results appear to be in the same order of magnitude. After comparing the data, it is decided to use the data from Universidad Nacional de Córdoba (2022) that can be seen in Table 4.1. Still, there is a high uncertainty in this data, but it seems to be the dataset that best approximates the real wave climate.

The swell waves under normal conditions are thought to be the main driver of longshore sediment transport (Savioli et al., 2011). According to Hugo Juan Donini (2021) these waves have a height of $0,5$ to 1 metres and a period of 10 to 20 seconds. The predominant directions are between SSE and E.

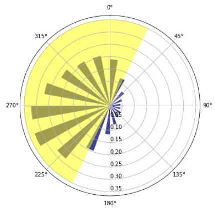
4.1.2. Wind climate

Figure 4.2 show the relevant wind roses for the area, acquired from the available data of different literature sources. Figure 4.2a shows a wind rose for the area obtained by Serman y Asociados s.a. (2019) via the global meteorological model by the European Center for Medium-

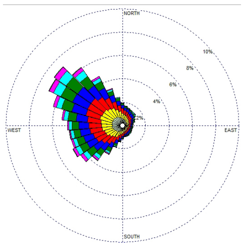
Range Weather Forecasts. Figure 4.2b shows a wind rose that is made based on the data from Savioli et al. (2011) and Figure 4.2c and Figure 4.2d are acquired from Universidad Nacional de Córdoba (2022). The dominant directions of the wind are between south-west and north-west. So, for the vast majority of the time, the wind is directed offshore. Strong winds are frequent in the area, with wind speeds of more than $5m/s$, or 4 Beaufort, present over 70% of the time.



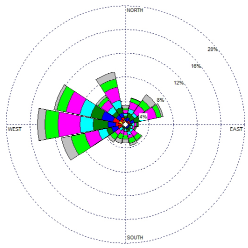
(a) Data for 2009-2018 from Serman y Asociados s.a. (2019)



(b) Data from Savioli et al. (2011)



(c) Point 2 from Universidad Nacional de Córdoba (2022)

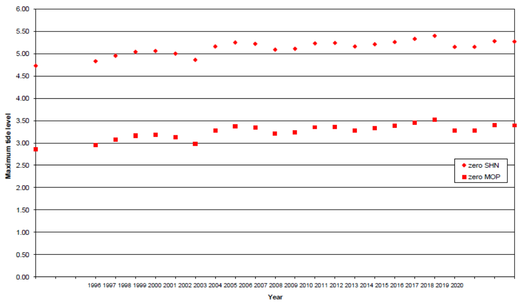


(d) Estación Fitobiología from Universidad Nacional de Córdoba (2022)

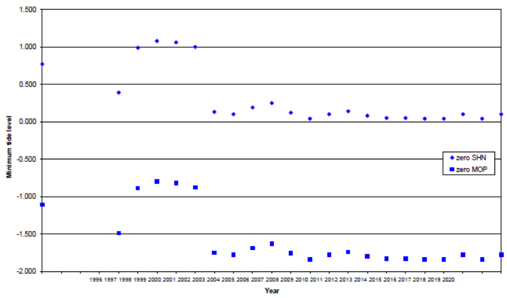
Figure 4.2: Different wind roses required from available data

4.1.3. Tidal currents

According to Hugo Juan Donini (2021) between the years 1996-2020 the maximum high tide was $+5,4$ metres SHN equal to $+3,52$ metres MOP and the minimum low tide was $-1,84$ metres MOP, which can be seen in Figure 4.3a and 4.3b. The mean low tide value corresponds to $-1,49$ metres MOP equal to $+0,39$ metres SHN. In his report it is mentioned that the astronomical tidal regime is semi-diurnal, meaning two high tides and two low tides per day. The tide has amplitudes between 1 and $2,5$ metres and a clear spring-neap cycle. An example of tides for 4 October until 11 October 2023 is given in Figure 4.4.



(a) Maximum high tide levels, 1996 to 2019 (Hugo Juan Donini, 2021)



(b) Minimum low water levels, 1996 to 2019 (Hugo Juan Donini, 2021)

Figure 4.3: High and Low Tide Levels

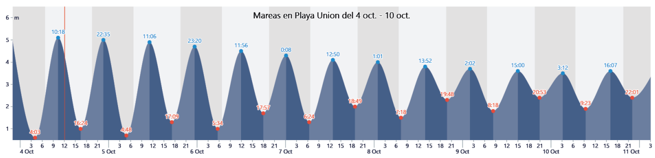


Figure 4.4: Tides $4^{th} - 11^{th}$ of October 2023 ("Tides Chart", 2023)

4.1.4. Climate impact and sea level rise

In the most recent IPCC report, multiple scenarios for the rate of climate change are defined, but no likelihood of each scenario is given. These scenarios lead to different amounts of sea level rise. For this report, the SSP 2–4.5 scenario is chosen, also known as middle-of-the-road development. This scenario includes intermediate greenhouse gas emissions, with CO_2 emissions remaining around current levels until 2050. Because the middle-of-the-road scenario does not include overly optimistic or pessimistic predictions, it is deemed appropriate to use in this report. Since this report looks at the effectiveness of interventions up to 2050, the choice of emission rate matters less. The amount of sea level rise only diverges seriously for the scenarios up to 2100. (Masson-Delmotte et al., 2021)

From Figure 4.5 it can be concluded that the sea level rise at the Argentine coast around Playa Unión is lower or similar to the global average sea level rise. Thus, the worldwide mean sea level rise prediction will be used for the projected sea level rise at the project site.
The total global mean sea level rise for the $SSP\ 2-4,5$ relative to a baseline of 1995-2014 is in the range of $0,17$–$0,26$ metres by 2050 (Fox-Kemper et al., 2021). Therefore, in this report the sea level rise at Playa Unión which is considered for the design interventions is set to $0,2$ metres in 2050.

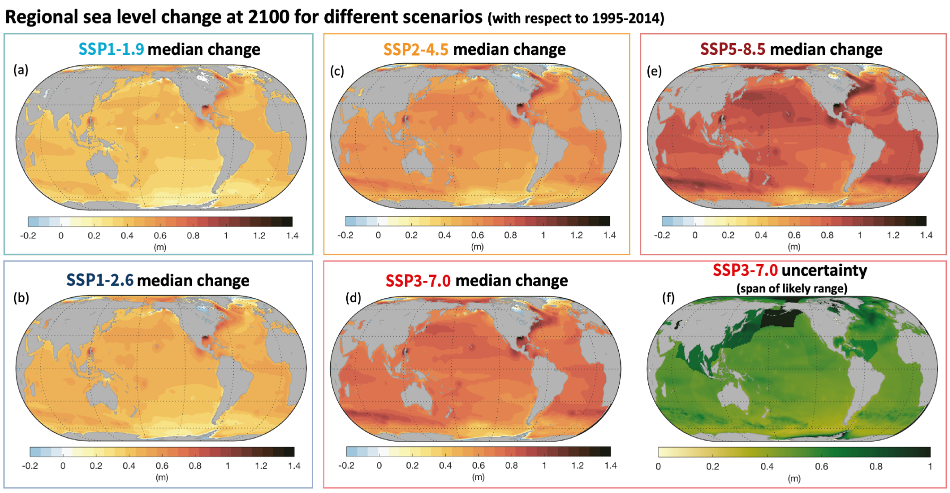


Figure 4.5: Regional sea level change at 2100 for different scenarios (Fox-Kemper et al., 2021)

Seneviratne et al. (2021) conclude that the impact of climate change on the severity of storms outside the tropics is limited, and the future change in wind speed is expected to be small. There is a possible shift of the storm tracks towards the poles, but this has an unclear impact. There is limited evidence for an increased frequency of storms in this region. Thus, the impact of climate change on wind speeds and wave energy is expected to be negligible and not taken into account in this report.

4.2. Morphological analysis of the coastline

4.2.1. Morphological characteristics

This coastal morphology section is a study of the structure and shape of the coastal system of Puerto Rawson and Playa Unión. The coastline has a high susceptibility to marine erosion. The beach has a steep upper section and a gentle lower slope with finer material. This is classified as a reflective beach with a low-tide terrace (Hugo Juan Donini, 2021). The same source states that the reflective upper slope has predominantly coarse granular material with a nominal diameter D_{n50} of 13 millimetres. At high water levels, waves break in a plunging manner on this slope. The lower slope has fine granular material with typical surging wave breaks. The fine material has a D_{n50} between 0.2 millimetres and 0.4 millimetres. The beach gradually changes characteristics to a more dissipate behaviour, as the distance to the mouth of the Chubut River increases. According to Savioli et al. (2011), the area prone to erosion is located behind the northern breakwater up to the ”Plazoleta Las Toninas”. This is a statute of dolphins of the local species at the northern end of Playa Unión. The length of this zone is $3,3$ kilometres.

The morphological developments which lead to the current situation of the coast are caused by human and natural influences. Natural influences are fluxes of sediment transport in and out of the area. To start off, the three main fluxes in the project area will be pointed out. The first is due to antarctic storms, these storms create a wave driven transport directed from south to north (Hugo Juan Donini, 2022). The second flux from sediment is the outflow of sediment to the north of the study area, caused by the same wave driven transport. The final flux of sediment comes from the Chubut river. The largest part of this sediment is sand with a diameter between 150 and 431 micrometres (Kaless et al., 2019).

Based on site visits, the following insight is gained: the most clear area where erosion occurs is on the north side of the short breakwater. The beach is eroded to such a point that during a storm, the boulevard beside the beach has been destroyed. This is clearly visible in Figure 4.6a and 4.6b. Even though it is high tide in Figure 4.6a and low tide in Figure 4.6b it can be seen that the erosion and corresponding damage caused to the boulevard by a storm in less than a month during the time of this project. During the site analysis on the 19^{th} of September 2023, during high tide, it is clearly visible that the beach is almost completely submerged by the sea.

(a) Erosion north of the short breakwater, site analysis, 19/09/2023

(b) Erosion north of the short breakwater, site analysis, 04/10/2023

Figure 4.6: Erosion north of the short breakwater at two different dates

In Figure 4.6 it can be seen that an attempt to create a temporary sea defence had been made. Pieces of the temporary sea defence are scattered over the beach. The run-up of the waves in Figure 4.6a also comes close to the place where the boulevard used to be. This was during a calm day.
Different parts of the coastline of Playa Unión are photographed during a site analysis on the 14^{th} of September, 2023. This site analysis was done during low tide on a calm day. The photos can be seen in Figure 4.7.

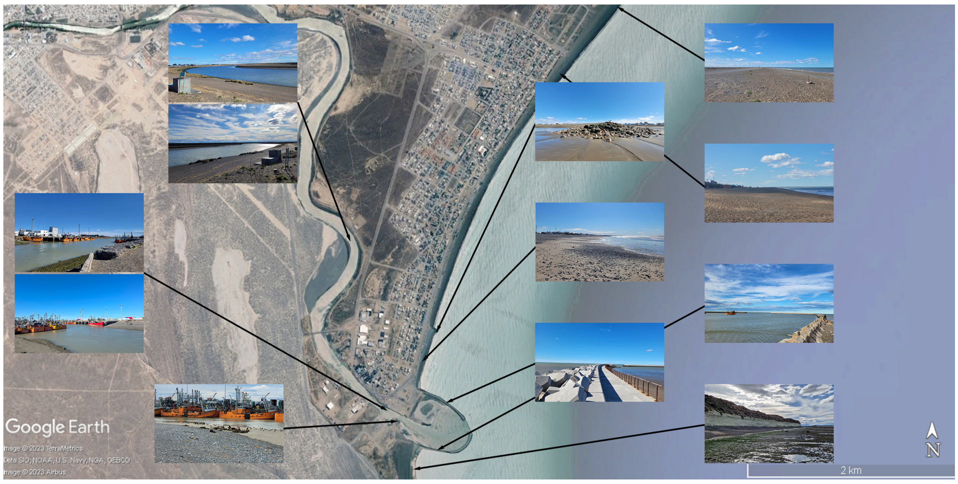


Figure 4.7: Site analysis, 14/09/2023 (Adapted from Google Earth 2023)

4.2.2. River sediment

The amount of sediment transported in the lower Chubut river has decreased majorly following the construction of the Florentino Ameghino dam (Hugo Juan Donini, 2021). Kaless et al. (2019) conducted a 1D HEC-RAS simulation of a large stretch of the lower river. When the Ackers-White transport formula is used, the model predicts transport of 5253 $m^3/year$. According to their modelling results, the maximum shear stress exerted by the river current on the bottom allows for transport of material with a diameter of up to 3-4,5 millimetres. The yearly sediment inflow is estimated using the sediment trap installed in January 2004. For the first period, from mid-January to September 2004, this amounted to 6600 $m^3/year$. 8400 $m^3/year$ is recorded over the following period through the end of 2005, when the trap was completely filled (Kaless et al., 2019). A 2D simulation of the port region, from the bridge to the mouth of the breakwaters, was also carried out. CCHE2D is utilized for this, a finite element numerical model, with the Ackers-White transport formula. The model depicts the tide's dominance in this area, with significant sediment settling between the breakwaters as the flow expands. The area between the two northern breakwaters is highly susceptible to siltation. The study also looked at the impacts of dredging projects in the port, this will be discussed in Chapter 5.

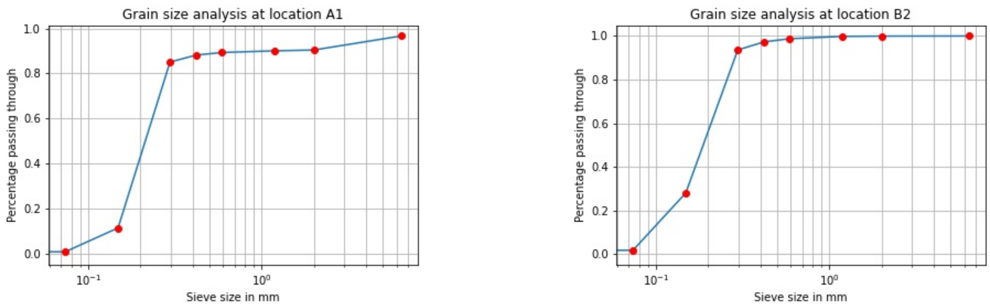
4.2.3. Sediment between the northern breakwaters

Between the new and old northern breakwaters, large amounts of sediments have been accumulated, as can be seen in Figure 4.8. The characteristics of this accumulation has been investigated for this project. Kaless et al. (2019) confirmed with 2D numerical simulation of the port area that sediments transported by the river tend to accumulate in the area between the breakwaters, as a result of the characteristic of the tidal current between the breakwaters.

To find out what kind of sediment accumulates here, a grain size analysis was performed on the 4^{th} of October 2023. The results of this analysis will be used for designing the possible interventions in Chapter 8. Nine samples were taken in a grid form from the sedimentation zone, as can be seen in Figure 4.8. The locations are labelled from A to C for the rows and from 1 to 3 for the rows. A1 is the most northern location closest to the coast and C3 is the most southern location closest to the sea. The exact coordinates of the sample locations are given in Table B.1. Eight locations were chosen on the sedimentation zone, only A1 was chosen on the beach to see if this gives a different result. Sampling was done by taking between 300 and 500 grams of sediment from more than four centimetres below the surface.

Figure 4.8: Location of the nine samples (adapted from Google Earth 2023)

Details about the granulometry test can be found in Appendix B. The results of locations A1 and B2 can be seen in the Figure 4.9. Both results show that most sediment gets trapped in the 149 micrometre sieve, this suggests that the sediment zone consists mostly of fine sand. It is however interesting to point out that at location A1, there is some sediment in the largest sieve, this shows that the sample consists of fine sand mixed with pieces of gravel.



(a) Grain size analysis A1

(b) Grain size analysis B2

Figure 4.9: Results grain size analysis

4.3. Bathymetry analysis

In this chapter, a bathymetry analysis is carried out based on morphological data gathered in the 'Estudio de Protección de Costas Playa Unión, Chubut, Argentina' [Microsoft Excel spreadsheet] study by Savioli et al. (2011). The data used is from 2011 and is outdated data. However, it gives a starting point for making comparisons and predictions of the bathymetry of the coast. The programming language Python is used, to plot the different cross sections and to evaluate the bathymetry of the coastline.

The used cross sections from the data provided by Savioli et al. (2011) with their corresponding orientation can be seen in Figure 4.10 and are numbered S01 to S20 and M01 to M13. The S cross sections have a spacing of 100 metres between the cross sections (yellow in the figure). The M cross section have a spacing of 250 metres between the cross sections (pink in the figure). For the analysis, all the S cross sections and cross sections M01 to M13 are used. These are the cross sections that are located in the project area.

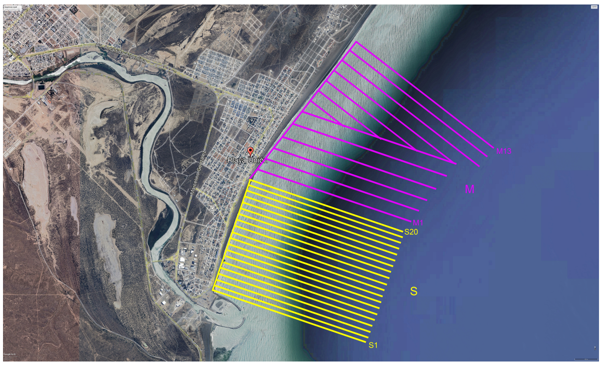
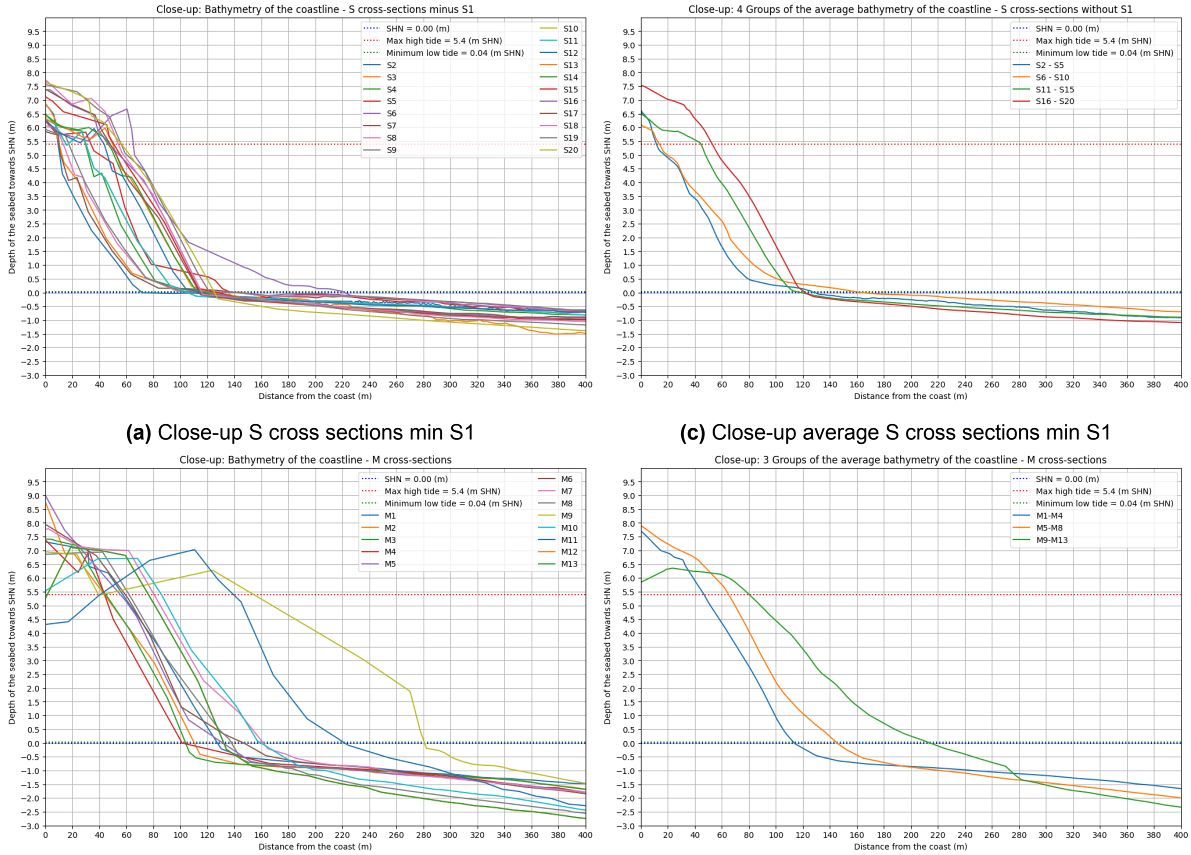


Figure 4.10: Place of the cross sections of the bathymetry data adapted Google Earth, 2023

The relevant results of the analysis are shown below in Figure 4.11. The full results of the analysis can be found in Tables C.3 and C.4. The cross sections that can be seen in Tables 4.11a and 4.11b are divided into groups of four or five cross sections. The results of the average bathymetry of the cross section groups can be found in Figures 4.11c and 4.11d.
A clear distinction between the lower and upper profile of the bathymetry can be seen in Figure 4.11. The slopes of the upper profile and lower profile are determined from Figures 4.11c and 4.11d. The determined slopes can be found in Table 4.3.

Table 4.3: Slope of the lower and upper profile for the different cross sections

Cross section	Upper slope	Lower slope
S2-S5	1:13,3	1:236,8
S6-S10	1:18,2	1:240,9
S11-S15	1:15	1:281,9
S16-S20	1:13,6	1:255
M1-M4	1:17,1	1:254,5
M5-M8	1:18,8	1:268,8
M9-M13	1:29,3	1:300



(a) Close-up S cross sections min S1

(c) Close-up average S cross sections min S1

(b) Close-up M cross sections

(d) Close-up average M cross sections

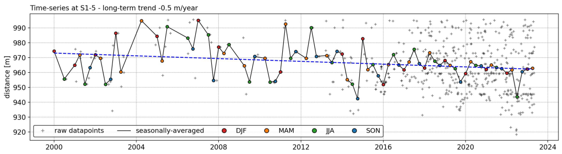
Figure 4.11: Close-up of the S and M cross of the bathymetry analysis of the bathymetry data provided by Savioli et al. (2011)

4.4. CoastSat analysis

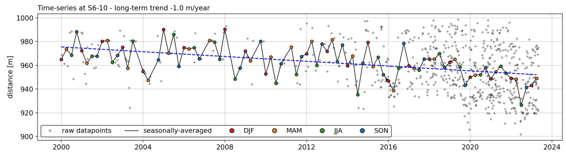
An analysis of the erosion in the area is done. This research step is carried out using the CoastSat tool. This tool can detect the position of the shoreline from publicly available satellite imagery. It is developed by Vos, Splinter, et al. (2019) and available as an open-source software toolkit on GitHub. The "satellite-derived shoreline accuracy is assessed at diverse sandy beach sites in Europe, Australia, the USA and New Zealand. Rapid changes like storm erosion and nourishment can be detected, as can longer term developments like seasonal and inter-annual shoreline developments" (Vos, Harley, et al., 2019).

The method of obtaining the satellite data and extracting the shorelines can be found in Appendix D. To visualize the results, cross sections are made. These cross sections approximately correspond to the averaged S cross sections of the previous chapter. Two more cross sections are added for the northern part of the study area. The locations can be seen in Figure D.2. The data is post-processed to find seasonal trends. The result can be seen in Figure 4.12. From August 2015, there are many data points, because more satellites became available. The data is not tidally corrected, because of the limited time in this research. Therefore, short-term trends are more difficult to detect, especially before August 2015, when the data is more scattered. There is a possible oscillation with a period of four to five years that can be observed in the coastline positions. In the winter of 2022, strong erosion can be noticed in the seasonal averaged trend. In all transact, except Figure 4.12f, the coast has only partially recovered from this erosion event.

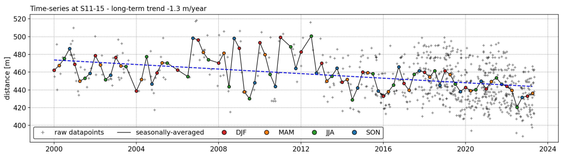
A crude calculation of the eroding volume along the coast can be made. Using the data of the coastline evolution and the bathymetry obtained in section 4.3. Twelve cross sections are drawn along the eroding part of the coast, up to the school cross section. The largest erosion is indeed directly behind the short breakwater, here the retreat is 2 metres per year. The satellite only detects the shoreline position, this is assumed to be on the upper slope only. Thus, the calculated volume will only be the volume eroding on the upper slope. The calculated eroding volume for the 2,4 kilometres is $14.890m^3/year$. For the calculations and discussion, see appendix D.



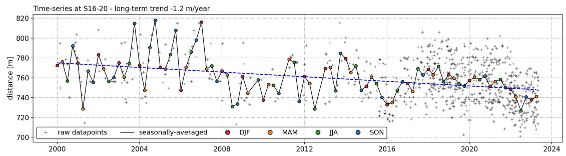
(a) cross section corresponding to S1-5



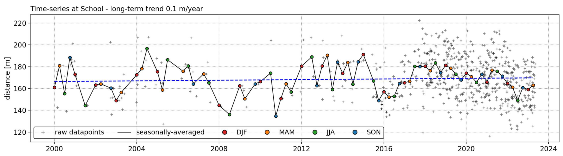
(b) cross section corresponding to S6-10



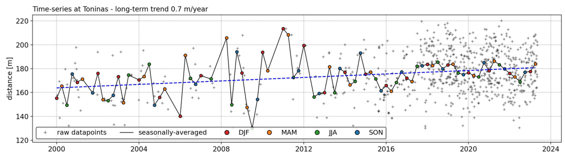
(c) cross section corresponding to S11-15



(d) cross section corresponding to S16-20



(e) cross section near the school



(f) cross section near the Toninas statute

Figure 4.12: Seasonally averaged and long term trend of coastline change in six cross sections

4.5. Comparison of erosion rates

The erosion rate of the coastal zone was calculated by (Hugo Juan Donini, 2021) based on 27 profiles of the shoreline north of the port. These were made in 2000, 2008 and 2014. The erosion rates are separated for the sands between 0,3 and 0,1 mm on the lower zone of the beach and for the coarser material on the upper slope. The results can be found in Table 4.4.

These values can be compared to the transport rates and sediment budget found by Savioli et al. (2011). Based on analysis of images of the coast, a total erosion rate between the northern breakwater and the statute of $24.000m^3/year$ is obtained for the period 1985-2007. This is calculated based on the position of the shoreline that is recorded with aerial photography. The retreat of the shoreline they found was in the order of 1 metre per year. With the same method, an accumulation of $41.000m^3/year$ is recorded, In the sector north of the statute to the end of Playa Unión. It is important to note the extension of the breakwater started in 2000. In this same study, a numerical model is used to simulate the transport and erosion-sedimentation rates in the period 1990-2010. The results are shown in Table 4.4. In the report, it is mentioned the values from the numerical simulation give an indication of the transport rates and should not be compared with the historical erosion rates. The model does result in a similar order of magnitude estimate for the sedimentation north of the Toninas statue, as the historical data.

The volume calculated by the CoastSat method is less than the volumes found in the literature. The values found in this analysis could be seen as a stand-in for the upper slope erosion values. It is not apparent why the difference in magnitude exists. It could be due to the assumptions on the height of the upper slope. The lower slope erosion is hard to estimate from the satellite images. Especially because the depth of closure is not known. This is the depth at which the lower slope does not show changes any more. It is also possible that the difference is due to the oscillations in the coastline. It could be that for both the considered periods 2000-2008 and 2008-2014, the erosion rate was higher. This is difficult to see due to the fact that the data is not tidally corrected. The time of the year of the measurements could also play a role, as the coastline position oscillates over the year. The study by Savioli et al. (2011) also includes the period before the breakwaters were constructed. It could be expected that the erosion rate will be less for this period because the breakwaters are thought to be the cause of the erosion to their north. The erosion rate is lower compared to other literature values.

In conclusion, valuable information can be obtained with the CoastSat method about the evolution of the coastline. However, the calculated volume of erosion only applies to the upper slope and differs much from the values found in the literature. More information and validation is necessary to check the assumptions made and to be able to come to a good estimation of erosion volumes via this method.

Table 4.4: Erosion rates, from different sources compared to the coastsat analysis

Study	Period	Erosion of fine material $m^3/year$	Erosion of coarse material $m^3/year$	Coastline analysis $m^3/year$
Hugo Juan Donini (2021)	2000-2008	93.420	35.177	-
Hugo Juan Donini (2021)	2008-2014	283.812	29.623	-
Savioli et al. (2011)	Simulation	174.000	48.000	-
Savioli et al. (2011)	1985-2007	-	-	24.000
Coastsat analysis	2000-2023	-	-	14.890

4.6. Conclusion on sediment fluxes

Using the estimates from relevant literature, site investigations and satellite analysis, an overview of the sediment fluxes is made to come to a detailed understanding of transport and the erosion and accumulation zones. A visual representation of this conclusion can be found in Figure 4.13.

Coarse material is supplied from the south by the longshore transport. It originates from the eroding cliffs and the drainage channels running from the inland plateaus to the sea. It is assumed there is no transport of coarse material past the port's breakwaters, causing an accumulation south of the breakwaters. The lack of supply of coarse sediments causes the retreat of the shoreline.

There is a sediment sink of fine material between the northern breakwaters. River sediment is naturally deposited there by the circulation of tidal currents between the breakwaters of the port. This deposition of sediment will also limit the supply of fine sediments to the shore. This is not thought to explain the full magnitude of erosion estimated by Hugo Juan Donini (2021).

The erosion on the lower slope could be caused by the erosion of material on the upper slope and the subsequent retreat of the upper shoreface. The slope and depth limit for the fine material on the lower shoreface remains the same due to the waves and tides. In order to return to the existing profile in the new location, the fine sediment on the lower shoreface will have to be removed. So, retreat of the shoreline on the upper profile causes a retreat of the entire shore profile. See the lower and upper slope in Figure 4.11. There is also the effect of the lower of supply of fine sediments from the Chubut River, as a consequence of the construction of the Florentino Ameghino dam. It is not known if this still has an effect on the current retreat of the shoreline. Nor is the magnitude of this effect compared to the reduced supply of coarse sediments known.

In the northern part of the study area, the erosion rates decrease up to the northern boundary of the study area, where accumulation of sediments can be recorded. The longshore transport to the north in the study area is caused by the angle between the nominal direction of the waves and the shore normal, the larger this angle, the stronger the transport (Bosboom & Stive, 2023). The nominal direction is thought to be SE or SSE. The angle decreases in the north of the study area, where the coast rotates towards the northeast. It is even possible that the change of the angle of the coast leads to transport in the southwest direction, further to the north from the study area. Sediment is transported from the southern sector of the study area by the large longshore transport rate. Coarser sediments are transported less easily. The large transport leaves only very coarse sediments on the upper part of the beach in the south. This results in a steep upper profile with reflective breaking of the waves. The smaller transport rate north of the study area reduces the selective pressure between sediments of different grain sizes. This corresponds with the more even distribution of sediment sizes found in the north, see Figure 4.7 and Figure C.5. Because the average size of the material on the upper profile in the north is smaller, there is more dissipative wave breaking.

Sea level rise will lead to a retreat of the coastline by submerging part of the profile. The amount depends on the slope of the beach. On this coastline, a sea level rise of 0,2 metres up to 2050 will lead to a retreat of the coast between 3 and 4 metres, depending on the exact slope in that location. This only takes submergence into account. There could also be cross-shore redistribution and change in the position of the upper and lower slopes. This could further cause the retreat of the coastline, but also the opposite effect. The higher sea level could also lead to a change in the long-shore transport rates. To determine the exact consequences, simulation will be necessary.

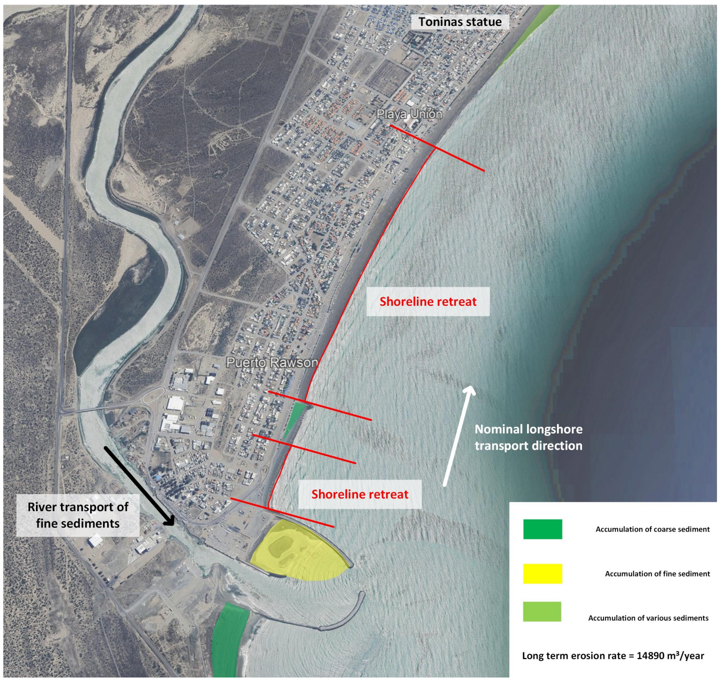


Figure 4.13: Overview of the sediment fluxes in the study area (Adapted from Google earth 2023)

5
Development of the port

In this chapter, the following sub-question will be answered: "how will the planned developments of the port area influence the direct area of Puerto Rawson and Playa Unión?" To formulate an answer, the current dredging project and public and private expansion plans will be discussed. An overview of the port and development plans can be seen in Figure 5.1.

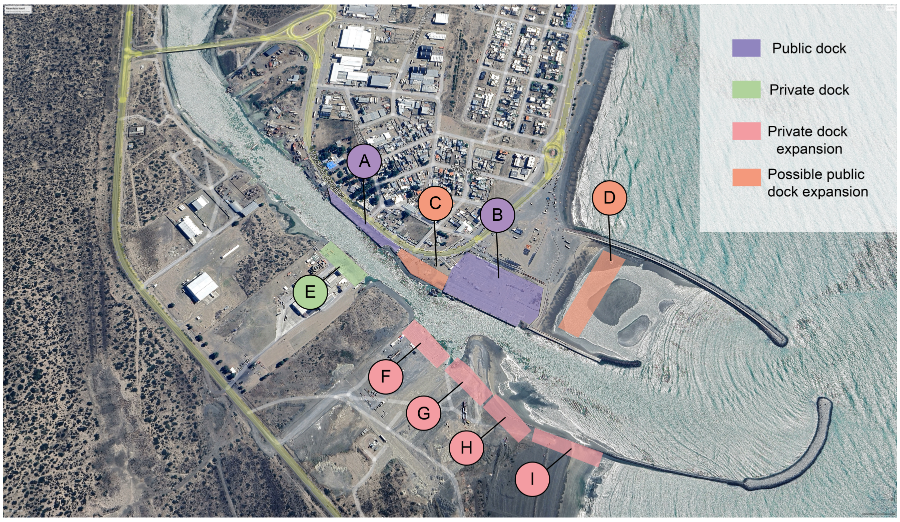


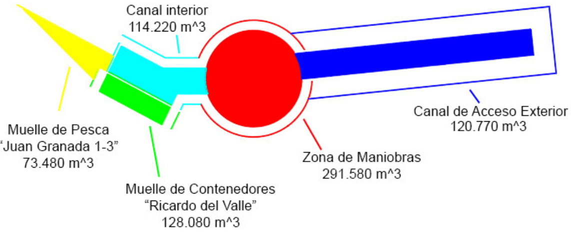
Figure 5.1: Overview of the port and development plans (Adapted from Google Earth 2023)

5.1. Public expansion plans

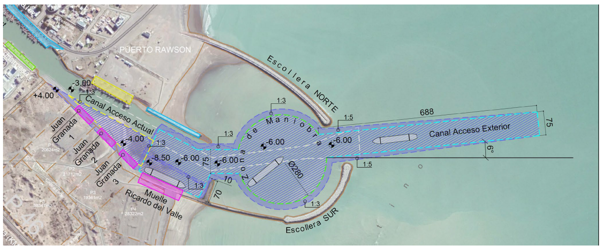
There are some plans to expand the currently existing public quays (A and B in Figure 5.1). The DPI is developing plans to build a new quay between them, marked C in the same figure. These are awaiting approval by the provincial government. See the interview with the DPI in Appendix F.3. Another option is in between the old and new northern breakwaters according to a study by del Vecchio (2018) (marked with D). These plans are also mentioned by the mayor of Rawson. It could be used as a small marina, to encourage tourism. See the interview in Section F.2. Currently, this area is filled with sediment. One of the interventions of this report considers the use of this sediment. See Section 8.3.

5.2. Private expansion plans

The private contractor Industrias BASS is developing the port on the southern bank of the river. They built and sold one quay already (indicated as E in Figure 5.1). Their next plans include the development of four new quays. Three will be for fishing vessels, F, G and H. The last quay, indicated as I, is designed to accommodate small container vessels. The first of the fishing quays (F) is already operational, and the second is under construction, as indicated in section 3.2.1. The plan also calls for dredging of the port. This is designed so a container ship with a draft of 7,33 metres can enter the port and perform a turn in the port, at high tide levels. This will make it possible for fishing vessels of the yellow and red fleet to enter the port during the whole tidal cycle. An overview of the plan can be seen in Figure 5.2.



(a) Dredging volume calculations adapted from Serman y Asociados s.a. (2019))



(b) Conceptual nautical design by Serman y Asociados s.a. (2019) depths in SHN

Figure 5.2: Location of the new docks and conceptual design for the new port

The fishery quays, called Juan Granada I-III, will be reinforced concrete docks with a length of 65 metres and a width of 20 metres on a pile foundation. This is comparable to the existing quays in the port. The quay that can accommodate the container vessel will be called Ricardo del Valle. The feeder container ship that it is designed for by Serman y Asociados s.a. (2019), has a typical length of 135-141 metres, a maximum width (beam) of 22 metres and a maximum draught of 7,33 metres. Thus, in front of this quay, the bed level should be lowered to -8,5 metres SHN. At low tide, the clearance for the large vessels is very limited. During high wave conditions, the container vessel might contact the bottom when in the trough of a wave. From Serman y Asociados s.a. (2021) studied the wave climate in the port for the new situation after dredging. Their numerical simulations showed that the new piers would be exposed to the incoming waves, so a breakwater perpendicular to the line of piers should be constructed. The designed breakwater has a length of about 70 metres. Furthermore, the old northern breakwater should be shortened with 45 metres to generate enough space for the access channel.

5.3. Maintenance dredging project

From 2020, plans were developed, by the MIEP of Chubut province, to commission maintenance dredging in the port. The project is funded by the national government. The goal is to lower the bed level in the port. As mentioned in Section 3.2.1, the high bed level in the access channel causes congestion and damage to ships. The project was awarded to Servimagnus S.A. and Sudelco in 2022. However, due to environmental concerns, the project was delayed multiple times. For detailed information see Appendix F.1 and Appendix F.10. Halfway through September 2023, dredging in the port recommenced. The dredging will have to be suspended in December because of the large amount of ships entering the port during the fishing season. If the project is not completed, dredging might recommence after the season has ended in April 2024. The project has been scaled down multiple times due to the delay, technical difficulties and financial issues. As a result, the plans have been changed to only dredge from the Murray Thomas Quay up to the mouth of the breakwaters. An extra box on the south side of the channel will be dredged to create a sediment trap. The total volume will be around 300.000 m^3. As required by the tender, the dredged sediment will be disposed directly north of the northern breakwater, a picture of which can be seen in Figure 6.7. The ship used for the dredging is a cutter suction dredger.

The deepening of the channel will allow ships to come into and exit the port for a longer period during high tide, possibly resulting in less congestion during the fishing season. This could have a positive impact on the productivity of the port. The upcoming fishing seasons will reveal how much the congestion will decrease.

Some of the dredged sediment can be seen in Figure 5.3. The exact fractions of each type in the dredged sediment are unknown.

Figure 5.3: Some remaining material in the pipe used to dispose the dredged sediment (De Vincenzi, 2023)

5.4. Impact on the coast and port

The impact that the expansion of the port and the maintenance dredging have on the port and coast are highlighted in this section.

5.4.1. Public plans

The expansion of the public side of the port will have none to very little effect on its surroundings. The dredge works that would be carried out for this might, however. Because these are also necessary for the private port expansion, this will all be explained in Section 5.4.2.

5.4.2. Private plans

The expansion of the private side of the port might have some effects on its surroundings. The two things that might have an effect are the construction of the parallel breakwater and the dredging works that need to be done for port expansion.

Parallel breakwater

The parallel breakwater might cause sediment to settle on its seaward side. This would be due to reduced currents as a result of expansion and re-circulation of the flow behind the structure. Waves can also push sediment towards the seaward side of the structure. On the landward side sedimentation due to reduced currents is also possible. The sediment deposited there would otherwise maybe exit the port and get pushed towards the shore. Here it would settle on the beach and help protect it against coastal erosion.

Another influence it might have is a safety issue. As explained in Section 5.2 the plan is to make the breakwater 70 metres long. This could cause ships to collide with it when trying to dock in the port. The current of the river might push the ship against it, causing a lot of damage to the ship and the breakwater.

Dredging works

Dredging works that would be necessary within the port for the expansion will have an effect on surrounding structures and the sediment flow. To start off with the stability of the breakwaters. When dredging too close and too deep in the vicinity of a structure, it might cause it to become unstable and collapse or slide. Serman y Asociados s.a. (2021) did a calculation for the possible parallel breakwater to see if it would be stable in combination with the dredging works needed for the port expansion.
However, such calculations and designs should also be done for already existing breakwaters. If the turning circle for container ships were dredged, it is essential to make sure that the old, northern and southern breakwaters will not collapse due to instability.

Another influence that dredging in the port might have is that it could recreate the effect of a sediment trap. Fine sediment that would normally exit the harbour and get pushed to the shore might settle in the port now. This because of the reduced flow speeds in the channel with a larger depth. Resulting in a reduced supply of fine sediment to the beach. The amount of sedimentation after the dredging in the port is not known. It is important to estimate this in order to have an indication of when maintenance is required. The location of the deposition of the dredged material will also have an impact on the coast. This is explained in Section 5.4.3.

5.4.3. Maintenance dredging

The deposition of the material that is being dredged for the port maintenance will have an impact on the coastal zone. The sediment will probably be transported along the shoreface by the waves. As described in Section 4.6, this transport will be directed mostly northward. The difference in mobility between fine and coarser sediments will cause them to end up in different parts along the shore.

The very fine sediment consists of silt and particles of the tuff stone. These small particles are not likely to end up on the active shoreface. Due to the high energy of the waves, the particles will be suspended and transported. A fraction might be transported back into the port by the flood current and waves propagating into the mouth. It is difficult to predict the extent to which this might happen. It is not known if disposing of the sediment farther away from the port, might reduce this effect. The rest of the fine sediment will likely be transported farther along the coast. It could settle in a low wave energy area along the coast or on the outer shoreface, with limited wave influence.

Fine sediment, like sand and small gravels, are mainly found on the lower slope of the shore profile, see Section 4.6. This part of the dredged material will therefore likely settle in this part of the shoreface. From there it will likely be distributed northward by the waves. Since the short breakwater, mostly extends over the upper slope it is unlikely this will interrupt much of the transport of the fine sediment. This will lead to nourishment of the lower slope. Hugo Juan Donini (2021) found that between 2008 and 2014 the material on the lower slope of the shoreline has eroded with a rate of $283.812 m^3/year$ up to the Toninas statue. Nourishment with the dredged material might counteract this erosive process partially. The effectiveness will be limited since the estimated annual erosion rate of fine sediment is about the same as the total volume of dredged material.

The coarser sediment is expected to end up on the upper slope of the beach profile. It is likely

Figure 5.4: Damage to the old southern breakwater and accumulation of cobbled sediment

most coarse sediment will be trapped behind the short breakwater. Since the shore characteristically expands near the breakwater, very little coarse sediment can be found behind it. This suggests most coarse sediment is not transported beyond. The beach might expand between the port and the short breakwater as a result of the disposed material. This depends on the volume of coarse material in the dredged material. If so, the beach will remain at the same angle as it is now, as this is due to the nominal direction of the waves. It is also possible part of the coarse sediment will pass the short breakwater. This is unlikely to have a large impact on the rate of erosion, because of the large amount of estimated yearly erosion, see Section 4.6.

The dredging project presents some research opportunities to better understand the system in the future. The level to which the bed will be dredged is known. Thus, by regularly measuring the bed level in the future, the sedimentation rate in the port can be determined. Also, what parts are most prone to sedimentation can be determined. This information could be used to validate a hydrological model of the area. The material that aggregates above the dredged bed level can be of marine or fluvial origin. By taking samples of this material this can be determined as it is not known at the moment where the sediment in the port comes from. In the port, multiple aggregations of cobbles can be found. As described in Section 3.1, these are of marine origin. It is unknown if these were present in the mouth of the river before construction of the breakwaters, or if these have been transported past the southern breakwaters. The old southern breakwater is damaged and might not be impermeable or could be outflanked at very high water levels. There is also accumulation of sediment near the shore side of the southern breakwater, that sediment might be transported over the breakwater during high wave conditions, see Figure 5.4.

The effect of the deposition of a large volume of sediment on the beach could also be monitored. This can be done by taking regular measurements of the cross section of the beach, to determine the effect this nourishment has on the profile. The last measurements date to 2014, according to Hugo Juan Donini (2021), so a single measurement of the beach cross sections would not suffice to determine the effect of the nourishment. Ways to monitor these processes are explained in Appendix O.

6

Stakeholder analysis

In this chapter, the stakeholder analysis is presented, as an answer to the sub-question: ”who are the relevant stakeholders and what are their interests?” First, the results of the questionnaire for the local inhabitants are presented. After that, a short description per stakeholder is provided. Section 6.3 gives an overview of the power and interest of the stakeholders. To conclude the analysis, each stakeholder is summarized by stating their role, interest and attitude.

6.1. Results questionnaire inhabitants

To get insights in the opinions and visions of the inhabitants and touristic companies of Playa Unión, Puerto Rawson, Rawson and the surroundings, an online questionnaire has been made to be able to reach a large group in a short time. In total, 85 people have filled in the form.

First, some general questions were asked. The results are visible in Figure 6.1 and Figure 6.2. Most of the respondents are of the age between 20 and 65 years. 62,4% lives in Playa Unión. The beach area was divided into three parts. Part A, where there is accumulation of settlement. Part B, which is highly subjected to erosion. Part C, where there is partly accumulation of settlement due to the short breakwater. Approximately 70% of the respondents go to the part of the beach that is prone to erosion, however this is also the biggest section, see Figure 6.2.

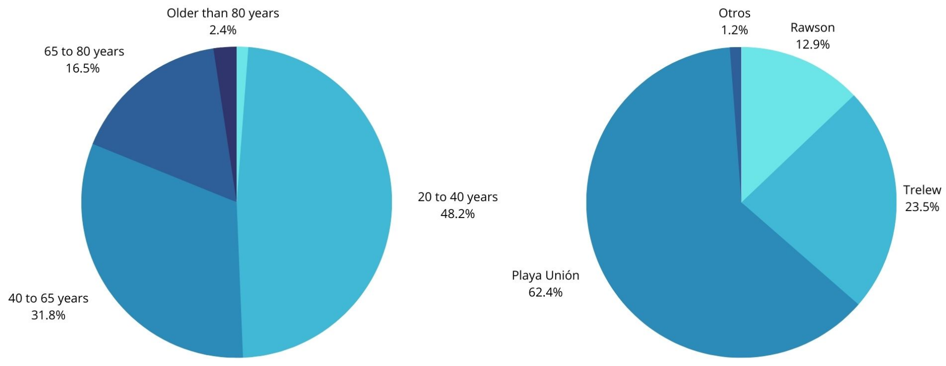


Figure 6.1: Age and residence location of respondents

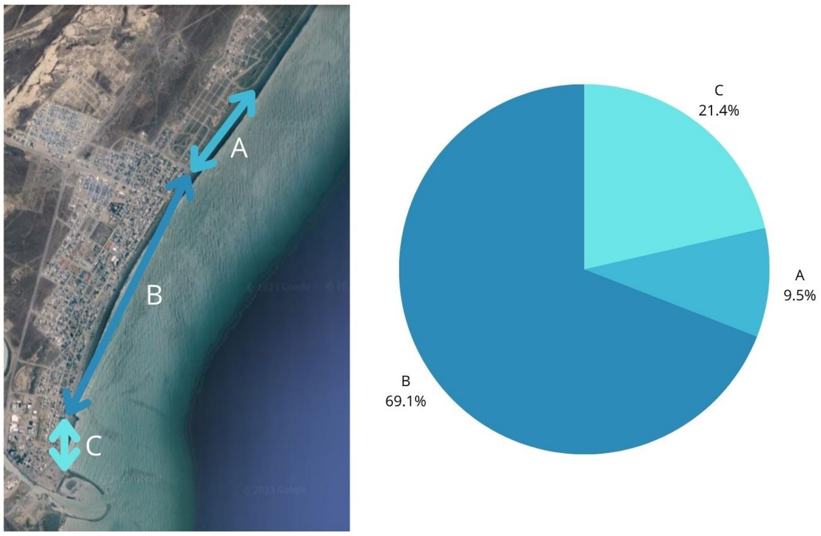


Figure 6.2: Beach division into three zones and beach use of respondents

In an open question, the respondents were asked to what the positive and negative aspects of the beach are. Figures 6.3 and 6.4 show the answers to these question in the form of a word map. Responses that occurred more often, are shown bigger in these figures. Tranquillity, recreation, nature and sports are one of the mostly mentioned positive aspects. Different kinds of pollution and the erosion of the coast are the negative aspects that clearly stand out.

Figure 6.3: What are the positive aspects of the beach that the respondent experiences?

Figure 6.4: What are the negative aspects of the beach that the respondent experiences?

The vast majority, 94% are aware of the coastal erosion happening in Playa Unión and Puerto Rawson. Figure 6.5 shows the distribution of the level of effects the respondents experience. More than 90% of the respondents experience little to a lot of effects from the coastal erosion.

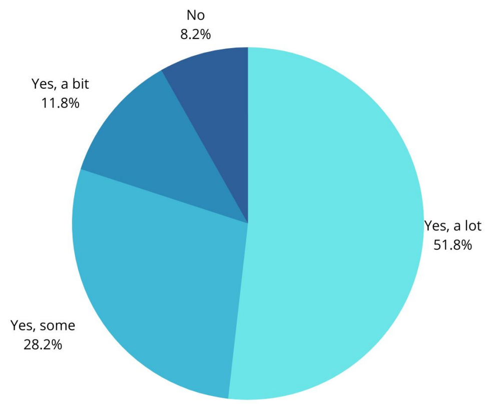


Figure 6.5: How many effects do the respondents experience?

What these effects of coastal erosion are, is asked in an open question. The result is shown in a word map in Figure 6.6. A lot of people mention the fact that there is a smaller coast and more sea. The houses are in danger, the defences and the roads are destructed, and the beach has become less safe.

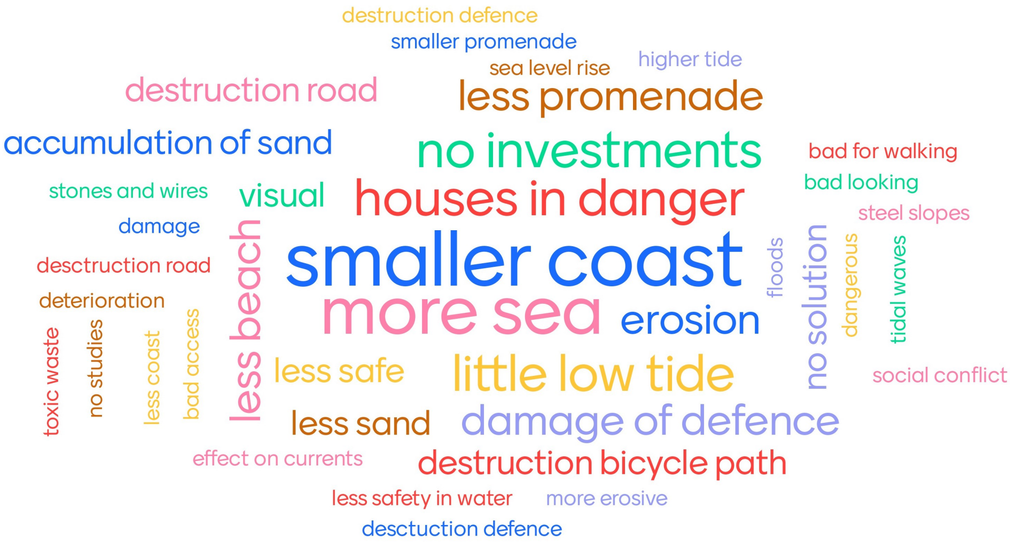


Figure 6.6: What effects of coastal erosion does the respondent experience?

Some questions about the port expansion have been asked. 55% of the respondents did not know about any port expansion. The other respondents mentioned multiple times the dredging, deeper dredging for the access of larger ships and extension of the dock. Someone also mentioned a new port on the private side and two respondents mentioned some pre-feasibility studies, but that there are no concrete plans.

55% of the respondents who knew about any port expansion do not believe that the expansion will be beneficial for Puerto Rawson and Playa Unión. The benefits mentioned were the improvement in port activity and the economy. The disadvantages mentioned are the sacrifice of Playa Unión and the prioritizing of the port over the beach. The main disadvantage mentioned by most of the respondents is the lack of care for the environment and flora and fauna and the increase of pollution caused by the expansion.

As a response to the question Any other questions?, the majority of the respondents raised points similar to the one above; The port activities can favour the economy of the place and thus expansion or improvement can be necessary. However, this is currently not done in an environmentally friendly way. The biggest example is the dredging currently being done (August 2023). People are concerned and angry about it because the dredged material contains waste, and it is directly being dumped on the beach. Pictures taken during the field trip clearly show a difference in water colour due to the dredging, see Figure 6.7.

Another point that is mentioned, is that it seems that there is no work or sufficient investments being done to protect the coast. People think it is because the port has a bigger priority due to its monetary proceeds.

Figure 6.7: Difference watercolour, before and during dredging (taken on 19/09/2023, Playa Unión)

6.2. Description of stakeholders

Figure 6.8 shows all the stakeholders that are relevant for this project. Every stakeholder is introduced, and their interests are summarized after the figure. The complete interview, on which this summary is based, can be found in Appendix F.

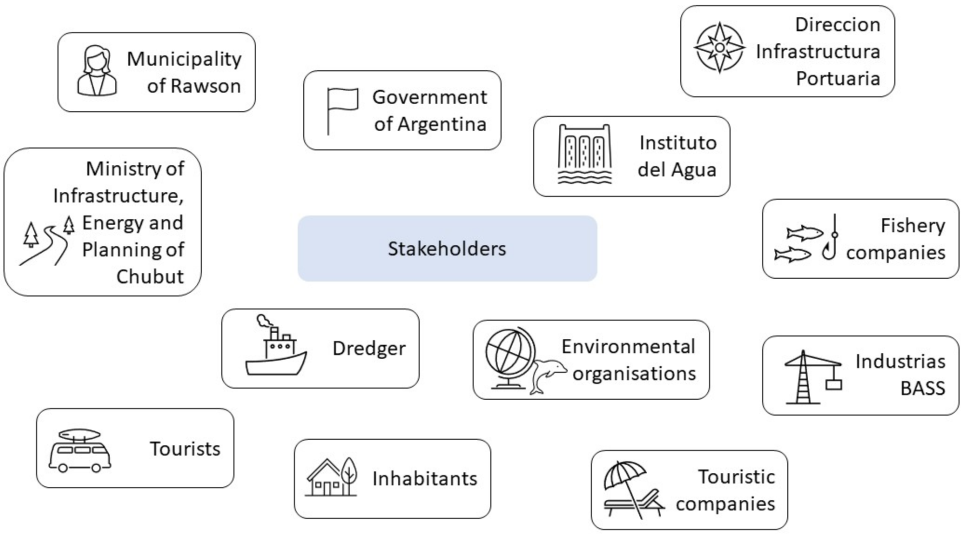


Figure 6.8: Relevant stakeholders

Industrias BASS is an industrial and construction company based in Trelew. They constructed the new public quay walls and, from 2018, started working on a plan to expand the port on the southern shore of the Chubut River. It includes three new planned docks for fishing vessels and a multipurpose dock that will allow large container vessels to dock in the port. They see a lot of opportunity in the fishing industry and their goal is to design, construct and then sell the docks they build. Industrias BASS is not limited by time, finance and effort. Thus, their interest in port expansion is big. History shows that their power is quite large, but not endless, since they do need approval for their plans. Their interest in a solution for coastal erosion is less than their interest in the port expansion. It is mainly relevant if it could be combined with their expansion plans.

The **Ministry of Infrastructure, Energy and Planning of Chubut** (MIEP) is one of the ministries of the province of Chubut and is concerned with the execution of projects related to public infrastructure and services within the province of Chubut. The ministry consists of several departments, including a department which concerns the exploitation of Puerto Rawson and Puerto Camarones. The public part of the port of Rawson is owned by the province, thus they have a lot of influence. Their interest in port expansion is also high, because it can lead to economic benefits. As the coastal erosion is an urgent challenge, the province is eager to solve it, but there is a lack of funds. The province is able to fund medium-sized projects, but for bigger projects funds from the national government are needed.

The **Municipality of Rawson** is the governing body of Rawson, Puerto Rawson and Playa Unión. The erosion in Puerto Rawson and Playa Unión is an urgent problem for the municipality, because it causes damage and dangerous situations. Although the interest is very high, the power is quite low. The municipality is dependent on the province and the national government for funding. Currently, a lobby is under way to declare the coastal erosion an emergency, in this way they hope to get the funding and attention to undertake required measurements. They also have an interest in the port expansion, since it provides work and income.

The **Government of Argentina** is the highest governmental body of the country. They usually only intervene if a province does not act according to the law. But approval for projects like flood defences and port expansions go through the national government and not through the province. Each province has a senator representing them in the national government. The power they have in case of the coastal erosion is quite high as they have the funds. The interest is not really high, because Puerto Rawson and Playa Unión are small villages with no substantial importance next to the port. The interest in port expansion is bigger, since it brings economic benefits for the state.

The **Water Institute** was created in 2010 to regulate all bodies of freshwater in the province of Chubut. This includes the coast, all lakes, the rivers, canals but excludes glaciers. The coastal erosion is part of their pursuits, thus their interest is high. They have regulations which companies have to comply with if they want to do something with water. Regarding the port, there is hardly any regulation. Furthermore, the Water Institute is regurlarly passed over, since the governor of the province has full authority and the Water Institute does not. Thus their power is quite low.

The **Direction of Port Infrastructure**, DPI, is responsible for the surveying of projects and supervision of the works of the ports in Chubut. Furthermore, they also do the the maintenance for the Port of Rawson, because it is a smaller port. The port infrastructure department works for the state and the public sector. Their power is not very large: plans regarding port expansion need to be presented to them, but it only needs approval at a national level. Their power and interest regarding the coastal erosion is not substantial, it is not part of their work and they do not have much say in it. They are not positive about the port expansion, because they think that more boats navigating in the port lead to more channel collapsing. They do think that the extension of the public docks is a good idea.

There are several **fishery companies** that are active in the port of Rawson. They pay some fees in order to be able to dock. The current breakwater infrastructure is there in order for their boats to safely arrive, so keeping the port accessible is their main interest. However, they do not have much power regarding this. Furthermore, their interest and power regarding any shoreline protection is very minimal.

In the area, there are some **touristic companies** like surfing schools and boat tour organizations. They use a little part of the harbour and the beach for their activities and are thus influenced by the state of the beach and shoreline. Other people involved are restaurant and café owners (Brágoli & Donini, n.d.). Their interest in port expansion is not high, they have a bigger interest in coastal erosion and the effect of it on the attraction of tourist. Their power regarding both is not big.

The **inhabitants** of Puerto Rawson and Playa Unión have very high stakes when it comes to finding a solution to the coastal erosion challenges. Besides recreational use of the beach, it should also form a protection against the sea and avoid flooding. From the questionnaire that was elaborated on in Section 6.1, it becomes clear that there is a high but negative interest in the port expansion. The power of the inhabitants is small, and they feel frustrated about that. However, it is not negligible, as could be seen in their protest against dredging.

The area is visited by many **tourists** that mainly like to visit the beach and engage in water sports or animal-watching activities. Especially during summer, where the high temperatures are calmed by the constant and gentle breeze that occurs in this region (Brágoli & Donini, n.d.). So, in a way, they have an interest in the preservation of the beach. Their interest in port expansion is non-existent. Regarding both, they do not have any power.

In Argentina there are several **environmental organisations**. The biggest organisation is the Fundación Vida Silvestre Argentina, the representation of the World Wildlife Fund in Argentina. A more local organisation is the Estación de Fotobiología Playa Unión, EFPU. The EFPU is an investigation centre with the aim to study the effect of global change, such as solar radiation on different species, primarily aquatics. The area around Puerto Rawson and Playa Unión is not a natural protected area in Argentina (AMP Argentina, 2022). But sea lions live inside the port and Commerson's dolphins do live in front of the coast. Regarding the port expansion, the sea lions most likely need to find another home. The dolphins sometimes get caught in the fishnets of the vessels, thus an expansion of the port will most likely result in a bigger bycatch of dolphins. These organisations have less interest regarding coastal erosion and a bit more regarding port expansion. However, their power is very limited.

Servimagnus S.A. is a dredging and salvage company based in Buenos Aires. They share a mother company with Sudelco who won the tender for the dredging works in Puerto Rawson. Sudelco does not own a dredge barge and Servimagnus is not based in Chubut, so they work together to complete this project. Since, it is a requirement from the province that the company must be based in the province where the project is executed. They have a high interest but not much power regarding the port expansion. There is no interest in, nor power over coastal erosion solutions. RYTEC is a Consultant Agency that was hired by SUDELCO and was assigned to elaborate an "Environmental Management Plan" needed in order for the authorities to approve the dredging. Besides their involvement with the dredging, they do not have interest nor power related to any additional shoreline protection that is researched in this project.

6.3. Power interest grid

In Figures 6.9 and 6.10, every stakeholder is placed based on their power, y-axis, and interest, x-axis, for both port expansion plans as coastal erosion interventions.

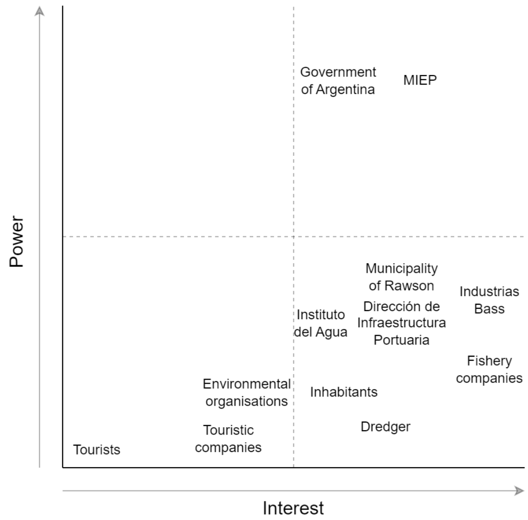


Figure 6.9: Power interest grid port expansion

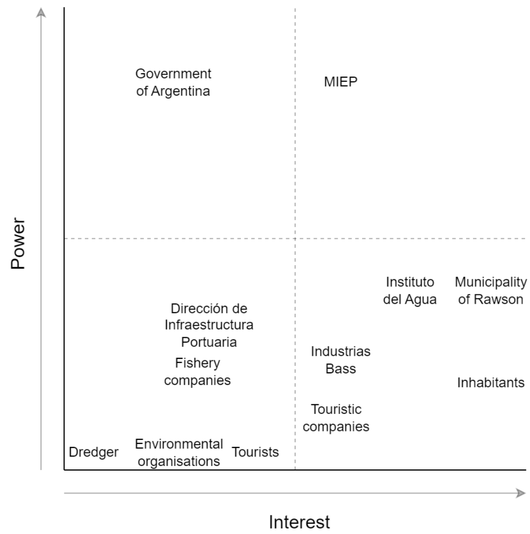


Figure 6.10: Power interest grid coastal erosion interventions

6.4. Conclusion

To conclude the stakeholder analysis, each stakeholder is once again summarized by stating their role, interest, influence and attitude towards port expansion and coastal erosion. The information gathered with this stakeholder analysis is used in the rest of the report to define design boundaries and criteria for the multi-criteria analysis. It will also be used for consulting a strategy for cooperation between the different stakeholders.

Table 6.1: Conclusion stakeholder analysis

Stakeholder	Role	Interest	Influence	Attitude port expansion	Attitude coastal erosion
Industrias BASS	Constructor and investor of the port expansion	Combining port expansion with interventions against erosion	Low to medium influence	Highly positive	Neutral positive
MIEP	Decision making power and financer	Financial interest in the port	High influence	Highly positive	Neutral positive
Municipality of Rawson	Planning of the terrestrial territory and raising awareness	Creating a safe and pleasant living area for the inhabitants	Medium influence	Highly positive	Highly positive
Government of Argentina	Controlling power and financer	Financial interest in the port	Medium to high influence	Positive	Neutral
Water Institute	Making regulations regarding water	Solving the coastal erosion problem	Low to medium influence	Neutral	Highly positive
Direction of Port Infrastructure	Surveying of projects and supervision of the ports in Chubut	Keeping the port accesible and workable	Low to medium influence	Negative on private side, positive on public side	Neutral
Fishery companies	Fishing in the Argentinan sea	Increasing fish catch	Low influence	Positive	Neutral
Touristic companies	Providing touristic activities	Increasing number of tourists	Low influence	Neutral positive	Neutral
Inhabitants	Living in the area	Living in a safe and pleasant area	Low influence	Neutral negative	Highly positive
Tourists	Creating economic activity in the area	Enjoying the coast of Playa Unión and Puerto Rawson	Very low influence	Neutral	Neutral
Environmental organisations	Preserving the environment	Ensuring sustainability and biodiversity in the area	Low influence	Negative	Neutral
Dredger	Dredging of the port	Financial interest in dredging	Very low influence	Neutral	Neutral

7 Boundary conditions

In this chapter, the boundary conditions for the possible interventions are elaborated. The boundary conditions are partly determined with the input of the stakeholders and partly by the authors of this report.

1. **The location of the intervention must be within the boundaries of the project area**
   The project area is defined in Figure 1.2. This comes forth from the scope of the project and to limit the location of possible interventions.
2. **The maintenance required must not be done more frequent than one third of the design lifetime**
   This boundary condition is implemented to discard interventions that require regular maintenance. These are usually short term solutions. Interventions that need constant monitoring, for example dredging, do not fall under this requirement. This boundary condition comes forth from the DPI, they require a sustainable intervention that does not need constant maintenance.
3. **The main intervention against erosion must be effective for the long term**
   Long term is defined as at least 30 years. Since, the design lifetime for a breakwater is usually between 30–50 years. An effective erosion interventions results in the growth of the width of the coastline. This boundary condition was selected to ensure that the possible interventions fulfil their purpose of protecting the coast.
4. **The material must be local materials**
   Local materials implies materials coming from the province of Chubut. This boundary condition comes forth from the nature-based framework. Using local materials creates a more sustainable intervention.
5. **The construction must be executable by provincial companies**
   This is a law from the provincial government for any construction plans in the region. Local companies are permitted to work with other companies not from the region.
6. **The intervention may not physically hinder maritime accessibility operations during the fishing season**
   During the fishing season, the port is very hectic. A lot of fishing vessels enter and leave the waterway at high tide. This is within a time frame of four hours. This boundary condition comes from the demands of the Direction of Port Infrastructure and fishery companies.
7. **The intervention must result in a safe use of the beach by people**
   Safety means no harm of any kind caused by interventions by normal usage of the beach area and its residents within the boundaries of the project area. This boundary comes from the desires of the inhabitants for their vision of the beach.

8
Possible interventions

The sub-question that will be answered in this chapter is: ”what are possible, preferably nature-based interventions, to avoid negative consequences of port expansion?” Per intervention the global idea is given, location, the basic dimensions and the effectiveness and possible consequences are discussed. The feasible interventions that are considered within the scope of this report are: groynes, dredging and moving sediment, opening northern breakwater, port expansion and sediment bypass in the south, creating a sediment trap, temporary longitudinal flood barrier, plant vegetation with beach nourishment and beach nourishment and gravel engine. An overview of the conceptual interventions can be found in Figure 8.1.

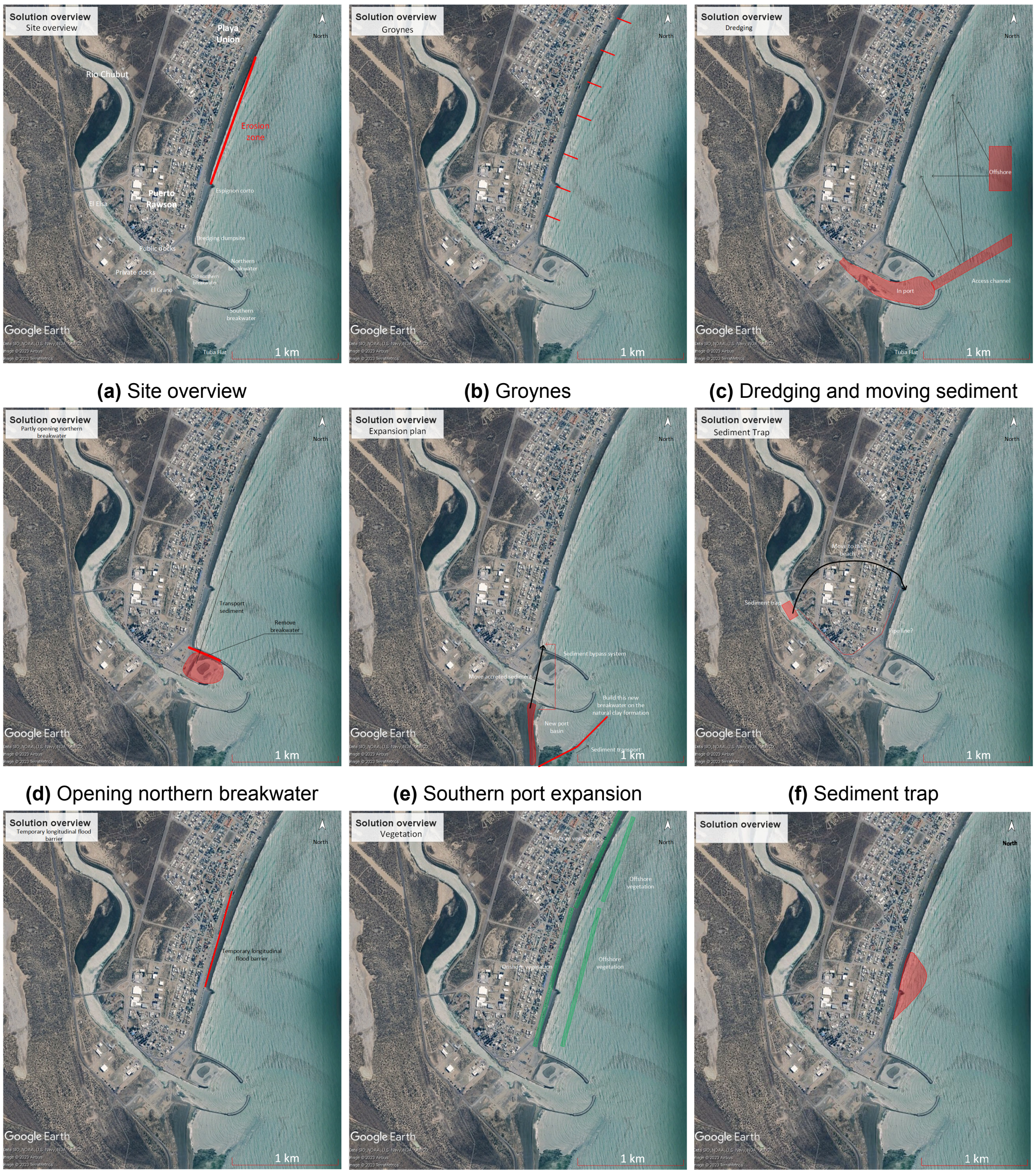
8.1. Groynes

There are two types of groynes, namely the impermeable high-crested and the permeable low-crested structure. The impermeable high-crested groyne keeps the sediment within the compartment. Therefore, an impermeable high-crested structure will translate the erosion problem to behind the structure. In contrast with that, the permeable pile and low-crested groyne only reduce the longshore transport (Bosboom & Stive, 2023).

Therefore, design for a permeable pile groyne and a permeable low-crested groyne is made, that still make part of the longshore sediment transport possible. Another advantage is that groynes do not negatively influence the up drift coast of the groyne field.

From experience in practice, groynes must be constructed beyond the breaker line of a summer wave climate at mean high tide level according to Perdok et al. (2004) and Crossman et al. (2003). Since, the beaches are being built up during summer. The breaker line corresponds to the beginning of the surf zone. Waves break when their height is equal to 0,75 to 0,88 of the water depth. The groyne should end far enough up the beach to avoid outflanking of the beach by large waves. What would cause erosion at the land end of the groyne Furthermore, the length of the groyne depends on the beach material and corresponding slope steepness. At Playa Unión, the upper part of the beach is steep with shingles and the lower part of the beach has a gentle slope with sand. For this type of beach alternating long and short groynes could be useful (Perdok et al., 2004).

The groyne is designed for normal condition swell waves with a wave height of 1 metre (Hugo Juan Donini, 2021) and a period of ten seconds (Universidad Nacional de Córdoba, 2022). This is expected to be the main sediment-transporting wave. To prevent outflanking, the groyne should have a certain length on the beach. To determine this, the 2% run-up for a wave with a 10-year return period is used. Outflanking during one storm does not result in



(a) Site overview **(b)** Groynes **(c)** Dredging and moving sediment

(d) Opening northern breakwater **(e)** Southern port expansion **(f)** Sediment trap

(g) Temporary flood defence **(h)** Vegetation **(i)** Gravel engine

Figure 8.1: The eight proposed intervention types that will be elaborated in this report

failure of the structure, so this return period is deemed enough to ensure the functionality of the groyne. To calculate the 2% wave run-up the formula of Stockdon et al. (2006) is used. In this formula, the offshore wave parameters and the upper slope of the beach are implemented.

The slopes of Table 4.3 are simplified and rounded in an average for the S- and M-cross section, see Table 8.1.

Table 8.1: Average cross section slopes for design

	Upper	Lower
S-section	1/15	1/250
M-section	1/22	1/274

The coastline subjected to erosion is 3,3 kilometres long, the M-cross sections cover 1,3 kilometres and the S-cross sections cover 2 kilometres. After those 3,3 kilometres, there is a natural accumulation of sediments. The rule of thumb for the spacing between groynes is the ratio between the groyne length and spacing, which is equal to 1:1,5-1:3 (Bosboom & Stive, 2023).

If the groyne is designed for the wave climate as mentioned before and with all the simplifications, the total length is relatively short, 60 metres in the M-slopes and 47 metres in the S-slopes. The groyne is only active on the upper profile and will probably not interrupt the transport of finer material on the lower shoreface. This length does correspond to the average groyne length for this type of beach, according to Simm et al. (2020). Groynes of this length will result in at least 21 groynes along the coast. This is probably expensive and separates the coastline into many small pockets. The types of groynes are chosen to limit this hindrance to the visitors of the beach. See Table 8.2 for all the results and Appendix I for a more detailed calculation.

Table 8.2: Groyne results

	S-section	M-section	Total
Groyne length	47	60	
Spacing (1,5)	70,5	90	
Number of groynes	28	14	42
Spacing (3)	141	180	
Number of groynes	14	7	21

Furthermore, the high tidal difference and wave activity at Playa Unión also account for difficulties in designing of the groyne. For locations with significant wave activity, the performance for groynes is less predictable. Because of the large tidal difference, a groyne that also has an effect on the lower beach face must be quite long in order to stretch through the surf zone at low tide. This would give a length of over 350 metres, as calculated in appendix I. In the literature, there is little information about the effectiveness and design of long groynes on this type of coastline. It is also possible to use alternating long and short groynes. These could reduce the number of groynes needed and improve the effectiveness because the transport of fine sediment is also interrupted.

It is possible that the short breakwater that cause stabilisation of the upper shoreface will also stop the erosion on the lower shoreface. It is derived from Section 4.6 that the main cause of erosion is the lack of supply of coarse sediments. This causes retreat of the upper shoreline.

Because the wave climate remains the same, the slope and depth limit for the lower shoreface remains as before. In order to archive this, the fine sediment on the lower shoreface will also erode, to return to the existing profile in the new location. So, by limiting erosion on the upper shoreface, the groynes will also prevent erosion on the lower shoreface. This is dependent on the supply of fine sediments, and should be proven by data and modelling.

Groynes could also be designed in combination with sediment supplementation. Groynes will only limit the transport out of the field, so it is not likely to reverse the erosive process along the whole coast by itself. Therefore, groynes are regularly combined with nourishment of the coast. It could be valuable to combine groyne construction with deposition of dredged sediments from the port. This supplementation of the coast by sediment from the port is described in Section 8.2.

The effectiveness of the groynes and the lifespan for which they are effective can be determined by the reduction in transport rate. In order to do this, numerical simulation should be used and more data on the current transport rates should be gathered.

8.1.1. Permeable pile groynes (PPG)

The pile groynes are chosen as a possible intervention because it is a relative affordable option. PPG's have been proven to be an effective measure for building up beaches. "Compared to a natural coast without groynes, the evolution of beach profiles in response to PPGs is that the beach elevation was built up, and the beach slope became much gentler from the shoreline to the trough" (Zhang et al., 2023). However, after construction the effect must be well monitored, since the behaviour of groynes is hard to understand and predict. Furthermore, the piles are vulnerable to vandalism and must be safe for users of the beach. In addition, due to dry rot, maintenance is required on a regular basis. PPG has the advantage of resulting in a continuous beach due to less down-drift erosion.
An example of a permeable pile groyne system can be seen in Figure 8.2.

Figure 8.2: Example of permeable pile groynes (Bosboom & Stive, 2023)

8.1.2. Low crested groynes

Besides the PPG's, another option would be to use low cost rock groynes. Like the 'reef' type breakwaters developed in the USA. These structures have a low crest, no core and large porosity, which increases armour stability. The structures are expected to deform under wave loading, but continue to perform. In reference projects, alternating long and short groynes have been used to minimise the cost. The crest of the groynes has to be set to a minimum of 1 metre above the design beach profile to operate as a considerable barrier to long-shore transport during storm conditions. Transportation is still possible over this crest level. The groyne's berm should be situated at the same level as the beach's natural berm (Crossman et al., 2003).

To calculate the median block diameter of the groyne blocks, the design formulas rubble mound breakwaters are used. The damage level is set to eight, S=8. This is for a groyne design in service limit state (SLS). Furthermore, the Van der Meer formula is used with waves with a return period of 50 years. This is chosen since it is designed for the SLS with low consequences. Because of the very steep beach, surging waves are assumed. Resulting in a D_{n50} of 0,714 metres for both cross section. According to CIRIA and CUR and CETMEF (2007) $D_{n50} = 0,84D_{50}$. So this gives a median block diameter of 85 centimetres, with a density for reinforced concrete of 2400 kg/m^3. A detailed calculation can be found in Appendix I.1.1.

This is a preliminary design of a low crested groyne. The necessity of a filter layer or for example the exact shape of the block should be determined in the next design phases, as well as the optimisation of the angle of the seaward slope of a groyne.

8.2. Dredging considering the port expansion

The idea of this intervention consist of using the planned port expansion and the dredging works that accompany it as a way to re-nourish the coast. The planned port expansion at the private side of the harbour by Industrias BASS requires a lot of dredging work. Besides, there are plans to expand the port southwards as stated in Section 5.1. This dredged sediment could be used to re-nourish the shore north of the short breakwater.

Industrias BASS plans to move 700.000 m^3 of sediment for their expansion plans. It is however unclear what kind of sediment this is. If the sediment is too fine, it will quickly erode again or it does not even settle at the designated locations. A thorough investigation of the material that will be dredged must be done to map the useful amount and size. During a site analysis, it was concluded that south of the southern breakwater there is a tuba flat. This is not very viable material due to it being very fine material once dredged. Between the two northern breakwaters there is fine sand and some gravel, this could be more suitable. Inside the port there is a land tongue called 'El Grano' which consists mostly of gravel and sand. This would be more viable. However it is uncertain what kind of material there is at a deeper depth at all these locations. It would be important to know this to figure out how much available material there is.

The dumping location of the sediment is also an important aspect in this intervention. At the moment all dredged material gets dumped just north of the northern breakwater. This causes all coarse material to get stuck behind the short breakwater. It is uncertain what happens with the small sediment. It might drift of to sea and settle in front of the opening of the port which would have a negative effect.

Considering this it is important that the correct location gets chosen for depositing the sediment. It is important that the sediment gets distributed equally over the erosion zone. This way the effect will be more immediate instead of having to wait for the waves to distribute it to the correct location. It would also be more effective if the sediment gets held into place. That is why this intervention would be more effective in combination with the groyne intervention.

8.3. Opening northern breakwater

Another intervention is opening up a part of the northern breakwater. The aim of this intervention is to restore the sediment transport too a state before the northern breakwater was constructed, without the need to completely disassemble the breakwater. In this intervention it is assumed that the sediment that is located between the two northern breakwater originates from the river. This assumption is based on a granulometry test conducted as part of this report in Appendix B.

As can be seen in Figure 8.1d sediment is accumulated between the two northern breakwaters. The idea of the first two variants is that a passage is created to let the sediment flow from the river towards the beach of Playa Unión via the passage. The incoming waves from the sea into the harbour, are the driving force that pushes the sediment through the passage created by the opening of the breakwater. These waves do not have a lot of energy so this intervention might require the partial dredging of the sediment between the two northern breakwaters, the waves then make sure that all new sediment from the river will quickly get pushed towards the shore. Another driving force of this idea will be gravity. Especially in the first stage after constructing the passage, since the height difference between the accumulated sediment and the beach directly after the passage will be maximal. The third variant will make use of sediment pumps to transport the sediment.

The amount of sediment between the two northern breakwaters can be estimated at around 220.000 m^3 when lowering the bed by 4 metres. The estimation is made by studying the area with Google Earth (2023). By measuring the area of the accumulated sediment and making an assumption about the depth that is needed, the amount of accumulated sediment is calculated. Savioli et al. (2011) predict that annually 24.000 m^3 of sediment erodes away from Playa Unión. The amount of sediment between the breakwaters could balance out the sediment budget for approximately nine years. this eroding sediment volume is thought to be mostly coarse sediments, while between the breakwaters more fine sediment accumulates, see appendix B.

There are different ways this passage could be created. The different ideas are listed below.

8.3.1. Opening the northern breakwater with curve

This idea consists of creating a large opening at the coast side of the breakwater. The breakwater will be disassembled between the highest and lowest point that the waves reach during a tidal cycle. This ensures that the waves can push sediment through the opening at all times. The pathway on the breakwater can be replaced by an elevated pathway so that it is still possible to walk to the head of the breakwater. This variant of the intervention preserves the most crucial part of the breakwater that protects the harbour from waves but takes away the part that causes the sediment to be trapped. The breakwater could also be redesigned that it does not extend all the way to the beach but curves towards the north so that it still protects the old breakwater from incoming waves from the north. In Figure 8.3 a possible configuration of this variant is given.

Figure 8.3: New design of opening up the northern breakwater

8.3.2. Tunnel

Instead of taking away a large part of the breakwater, this variant of the intervention aims to create smaller passages. By creating multiple tunnels underneath the breakwater, the sediment can be transported towards the beach. This will keep the entire breakwater intact since the tunnels will be at the height of the seabed up until the waterline. The tunnels will be placed higher than the sea level during low tide so that they can be maintained when they become blocked. In Figure 8.4 a possible configuration of the variant with tunnels is given.

Figure 8.4: Schematizing of the tunnels underneath the breakwater

8.3.3. Sediment bypass

Since the northern breakwater withholds a lot of sediment the northern breakwater functions like a sediment trap. This feature can be used to create a sediment bypass. A possible configuration could be installing pumps at the south of the northern breakwater. This pumps could continuously pump sediment that is coming from the river past the northern breakwater to the beach of Playa Unión. Different configurations can be made of this idea, for example, at which time sediment will be pumped past the breakwater. In Figure 8.5 a possible configuration of the sediment bypass using pumps is given. Normally sediment bypasses are located away from populated areas for safety reasons and noise hindrance. Here this would be more difficult due to the location of the intervention. Safety measures should be taken like a filter for the bypass and a designated area should be set-up where the sediment will be dredged.

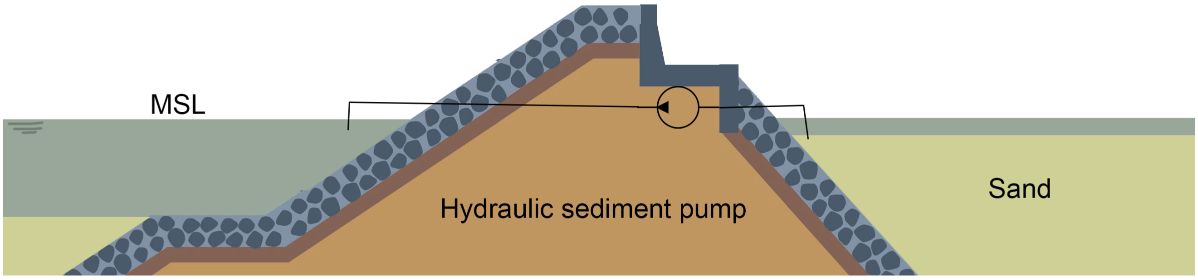


Figure 8.5: Schematizing of the sediment bypass using pumps on the northern breakwater, adapted from Van der Meer et al. (2018)

There is a high level of uncertainty for this intervention. It is not possible to run models or simulations due to the limited data available and the short run time of this project. That is why it is not possible to say with certainty that waves would indeed push sediment northward through the opening. Another difficult aspect is the lack of reference projects. This is very location specific intervention. Besides that there are not a lot of examples of existing ports where they deconstructed the breakwaters to make sediment transportation possible. This intervention needs research into the wave energy of the waves that enter the harbour and propagate to the accumulated sediment to calculate the driving force and make predictions on the effectiveness of the different configuration of this intervention, as well as a research into the stability of the breakwater when it will be partly removed or relocated.

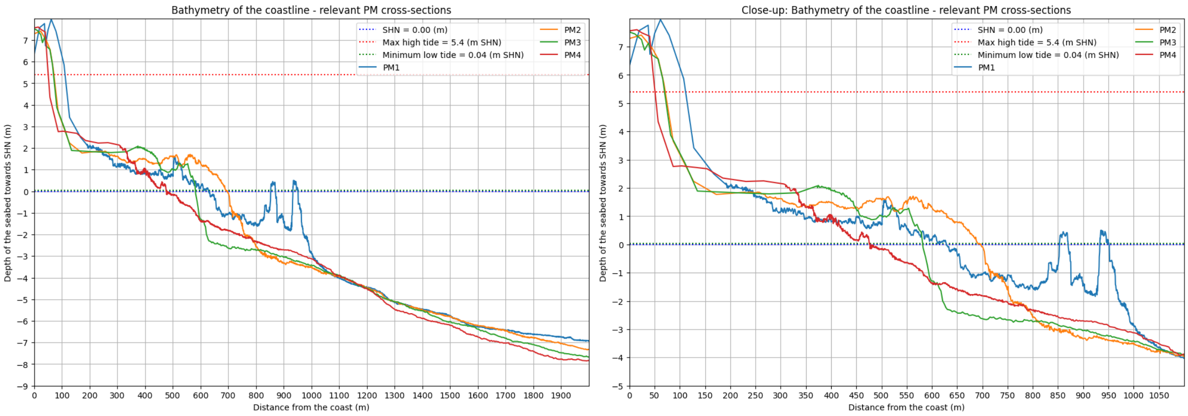
8.4. Port expansion and sediment bypass in the south

This is an idea mentioned by Industrias BASS. There are no studies done about the coastal environment south of the southern breakwater. The placing of the harbour and the origin of the very conceptual plan can be seen in Figure 8.6. The main focus of this intervention is on the concept design of the breakwater of the new port and an on investigating sediment bypasses to counter the erosion challenges of Puerto Rawson and Playa Unión.

Figure 8.6: Area of interest southern port expansion

8.4.1. Bathymetry analysis

Based on the data provided by Savioli et al. (2011) about the cross section of the coastline, a bathymetry analysis was carried out. The same analysis was done in subsection 4.3 but with the data for the relevant cross section of the coast south of the southern breakwater. Four cross sections are used: PM1, PM2, PM3 and PM4, with PM1 closest to the southern breakwater and with a spacing of 250 metres between each cross section. The data is from 2011, so it is outdated. However, the data is used as a starting point for calculation and making predictions since there is no newer data available. The results can be seen in Figure 8.7.



(a) Relevant cross sections of the coastline south of the southern breakwater

(b) Close-up of the relevant cross sections of the coastline south of the southern breakwater

Figure 8.7: Analysis of the bathymetry data south of the southern breakwater

There is a relatively flat foreshore for the first 600-700 metres. From a site analysis, it is obtained that this flat plane consists of tuff stone.

8.4.2. Types of ships to be accommodated in the new port

It is researched what kind of ships the designed port should be able to accommodate. This is done by looking into different fleets of shipping companies operating in the Argentine sea and by searching on different AIS (Automatic identification system) for ships tracking websites. It can be concluded that there currently operate an insignificant amount of ships of the feeder type with a length from 135-140 metres in the Argentine sea. Bigger ships are operating on the Argentine sea. However, it is unrealistic to make it possible to accommodate feeder type ships with a length up to 200 metres, because of the dimensions. A more realistic approach for port expansion would be to design for the red fleet as the biggest ship in the port. These type of ships have a length of 30 metres, a beam of $7,4$ metres and a draft of $3,5$ metres according to del Vecchio (2018). A more extensive argumentation for the type of ship chosen for this intervention can be found in Appendix J.1.

In Figure 8.7a it can be seen that between that the tuff stone flat lies on approximately $1,5$ to $2,0$ metres SHN. To accommodate the ships of the red fleet around $5,5$ to $6,0$ metres of tuff stone needs to be removed. In this case an area of 100.000 m^2, approximately the marked area in Figure 8.6, would result in a removal of 550.000 - 600.000 m^3 of tuff stone.

8.4.3. Conceptual design of breakwater

A breakwater needs to be constructed to guarantee the safety inside the new port. It is most efficient to make use of a multipurpose breakwater. With multipurpose it is meant that the breakwater guarantees the safety of the port, and it will also be functioning as a pier where simple operations can take place, for example loading and unloading of a truck parked next to the boats. For this conceptual design a conventional rubble mound breakwater with a crown wall is chosen. Similar as option 2 in Figure J.1. The crown wall will be extended with the construction of a quay to the necessary length to accommodate the port operations. The extension could be founded on piles, just like the other quays that are constructed by Industrias BASS in the private part of the port. A major advantage is that Industrias BASS is known for constructing these types of piers and this type of breakwater is similar to the northern and southern breakwater.

First, the return period is determined for the design of the conceptual breakwater. A return period of 50 years is chosen. This is based on the stated boundary conditions. For a detailed design of the breakwater, the return period and corresponding failure probability can be determined with the guidelines stated in the book "Criteria for the Selection of Breakwater Types and their Related Optimum Safety Levels" by PIANC (2016).

Next, the design water level (DWL) is determined. The design water level is equal to the maximum high tide (MHT) plus the sea level rise (SLR) plus the expected settlement of the structure plus the wind setup. The maximum high tide of $5,4$ metres SHN and the expected sea level rise of $0,2$ metres, are determined in chapter 3. Since the subsoil of the breakwater will be tuff stone, it is unlikely that settlement will occur. To have a margin. the settlement is assumed to be $0,1$ metres. Since the dominant wind direction is from East to West, it is unlikely that wind setup will occur, so the wind setup is assumed to be zero. Together this leads to a design water level of:

$$DWL = 5,4 + 0,2 + 0,1 + 0 = 5,7\ m\ SHN \tag{8.1}$$

The significant wave height at the toe of the structure is determined by propagating the significant wave height from Table 4.1 according to Goda's wave propagation formula. Goda's wave propagation formulas that are used together with the calculations made can be found in Appendix J.2.1. The corresponding peak period from Table 4.1 and a average slope of 1:70 determined from Figure 8.7 are used in these calculations. The calculated significant wave height at the toe of the structure is $4,96$ metres.

Subsequently, the free-board height of the breakwater was calculated. For this calculation, the overtopping formulas of Van der Meer et al. (2018) from the EurOtop manual were used. Since the breakwater will also be part of the pier where the ships will dock, it is assumed that there will be equipment installed on the breakwater. Therefore, the mean overtopping discharge should be less than 1 litre per second per metre, so: $q \leq 1m/s/l$ (Van der Meer et al., 2018). The breakwater is calculated as being a rubble mound breakwater with a simple armoured slope. It is assumed that the breakwater will have a slope of 1:1,5. The free-board height of the breakwater is calculated with the design approach equation 6.6 from the EurOtop manual by Van der Meer et al. (2018). The equation together with the calculations made can be found in Appendix J.2.2. Tetrapods are used as armour layer, since they have similar properties as the Akmons used in the northern- and southern breakwater. The corresponding roughness factor is $0,38$ according to Table 6.2 from the EurOtop overtopping manual by Van der Meer et al. (2018). The waves are assumed to be oblique, so $\gamma_\beta = 1$, since this is the worst-case scenario. The calculated free-board of the breakwater is $7,03$ metres.

A possible design of the breakwater for this possible intervention can be found in Figure 8.8. The crown wall functions as the end of the armour layer of the breakwater and allows access to the breakwater. In this case, the crown wall also functions as the starting point of the pier.

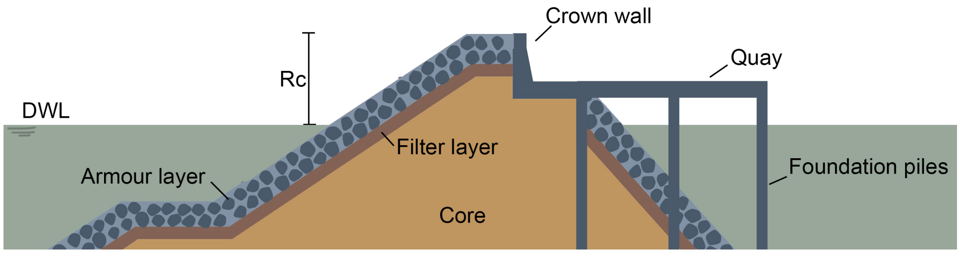


Figure 8.8: Cross section of the design of the new breakwater, adapted from Van der Meer et al. (2018)

There are a lot of variables that can be optimized in the design of the breakwater. It is advised that an optimization will be done after more data is known.

An interesting nature-based solution for the construction of the breakwater could be the Sandbar breakwater at Lekki in Nigeria (Spek et al., 2020). More information about this breakwater can be found in appendix J.3.

8.4.4. Sediment bypass

An option to mitigate the effects of coastal erosion would be to artificially restore the sediment transport from south to north along the coast, that has been interrupted by the breakwaters. The artificial sand bypass could be either done over land, the land-route, or via the sea, the sea-route, as can be seen in Figure 8.9. For the sea-route, a hopper dredger could be used. However, it could be hard to operate in a small zone close to the waterline, where the dredging should take place (van de Graaff, 2022). Another option would be using a submerged pipeline to transfer material across the navigation channel (Loza, 2021). This permanent intervention, would be a preferred option for Industrias BASS, is concluded from the interviews that can be found in Appendix F. For the land-route, the system would depend on the volume to be by-passed. If it is a small amount, a simple system using trucks could be used. What is seen more often is a permanent pipeline that transports the sediment (van de Graaff, 2022).

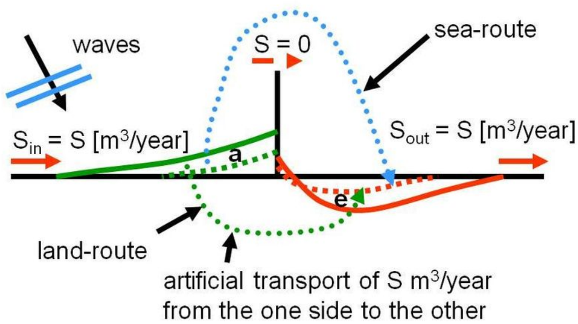


Figure 8.9: Principle sand by-pass system (van de Graaff, 2022)

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To gain a better understanding on how a sediment bypass works, research is done into reference projects. The Sand bypass system on the Gold Coast of Australia is looked into. More information on this project can be found in Appendix J.
In order to design a sand bypass system, input information is necessary. The amount of sediment transport that is occurring should be known, as well as the flow of this sediment. However,

for this area, there is no data regarding the amount of sediment that flows here. This design is thus based on the big assumption that this flow is substantial, and the flow directs in northern direction.

The bypasses can be classified by different types, according to Loza (2021):

- **Purpose:** It is a man-induced transfer of sand from a certain area to a downdrift beach.
- **Mobility and Flexibility:** Three systems can be distinguished, although a combination is possible. It could be a land-based mobile system, a fixed system or a water-based mobile system. A mobile system can be physically moved and is considered water-based if it is a floating dredger. The location of a fixed system is set. To be able to work, the littoral transport should be predicted to a high degree.
- **Operating Mode:** It is either an interception-mode system or a storage-mode system. If there is a high certainty in the transport of sediment, the interception-mode system is a good option. The littoral drift will move the sediment into the bypass. With a storage-mode bypassing system, some storage capacity is added to the system. In this sediment trap, the sediment can accumulate.
- **Operating Schedules:** The system could be operated periodically or continuously. A continuous system is a good option when the littoral rate is close to constant or combined with a storage-mode system. Periodic systems operate when bypassing is necessary.
- **Capacity:** The capacity of the bypass system depends on the amount of sediment that goes into the system. It should be kept in mind that due to compaction, the volume of dredged sediment is different from the discharged volume.

There is different equipment for each step of the process: dredging, transporting and discharging. In this intervention, the focus lies on a fixed system. The focus lies on pumps, so the options are a jet pump or eductor, submersible pump or a fluidizer system. In Table 8.3, these three options are explained and evaluated.

Table 8.3: Evaluation of types of pumps for bypass system

System name	Explanation	Applicable or not?	Reasoning
Jet pump or eductor	A high-energy stream of liquid comes from a separate pump. It draws in material to be pumped through a pipe and discharged elsewhere. There are no moving parts in the system.	Yes	Combined with a sediment trap.
Submersible pump	Small-sized pumps, used for systems which need more flexibility.	No	Moving parts lead to higher susceptibility to premature failure. Regular inspection and service is needed.
Fluidizer system	A trench is created. A pump supplies water into a pipe which is perforated and buried beneath the sand. There is a low flow rate at first, but is increased to start fluidization. The region above the pipe flurized and the slurry can be removed.	No	Since the bypass will be combined with port expansion, such system close to a hard structure could cause stability problems.

The sediment bypass will be located on the east side of the new port. The advantage of this location is that the supporting structure of the pumping system (the jetty) can be partly combined with the hard structure of the port/existing breakwater. With the assumption of a sediment transport from south to north, the location of the system can be seen in Figure 8.10. The reason of the placement at this place is that the sediment will be intercepted so it will not end up in the existing approach channel of the port.

Due to the almost continuous presence of wind in the region, a windmill can be used as a power source for the pumps. In the study of Rutteman (2021), the concept of the sandwindmill is researched. This could be a nature-based power source for the sediment bypass. A more detailed explanation of this concept can be found in Appendix J.

To transport the sediment, a pipeline is necessary. Different systems ask for different types of pipelines (Loza, 2021). Possibilities are a floating pipeline or a submerged pipeline, both are possible for this project. A submerged pipeline will be shorter, since it has a more direct path. However, it is subjected to the risk of fluidization if not covered adequately. It could also get damaged by boat anchors or while dredging. A pipeline could also be laid across the land. However, the distance to the northern beach is long and it should still be submerged to cross the Chubut River. Thus, a submerged pipe seems to be the most logical option.

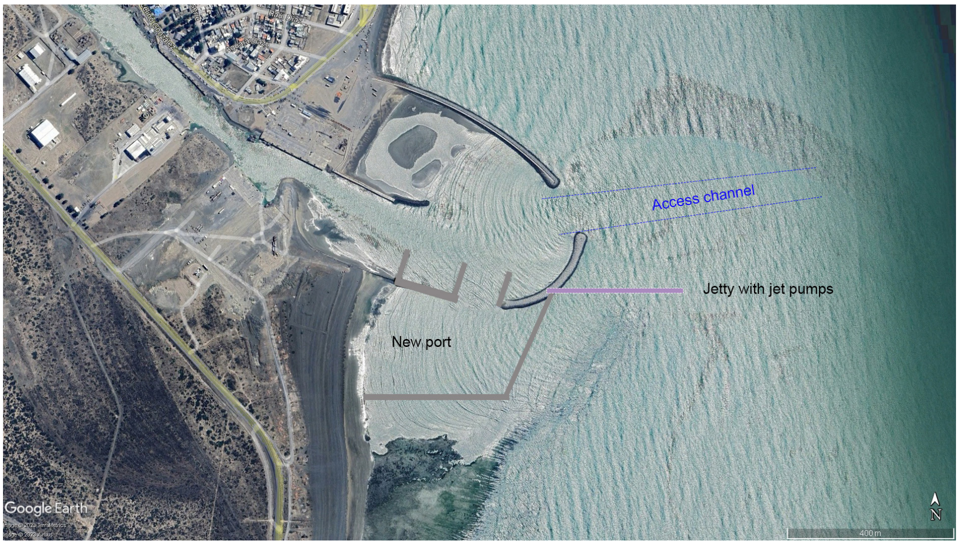


Figure 8.10: Layout new port with sediment bypass

The earlier mentioned reference project of the sand bypass in Australia intercepts about 500,000 cubic metres of sand per year, using ten jet pumps. The quantity of sediment that flows in this area is unclear, so further research is needed in order to be able to design the complete system. A technical analysis from Loza (2021) shows by analysing the Nerang Bypassing System that the amount of sediment per pump also differs, depending on their location along the jetty.

8.5. Creating a sediment trap

This intervention is based on the idea of bypassing the port to restore the sediment flow from the river towards the beach. The idea is to dredge a sediment trap downstream of the Elsa bridge but upstream from the port. After this trap has been dredged, a fixed system will be installed that can dredge the trap when it fills up again. This system leads from the sediment trap towards the north side of the short breakwater and drops the sediment over here so that it can restore the shoreline.

For this intervention, the yearly erosion on the beach and the sediment supply into the trap have to be of a similar magnitude. For both these volumes, estimates exist in literature. Savioli et al. (2011) estimated that 16.000 m^3 of material erodes away on a yearly basis. Kaless et al. (2019) estimated that approximately 8.000 m^3 of sediment flows through the Chubut river. This was measured by dredging a sediment trap and monitoring the rate that it filled up. This still leaves a large shortage in sediment, leaving to conclude that this intervention should be combined with other interventions like the groynes or vegetation. It is also thought that the erosion is mainly caused by a lack of coarse sediment supply to the shore line, while the river mostly transports fine sediment. A later study by Hugo Juan Donini (2021) estimated a much higher erosion rate of $283.812m^3/year$ between 2008 and 2014, for fine sediments. Thus, making the supply of fine sediments via the sediment trap insignificant. This number is however, measured to a distance 4,5 kilometres away from the coast. For more information about the sediment balance, see Section 4.6. This intervention will still be worked out for the case that it might be incorporated with another intervention.

This intervention could incorporate the idea of the sediment bypass of Section 8.4.4. There is an abundance of wind in Chubut, so a windmill could deliver the green energy for the pump of the bypass.

In Figure 8.11 a possible lay-out is shown for the sediment trap and the pumping system. In green is the location of the trap and in blue the pumping station. This is located in a vacant plot of land in an industrial area. The pipes follow the road so that there is no need for the destruction of homes, and this reduces the noise pollution. The entire length of the pipes is 1,2 kilometres. After the construction of the pipes a new layer of asphalt can be paved over the road, this way the intervention also contributes to the local society.

Figure 8.11: Lay-out of the sediment pass pumping system

8.6. Temporary longitudinal flood barrier

Temporary flood barriers are a short-term solution. They can be permanently on site, but usually, temporary flood defences are assembled when storms or high water levels are expected. Next to that, the barrier will protect the hinterland but not reduce the coastal erosion. Even more so, if the temporary flood defence change the sediment transport, it could increase the erosion rate.

Temporary flood defences, such as sandbags, are usually only used for extreme situations and are employed directly on site. Sandbags are really labour-intensive to deploy. However, there are already a lot of innovative possibilities to replace the sandbags. A number of these possibilities will be covered in Appendix K but due to the large number of barriers, it is not possible to cover them all. A lot of innovations are already tested in real-life situations, while others are still in the conceptual phase. The sandbag, however, is still used as coastal armouring.

Due to the retreat of the coastline by erosion, flooding and overtopping towards the Av. Guillermo Rawson, the street behind the coast, have become more frequent. This year the number of events was over five, while before 2018 it rarely happened once a year (R. Bastida Arias, personal communication, 19 October 2023). This could express the need for a short-term intervention.

When there is a risk of flooding, temporary flood defences can be deployed and otherwise dissembled and stored, not taking up any spaces in the coastal area. Temporary flood defence can be prone to theft and vandalism since they are easy to install, light-weighted and have no fixed foundation. Therefore and depending on the material, usually metal or plastic, the quality could degrade when not dissembled after the event. But one could also look into a different type of temporary flood defences, more like a temporary seawall. Which will protect

the hinterland, but not reduce erosion, is heavy-weighted and less easy to install. Another option could be to install temporary flood defences during winter, when the risk of overtopping or flooding onto the streets is more regular.
The disadvantages of temporary flood defences are, as mentioned before, that they will not reduce the coastal erosion. Furthermore, typical failure rates are 20% to 30% higher compared to permanent structures. Also, often a pump is needed due to the leakage of the system (Street Solutions, 2021). It is important to know beforehand if a storm or bad weather is coming and what the wave energy is, because it takes some time to erect a temporary flood defence.

Next to that, most of them are proven well functioning along rivers and inside cities, so large wave actions are difficult to handle, and some systems may topple. So, when they are implemented at Playa Unión, they must be placed carefully. Some may only be placed behind the wave attack zone at the street, only preventing flooding of the hinterland by creating a water buffer at the street zone. Then, they are only useful if the water rises and reaches the first row of houses. Others, heavier ones or with better embedment or foundation, can be placed at the line of wave attack. But if they are placed in the zone of wave attack, like longitudinal flood defence on the coast now, they must be able to handle the forces of the incoming waves on the structure. Extra stabilizers or foundation may be needed. Examples of temporary flood defences can be seen in Appendix K.
Therefore, this intervention is only advised as a temporary alternative, providing safety on short term for the hinterland, since flooding of the street happens more frequently.

In conclusion, a temporary longitudinal flood barrier can be used to prevent the hinterland from flooding and overtopping of seawater. However, one has to be aware that this will not reduce the erosion and one has to make sure that it will not increase the erosion rate due to changes, or blockage, in the movement of the soil particles. Take care that the implied intervention is stabilized at the zone of placement, preventing the system itself from sliding, overturning, drifting, overflowing, and it must be stable in combination with waves. Furthermore, it must not have any negative side effects for the beach itself, for example, not affect the macro stability of the beach due to the applied load of the bags. However, most temporary flood defences will be placed on the road next to the beach. Additionally, some are only interesting if the situation worsens. Because they need the weight of water to function, and now there are only a few centimetres of water on the road in a storm situation. Underflow must be prevented. Next to that, monitoring is important. This can be visual monitoring, meaning going to the barrier and inspecting the completeness of the barrier and inspecting if the leakage rate is below the allowable rate. If all this is applied and checked, a temporary longitudinal flood barrier could face the temporary challenges regarding flood protection.

8.7. Plant vegetation with beach nourishment

This intervention uses plant vegetation with beach nourishment to strengthen the coast in a nature-based way. The advantage of vegetation is that it stabilizes the beach surface against erosion and also be of additional value for animals.

Due to the limited available space, as described in Appendix L, beach nourishment or foreshore nourishment is needed for vegetation to function as coastal protection. Beach nourishment does not stop erosion, but provides extra sediment from an external source. The nourishment also can act as a protection for the vegetation against the big tidal differences and the waves. The vegetation needs to be extra protected according to the article of Massachusetts Office of Coastal Zone Management (2018). Depending on the beach conditions and the type of maintenance, the intervals between nourishment range from two to ten years

("Beach and shoreface nourishment", 2023). The soil, used for nourishment, can originate from somewhere on land or from large distance offshore.

To select suiting vegetation, thirteen plants are compared with each other. The plant comparison can be found in Appendix L. Non-native plants are not considered because they could be invasive and thus can potentially harm the existing ecosystem. The plants chosen are endemic and native to the region of Chubut and found in "El estudio de prefectibalidad" (del Vecchio, 2018) and "Declara especies protegidas" (Gonzalez et al., 2016). The following criteria are taken into account when comparing the plants:

- **Salt-tolerance:** The plants are at the coastline, consistently subjected to seawater.
- **Soil type:** The plants must be able to grow in sandy soils, or sand and gravel mixed soils.
- **Blooming period:** During storm season, with peaks in the winter, it is beneficial if the plants are blooming to absorb extra energy.
- **Life-span:** Plants with a long lifespan are preferred, as less replacement is needed. Perennial plants live multiple years, annual plants live a year or less.
- **Root system:** An extensive root system is preferred, since it will trap the sand and improve the soil structure by adding organic material and moisture. The roots will hold sediment in place to reduce erosion. Roots with a tap root system penetrate the ground deeply. A fibrous root system is more shallow and has an extensive and dense root network. This network prevents soil erosion.
- **Plant size:** The size of the plant is interesting for knowing how many plants are needed. Next to that, larger/wider plants trap more sediment. Plants with rhizomes are beneficial because these plants have plant stems growing horizontally above or below the surface and this allows new shoots to grow upwards.
- **Beach Safety:** Plants should be safe for beach users, thus for example not poisonous.

Maintenance is also an interesting criterion, but little information has been found on that thus it is left out of the analysis. It is assumed that the maintenance is low because these plants live in the steppe climate of Chubut, thus they can survive harsh circumstances.
Out of the plants comparison follows that the following nine plants are suitable for Playa Unión: Chuquiraga Avellanedae, Larrea Divaricata, Grindelia Chiloensis, Calystegia Soldanella, Sesuvium Postulacustrum, Baccharis Divaricata Hauman, Distichlis Scoparia, Sporobolus Rigens and the Lycium Chilense. All plants are tolerant to seawater and can survive in humid circumstances. The Sporobolus Rigens is a good option, especially because it is already used for reinforcing dunes. A combination of a couple of these plants is advised. It is beneficial to implement a diversity of plants, to make them less prone to diseases. A staggered planting pattern is advised, because it results in twice the amount of sand trapped around the vegetation, also called nebka, as with a non-staggered configuration (Charbonneau et al., 2020).

Furthermore, it is important to monitor the plants throughout their lifetime. One has to make sure maintenance is applied after natural hazards such as storms but also regular maintenance because of human interference with the vegetation. Or even protect the area from pedestrians, so there is no damage to the plants.

8.8. Gravel engine

This intervention is based on the 'Sand Engine' utilized in the Netherlands to protect the coast. In the Netherlands, in the province of South-Holland, an artificial stretch of beach was created as an innovative way of coastal protection. An amount of 21,5 million cubic metres of sand was used to create a bell-shaped piece of land in front of the coast as seen in Figure 8.12. The purpose of this land is that the waves and wind redistribute the sand over a long stretch of time to re-nourish the beaches and the dunes (De Zandmotor, n.d.). The advantage of this compared to constant dredging is the impact it has on the environment. The sand engine was designed to last 30 years and was constructed in 2011. This means it had a one-time impact on the environment at the location where sediment was taken from and placed. After the construction, nature has 30 years to prosper and grow again. With constant dredging along the coast, this is not the case and nature gets damaged on a more regular basis and does not have the time to grow back.

Besides the protection of the coast, the Sand Engine has a positive influence on recreation and tourism. It gives the opportunity for tourists to go swimming, surfing, bird-watching and much more. Since its construction in 2011, it has proved to distribute sand towards the dunes, refilling them and making them grow. Since the project shows it can achieve its goals, the concept will also be used in other locations. A similar coastal defence project was completed in 2019 in Bacton & Walcott Beach in the United Kingdom (Flikweert, n.d.).

Figure 8.12: The Sand Engine in 2020 (Rijkswaterstaat, 2020)

This intervention always has a unique blueprint. Every location has a different bathymetry, available sediment, wind and wave conditions and physical barriers. That is why it is not possible to copy and paste the concept. For this intervention, the conditions will be compared to the Sand Engine in the Netherlands to see if it is a feasible option. The details for the comparison of the different design conditions can be found in Appendix M. In Table 8.4 a small summary of compared data is shown.

Table 8.4: Data comparison Playa Unión and Hoek van Holland

	Playa Unión	Hoek van Holland	
Average wave height	1,85	1,76	(m)
Main wind direction	Offshore	Onshore	(-)
Average wind velocity	7,02	7,12	(m/s)
Tidal range	2 - 5	1 - 2,25	(m)

8.8.1. Conceptual design

Taking all this into consideration, a conceptual design can be made for this intervention. The largest difference in comparison to the Netherlands might be that the wind is largely offshore in Playa Unión. The wind plays a key role in the distribution of the sediment at the Sand Engine. However, it is not useful to blow all sediment away into the sea. There are two ways this might be prevented. The first is to use larger sediment, coarser sand or gravel will not get blown away as easily, and there is quite some gravel already present in the area. This could be used to create a 'worlds-first' gravel engine. Another way to get around the wind in an offshore direction is to work with the large tidal range. A design could be made where there is a gravel layer on top of a sand layer. During each tidal cycle, the sand layer will be underwater, and the wet sand will be more cohesive and will not be blown away.

The location of such an intervention is a key part of the success. It can not be placed in front of the port because it would block the ship's access. The best place in this scenario might be right in front of the small groyne. The general wave direction at Playa Unión is from south to north, as can be seen by the accumulation locations of sediment. So if this intervention would be placed at the south side of the erosion zone, it could spread out northwards to re-nourish the coast.

9 Evaluation of proposed interventions

In this chapter, the proposed interventions are evaluated. First, the degree to which each intervention is nature-based is described. Then, criteria are explained that will be used to evaluate the interventions, in order to answer the sub-question: "what are relevant criteria to evaluate the proposed interventions?" In Section 9.2, the multi-criteria analysis (MCA) is performed. After that, a sensitivity analysis is performed on the MCA.

9.1. Nature-based evaluation

Per intervention, it is described to what extent the intervention is nature-based. The aspects discussed are if the intervention uses nature-inspired processes and nature-friendly material, and also if the intervention has multiple design uses and other benefits. In Table 9.1 an overview is shown of this evaluation.

Temporary longitudinal flood barrier

The temporary flood defence intervention is not designed to be a nature-based solution. It is a relatively cheap and easy-to-implement intervention which will be a fast way to protect the hinterland. Most materials used for this type of intervention are not nature-friendly. They do tend to be fairly durable as they can be used multiple times.

Groynes

Recycled timber can be used to construct permeable pile groynes (PPG). The low crested groynes (LCG) can be built with locally made concrete. The LCG's have some limited recreational value, but do also negatively impact the view on the beach, as do the PPG's. Groynes do not have other uses nor additional benefits.

Dredging and moving sediment

This intervention uses natural materials to restore the shoreline. This could increase the recreational value of the beach. It does not necessarily have any further benefits for tourism or recreation.

Opening the northern breakwater

The breakwater with curve will be relocated by recycling the materials from the current breakwater. The design will retain its function to protect the port, but it loses its function of recreation unless a pathway is created. The tunnels will be placed underneath the breakwater. Concrete will be used for constructing the tunnels, which can be acquired locally. The breakwater will

Table 9.1: Nature-based evaluation

Intervention	Nature-inspired processes	Nature-friendly materials	Multiple design uses and other benefits
Temporary longitudinal flood barrier	No	No	No
Permeable pile groynes	No	Yes	No
Low crested groynes	No	Partly	No
Dredging and moving sediment	No	Yes	No
Opening northern breakwater: with curve	No	Yes	No
Opening northern breakwater: tunnels	No	Partly	No
Opening northern breakwater: sediment bypass	No	No	No
Southern port expansion	No	No	Yes
Sediment trap	No	Yes	No
Plant vegetation with beach nourishment	Yes	Yes	Yes
Gravel engine	Yes	Yes	Yes

stay intact, so it will keep its functions. For the sediment bypass, pumps will be installed in or on the breakwater that will pump the sediment passed the breakwater. These sediment pumps are assumed to be not locally available. Depending on how the pumps will be installed determines the hindrance that will occur to the area. Hindrance in the form of noise that the pumps make or blocking the pathway over the breakwater. Both will have a negative effect on the recreational function of the breakwater and the recreational quality. All these interventions aim to restore the natural flow of sediment from the river making use of the incoming waves.

Port expansion and sediment bypass

To a certain extent, the shape of the breakwater for the new port follows the shape of the coast. A shape should be chosen that naturally guides the sediment from north to south, meaning it is a nature-inspired process. The structure will be built using concrete, a material that is not natural but is locally producible. The design has multiple uses, since it functions both as port for the industry and as an intervention against erosion due to the sediment bypass. In the design, there is enough opportunity to create extra benefits, like touristic benefits. In conclusion, this intervention scores positively in the nature-based evaluation.

Creating a sediment trap

This intervention restores the natural sediment transport to strengthen the shoreline. This is considered a natural building material. It does not however have any additional uses, and neither does it use nature-friendly material to build the installation. It also does not have any extra benefits.

Plant vegetation with beach nourishment

This intervention makes use of nature-inspired processes. Nature-friendly materials have been used in the design of the intervention. The materials used are sandy soils and plants. The plants are all native and can be collected locally. If the soils needed for the nourishment of the beach need to be imported from far away, it is less nature-based. The beach nourishment covered with plants can also provide, next to protection of the coast and mitigation of erosion, a home for flora and fauna. However, the plants should not be accessed by people to prevent human interaction, thus in the beginning, the beach will be less accessible for inhabitants and tourists. The nourishment of the beach results in a wider beach, which will make the beach more appealing. This will eventually attract more tourists. However, every time nourishment is needed, the natural processes are disturbed.

Gravel engine

This intervention uses the current, the waves and the wind to protect the coast. These are all natural phenomena. It is a one-time operation with long-lasting results. This makes it possible for marine life to grow again at the place where intervention is placed. The gravel engine uses local material from the seabed or the riverbed. The design could also have multiple uses. It creates a good beach area for tourism and water sports. Besides that, a lot of different fauna can find a home on this artificial beach.

9.2. Multi-criteria analysis

The proposed interventions will be compared using a MCA. The temporary flood defence intervention is not considered within the MCA, since this alternative is not comparable with the other interventions due to the big differences. This intervention will not influence the status of the beach, nor be a long-term solution for the coastal erosion. It will only be a fast way to protect the hinterland and therefore be relatively cheap and easy to implement.
The criteria used in this MCA are stated below.

- **Effectiveness:** Interventions which provide safety of the hinterland sooner and accumulate more sediments, score more points. With 'sooner', the time between the finishing of the construction and the active protection against flooding is meant. For the interventions to function as protection, the beach at Puerto Rawson and Playa Unión have to become wider thus sediments need to be accumulated.
- **Easiness of implementation:** Interventions that are easy to implement score more points. Thus, interventions that require less initial investment costs, construction time and equipment to implement are scored better. One of the issues is the shortage of financial resources. It was mentioned by the MIEP that a previous project had never been finished due to the shortage of money. Less time is better since the governmental period in Argentina consists of four years. Every time a new government gets elected, the national finances get reevaluated and redistributed. This creates the risk that existing plans will get suspended due to budgetary issues.
- **Maintenance:** Interventions which require less and simpler maintenance score more points. With this, it is meant that maintenance is less frequently needed and not complex. This is important because the financial resources are limited.
- **Environmental impact:** Interventions that do not intervene with the natural environment and are easily adaptable to climate change score more points. With this, it is meant that it does not disturb the habitat of the living flora and fauna in the close surroundings. Protection of the beach in the project area should not result in erosion of the neighbouring beach. The climate change taken into account in this report is mentioned in Chapter 4.1.4. This includes sea level rise but excludes other impacts of climate change.
- **Recreation:** Interventions that create extra opportunities for tourism and recreation

score more points. Besides that, improving the condition of the beach, meaning a more gentle slope and sandy sediment, scores better. Furthermore, interventions that do not obstruct the wide views over the sea score more points. The obstruction of the view close to the beach of Playa Unión is more significantly weighted than views in less populated areas. These last two points followed from the questionnaire, see Section 6.1.

In Figure 9.1, the scores of the various interventions are shown. The reasoning behind the scores can be found in Appendix N. These are the two highest-scoring interventions:

1. Gravel engine
2. Plant vegetation with beach nourishment

The gravel engine and plant vegetation with beach nourishment score very high. The gravel engine scores high on every criterion, except for the easiness of implementation. Opening the northern breakwater with a sediment bypass and dredging and moving sediment both score quite high. The low-crested groynes, tunnels, southern port expansion and sediment trap score the least amount of points.
Also, a MCA with weights is conducted, this can be found in Appendix N. The top 4 stays the same with weights as the top 4 without weights.

	Groynes: PPG	Groynes: low crested	Dredging and moving sediment	Opening Northern breakwater: with curve	Opening Northern breakwater: tunnel	Opening Northern breakwater: sediment bypass	Southern port expansion	Sediment trap	Plant vegetation	Sand/gravel engine
Effectiveness	2,8	3,3	3,5	2,8	2,8	3,7	4,0	2,0	4,0	4,3
Easiness of implementation	4,0	2,3	4,2	2,5	2,7	3,3	1,2	2,8	3,3	2,2
Maintenance	3,0	4,0	2,3	4,2	3,0	3,2	2,7	2,7	3,0	4,3
Environmental impact	3,3	1,7	3,0	2,5	2,7	3,5	2,2	3,5	4,7	4,5
Recreation	1,7	2,2	3,5	2,5	2,3	3,3	3,7	3,0	3,8	4,2
total	14,8	13,5	16,5	14,5	13,5	17,0	13,7	14,0	18,8	19,5

Figure 9.1: MCA without weights

9.3. Sensitivity analysis

A sensitivity analysis is performed to gain insight into the variation in the selection of alternatives when the weight factors of the criteria are varied. Per criterion, the weight was increased three times while keeping the weights of the other criteria equal to one. From the sensitivity analysis, it appears that the alternatives are not really sensitive to different weights. More detailed results can be found in Appendix N.

The criterion easiness of implementation did cause a change in the order when the weight was increased. PPG and dredging and moving sediments scored higher because they are easier to implement than the gravel engine. varying the other criteria did not result in a significant change in the output. The alternatives gravel engine, vegetation, sediment bypass and dredging are in almost all situations the best options.

Furthermore, the last line in the table is an analysis without the criterion of easiness of implementation. This was a wish from the client Industrias BASS. They have expressed that they also want to know what the result is when costs and the complexity of implementation are left out. However, if this is left out, the MCA still has the same top 3. But, what is interesting to see is that the southern port expansion goes to the middle, instead of being at the lower half, ending at the fourth place.

10

Conclusion

This report aimed to find an answer to the research question: **What are valued, preferably nature-based, interventions that can mitigate the coastal erosion in Playa Unión and Puerto Rawson considering the planned expansion of the port?** To arrive at an answer to this question, the six sub-questions are answered first.

What is the geology, ecology and history of Puerto Rawson and the coastline of Playa Unión up to 2023?
The geo-morphological areas that can be differentiated in 2023, all trace back to the presence of the Chubut River (water), the sea (marine) and the climate (wind) that caused erosion of the layers formed over 2.6 million years ago. Remarkable events in the history of the port area are the founding of Puerto Rawson (1923), the opening of the public Murray Thomas Quay (1981) and Muelle Neuvo (2010), and the expansion of the port on the southern bank (2018). Port expansion went hand-in-hand with the construction of hydraulic structures like breakwaters, of which, in 2023, a combination of older and younger structures are still in use. The combination of all these factors resulted in the fact that the situation is declared as coastal emergency (Política Chubut, 2023). From the ecosystem analysis, it can be concluded that due to the steppe climate, small thorny vegetation is growing. Animals that occur in the area are birds, sea lions, rodents and other mammals.

What is the morphology of the coastline of Playa Unión and what are its drivers?
The coastline of Playa Unión consists of steep upper slopes of coarse material and long stretching gradual lower slopes of fine material. The results of the CoastSat analysis show that there is a trend of erosion on the coast. The large tidal difference and the incoming predominantly swell waves from the SSE-SE direction are the main drivers of the coastal erosion. Due to the construction of the port's breakwaters, the longshore sediment transport from the south- to the northern direction is interrupted, which causes an imbalance in the incoming and outgoing sediment flow of the system. More sediment flows out of the system than enters, causing the coastal erosion. Possible sea level rise due to climate change can lead to a retreat of the coastline and can alter the longshore transport rates.

How will the planned developments of the port area influence the direct area of Puerto Rawson and Playa Unión?
Most of the planned developments are port expansion plans that do not directly influence the surrounding area. However, their dredging maintenance will have an effect, especially if the dredged material is distributed north of the breakwater.

Who are the relevant stakeholders, and what are their interests?
The following relevant stakeholders and their interests are identified:

- Industrias BASS sees an opportunity to combine new port expansion with an intervention against coastal erosion.
- The municipality of Rawson wants to create a safe and pleasant living area for the inhabitants. Protection of the coast is part of that.
- The MIEP and the national government have a financial interest in the port.
- The water institute wants to solve the coastal erosion problem.
- The direction of port infrastructure and the fishery companies want to keep the port accessible and workable. The fishery companies also want to increase the fish catch.
- Touristic companies want to increase the number of tourists.
- The inhabitants want to live in a safe and pleasant area.
- Tourists want to enjoy the coast of Playa Unión and Puerto Rawson.
- Environmental organizations want to ensure the sustainability and biodiversity in the area.
- The dredging company has a financial interest in the dredging project.

What are possible, preferably nature-based, interventions to avoid negative consequences of port expansion?
Eight possible interventions are given to avoid the negative consequences of the port expansion on the coast of Playa Unión. The interventions were limited during design by the defined boundary condition. The interventions as described in this report are: groynes, opening northern breakwater, port expansion and sediment bypass in the south, creating a sediment trap in the river, temporary longitudinal flood barrier, plant vegetation with beach nourishment and the gravel engine. Some interventions are more nature-based than others.

What are the relevant criteria to evaluate the proposed interventions?
The proposed interventions are evaluated in an MCA. The criteria used are effectiveness, easiness of implementation, maintenance, environmental impact and recreation. For the evaluation of the extent the interventions are nature-based, it is determined if the intervention uses nature-inspired processes and nature-friendly materials, and if the intervention has multiple design uses and other benefits.

So to conclude this report, the research question is answered:
The highest scoring at the MCA and thus the most promising interventions on a conceptual level are the gravel engine and the plant vegetation with beach nourishment. In the nature-based evaluation, both do score well. Since, the interventions are inspired by or use natural processes and use mainly nature-friendly materials. However, the gravel engine could need external material, which is less nature-based. The engine will once disturb the natural processes, giving the system time to find a new balance. For the plant vegetation, beach nourishment could be needed multiple times during the design lifetime. The planned expansion of the port has little effect on the coastal erosion. However, dredging could affect the stability of the breakwaters and the sediment transport will find a new balance. Additionally, discharging the sediment on the coast could have a positive effect against the coastal erosion.

The situation in Playa Unión is a coastal emergency. Therefore, the construction of the gravel engine and the plant vegetation with beach nourishment could take too long. A possible outcome for that could be, to combine the intervention with the placement of a temporary longitudinal flood barrier, when the situation worsens. To provide immediate safety of the hinterland, during the construction of a permanent intervention.

11 Discussion

Several obstacles were encountered during the research.

A lot of used literature was originally in Spanish and was scanned in Spanish but mainly automatically translated to English. This direct translation may cause some errors.

For the interventions, a lot was designed according to the morphological development and drivers. However, there was a lack of real data, due to the fact that there are almost no measurements in the project area. When there was data available, it was often outdated. Furthermore, the literature is assumed to be correct and reused in this report. However, the literature also struggled with the lack of data.

In general, adjusting to a different culture takes time and effort. The new language, political system, different organisations etc. need time to adapt to. This resulted in an iterative process. Those new perspectives on how things work in Argentina, had to be incorporated. This sometimes slowed down the progress.

During the interviews, the language barrier has sometimes led to miscommunication. Separating the main issues and side issues could be hard because there were often enormously detailed answers. This also often made for very long interviews. Better time management could have prevented some of this. Some Argentinians have helped as a translator during the interviews. This was very helpful, but the information could get lost in translation. This made it sometimes difficult to understand what the stakeholder really meant. Also, asking follow-up questions was hard because of this. To be sure the information was correctly interpreted, information was rephrased in different words or in a mixture of English and Spanish. After an interview, a summary was sent to the stakeholder not only to ask permission to use it in the report, but also for confirmation of the discussed content.

The interventions were designed by using wave data from 2022 combined with the bathymetry from a report out of 2011. Technically, these situations cannot actually be compared and used interchangeable. In addition, the data from 2011 is really outdated. Therefore, the real bathymetry at the moment in the project area, could be totally different from the bathymetry which is used for the design. This could result in errors being made in the conceptual design for the interventions.

A very comprehensive nature-based framework has been used in the research. The nature-based concept and Building with Nature concept are quite new in the research field and because of that few concrete frameworks are available. Several sources have been used to back up the framework, but with the limited knowledge about this subject, the framework is very compact.

To obtain a proper and comprehensive MCA a lot of time is needed. But, due to the limited time and the conceptual level of the interventions, the MCA is not irrefutable and fully objective. To maintain objectivity, it was chosen to ask externals to score the interventions as well. However the externals had less knowledge about the project details and the MCA was conducted quite late, thus the scoring had to be done on very limited information.

In addition, the criteria were rated on assumptions and estimations. For example, actual effectiveness of the interventions has not been examined at all, further research is therefore needed. Furthermore, all interventions are on conceptual level. So, for example, the amount of beach nourishment needed for the intervention plant vegetation is not known for sure. Also, the breakwater of the south port expansion is designed for the worse case scenario of waves, so no optimization is done for the design due to the conceptual phase. However, if the designs are in a more extended level, it could result in different valuation of the MCA. This results in some uncertainties. Furthermore, the interventions containing the port expansion in the south with the sediment bypass could also be unplugged. For example, if only the sediment bypass from the south to the north would be considered. This intervention would score better on easiness of implementation and environmental impact. Thus, resulting in a different conclusion of the MCA.

In the MCA all the criteria got the same weight. However, for this the trade-off between what is technically feasible and practically possible is made. In Argentina, a large hydraulic project has to be funded by the national government and a project with low expenses will get approved easier. For this reason, it is from the point of view of the inhabitants in Puerto Rawson and Playa Unión better if the criteria easiness of implementation were graded of greater importance. But for the scope of this project, pushing the technical limits and giving a new perspective was also important. That is why, it was chosen to not let costs, and therefore easiness of implementation, limit the outcome of the interventions.

The short solution, so the placement of a temporary longitudinal flood barrier must be researched more thoroughly. Since some defences function best at higher water levels since the weight of incoming water provides the stability of the barrier. Whereas in Playa Unión it is only some centimetres above the height of the road. So, then underflow can become a difficulty. Furthermore, the applicability of the system must be researched.

12
Recommendations

This chapter will contain recommendations for further research and suggestions on organizational steps that can be undertaken. It will follow a road map of steps shown in Figure 12.1 that can be done to find a solution for the coastal erosion.

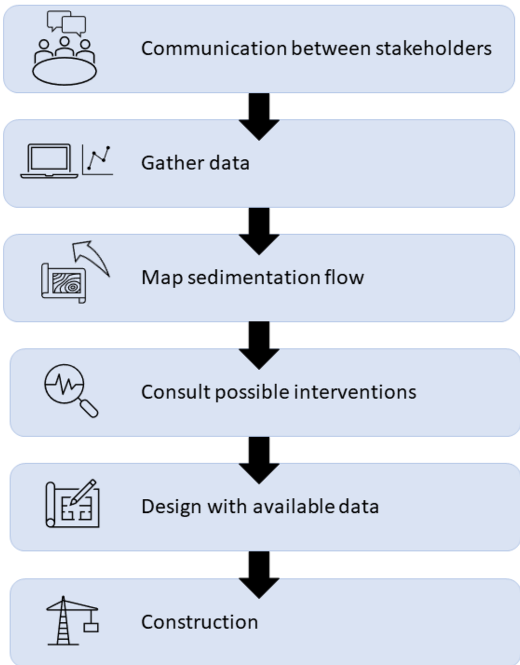


Figure 12.1: Road map recommendations

Communication between stakeholders

One of the biggest challenges encountered in the region is the cooperation between stakeholders. There are a lot of different organisations with different responsibilities. After conducting all stakeholder interviews, it was apparent that many have the same interest: the conservation of the coast of Playa Unión. However, there is now little communication between stakeholders and cooperation should be encouraged. The first step of the road map is communication and cooperation. It is recommended that information, data and knowledge are more openly shared. A strategy to engage the stakeholders more actively is provided in Figure 12.2. Better engagement of stakeholders may result in more positive attitudes and interest towards mitigating the coastal erosion. It is advised to regularly evaluate if the stakeholders are engaged and to update the stakeholders' network when new stakeholders are introduced.

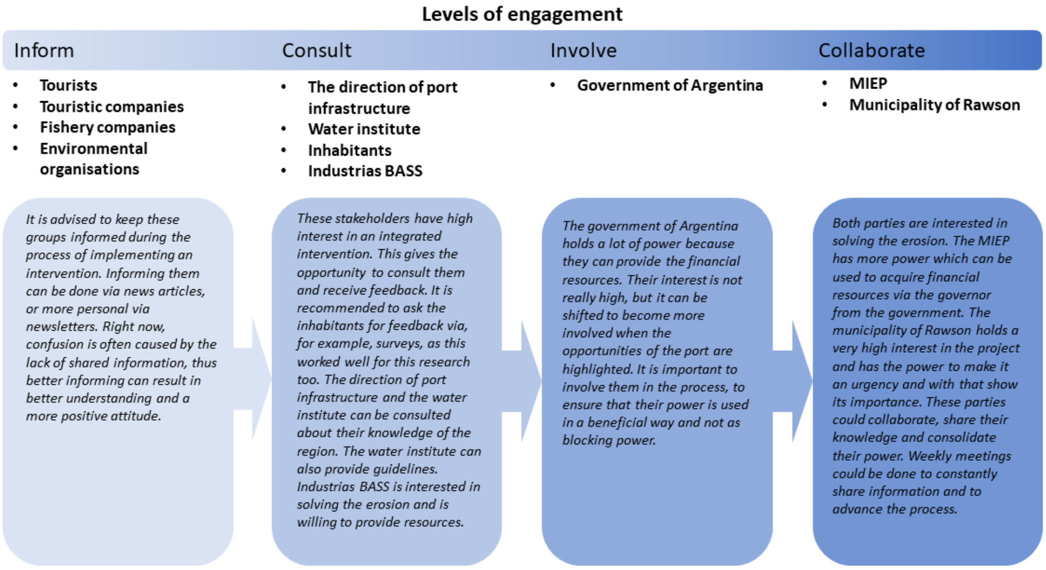


Figure 12.2: Engagement of the stakeholders

Gather data

One of the largest challenges during the project was the lack of data to work with. There are a lot of simple and cheap methods to gather useful data. See Appendix O for different instruments and methods. UNPSJB would benefit from gathering and processing data to educate students and get more knowledge about the region. Because some instruments are quite expensive, a private contractor or governmental institution could finance this. The conservation of data is an important aspect. A lot of data gets lost due to the lack of responsibility to preserve it. The DPI or the IDA could be made responsible for preserving the data that students measure.

Map sedimentation flow

Once there is enough data, sedimentation flows in the region can be mapped out using open-source models like Delft3D and CoastSat. See Appendix O for more explanation. This is a difficult process, so it is recommended to seek professional help from other institutes like the UBA or the TU Delft. A master thesis could be constructed to make these models. Collaboration with such institutes could generate a lot of useful knowledge that can be used by the parties involved.

Consult possible interventions

When a lot of data is collected and there is a clear understanding of the sedimentation flows, the next step can be done. This report provides eight different possible interventions that can be done to protect the coast. These are however all designed on limited data and a lot of assumptions. With all the newly measured data, all interventions could be reevaluated, and maybe even new ones can come to mind finding a fitting solution for this specific challenge. Cooperation and consultation between all stakeholders will be of importance in this stage to determine a solution that satisfies the most needs and wishes. Financing the project is of course a different concern, since the problem has been declared a coastal emergency it might be easier to find funding for the project (Política Chubut, 2023).

Design with available data

After the best intervention or a combination of interventions has been chosen, a design should be made. Industrias BASS and the DPI should work together to make sure that the design benefits all stakeholders. Other stakeholders could also be involved in the design, depending on the intervention that will be designed.

Construction

Due to the laws of the province, construction should be carried out by a company based in Chubut. It is still highly recommended cooperating with more experienced companies depending on the intervention chosen. This could be on a consulting level or even on a construction level. This can be done in for example a consortium between a local company and a foreign company, similar as described in Section 6.2.

References

AMP Argentina. (2022). Coastal and Marine Protected Areas.

Aquasafe. (n.d.-a). *Noaq boxwall bw52 faq*. Retrieved October 20, 2023, from https://buyaquasafe.com/pages/noaq-boxwall-faq

Aquasafe. (n.d.-b). *Zandmotor deltaduin*. Retrieved October 24, 2023, from https://nl.wikipedia.org/wiki/Zandmotor_DeltaDuin#:~:text=Naar%20verwachting%20zullen%20door%20deze,plaatse%20geen%20verdere%20zandsuppleties%20nodig.

Ardolino, A., Panza, J. L., & Ylláñez, E. (2003). Hoja geológica 4566–i, garayalde, provincia del chubut. *Programa Nacional de Cartas Geológicas de la República Argentina*, *Boletín No 264*.

Beach and shoreface nourishment. (2023). Retrieved October 11, 2023, from https://climate-adapt.eea.europa.eu/en/metadata/adaptation-options/beach-and-shoreface-nourishment

Benders, L. (2023). *Het gebruik van online/offline enquêtes in je scriptie | uitleg en tips*. Retrieved October 4, 2023, from https://www.scribbr.nl/onderzoeksmethoden/enquete-in-je-scriptie/

Bosboom, J., & Stive, M. (2023). *Coastal dynamics*. Delf University of Technology. https://doi.org/https://doi.org/10.5074/T.2021.001

Boxbarrier, water versus water. (2021). Retrieved October 18, 2023, from https://boxbarrier.com/wp-content/uploads/2021/10/Flyer-BoxBarrier.pdf

Brágoli, P. K. A., & Donini, I. H. J. (n.d.). Impactos de la actividad portuaria en el espacio litoral de Playa Unión.

Britannica. (2023, October 17). *River | definition, examples, importance, & facts*. https://www.britannica.com/science/river/Floodplains

Bruining, J. (1994). Wave forces on vertical breakwaters: Reliability of design formula. *TU Delft*. https://repository.tudelft.nl/islandora/object/uuid%5C%3A9a8d906c-9357-4f46-b2dd-0953a9a307df

Charbonneau, B., Dohner, S., Wnek, J., Barber, D., Zarnetske, P., & Casper, B. (2020). Vegetation effects on coastal foredune initiation: Wind tunnel experiments and field validation for three dune-building plants.

CIRIA and CUR and CETMEF. (2007). *The rock manual. the use of rock in hydraulic engineering.* (2nd ed.) [chapter 2]. C683, CIRIA, London.

Crossman, M., Segura-Domínguez, S., & Allsop, W. (2003). Low cost rock structures for beach control and coast protection. http://www.defra.gov.uk/environ/fcd

De Graauw, A. (2022). Ancient Port Structures. *Méditerranée*. https://doi.org/10.4000/mediterranee.12715

De Vriend, H., & Van Koningsveld, M. (2012). Building with nature: Thinking, acting and interacting differently. https://www.ecoshape.org/app/uploads/sites/2/2016/07/ECOSHAPE_BwN_WEB.pdf

De Zandmotor. (n.d.). *Over de zandmotor*. https://dezandmotor.nl/over-de-zandmotor/

del Valle, H., R., Donini, & J., H. (n.d.). Caracterización morfodinámica y predicción de los cambios de perfil de playa unión, rawson.

del Vecchio, A. (2018). Estudio de Prefactibilidad para la Remodelacíon y ampliación maritima de Puerto Rawson. *1*. https://www.argentina.gob.ar/sites/default/files/estudio_de_prefactibilidad_para_la_remodelacion_y_ampliacion_maritima_de_puerto_rawson_.pdf

Dingemanse, K. (2015). *Soorten interviews: (on- of semi-)gestructureerd en focusgroep*. Retrieved October 4, 2023, from https://www.scribbr./onderzoeksmethoden/soorten-interviews/

Ecoshape. (2023). *What is building with nature?* [Accessed: October 5, 2023]. https://www.ecoshape.org/en/the-building-with-nature-philosophy/

Elmansy, D. R. (2021, September). *The double diamond design thinking process and how to use it*. Retrieved October 6, 2023, from https://www.designorate.com/the-double-diamond-design-thinking-process-and-how-to-use-it/#Step_1_Discover

European Commission. (n.d.). *Bathymetry*. Retrieved October 18, 2023, from https://emodnet.ec.europa.eu/en/bathymetry

Flikweert, J. (n.d.). *A uk first sandscaping in bacton norfolk |royal haskoningdhv*. https://www.royalhaskoningdhv.com/en/projects/a-uk-first-sandscaping-building-with-nature-in-bacton-norfolk

Fox-Kemper, B., Hewitt, H., Xiao, C., Aðalgeirsdóttir, G., Drijfhout, S., Edwards, T., Golledge, N., Hemer, M., Kopp, R., Krinner, G., Mix, A., Notz, D., Nowicki, S., Nurhati, I., Ruiz, L., Sallée, J.-B., Slangen, A., & Yu, Y. (2021). Figure 9.28 in climate change 2021: The physical science basis (V. Masson-Delmotte, P. Zhai, A. Pirani, S. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. Matthews, T. Maycock, T. Waterfield, O. Yelekçi, & B. Zhou, Eds.).

GEOBAGS, INSIGHTS. (2021). *Geobag for slope protection*. Retrieved October 19, 2023, from https://oceangeosynthetics.com/geobag-for-slope-protection/#:~:text=Nonwoven%20geotextile%20bags%2C%20also%20known,from%20severe%20erosion%20and%20scouring.

Geodesign Barriers. (n.d.). *Geodesign barriers*. Retrieved October 19, 2023, from https://geodesignbarriers.com/

Gonzalez, M., Marcelo, M., Curtale, S., & Artero, R. (2016). Declara especies protegidas.

Hernán, C., Ayelén, M., & Ariel, L. (2019). Estudio sobre la deficiente capacidad administrativa, operativa, funcional y Ambiental de Puerto Rawson.

Hugo Juan Donini. (2021). Los procesos de erosión costera en Playa Unión desde 1963: análisis retrospectivo e incidencias de las obras portuarias y de protección ejecutadas. *Universidad Nacional de la Patagonia San Juan Bosco*.

Hugo Juan Donini. (2022). Paper CA1205 Donini. H - Modificaciones en la costa de playa. *AADIP*, *05*.

Huthoff, F., Ten Brinke, W., Schielen, R., Daggenvoorde, R., & Wegman, C. (2018). Evaluating naturebased solutions. https://northsearegion.eu/media/6959/report_pr3812_evaluatingnbs_final_29112018.pdf

Kaless, G., Donini, H., Bastida, R., & Iglesias, S. (2019). Estudio hidrodinámico, sedimentológico y verificación de niveles verificación de niveles.

KNMI. (2023). *Knmi - uurgegevens van het weer in nederland*. https://www.knmi.nl/nederland-nu/klimatologie/uurgegevens

Loza, P. (2021). Sand bypassing systems masters in environmental engineering. *Universidad Nacional de la Patagonia San Juan Bosco*.

Massachusetts Office of Coastal Zone Management. (2018). Stormsmart properties fact sheet 3: Planting vegetation to reduce erosion and storm damage. *StormSmart Coast*. https://www.mass.gov/doc/stormsmart-properties-fact-sheet-3-planting-vegetation-to-reduce-erosion-and-storm-damage/download#:~:text=Northern%20bayberry%2C%20bearberry%2C%20and%20marsh,while%20the%20shrubs%20become%20established.

Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M., M. Huang, K. L., Lonnoy, E., Matthews, J., Maycock, T., Waterfield, T., Yelekçi, O., Yu, R., & Zhou, B. (2021). Ipcc, 2021: Summary for policymakers in climate change 2021: The physical science basis. contribution of working group i to the sixth assessment report of the intergovernmental panel on climate change. https://www.ipcc.ch/report/ar6/wg1/chapter/summary-for-policymakers/

Ministerie van Infrastructuur en Waterstaat. (2023, October 4). *Getij*. https://www.rijkswaterstaat.nl/water/waterdata-en-waterberichtgeving/waterdata/getij

Miros BP. (2023, August). Wave Buoys: Pitfalls, price tags and piracy on the high seas - Miros Group. https://www.miros-group.com/wave-buoys-pitfalls-price-tags-and-piracy-on-the-high-seas/

Mobildeich. (n.d.). *Mobildeichb - ihre vorteile*. Retrieved October 19, 2023, from https://www.mobildeich.de/test-2.html

Obscape. (2023, October). Obscape. https://obscape.com/site/

oceanweather inc. (2007). Global reanalysis of ocean waves (grow).

OpenStreetMap contributors. (2017). Planet dump retrieved from https://planet.osm.org.

Perdok, U., Crossman, M., Verhagen, H., Howard, S., & Simm, J. (2004). Design of timber groynes. https://repository.tudelft.nl

Política Chubut. (2023, October). El Concejo Deliberante de Rawson declaró la Emergencia Costera y le reclama al Ejecutivo Nacional obras de defensa. https://politicachubut.com.ar/noticia/72633/el_concejo_deliberante_de_rawson_declaro_la_emergencia_costera_y_le_reclama_al_ejecutivo_nacional_obras_de_defensa

Portal Portuario. (2023). Argentina: Empresa a cargo del dragado de Puerto Rawson solicita rescisión del contrato. https://portalportuario.cl/argentina-empresa-a-cargo-del-dragado-de-puerto-rawson-solicita-rescision-del-contrato/

RBR. (n.d.). *Rbrsolo³ d | depth logger*. https://rbr-global.com/products/compact-loggers/rbrsolo-d/?utm_feeditemid=&utm_device=c&utm_term=measure%20water%20depth&utm_source=google&utm_medium=ppc&utm_campaign=RBR+Temperature+%26+Pressure:+07.08.2022&hsa_cam=17693031297&hsa_grp=135683722941&hsa_mt=p&hsa_src=g&hsa_ad=610021923839&hsa_acc=2272824366&hsa_net=adwords&hsa_kw=measure%20water%20depth&hsa_tgt=aud-2008496403752:kwd-315939694715&hsa_ver=3&gclid=CjwKCAjw-eKpBhAbEiwAqFL0mlOqOKok9L1de_6cBroknkKRXG7sk4Ss32T9HAZBcFzuyKyTJGFemRoCxJIQAvD_BwE

Rijkswaterstaat. (n.d.). *Rijkswaterstaat waterinfo*. Retrieved October 19, 2023, from https://waterinfo.rws.nl/#/nav/index

Rutteman, H. (2021, October). *The application of continuous nourishment on wave and tide-dominated systems*.

Savioli, J., Mangor, K., Marazzi, M., Busquets, M., & Akaprahamyan, V. (2011). Estudio de protección de costas playa unión informe final. *1*.

Schillizzi, R. A., Spagnuolo, J. ., & Luna, L. (2014). Morfología de la costa atlántica entre punta ninfas y cabo dos bahías, chubut, argentina. *Revista del Museo de La Plata*, *Sección Geología, 14 (117)*, 1–15.

Seneviratne, S., Zhang, X., Adnan, M., Badi, W., Dereczynski, C., Di Luca, A., Ghosh, S., Iskandar, I., Kossin, J., Lewis, S., Otto, F., Pinto, I., Satoh, M., Vicente-Serrano, S., Wehner, M., & Zhou, B. (2021). Weather and climate extreme events in a changing climate. In V. Masson-Delmotte, P. Zhai, A. Pirani, S. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. Matthews, T. Maycock, T. Waterfield, O. Yelekçi, R. Yu, & B. Zhou (Eds.), *Climate change 2021: The physical science basis. contribution of working group i to the sixth assessment report of the intergovernmental panel on climate change* (pp. 1513–1766). Cambridge University Press. https://doi.org/10.1017/9781009157896.013

Serman y Asociados s.a. (2019). Estudio náutico muelles corporación Puerto Rawson.

Serman y Asociados s.a. (2021). Dimensionado de espigón interior en Puerto Rawson.

Shore protection vegetation - coastal wiki. (n.d.). Retrieved October 11, 2023, from https://www.coastalwiki.org/wiki/Shore_protection_vegetation#cite_note-4

Simm, J., Orsini, A., Blanco, B., Lee, A., Sands, P., Williams, J., Camilleri, A., & Spencer, R. (2020). *Groynes in coastal engineering, guide to design, monitoring and maintenance of narrow footprint groynes*. Ciria.

Spek, B.-J., Bijl, E., Sande, B., Poortman, S., Heijboer, D., & Bliek, B. (2020). Sandbar breakwater: An innovative nature-based port solution. *Water*, *12*, 1446. https://doi.org/10.3390/w12051446

Stanley, M. (n.d.). *Steppe*. Retrieved October 6, 2023, from https://education.nationalgeographic.org/resource/steppe/

Stockdon, H. F., Holman, R. A., Howd, P. A., & Sallenger, A. H. (2006). Empirical parameterization of setup, swash, and runup. *Coastal Engineering*, *53*(7), 573–588. https://doi.org/https://doi.org/10.1016/j.coastaleng.2005.12.005

Street Solutions. (2021). *What are temporary flood barriers? here is a complete guide*. Retrieved October 18, 2023, from https://streetsolutionsuk.co.uk/blogs/news/what-are-temporary-flood-barriers

Tides chart. (2023). Retrieved October 4, 2023, from https://es.tideschart.com/Argentina/Chubut/Departamento-de-Rawson/Playa-Union/Weekly/

Tolosano, L. J., Oviedo, L. L., Cochia, L. P., & Lista, T. A. (2022). Relevamiento de flora y fauna parque industrial rawson.

TU Delft. (n.d.). Measuring the waves with a smartphone. https://www.tudelft.nl/en/ceg/research/stories-of-science/measuring-the-waves-with-a-smartphone

Universidad Nacional de Córdoba. (2022). Estudio de la dinámica costera de playa unión y propuesta de protección para la costanera, provincia de chubut.

van de Graaff, J. (2022). *Sand by-pass systems*. Retrieved October 5, 2023, from http://www.coastalwiki.org/wiki/Sand_by-pass_systems

Van der Meer, J., Allsop, N., Bruce, T., de Rouck, J., Kortenhaus, A., Pullen, T., Schüttrumpf, H., Troch, P., & Zanuttigh, B. (2018, December). *EurOtop: Manual on wave overtopping of sea defences and related structures* (tech. rep.). www.overtopping-manual.com

van der Bos, J., & Verhagen, H. (2018). *Breakwater design*.

Van Zanten, B., Gutiérrez Goizueta, G., Brander, L., Gonzalez Reguero, B., Griffin, R., Kapur Macleod, K., Alves, A., Midgley, A., Herrera, L., & Jongman, B. (2023). Assessing the benefits and costs of nature-based solutions for climate resilience: A guideline for project developers. https://openknowledge.worldbank.org/entities/publication/9ed5cb4b-78dc-42a4-b914-23d71cef24a2

Vos, K., Harley, M. D., Splinter, K. D., Simmons, J. A., & Turner, I. L. (2019). Sub-annual to multi-decadal shoreline variability from publicly available satellite imagery. *Coastal Engineering*, *150*, 160–174. https://doi.org/https://doi.org/10.1016/j.coastaleng.2019.04.004

Vos, K., Splinter, K. D., Harley, M. D., Simmons, J. A., & Turner, I. L. (2019). Coastsat: A google earth engine-enabled python toolkit to extract shorelines from publicly available satellite imagery. *Environmental Modelling & Software*, *122*, 104528. https://doi.org/https://doi.org/10.1016/j.envsoft.2019.104528

Wiki Noodmaatregelen. (n.d.). *Verhogen dijkkruin met zandzakken*. Retrieved October 19, 2023, from https://v-web002.deltares.nl/sterktenoodmaatregelen/index.php/Verhogen_dijkkruin_met_zandzakken

Wilke, C. (2023). *Plants build dunes but can speed erosion during severe storms*. Retrieved October 10, 2023, from https://www.preventionweb.net/news/plants-build-dunes-can-speed-erosion-during-severe-storms

Wolfert, A. (2023, August). *Open Design systems*. IOS Press.

Zhang, R., Chen, Y., Yao, P., Stive, M. J., & Zeng, J. (2023). Numerical simulations of effects of the layout of permeable pile groin systems on longshore currents. *Journal of Marine Science and Engineering*. https://doi.org/10.3390/jmse11091823

A

Extreme value analysis of the wave climate

Relevant data by Savioli et al. (2011) is selected from the data-set. The following data is extracted from the data-set: wind-speed, wind direction, resulting significant wave height ($H_s res$), peak period and wave directions. This data is subjected to an extreme value analysis (EVA). The EVA was implemented using the pyextreme python library. The waves travelling in westward direction, in the direction of Playa Unión and Puerto Rawson are considered. The extremes are selected with the peak over threshold (POT) method. A threshold of 4 metres for wave height and 10 m/s for wind speed were used. A declustering time of 72 hours was used. A generalized Pareto distribution was found to be a good fit for the data, on which the different values of significant wave height and wind speed belonging to the different return periods were determined. The peak period corresponding to the return periods is determined by making a fit of peak periods with the corresponding significant wave heights and extrapolating this fit. The results of the EVA can be found in Table 4.2.

Significant wave height and wind speed for different wave directions were calculated. The wave direction range from 130-140 degrees is calculated because the waves propagate in this direction to Playa Unión and Puerto Rawson. A threshold of 2 metres of significant wave height is used because there were too few extremes to conduct a viable extreme value analysis with a threshold of 4 metres. The results of the EVA are shown in Table A.1. Since the assumption was made that both examined points have the same sea state the waves originating from the wave direction 25-190 degrees to Playa Unión and Puerto Rawson are also subjected to the EVA. Here the threshold of 4 metres significant wave height is used. To analyse the impact of the wind on the wave climate, different wind directions were also analysed and subjected to an EVA to calculate significant wave height and wind speed. The same direction ranges as for waves are used to calculate the wind speed with the corresponding return periods. The threshold used for the EVA is 10 m/s. The results for the different direction ranges can be found in Table A.3 and Table A.3.

Table A.1: Waves from 130-145 degree range

Return period (Years)	Yellow point Figure 4.1		
	Hs (m)	Tp (sec)	Windspeed (m/s)
5	3.93	9.0	15.80
10	4.13	10.9	16.53
25	4.36	13.2	17.40
50	4.50	14.5	17.97

Table A.2: Waves from 25-190 degree range

Return period (Years)	Yellow point Figure 4.1		
	Hs (m)	Tp (sec)	Windspeed (m/s)
5	6.71	10.3	19.98
10	7.00	12.2	20.47
25	7.34	14.4	20.97
50	7.55	16.0	21.26

Table A.3: Wind from 130-145 degree range

Return period (Years)	Yellow point Figure 4.1		
	Hs (m)	Tp (sec)	Windspeed (m/s)
5	4.04	8.8	12.40
10	4.50	9.7	13.40
25	5.09	10.9	14.85
50	5.54	11.6	16.06

Table A.4: Wind from 25-190 degree range

Return period (Years)	Yellow point Figure 4.1		
	Hs (m)	Tp (sec)	Windspeed (m/s)
5	5.55	11.2	16.41
10	6.01	12.4	17.18
25	6.60	13.9	18.10
50	7.02	15.0	18.74

During this research, a storm surge duration of a week was mentioned in one of the interviews. Therefore the analysis was also done with a declustering time of 168 hours. However, the difference was insignificant compared with the analysis with a declustering time of 72 hours. The results of the EVA with a different declustering time and with different wind and wave directions can be found in Table A.5, Table A.6, Table A.7 and Table A.8.

Table A.5: Waves from 130-145 degree range (168 hours)

Return period (Years)	Yellow point Figure 4.1		
	Hs (m)	Tp (sec)	Windspeed (m/s)
5	3.93	9.0	15.82
10	4.14	10.9	16.58
25	4.37	13.2	17.47
50	4.51	14.5	18.06

Table A.6: Waves from 25-190 degree range (168 hours)

Return period (Years)	Yellow point Figure 4.1		
	Hs (m)	Tp (sec)	Windspeed (m/s)
5	6.75	10.3	20.26
10	7.03	12.2	20.63
25	7.34	14.4	20.96
50	7.53	16.0	21.11

For waves from the 25-190 wind range, a threshold of 3 metres is used.

Table A.7: Wind from 130-145 degree range (168 hours)

Return period (Years)	Yellow point Figure 4.1		
	Hs (m)	Tp (sec)	Windspeed (m/s)
5	4.05	8.8	12.40
10	4.50	9.7	13.40
25	5.08	10.9	14.85
50	5.52	11.6	16.06

Table A.8: Wind from 25-190 degree range (168 hours)

Return period (Years)	Yellow point Figure 4.1		
	Hs (m)	Tp (sec)	Windspeed (m/s)
5	5.55	11.2	16.49
10	6.01	12.4	17.20
25	6.58	13.9	18.02
50	6.98	15.0	18.56

B

Grain size analysis

On the 4th of October 2023 a grain size analysis was performed between the two northern breakwaters. The goal was to determine the sort of sediment that accumulated there. The locations of the samples can be seen in Figure 4.8. The exact coordinates of the locations of the samples can be found in Table B.1.

Table B.1: Coordinates of the nine sediment samples

Locations	Coordinates
A1	43° 20' 23.4" S 65° 3' 12.3" W
A2	43° 20' 26.1" S 65° 3' 5.4" W
A3	43° 20' 28.8" S 65° 3' 12.4" W
B1	43° 20' 23.3" S 65° 3' 12.4" W
B2	43° 20' 28.1" S 65° 3' 7.3" W
B3	43° 20' 30.7" S 65° 3' 2.1" W
C1	43° 20' 28.8" S 65° 3' 14.1" W
C2	43° 20' 30.9" S 65° 3' 9.2" W
C3	43° 20' 33.0" S 65° 3' 2.9" W

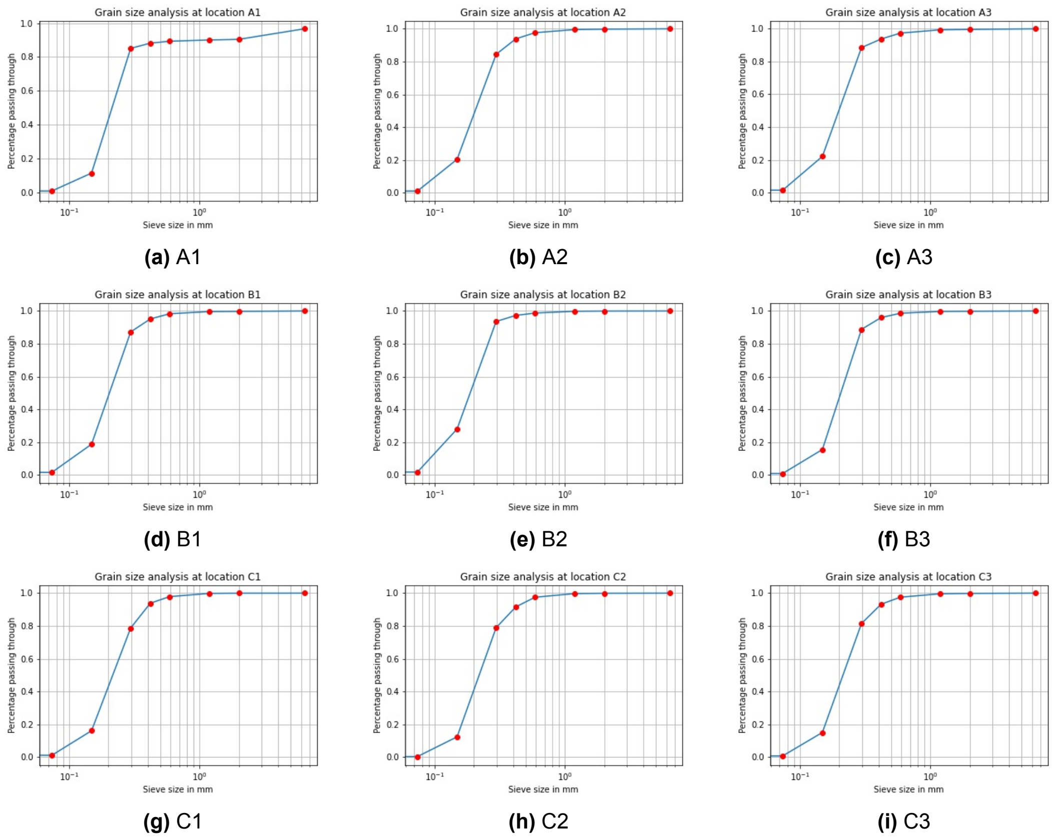
The samples were taken five centimetres below the surface and stored in plastic containers, as can be seen in Figure B.1a. The samples were dried and sieved in the Laboratorio de Investigaciones y Ensayos Viales (LABIEVI). There were only hand sieves available to conduct the tests, this makes the results not perfect, but they are still pretty reliable. In truth the samples would be a bit finer than presented, but this difference is negligible. The sieving process is shown in Figure B.1b.

(a) Collecting samples

(b) Sieving material

Figure B.1: Conducting the grain size analysis

The grain size analysis was performed by shaking hand sieves and weighing the sediment per sieve. This is not the most accurate method but the only one that could be performed at the project location. The sieve sizes that were selected for the test were 6,35mm; 2,00mm; 1,19mm; 0,59mm; 0,42mm; 0,297mm; 0,149mm and 0,074mm. This corresponds with sieve numbers 1/4", 10, 16, 30, 40, 50, 100 and 200. After sieving the different-sized residue was weighed on a scale that was precise to one decimal after the comma. The results are plotted in figure B.2, and the data to plot this is shown in Figure B.3.



(a) A1 **(b)** A2 **(c)** A3

(d) B1 **(e)** B2 **(f)** B3

(g) C1 **(h)** C2 **(i)** C3

Figure B.2: Plots of the grain size analysis

Sample		A1	A1 per	A1 cum	A2	A2 per	A2 cum	A3	A3 per	A3 cum	B1	B1 per	B1 cum	B2	B2 per	B2 cum	B3	B3 per	B3 cum	C1	C1 per	C1 cum	C2	C2 per	C2 cum	C3	C3 per	C3 cum
Sieve size																												
0,000		3,10	0,01	0,00	3,70	0,01	0,00	4,90	0,01	0,00	5,60	0,01	0,00	6,70	0,02	0,00	3,40	0,01	0,00	4,20	0,01	0,00	1,00	0,00	0,00	3,80	0,01	0,00
0,074		34,40	0,11	0,01	74,50	0,19	0,01	67,70	0,21	0,01	66,10	0,17	0,01	104,80	0,26	0,02	62,20	0,15	0,01	61,50	0,15	0,01	50,80	0,12	0,00	84,10	0,14	0,01
0,149		239,20	0,74	0,12	246,30	0,64	0,20	218,20	0,66	0,22	263,30	0,69	0,19	261,70	0,66	0,28	312,00	0,73	0,15	257,30	0,63	0,16	281,00	0,67	0,12	390,60	0,67	0,15
0,297		10,00	0,03	0,85	36,30	0,09	0,84	17,20	0,05	0,88	30,40	0,08	0,87	14,70	0,04	0,94	30,50	0,07	0,89	62,20	0,15	0,79	53,40	0,13	0,79	69,30	0,12	0,81
0,420		3,70	0,01	0,88	14,50	0,04	0,94	11,80	0,04	0,94	12,20	0,03	0,95	5,80	0,01	0,97	11,30	0,03	0,96	16,50	0,04	0,94	25,00	0,06	0,92	25,00	0,04	0,93
0,590		2,40	0,01	0,89	7,30	0,02	0,98	6,60	0,02	0,97	5,10	0,01	0,98	4,30	0,01	0,99	4,60	0,01	0,99	8,10	0,02	0,98	9,40	0,02	0,98	12,30	0,02	0,98
1,190		1,20	0,00	0,90	1,00	0,00	1,00	0,80	0,00	0,99	0,50	0,00	1,00	0,50	0,00	1,00	0,50	0,00	1,00	0,50	0,00	1,00	0,80	0,00	1,00	1,30	0,00	1,00
2,000		20,20	0,06	0,90	0,80	0,00	1,00	1,20	0,00	0,99	0,90	0,00	1,00	0,20	0,00	1,00	0,70	0,00	1,00	0,10	0,00	1,00	0,30	0,00	1,00	0,90	0,00	1,00
6,350		11,00	0,03	0,97	0,00	0,00	1,00	0,60	0,00	1,00	0,00	0,00	1,00	0,00	0,00	1,00	0,00	0,00	1,00	0,00	0,00	1,00	0,00	0,00	1,00	0,00	0,00	1,00
		325,20			384,40			329,00			384,10			398,70			425,20			410,40			421,70			587,30		

Figure B.3: Results Grain size analysis

C
Bathymetry

The most clear area where erosion occurs is on the north side of the short breakwater. The beach is eroded to such a point that during a storm the boulevard beside the beach has been destroyed. This is clearly visible in Figure C.1 and Figure C.2. Even though it is high tide in figure C.1 and in between high and low tide in Figure C.2 the difference in the deposition/erosion caused by human influences can be seen. In 2023 there is a difference in the distance the sea goes towards the coast, this indicates that the shape of the beach has changed.

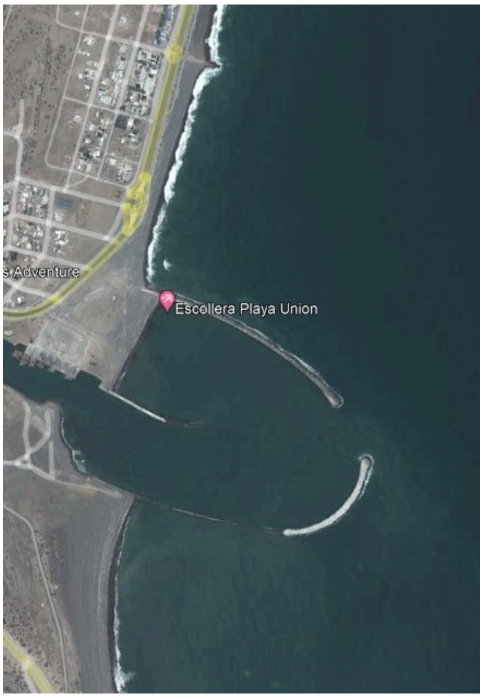
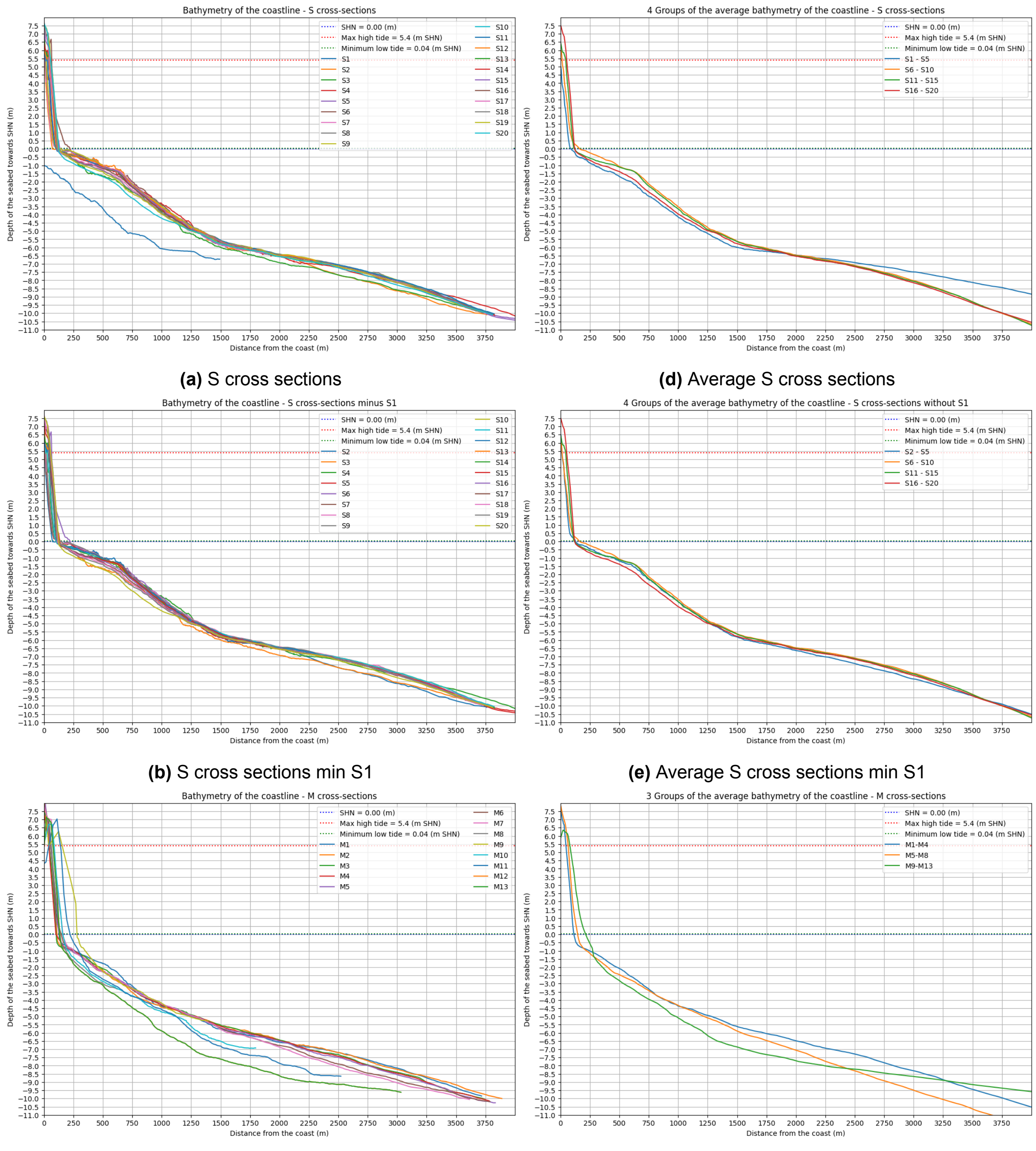


Figure C.1: Playa Unión, 13 December 2011 (Google Earth)

Figure C.2: Playa Unión, 5 January 2023 (Google Earth)

In Figure 4.10 the places of two of the different cross sections can be seen. The PM cross section is from Playa Magagna to the southern breakwater with a spacing of 250 metres between the cross sections (not in the figure).
The S cross sections have a spacing of 100 metres between the cross sections (yellow in the figure). The M cross section has a spacing of 250 metres between the cross sections (pink in the figure). The N cross section is from the Las Toninas statue to 6 kilometres north of the monument with a spacing of 500 metres between the cross sections (not in the figure). For

the analysis, all the S cross sections and cross sections M01 to M13 are used. These are the cross sections that are located in the project area.
The results of the analysis are shown below in Figure C.3. A relevant close-up closer to the beach is given in Figure C.4.



(a) S cross sections

(d) Average S cross sections

(b) S cross sections min S1

(e) Average S cross sections min S1

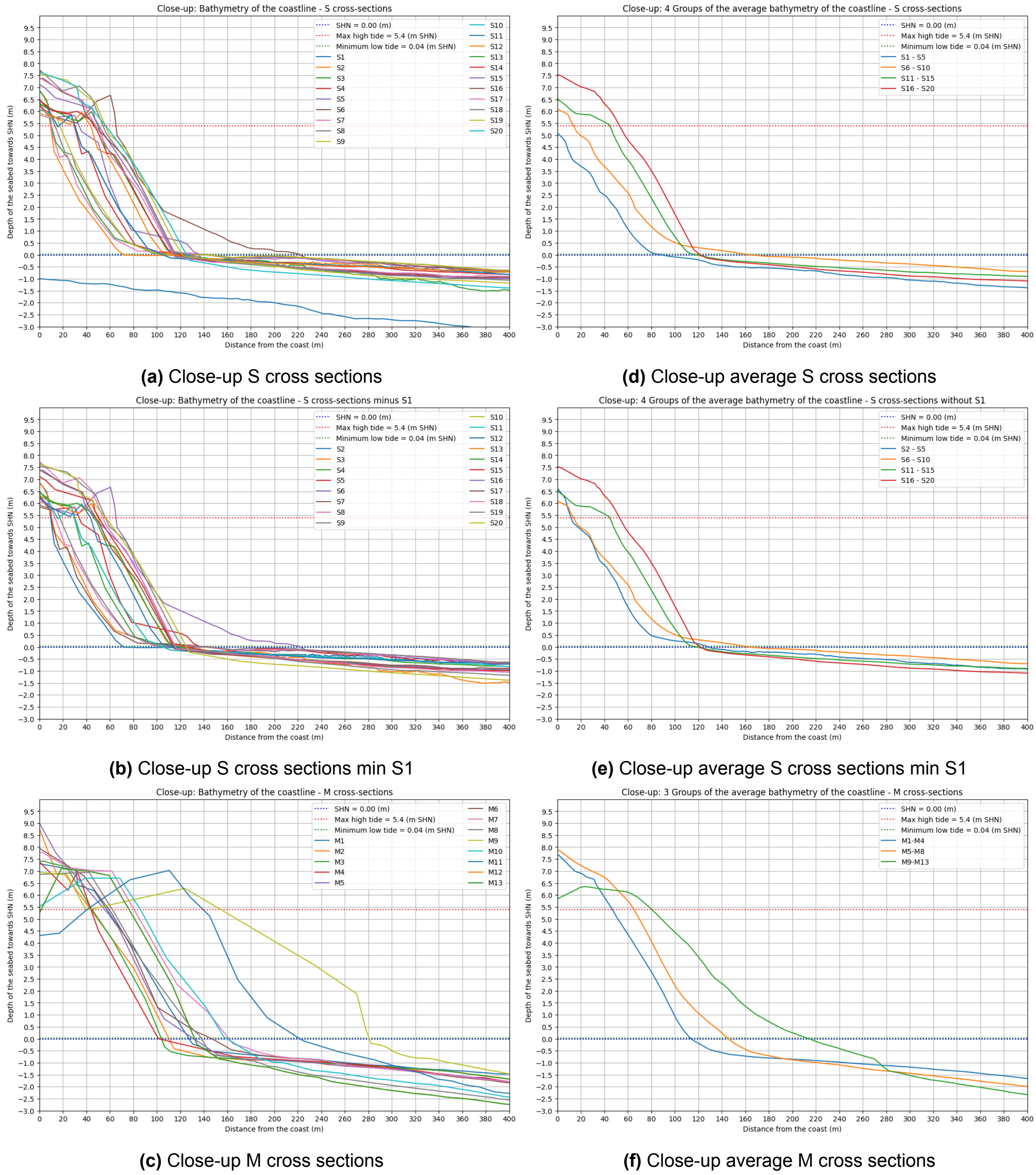
(c) M cross sections

(f) Average M cross sections

Figure C.3: Analysis of the bathymetry data

As can be seen in Figure C.3a The cross section S1 is an outlier. It seems that the reference frame during this measurement is shifted in comparison with the other measurements. So, when calculating the average bathymetry of the coastline, a calculation without S1 is also made. The cross sections are divided into groups of four or five cross sections. The results of the average bathymetry of the cross section groups can be found in Figures C.3d, C.3e and C.3f. From this, the averages slope of the lower profiles of the bathymetry are determined.

The slope of the lower profile can be found in Table C.1. For a better understanding upper profile of the bathymetry of the coastline a close-up of the graphs in Figure C.4 is made. The results can be found in Figure C.1 below.



(a) Close-up S cross sections

(d) Close-up average S cross sections

(b) Close-up S cross sections min S1

(e) Close-up average S cross sections min S1

(c) Close-up M cross sections

(f) Close-up average M cross sections

Figure C.4: Close-up of the analysis of the bathymetry data of (Savioli et al., 2011)

A clear distinction between the lower and upper profile of the bathymetry can be seen in Figure C.4. The slopes of the upper profile are determined from Figure C.4d, Figure C.4e and Figure C.4f. The determined slopes can be seen in Table C.1.

Table C.1: Slope of the lower and upper profile for the different cross sections

Cross section	Upper slope	Lower slope
S1-S5	1/16	1/233,3
S2-S5	1/13,3	1/236,8
S6-S10	1/18,2	1/240,9
S11-S15	1/15	1/281,9
S16-S20	1/13.6	1/255
M1-M4	1/17.1	1/254,5
M5-M8	1/18.8	1/268,8
M9-M13	1/29.3	1/300

During a site analysis on 14 September 2023 the particle size along the coastline was recorded, the overview can be seen in Figure C.5.

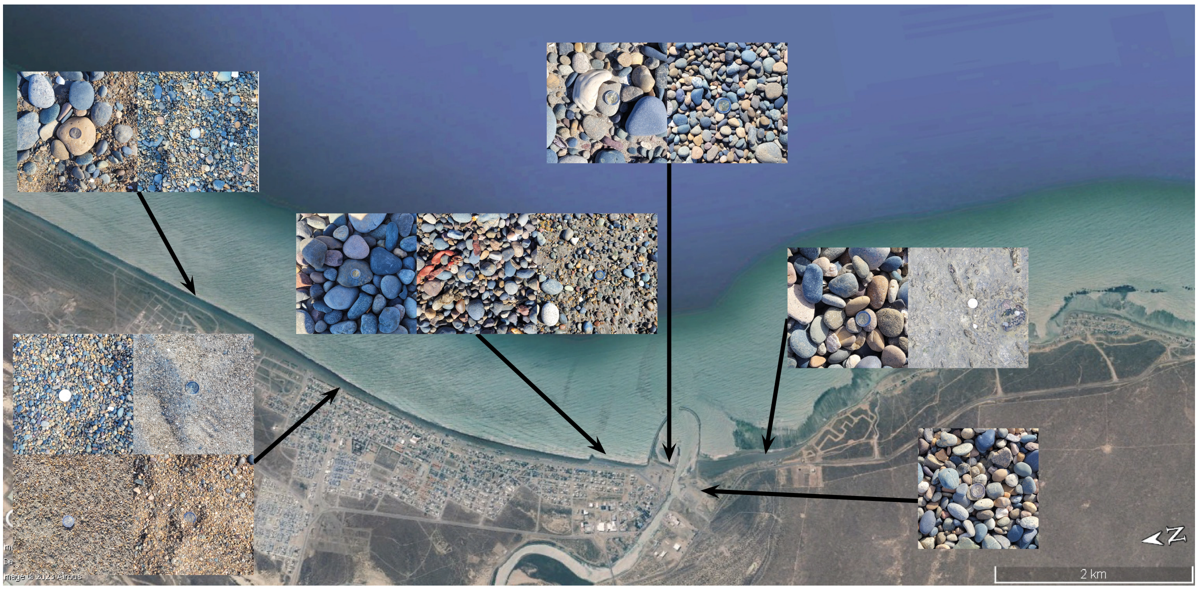


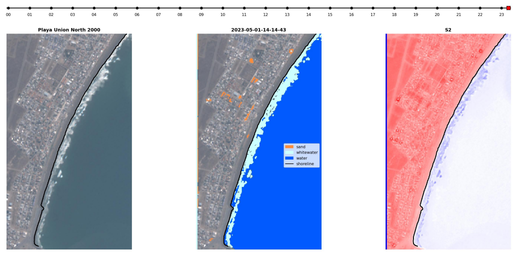
Figure C.5: Particle size according €2 coin, 14/09/2023 (Adapted from Google Earth 2023)

D Coastsat analysis

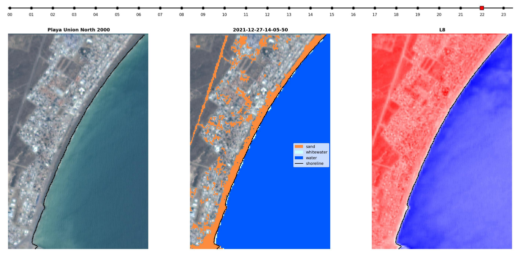
The analysis is done with images of three satellites, the Landsat-7 (L7), Landsat-8 (L8) and Sentinel-2 (S2). Between 27-07-2000 and 2023-05-10 images between the Toninas statute and northern breakwater are collected. The first image by L8 is from 22-03-2013 and the first image of S2 is from 19-08-2015. In total 866 images by L7 are used, 349 images by L8 and 1518 images by S2. The more recent images of L7 have gaps as seen in Figure D.1. For S2 part of the images only includes a small part of the requested shoreline and the mapping does not work. The other S2 images are high quality. Detection of sand is difficult for both dark and default settings in the tool. For S2 the detections of sand are not at all effective.

A reference shoreline is created by hand. The mapped shorelines are not further than 100 metres from this shoreline. The mapped shorelines are selected for use by hand. The full data set includes 926 shorelines. At the top and bottom of the image, there are more errors in detecting the shoreline, especially for the L7 satellite. There is less L7 data available close to the port.

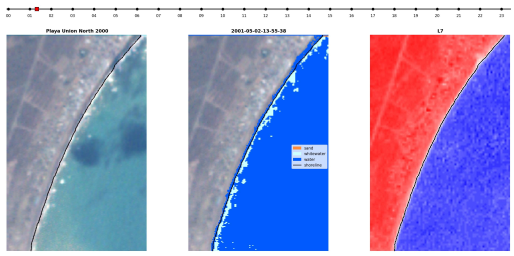
The data is post-processed to find the seasonal and long-term trend. As part of this outliers are removed. A value for the maximum allowed consecutive change can be set. When 40 metres is chosen, many points get removed. This is probably due to the data not being tidally corrected. When a max value of 50 metres is chosen, zero points are removed. It does not make a difference in the result for the long-term trend when outliers are not removed or not. The images are also tested with the Otsu criteria for the minimum and maximum intensity threshold used for contouring the shoreline. Based on this criteria an outlier could be removed.



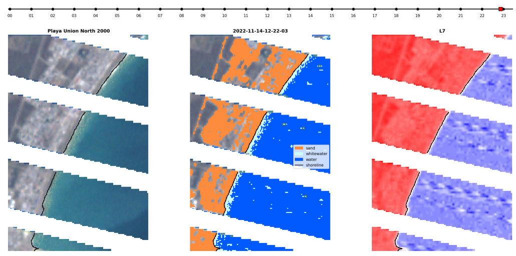
(a) Sentinel-2 14-05-2023



(b) Landsat 8 27-12-2021



(c) Landsat 7 02-05-2001



(d) Landsat 7 14-11-2022

Figure D.1: Examples of detected shorelines for the different satellites

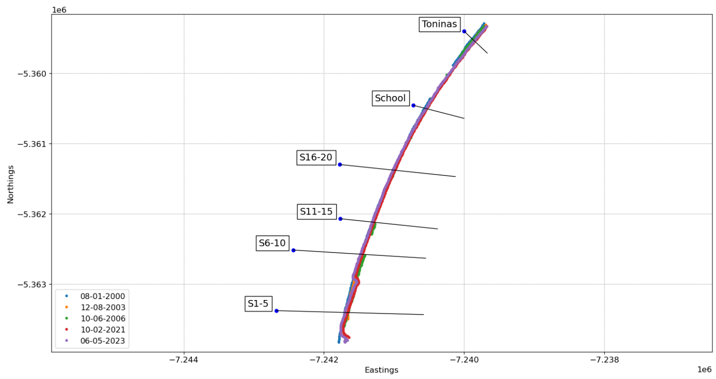


Figure D.2: Overview of the six cross sections used

D.1. Erosion calculation

This section presents a calculation of the erosion rate. It has to be mentioned that is not verified by any recent observations. Therefore, the accuracy is unknown. The averaged long-term erosion rate is used to determine an estimation of the yearly erosion rate along the shore. The first calculation can be seen in D.4. This calculation is done with the six cross sections presented in the main text.

To calculate the lost area per cross section, a parallelogram is used. With the approximate height of the upper slope and the observed coastal retreat as its length. The height of the upper slope is obtained from the corresponding averaged cross sections in section 4.3. These measurements were made in 2011 and might not closely resemble the present-day situation. Although the height of the upper slope is likely to be stable. The land behind the coast is flat. The level of the lower end of the slope is determined by tidal and wave forcing, those could be expected to be somewhat constant in the long term. If the beach slope is changing due to the erosion, the parallelogram calculation would not be valid anymore and erosion values could be different.

Figure D.3: Overview of the twelve cross sections used as shown on the map

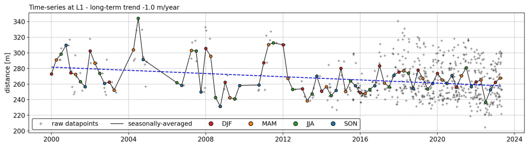
Total distance	3400	metre										
First calculation	Long term trend											
Transact	Coastline m/year	Represeted distance m	Upper slope	slope	Upper limit upper slope m SHN	Lower limit upper slope m SHN	Heigth	Eroded area m^2/year	eroded volume m^3/year			
Toninas	0,7	300	M5-M8	1/17,1	8	-0,5	8,5	-5,95	-1785			
School	0,1	800	M1-4	1/18,8	7,75	-0,5	8,25	-0,825	-660			
S16-20	-1,2	900	S16-20	1/13,6	7,5	0	7,5	9	8100			
S11-15	-1,3	500	S11-15	1/15	6,5	0	6,5	8,45	4225			
S6-10	-1	500	S6-10	1/18,2	6	0,5	5,5	5,5	2750			
S1-5	-0,5	500	S1-5	1/16	5	0	5	2,5	1250			
								total erosion	16325	m^3/year	total erosion over 2400 metres of the coast	
								total accumulation	2445	m^3/year	more setteling expected north of the study area	

Figure D.4: First calculation of the erosion rate

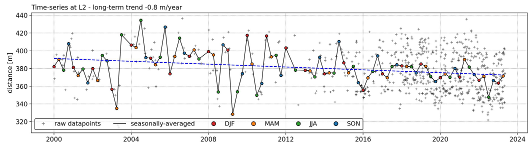
A first calculation is done with estimated distances between the transacts. This shows there is structural erosion over 2,4 kilometres of the coast, up to the school cross section. In this cross section there is however much coastal retreat in the winter of 2022, with only partial recovery. For the second estimate, the coast is divided into 12 cross sections with a spacing of 200 metres from the northern breakwater to the school cross section of the previous calculation, where the erosion zone ends. The first and last sections are 100 metres from those points. The calculation is shown in Figure D.6.

In the seasonally averaged time series, a retreat of the coast of almost 20 metres can be observed in the winter of 2022, in some cross sections. Afterwards, the coast has recovered partially. With a small calculation the required transport from the beach, for this retreat, can be calculated. However, not all of this erosion is permanent longshore transport, as can be seen by the recovery in the months after. The other part is due to cross shore redistribution of sediments. This is known to happen as a result of larger waves.

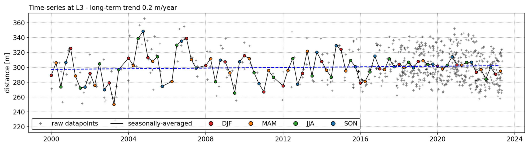
In Figure D.5c the long-term trend is positive. This cross section is located close to the up-drift side of the short breakwater. Here, sediment is accumulating as a result of that breakwater. The accumulation in the sector is subtracted from the total erosion rate.



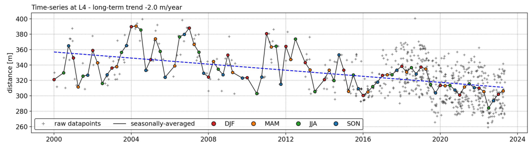
(a) Cross section L1



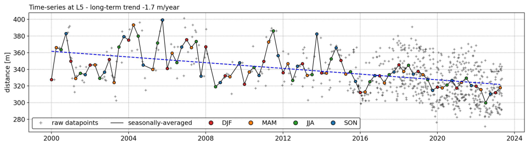
(b) Cross section L2



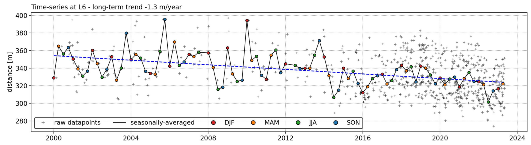
(c) Cross section L3



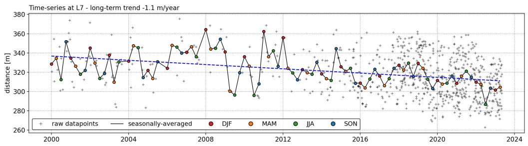
(d) Cross section L4



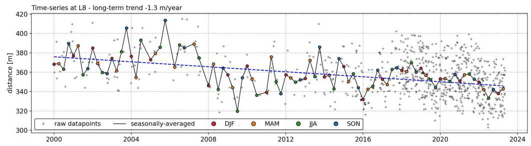
(e) Cross section L5



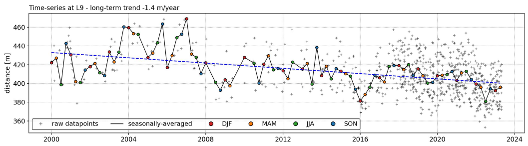
(f) Cross section L6



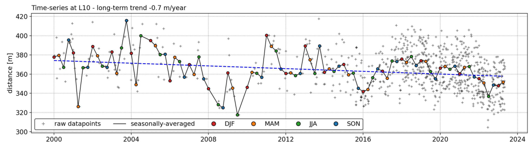
(g) Cross section L7



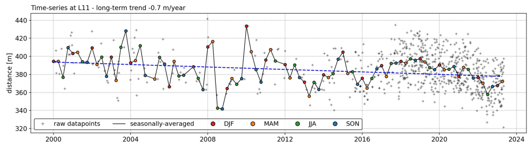
(h) Cross section L8



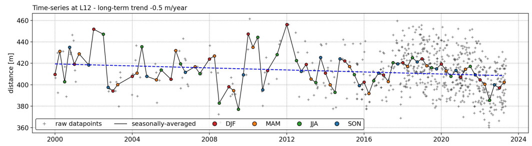
(i) Cross section L9



(j) Cross section L10



(k) Cross section L11



(l) Cross section L12

Figure D.5: Seasonally averaged time series with long term trend of coastline evolution, in twelve cross sections

Second calculation						
	Long term trend					
Transact	Coastline m/year	Represeted distance m	Upper slope	Heigth	Eroded area m^2/year	eroded volume m^3/year
L1	-1	200	S1-5	5	-5	1000
L2	-0,8	200	S1-5	5	-4	800
L3	0,2	200	S1-5	5	1	-200
L4	-2	200	S6-10	5,5	-11	2200
L5	-1,7	200	S6-10	5,5	-9,35	1870
L6	-1,3	200	S6-10	5,5	-7,15	1430
L7	-1,1	200	S11-15	6,5	-7,15	1430
L8	-1,3	200	S11-15	6,5	-8,45	1690
L9	-1,4	200	S11-15	6,5	-9,1	1820
L10	-0,7	200	S16-20	7,5	-5,25	1050
L11	-0,7	200	S16-20	7,5	-5,25	1050
L12	-0,5	200	S16-20	7,5	-3,75	750
					total erosion	**14890**
winter 2022	coastline retreat m	Represeted distance m		Average heigth m		
	-20	2400		6,125	-122,5	294000
Because of the recovery after, this erosion is probabliy largely due to cross shore transport						

Figure D.6: Detailed calculation of the erosion rate and erosion during the coastal retreat in the winter of 2022

D.2. Further research with this method

This report demonstrated that this method provides valuable information on the long-term evolution of the coast and can give information about seasonal trends. The method can be elaborated further in future studies.

The first step is to use the method provided in the CoastSat tool to correct the mapped shorelines for the tidal level. For even more accurate results measured water levels could also be used for this. The tidally corrected data should have a smaller spread. This allows for a more detailed time series analysis. It is interesting if this will change the detected long-term trend and show the possible four to five-year oscillation, or a different large-scale oscillation.

The CoastSat tool can be retrained in order to better function for the specific site. By retraining the model it might be able to detect the beach in the images. Especially the Sentinel-2 images, where the beach is not detected in this study, see Figure D.1. The retraining could result in a more accurate assessment of the shoreline position.

The Landsat-5 satellite was operational from 1984 to 2013, the images of this satellite can also be included in a future study. In this way, the evolution of the shoreline before the construction of the new breakwaters can also be traced. It will also help to understand the long-term variation.

The CoastSat method can be used to determine the accumulation rates south of the port and to the north of the study area for this report. This will help to better understand the system and the sediment budget in the area.

The cross sections taken with this method should be validated with observed profiles of the shore over multiple years. In such a way that the satellite images can be used thereafter to track the erosion rate of both the lower and upper shoreface accurately. For this, the depth of closure must be determined at least.

E

Interview script

To get a clear insight in the opinions and visions of the stakeholders, a number of interviews were conducted. For these interviews, a general script is used which is adapted to the stakeholder. Every interview started with a short presentation about the group and the aim of the project. With each interview, it is tried to get an answer on these three main questions:

1. What is your occupation?
2. What are the challenges you see?
3. What are the opportunities you see?

Depending on the stakeholder, there were also subcategories, for example, questions about the current dredging and the operation of the governmental bodies. Most of the time, not all questions needed to be asked and the scripts were used as support. Below is the script for the interview with the mayor as an example.

General Questions

- How long do you live in the area of Playa Unión and Puerto Rawson?
- What are you involved in as mayor of Rawson?
- Do you have authority in the port?
- How is your relationship with the parties involved in the port?

Erosion coast

- What is your opinion on the coastal erosion happening right now?
- What consequences does the erosion have on the port, Playa Unión, safety, infrastructure, and tourism?
- Are there countermeasures in place for the erosion?
- What possible solutions do you see?
- What is the current policy regarding the coastline?

Port expansion

- Are you involved with the expansion of the port?
- What is your view on the expansion of the port?
- What are the consequences of the port expansion? Positive and negative.
- Are there future expansion plans of the port?
- What are these plans?
- What is the goal of the port expansion in your view?

F

Interview Summaries

This appendix will contain the summaries of the conversations held during the project. These conversations not only formed the basis for the stakeholder analysis, but also provided valuable information on the context of which this project is situated. Figure F.1 shows an overview of the interviewees.

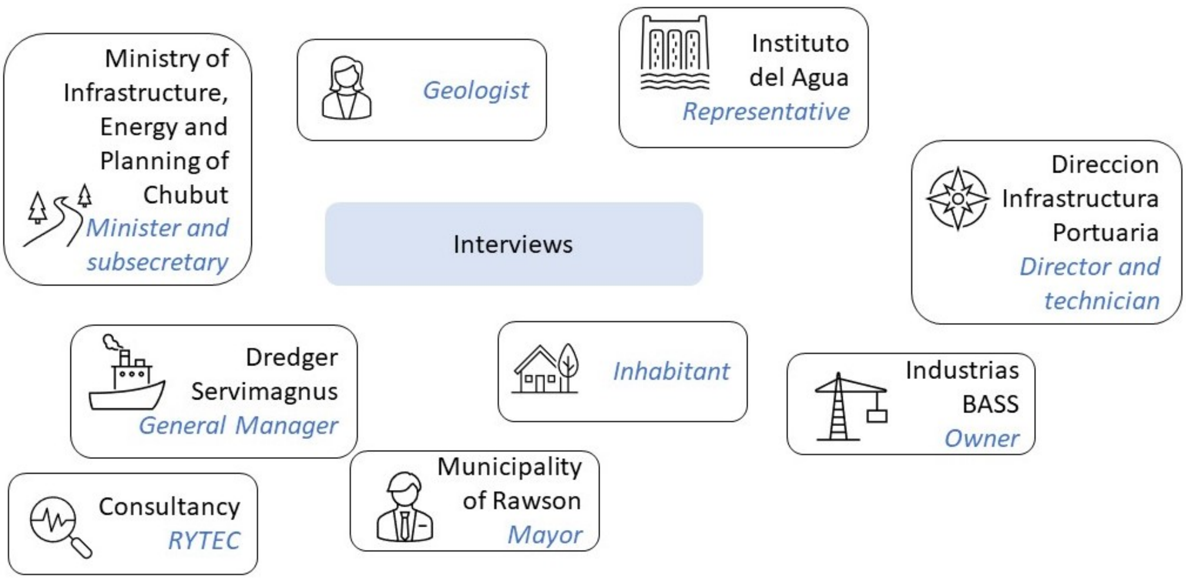


Figure F.1: Overview of the interviewees

Interviews were conducted with the following stakeholders:

- Martin Castillo: director of Industrias BASS
- Damian Biss: mayor of Rawson, Puerto Rawson and Playa Unión
- Gustavo José Aguilera: the minister of Infrastructure, Energy and Planning of Chubut
- Leandro Foletto and Jose Luis Quinones: project area technician and director of the Dirección de Infraestructura Portuaria
- Martin Nozijkoswki: employee of the Instituto del Agua Chubut
- Claudia Bracco: inhabitant of Playa Unión
- Lic. Ramirez Matías F. and Lic. Yauhar Nair: researchers of the consultant agency RYTEC
- Mercedes Bagalciaga: geologist

F.1. Rytec

Puerto Rawson's Dredging Project

RYTEC is a Consultant Agency that was hired by SUDELCO, the winning company of the public tender to execute Puerto Rawson 's dredging. The researchers of this Consultant Agency are Lic. Ramirez Matías F. and Lic. Yauhar Nair, both specialists with environmental degrees and experience both in the private and public sector.

Since hired (may 2022), they were assigned to elaborate an "Environmental Management Plan", for an "approved" environmental study that was made in 2007, requested by the province government. Although the consultants explain to their client and local government representatives that such and old study was questionable and the requested plan may not be enough, when insisted, they elaborated the requested document.

With that old study, the province government gave the green light for the public tender (hence SUDELCO's winning and then hiring RYTEC).

Since the dredging is for the provincial government, a provincial company gets the job. SUDELCO won because there are no dredging companies in Chubut and they associated themselves with SERVIMAGNUS (a dredging company from Buenos Aires).

The province's Environmental Authority, which originally gave the green light for the public tender, did not officially agree with RYTEC, but also considered that an Environmental Management Plan and the 2007 study was not enough. This happened in the last days of August 2022. It implied that an update of the original study had to be made, giving the consultants only two months to elaborate a new document (basically a new Environmental Impact Study that takes way more time, information and resources than the ones available).

The updated study was presented to the local and provincial authorities and then got to a "public consult" process. This process lets neighbours and interested parties take a look at the documents and send consults, objections and other opinions to the Environmental Authority. The entire process of receiving and answering the authorities' request, and the people's questions, took a lot of time for aspects that are not relevant to this summary.

Eventually, the project got approved, in May-June 2023 with local resistance from some neighbours.

RYTEC's conclusions, regarding the research on the project, were:

- The port's environment has not been natural for a long time, getting to a new balance between environment and fishing activities. This new environment has survived until now, despite some really pollutant activities that took place years ago, nowadays those activities are restricted. This evolution tends to mark that after dredging this environment will flourish again, but this will be a matter of time.
- Dredging must take place in autumn and/or winter. This is due to some estuary algae that cause a natural phenomenon called red tide ("Marea Roja" in Spanish). These algae flourish during spring and summer, due to the higher water temperatures. The stirring of the dredging can bring forward this red tide effect due to the the anthropic resuspension of these algae into the water. Mollusc and bivalves eventually filter this algae, incorporating the toxin and when people eat this seafood, they get poisoned.
- Dredging is not allowed in December until March (summer), and whenever possible, it should not be done in spring.

Due to the previously explained delay of the dredging, there needs to be dredged in spring to be done in time. The province government (through the companies SUDELCO and SERVIMAGNUS) is allowed to dredge in the months of September, October and November (spring) if three conditions are met:

1. There has to be a technical “translator” with environmental knowledge and expertise, between the two provincial authorities involved in the dredging operations (the environmental authority that controls the results and the Dirección de Infraestructura Portuaria that carries out the project through the companies). Lic. Ramirez took this role, making reports that included different aspects of the project and its execution.
2. The reports made by Lic. Ramirez has to be on a weekly basis.
3. The water and sediment parameters need constant monitoring in comparison with previous information provided by CENPAT, who did the ground analysis before the dredging took place. To make sure the toxic algae levels in the water are not too high. In addition, the consultants requested a baseline laboratory analysis of the beach sediments, due to the sedimentation processes that take place in the area.

The old plan was to dredge on both sides of the bridge, and also dredge more at the end of the harbour to create sediment traps. When the dredging was stopped, money still needed to be paid because the dredger was already hired and on location. So, now there is only money left to dredge the main canal.

Table F.1: Timeline actions Rytec

Year	Event
2006	1st CENPAT report, analysis the sediment and water quality.
2007	1st EsIA written.
2021	MIEP (project applicant, province government) asks MAyCDS (environmental authority, province government) and gets green light for the public tender. 2nd CENPAT report in November.
2022	SUDELCO/SERVIMAGNUS wins the public tender. May: SUDELCO hires RYTEC June/July: PGA presented, projects gets “started” by the MIEP. Dredger parts start arriving, land maneuvers start. August 26: PGA gets rejected, the MAyCDS request an update on the 1st EsIA. September 22: EsIA’s update gets presented (called “Adenda” in spanish) October-November: Public consult. RYTEC answers public questions and doubts. MAyCDS requests more information and impossible baseline studies for the sediments (considering the time frame and available laboratories).
2023	May/June: dredging approved. Land operation and planning re-starts 16 July: dredging starts. 18-19 July: dredging stops, because a Rawson’s mayor disregards the documents that got sent to him and his team, and presents a legal measure [1]. 14 August: dredging approval by judge, dredging can start again. 15 September: dredging re-starts again. The delay is due to climate conditions and necessary previous operations on land and vessel.

The dredging situation is taken to a judge, the first judge takes his hands off the subject and the second one deals with the situation.

When the dredging was stopped several people took samples, which were never examined and are not admissible because the people that took them were not authorized or did not have the expertise required, the samples did not get properly handled, etc:

- A biology teacher from a local university.
- The mayor, who stored the samples in Rawson's hospital.
- Prefectura Naval Argentina (naval authority).

Definitions

- EsIA: Estudio de impacto ambiental
- MIEP: ministro de Infraestructura, Energía y Planificación
- MAyCDS: Ministerio de Ambiente y Control del Desarrollo Sustentable
- PGA: Programa de Gestión Ambiental
- CENPAT: National scientific entity. Did a study of the water and sediment in the river (not necessary the dredged material at the bottom of the port)

Environmental Approval

In Argentina, if one wants to start a new project the following steps must be taken:

1. Send a short document, to the Environmental Authority, with a summary of the project's most important characteristics (process, impacts, equipment, etc.).
2. The Authority requests an environmental document according to the scope of the project:

Type of environmental documents:

1. Environmental Management Plan (EMP, PGA in Spanish), a simple plan to control impacts.
2. Environmental Project Description (EPD, DAP in Spanish), involves a detailed description of the process and impacts, of an EMP.
3. Environmental Project Report (IAP in Spanish), which goes through public consultation, is more complex than an EPD in both process description and impact management.
4. Environmental Project Study, (EsIA in Spanish) that goes through a Public Hearing, the most complex document, includes all of the above.

These documents become publicly available. During the public consult, every interested party has ten days to ask possible questions. During public hearings, interested parties have to register themselves and an official event takes place where the consults and objections are responded. Once the documents are presented, and exposed, they get analysed by technicians of the Environmental Authority. If they consider that more information or more measures must be taken, they request them from the project's applicant. Once there are no more requests, the project gets approved or declined.

F.2. Municipality of Rawson

Introduction

Damian Biss is the mayor of the city Rawson. Damian lives already for 38 years in Rawson, but was born in Buenos Aires. As mayor, he is involved in all kinds of things concerning Rawson, Puerto Rawson and Playa Unión. Also, Pablo Villalobos and Gustavo Zorrilla, from the tourism department, were present. Pablo Villalobos is an architect and is now looking into the urban planning of Rawson. For that, our project is really important.

Relation with other parties

Damian Biss has improved the relationships with the parties involved in the port after the last administration. He wants to improve the collaboration with these parties to stimulate the economy of Rawson. Currently, the fishery is the most important economic activity in this region. It is planned to boost the fishery activity in the port.

Port expansion

There is also contact with Industrias Bass about the port expansion on the private side of the port. This concerns the building of two more fishery piers and a pier for container ships. Damian approves this expansion. On the public side, two piers will be connected to form a bigger pier. To ensure that the ships can enter the port, it is absolutely necessary to dredge the port. Furthermore, there are plans to build a small marina in the area where a lot of sediment is accumulated. They want to make a harbour to encourage tourism, such as the dolphin (tonina) tours, touristic ships and restaurants etc. This land is not owned by the city of Rawson, but by the national government.

Coastal erosion

The coastal erosion problem is urgent to the mayor. Currently, a lobby is underway to declare the problem an emergency, in this way, they hope to get the funding and attention to undertaking the required measurements. Via the governor of Chubut, they hope to reach the national government. There has been a plan to build four short breakwaters parallel to the beach on the north of the port in previous administrations. This has not been executed. The mayor commissioned the University of Cordoba to undertake research into the sediment flows of the sea and the coast. A short-term solution is to build a short breakwater in the north to postpone the erosion problem.

F.3. Direction of Port Infrastructure

Introduction

Jose Luis Quinones is the director of the Direction of Port Infrastructure, DPI. Leandro Foletto is a project area technician, who has worked in the company only from 2010. The port infrastructure department is responsible for the surveying projects and supervision of the works of the ports in Chubut. It is not responsible for the maintenance, except for the Port of Rawson because this is a smaller port. So, in Rawson, they also do the maintenance of the docks. They work for the state and the public sector.

Plans of port expansion need to be presented to them, the plans however only need to be approved at a national level. They do not know if Industrias BASS presented and got their plans approved.

Port expansion

They have a negative vision of the expansion of the port. They think that more boats, which means more frequent dredging, will cause the dredged channel to collapse even faster. They think that more boats navigating inside the channel leads to more channel collapsing.

Besides that, they think that large ships of more than 140 metres will not be able to turn in the harbour. They think that such a large container ship will have a problem in this type of port, with its dock infrastructures and actual channel depth. They would like to see an expansion of the public side of the port since additional room is needed due to the high amount of ships.

Coastal erosion

In their opinion, the dam caused a slower flow and less discharge of the Chubut River (they mentioned a flow rate of 100 m3/s before the construction of the dam and after the construction a flow rate of 50 m3/s). This caused sediment to settle faster on the riverbed before reaching the sea and the sediment particles are smaller. The other problem is the vegetation that grows on the banks of the river and the need for maintenance.

Plants on the banks of the river also cause more sediment to settle. This in combination with the northern breakwater caused the erosion of the beach (in the northern zone of the Northern breakwater) of Playa Unión. They also think that the accumulation of sediments between the breakwater is due to the dynamics of the estuary and anthropic infrastructure.

The combination of pebbles/rocks on the beach is according to them coming from the southern part of the coast and only the sandy material is a result of the river sedimentation. North of the short breakwater, they constructed a small flood defence 4 years ago, this was done by the government and their consultants and contractors. Due to a small budget, the defense consisted of a line of rocks/concrete blocks parallel to the coast which got destroyed together with a part of the sidewalk and wall in a storm one and a half years ago.

So the approval of all hydraulic structures and the money comes from the national government. The last twenty metres of the head of the short breakwater are gone, this is due to the sea destroying it.

Dredging

The provincial government is responsible that the harbour is accessible and that the water depth is sufficient. They also receive taxes for barges entering the harbour. The provincial government therefore creates a contest for a tender for the dredging works.

This is financed by the national government. Because it is a tender on a provincial level, only a local company can tender for it. Sudelco wins this tender, but does not own a dredge barge. They cooperate with Servimagnus, a Buenos Aires-based company, to do the job. The view of DPI is that dredging needs to be done in order to keep the harbour accessible. And a plan for dredging for the maintenance of depth in the channel in the long term is necessary.

F.4. Ministry of Infrastructure, Energy and Planning from the province of Chubut

Introduction

Gustavo José Aguilera is the minister of Infrastructure, Energy and Planning (MIEP) of Chubut. The MIEP consists of several departments, one of which concerns the exploitation of two ports in Chubut. Puerto Rawson and Camarones depend on the province, and Puerto Madryn and Comodoro Rivadavia have their own administration. Big projects get their funding from the province or from the national government, in general, more expensive projects are funded by the state.

Erosion

Originally, there was a project to counter the erosion that's happening in Puerto Rawson and Playa Unión. The original project had five short breakwaters along the coast and one parallel to the coast. Only one short breakwater is constructed. The project was not completed because of the lack of money. The project was based on extrapolation of old data and assumptions. In 2019, they decided to go back to this project and to look again at what the short breakwater does. The University of Cordoba is looking further into it. The short breakwater should be a bit lower because a part of the sediment also needs to be able to pass it. They are now at the end of finishing this research and calculating how high the short breakwater should be. There is still no data. They tried smaller breakwaters, it holds some sediments, but when the weather is bad it does not protect. It is an improvement, but now an integral study has to be done.

The first small breakwater close to the Northern breakwater is not liked because it is too straight. Another one further away is more gradual, it follows the shape of the beach and is more efficient. See the drawing in Figure F.2, the gradual breakwater is in the north.

Figure F.2: Form of small breakwater Playa Unión

The road next to the beach is the place at risk. Initially, there were two more rows of housing, but they were taken away. The further you move north the steeper the beach gets. Close to the Northern breakwater the beach, at low tide, is more gradual and has more fine sands. The finer sand originates probably from the river.

The MIEP is working with the municipality of Rawson and there is an agreement to do something about the erosion after the election. They're thinking about a few more short breakwaters as a short-term solution. They also agreed to keep investigating the regions for the next few years to look into a long-term solution that will last for 30/40 years.

Port expansion

The current provincial expansion plans for Puerto Rawson consider the connection of the two piers. The orange part in the picture Figure F.3 is the land owned by the province. The ministry is also aware of the expansion plans on the private side of the port (the green part). In the future, it is likely that there will also be an expansion to the south of the southern breakwater (the yellow part). Expansion of the port of Puerto Rawson can be very interesting for the Flota Roja, because Puerto Rawson is closer to the fishing area than Puerto Madryn. Expansion of the port will lead to economic benefits for Rawson and Chubut. With the oil supplies running out in Comodoro Rivadavia, it is needed to look at other ways to boost the economy of Chubut.

Figure F.3: Possible locations for port expansions

Dam in the Rio Chubut

The dams in the Rio Chubut are trapping sediment that is being transported by the river. Therefore, it is unlikely that a lot of sediment is coming from the river. Before the dam was built, the fields along the river were damaged by the river. The dam was built to regulate the river and prevent damage to the fields alongside the river. The path of the river did not change after the building of the dam was completed. That sediment between the two northern breakwaters is possibly coming from the sea, see Figure F.4. The most sediment is coming from Magagna, it is eroding over there.

Figure F.4: Origin of sediments

F.5. Instituto del agua Chubut

Introduction

The interview was with Martin Nozijkoswki of the Water Institute of Chubut, named Instituto del agua Chubut. This institute was created in 2010 as a body with enforcement authority (Ley XVII N°88 to establish the Provincial Water Policy and strengthen the institutional management of the water sector in the Province of Chubut) and the Water Code of the Province of Chubut (Ley XVII N°53).

In particular, the text of the Water Code regulates everything necessary for the study, administration, use, control, conservation and preservation of water resources in the public and private domain in the provincial territory. It mainly refers to bodies of fresh water, including lakes, lagoons, rivers, canals, groundwater, and hydraulic works. However, the law establishes that it is the authority of application over public waters, watercourses, banks, riverbanks, river beds and hydraulic works in the provincial area, without specifying to which type of water it refers. Therefore, due to the occurrence of problems on the coast, and in the absence of a specific regulation, this responsibility was also assumed by the institute in 2013/14. The regulation on the endorsement of surveys, including legends of restriction to the domain and maritime line, was carried out.

Regulations of the Water Institute:

- They regulate the use of the water, beds and bedsides, e.g. if companies want to build docks or ramps, and payment of fees according to the requested use.
- They have regulations for any interference with water, set out in Ley XVII N°88 and Ley XVII N°53.
- There is a specific regulation for direct space near a waterline. Along the river there is a 15 metre restriction on the domain, so not to build within 15 m from the river bank, for the sea shore this distance is 100 metres. If people want to build there, they need the approval of the Water Institute.

- In the port area, mainly in the areas that are developed on the river shore, the occupation of these areas must be authorised by the IPA, except for the pre-existing ones.
- Port works are authorised directly from the governor's office, which has full authority.
- One of the main river basins in the province is that of the Rio Chubut. Work is underway with the national government to install hydrometric and meteorological stations. These transmit online to the national hydrological database, which can be viewed through a web page on the internet.
- Work is also being carried out on the other 6 basins in the same way.

Port expansion

One of the main incomes of the province is fishing, so this industry must be allowed to grow. The ports in the surrounding area have larger vessels, so expansion is necessary to continue to compete. In addition, the Port of Rawson is the only port in the province that is still administered by the provincial state, so it is lower cost for users.

However, on the south side of the port, there is also a private dock. One of the private berths' construction was already in place before the regulations were implemented and did not satisfy the regulations. However, the new dock projects, designed after the regulations were formed, received some corrections from the IPA. Those corrections were the need for dredging and the construction of an additional breakwater.

Dredging

The dredged material in its first layer is contaminated, due to the waste generated in the port area. However, Martin has not seen studies of their composition to know if they produce any harmful effects. The volume of dredged material brought to the beach area is affected by the lateral marine current from south to north, so it is necessary to carry out works on the coast to retain these sediments. Martin understands that the dredging work has not been submitted to the IPA. He is not sure as it does not correspond to his area within the institute.

Coastal erosion
Shoreline erosion at Union Beach There are several reasons why the beach began to erode significantly:

1. Construction of the Ameghino Dam, which caused sediment retention, decreasing sediment transport downstream.
2. Construction of the Boca Toma weir and irrigation canals, which further retained sediment, decreasing downstream sediment transport in the river.
3. Reduction of lateral sediment transport in the sea from south to north due to port breakwater works.
4. Due to the implementation and growth of urbanisation. Due to this growth, the city has become a barrier to sediment transport from the mainland by wind transport. Coastal dunes have disappeared.

These processes are difficult to control and must be adapted and mitigated.

Chubut River
There is a second dam or overflow after the Ameghino Dam, called Boca de la Zanja or Boca Toma. This dam also stops part of the sediment transport. This dam was built to raise the water level so that it can flow into the VIRCH irrigation canals, the north main and south main. These canals are used to irrigate the lower valley of the Rio Chubut (VIRCH).

F.6. Industrias BASS

The following is a summary of the first conversation with Martín

Introduction

Industrias BASS is an industrial and construction company based in Trelew. Martin Castillo is the owner of the company. He founded it when he was 20 years old and started by making industrial products. They shifted towards construction, building the new bridge in Puerto Rawson. They also built a publicly funded quay wall in the port. This project got them into port construction. According to the company, the Argentine sea near Chubut province is one of the world's cleanest and least-exploited seas. It has abundant fishing resources. Camarones, Comodoro, Puerto Madryn, and Puerto Rawson are the province's four main ports. Camarones and Comodoro are surrounded by large cliffs and rocks, making expansion difficult. Because Puerto Madryn is in Golfo Nuevo, ships from there must travel a considerable distance before they can begin fishing. The company therefore sees a lot of opportunity to expand Puerto Rawson.

From 2018, Industrias BASS started working on a plan to expand the port on the southern shore of the river. With three new planned docks for fishing vessels and a multi-purpose dock that will allow large container vessels to dock in the port. At this moment the company has completed and sold one of these new docks. It was sold to a fishing company. The second dock is also nearing completion and the firm is looking for potential buyers for the final fishing dock. The construction of the fishing docks is accompanied by dredging of the river bank. The majority of this soil will be used for site preparation at the docks. The dredging and construction of the new docks have allowed larger fishing vessels, of the red fleet, to enter the port for the first time.

Challenges faced

The company indicates that in Argentina, it is hard to plan ahead for a few years and to have a long-term vision. A new provincial government, which is formed every four years, might have a different view and not approve certain plans. They have good hope that the current, new government (elected in July 2023), will agree with their expansion plans. They will have to see, because they need to present a proposal and then get approval or not. Furthermore, there are usually very few collaborations; they are the only party at this moment working on expansion of the port.

Future plans

For the container ships to be able to enter the port the bed level will have to be lowered considerably. This will also allow all fishing vessels to enter the port at every tide. Whereas now they can only enter during high tide. To protect ships at the new docks from waves, a new small breakwater has to be constructed perpendicular to the river. If the sediment dredged from the port is suitable, it could be used to combat coastal erosion. However, this could cause social problems, as happened with the province-commissioned maintenance dredging project. As the local residents did not want river sediment they believed to be contaminated moved to the beach.

The following is a summary of the second conversation with Martín

Sediment

Martin thinks that the sediment between the breakwaters is not suitable for supplementing the coast. The sediment in the river is very small particles of sand and clay, which would not be suitable. The origin of this sediment is, according to him, because saltt water comes up to Rawson during high tide. The water rising in the river before high tide takes sand of marine origin with it. The river sediment is very small and does not include rocks. All stones on the shoreline are of marine origin.

As a second element, wind blows in some of the silt between the northern breakwaters. The southern breakwater is old and not structurally intact, it allows sediment to enter the northern zone. Also, stones from a coastal defense built on Playa Magagna ended up between the breakwaters/in the port.

Dredging

Any solution including dredging does not have their preference, since it is not a permanent solution. But it is an option. They will need to get approval from authorities if they want to dredge and put the material at another location, like along the coast up north.

About the stability of the breakwater, they think it is designed for dredging to a level of -3 metres. For their expansion plans, they want to dredge to -6 metres. Dirección de Infraestructura Portuaria is the owner of the breakwater and there is no documentation about the strength of the breakwater. They have to do a study into the strength of the breakwater.

He thinks that the foundation of the breakwater is put on/into the Retinga/tuba and that it is very stable. With the dredging, the area that is dredged deeper, will be smaller than the existing channel, so it does not touch the foundation of the breakwater. However, they are not sure.

Port in the south

Martin would like to alter the southern coastline to make the sediment pass the breakwaters. It could be combined with a port expansion. He is interested in the idea of building a sediment bypass, however he does want it to be a natural/permanent solution.

He would like that the intervention will solve the problems of erosion in the south as well. We told him that is outside of our scope. He would like to emphasize that he is looking for an integrated solution, so the expansion plans for the south should help with the erosion problem and definitely not make the situation worse.

In case the dredging in between the breakwaters cannot be done due to the foundation of the breakwater, another plan is needed. The expansion of the port to the south will need a hard structure and maybe this can then serve as a breakwater. In this case, the southern breakwater can be removed.

The preferred solution
After a question about the stability of the breakwaters, Martín let us know that he does want us to be restrained with the local concerns. They want us to study if the solution is possible, and find the best possible solution. He specifically wants this place to grow in the future, in a way that all the problems are solved.
Also, there is no limit in what they would like to do. They hear all the time that they can not do it, like with the new ports in the south of the river, but they will fix it! They already started thinking about the expansion 15 years ago. It is important to start thinking about the next step, as these things do take time.

F.7. Mercedes Bagalciaga, the Geologist

Introduction

Mercedes has been a geologist for many years, first mainly working in advising in the mining business and more recently in the public domain. She also taught geology at the UNPSJB. She advised Industrias Bass multiple times because this is necessary if they propose a new project.

History of the Chubut Valley

Both the river and the sea have influenced the current coastal situation of Puerto Rawson and Playa Unión. The area was formed by spits growing from north to south eventually enclosing a lagoon of salt water and forming the new coastline. When these lagoons dry up they sometimes form a salt lake. Otherwise, only a depression of the land remains. The municipality of Trelew uses these lagoons for wastewater. The tuba flats called restinga are formed by the erosion of the coast. This is a tougher layer of soil that erodes slower and therefore forms these bedforms. This happens mostly at points along the shore that stick out and experience most erosion.

Sediment from the river

The sediment in the river may originate from rainwater that falls down on the dry lands, taking the particles along to the river. This rainfall can become very heavy during storms, resulting in the overflowing of roads and lots of sediment in the river, which can even be seen with the eye at the river estuary, where the water turns brownish. Since the dam has been built, the river flow and bed has changed. It resolved some flooding issues that the area had before. Probably the amount of sediment discharge has been reduced.

Effect from the sea

For the coast of Playa Unión, the sediment of the river is very important, more than the cliff erosion! Small particles are blown away by the wind and do not end up in the river or on the beach. An important phenomenon here is the Coastal drift. Marine deposits from the sea/coast are bigger than the sediment from the river. So, the bigger stones are related to the energy of the sea and the waves. They are of marine origin. The storm with high waves with a lot of energy, moves the bigger particles and places them on the coast. The thin sediments are easily taken away. Mercedes thinks that putting an extra short breakwater will create the same effect as the one that is there now. So the big stones pile up. Depending on the availability of gravel. Mercedes argues that because before the construction of the big breakwaters, there was big gravel evenly distributed along the coast, mainly near the river, so availability will not be an issue.

Other effects

The beach is growing wider, north of Playa Unión. According to them, a big perpendicular breakwater was placed, where the line of houses now stops. This big concrete defence line structure was put there around 40 years ago. They think it works to catch the sand and that would be why the beach there is wider. This is however not heard of before, nor is there documentation about.

F.8. Claudia Bracco

Degree in Social Communication, National Broadcaster, specialist in Digital Journalism and Organisational Communication at the Universidad Nacional de la Patagonia San Juan Bosco

Introduction

Claudia Bracco is a resident of Playa Unión. She has lived her whole life in this area but moved last year to Playa Unión to live closer to the beach.

A lot of people make use of the beach. Most of the time only for leisure purposes. Some people from around the area have a house in Playa Unión to spend their time there at the weekends. In the summer there are a lot of tourists from all over the region. In Playa Unión there are no big hotels, but you have some small hostels/homestays. People are not familiar with any expansion plans of the port, especially not the ones that live far away from the port. Erosion of the beach is experienced. When the tide was low it used to be a long beach. Now it is only a few metres. Also, the slope of the beach is steep. Some people are now scared to swim because the water gets deep quickly. Also, something interesting is mentioned about the area South of the Southern breakwater. According to the interviewee, the land between the sea and the land of Industrias BASS is destined to be a living area. Houses will be built here.

The beach

Claudia uses the beach multiple times a week to run, swim and walk with her dogs. The positive aspects of the beach she named, were: clean air, winds, view, sea, field, and horizon with plants, rabbits, and guanacos close to the beach. The negative aspects for her are at the port and near the port: oil on the beach and a lot of litter from the port, which is not positive for the beach and the animals.

Playa Unión's beach is way more quiet. A lot of people from Trelew and Rawson have a house there for the weekend. Many people go to Playa Unión because it is quiet. It is not touristic. The tourists are the local people. In the summer there are a lot of tourists from all over the region. In Playa Unión there are no big hotels, but you have some small hostels/homestays.

The beach is also near for people. People in the region like to go to the beach, that's why they live close to the beach. The same goes for people that live in the mountains on the west side of the country like the mountains.

Claudia's requirements for the beach are the open views.

Erosion

Claudia does experience the effects of the coastal erosion. She went to the beach all her life. When she was little and the tide was low, there was a long beach. You needed to walk a long distance to swim. Now it is only a few metres, which is a big difference. Only in the centre of Playa Unión, the beach goes gradually. Everywhere else, the water is really high. It is better to have a more gradual beach like it is used to be. Some people cannot swim very well, so they are scared to go in the water.

About the short breakwater, she says that it works, but it does not accumulate sand smoothly, it accumulates the sand really abruptly. High up on the beach, the sand is coarse, gravel, and closer to the sea it is smaller.

Port expansion

Claudia was not aware of any port expansion plans. It is also not interesting for her because she lives quite far from the port. She was not really concerned about the port plans, but she was interested in getting to know more about the plans. Port seems to be quite private/not accessible for the inhabitants. She mentioned an idea of her dentist of a marina at the sand-plane in the port. A lot of people have boats and now they need to dock them at the marina in Puerto Madryn.

F.9. Eugenio Krämer

Eugenio Krämer is the sub-secretary of Energy of the Ministry of Infrastructure, Energy and Planning. He is also part of the Fundación Patagonia, a foundation concerned with the use of renewable energy. This is a non-governmental institution. They want a more pro-active attitude regarding green energy, e.g. hydrogen energy. Eugenio does not believe that expanding the port of Rawson is possible.

Role of province

Not all provinces in Argentina work the same. The province of Chubut has little say. The cities in Chubut are close to autonomous. They all have their own economy and are competitors in this way. There is not a lot of collaboration in the province of Chubut. In comparison, in the province of Cordoba the cities work more together and try to help each other. On a provincial level there is not an actual long term vision.

The Ministry of Infrastructure, Energy and Planning is the implementing party, the Ministry of Fishery makes the policy regarding the fishery and the ports.

Role of Puerto Rawson

In Chubut, there are several ports differing in size and function. Puerto Madryn is specialized in aluminium, tourists and fishery (the red fleet). Comodoro Rivadavia is specialized in oil. Camarones is a city with a port with a lot of potential. The water is very deep, and the area is very open but still in a bay, thus it is easily accessible for big ships. There is a national park closeby, thus also cruises are interested to go there. The province wants to give Camarones economic independence and political control to encourage the development. Puerto Madryn and Comodoro Rivadavia do already have this autonomy, and that is why they are working so well. Puerto Rawson is actually a very small player in the area, due to the lack of space to expand.

Provincial and national level

Approval for projects like flood defenses and port expansions go through the national government and not through the province. Each province has a senator representing them in the national government. In October these senators distribute the money for projects between the provinces. As everything is focused on Buenos Aires, everything goes to and from Buenos Aires. For the smaller provinces, this leads to a vicious circle. Money goes to the places with the most inhabitants, which attracts more inhabitants. This causes a bigger gap between Buenos Aires and the provinces of Argentina.

There is no vision of national development. The infrastructure is built to export products to other countries.

F.10. Servimagnus S.A.

Servimagnus S.A.

Servimagnus S.A. is a dredging and salvage company based in Buenos Aires. They work as subcontractor of Sudelco, who won the tender for the dredging works in Puerto Rawson. Sudelco is not a dredging company and Servimagnus is not based in Chubut, so they work together to complete this project. Since, it is a requirement from the province that the company must be based in the province where the project is executed.

Marcos De Vincenzi

Marcos De Vincenzi is the general manager of Servimagnus S.A. He is based in Buenos Aires and was in Chubut for 24 hours to supervise the dredging project in Puerto Rawson.

Dredging

The original tender consisted of a plan to dredge the access channel, the mouth of the harbour and create a long stretch of sediment trap upstream of the bridge. The material upstream of the bridge however, after a detailed soil study, was too heavy and stiff to be dredged. As an alternative to not being able to dredge this part, the headland in front of the new dock would be dredged.

The project got delayed twice before it really got started, and Sudelco-Servimagnus made claims for the lost time and the delay. See timeline below for the comprehensive overview of all the activities that have happened.

Due to the delay and consequential time-line challenges, the plans had to be adapted. It is chosen to only dredge from the Murray Thomas dock until the mouth of the harbour and a small extra space on the south side of the harbour as sediment trap. This is a total of 250,000 cubic metres. The dredging should be completed before December because then, when the fishing season starts, a lot of boats need to be able to access and leave the harbour.

Coastal erosion

The place where the sediment is dropped is according to the tender on the north side of the northern breakwater. It is not known if there were plans or conversations about different possibilities. It is however possible, according to the power of the dredging pump, to dump the sediment up to a distance of 2 or 2,5 kilometres. So it would have been an option to drop it on the north side of the groyne.

Table F.2: Timeline of the dredging project

October 2020	Original project was designed.
July 2021	Tender by MIEP
May 2022	Tender won by Sudelco, with Servimagnus as dredging subcontractor.
June 2022	Signing of tender and ready to start in August
July 2022	MIEP confirms that a previous EIA is still valid after consulting with MA. So, MIEP ordered to Sudelco-Servimagnus the mobilization of the dredger. Complaints from local inhabitants came. MA and MIEP retract the EIA once the dredger was on-site. The PGA in the EIA needs to be updated.
Augustus 2022	This new PGA gets declined by MA. and the whole EIA needs to be completely revised by MIEP. This takes 10 months.
June 2023	New EIA did it by MIEP gets approved and dredging can start.
July 2023	15: Dredging starts 17: Inhabitants assemble and start complaining about ‘polluted’ water. 18: The mayor from Rawson shuts down the project by going to a court.
August 2023	14: The claims of polluted water are shut down by the court and dredging may recommence.
September 2023	Dredging recommences

G

Online questionnaire

To get insights in the opinions and visions of the inhabitants and touristic companies of Playa Unión, Puerto Rawson, Rawson and the surroundings, an online questionnaire has been made to be able to reach a large group in a short time. In this appendix, the questionnaire in Spanish and English, can be found.

G.1. Form in Spanish

26-09-2023 15:30 Estudio sobre la zona costera de Puerto Rawson y Playa Unión

Estudio sobre la zona costera de Puerto Rawson y Playa Unión

1. Consentimiento informado *

Se le invita a participar en un estudio de investigación titulado "Estudio sobre la zona costera de Puerto Rawson y Playa Unión". Este estudio está siendo realizado por Jesper Bryan, Kim Damen, Deborah Dekker, Lucas la Poutré, Josephine Scholte y Benjamin Witmer de la Delft University of Technology (TU Delft) en cooperación con la Universidad Nacional de la Patagonia San Juan Bosco (UNPSJB) y la Universidad de Buenos Aires.

El propósito de este estudio de investigación es investigar los efectos que los cambios en la zona portuaria podrían tener sobre la erosión de la costa en Playa Unión, y le llevará aproximadamente 10 minutos completarlo. Los datos se utilizarán para un informe de asesoramiento. Le pediremos que responda a algunas preguntas relacionadas con los cambios costeros y la ampliación del puerto.

Como ocurre con cualquier actividad en línea, siempre existe el riesgo de que se produzcan filtraciones. En la medida de nuestras posibilidades, sus respuestas en este estudio serán confidenciales. La encuesta es completamente anónima.

Su participación en este estudio es totalmente voluntaria y puede retirarse en cualquier momento. Puede omitir cualquier pregunta. Sus respuestas permanecerán anónimas.

Si tiene alguna pregunta, puede enviarla a Josephine Scholte: j.m.scholte-1@student.tudelft.nl

Markeer slechts één ovaal. *(Mark one option)*

- [ ] Yo entiendo

Información general

Las preguntas siguientes tienen por objeto subdividir las respuestas de este formulario en diferentes grupos para poder analizar mejor los datos.

1/8

2. ¿Edad? *

Markeer slechts één ovaal. *(Mark one option)*

- Menores de 20 años
- 20 a 40 años
- 40 a 65 años
- 65 a 80 años
- 80 años o más

3. ¿Cuál es su ocupación?

____

4. ¿Dónde vive usted? *

Markeer slechts één ovaal. *(Mark one option)*

- Playa Unión
- Rawson
- Trelew
- Otros

5. ¿Cuántos años lleva en la zona? *

____

La playa

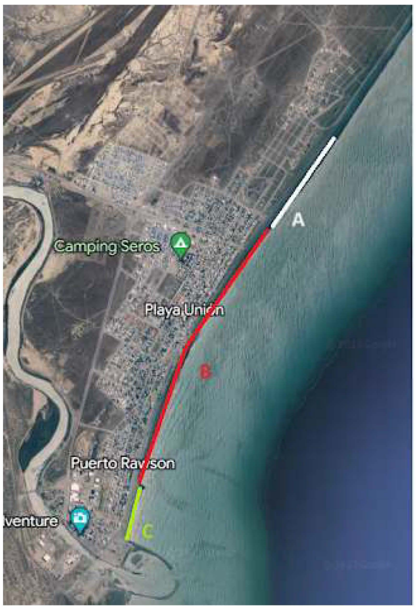
Las siguientes preguntas se refieren a la playa al norte de las escolleras del Puerto Rawson y a su utilización.

6. ¿Cuánto utiliza la playa? *

Markeer slechts één ovaal. *(Mark one option)*

- Nunca
- Unas cuantas veces al año
- Una vez al mes
- Cada semana
- (Casi) todos los días
- Anders: ______________________

7. ¿Qué parte de la playa utiliza más? *



Markeer slechts één ovaal.

- A
- B
- C

26-09-2023 15:30 Estudio sobre la zona costera de Puerto Rawson y Playa Unión

8. ¿Qué actividades practica en la playa? *

Vink alle toepasselijke opties aan. (Mark all good options)

- [ ] Al deporte
- [ ] Ocio o tiempo libre
- [ ] Trabajar
- [ ] Pasear al perro
- [ ] La naturaleza
- [ ] Anders: ______

9. ¿Qué importancia tiene para usted la playa? *

Markeer slechts één ovaal. (Mark 1 option)

Sin importancia

1 ◯

2 ◯

3 ◯

4 ◯

5 ◯

Muy importante

10. ¿Cuáles son los aspectos positivos de la playa?

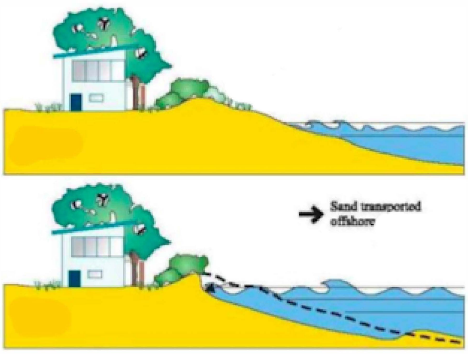
______
______
______
______
______

4/8

11. ¿Cuáles son los aspectos negativos de la playa?

Erosión costera

La erosión costera es el proceso por el cual los suelos y/o la arena de la costa se desgastan o son arrastrados. El impacto del oleaje provoca que la arena de la playa se transporte nuevamente al mar, produciendo un desplazamiento en la línea de costa y reduciendo el tamaño de la playa.



12. ¿Está familiarizado con la erosión de la costa? *

Markeer slechts één ovaal. (Mark one option)

- Sí
- No *Ga naar vraag 15*

26-09-2023 15:30 Estudio sobre la zona costera de Puerto Rawson y Playa Unión

13. ¿Siente los efectos de la erosión? *

Markeer slechts één ovaal. (Mark one option)

- Sí muchos
- Sí algunos
- Sí poco
- No

14. ¿Qué efectos experimenta usted?

Planes de ampliación del puerto

15. ¿Está familiarizado con algún plan de ampliación del puerto? *

Markeer slechts één ovaal. (Mark one option)

- Sí *Ga naar vraag 16*
- No *Ga naar vraag 19*

Familiarizado con planes de ampliación del puerto

16. ¿Con qué planes está familiarizado?

26-09-2023 15:30 Estudio sobre la zona costera de Puerto Rawson y Playa Unión

17. ¿Cree que los planes benefician Playa Unión y Puerto Rawson? *

Markeer slechts één ovaal. (Mark one option)

- Sí
- No

18. ¿Por qué sí/no?

Otros asuntos

19. ¿Hay alguna otra pregunta o comentario sobre los puntos aprobados en esta encuesta?

20. Puede dejar su dirección de correo electrónico para que podamos ponernos en contacto con usted en relación con su pregunta o comentario si es necesario.

G.2. Form in English

Questions Google forms English

Informed consent

You are being invited to participate in a research study titled "Study on the impact of Puerto Rawson's expansion on coastal erosion at Playa Unión". This study is being done by Jesper Bryan, Kim Damen, Deborah Dekker, Lucas la Poutré, Josephine Scholte and Benjamin Witmer from the TU Delft in cooperation with the Universidad Nacional de la Patagonia San Juan Bosco (UNPSJB), Universidad de Buenos Aires and Industrias Bass.

The purpose of this research study is to investigate the effects that changes in the port area might have on the erosion of the coast at Playa Union, and will take you approximately [XX] minutes to complete. The data will be used for an advisory report. We will be asking you to answer some questions regarding the coastal changes and the expansion of the port.

As with any online activity the risk of a breach is always possible. To the best of our ability your answers in this study will remain confidential. The survey is completely anonymous.

Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any questions.

If you have questions, you can send them to Josephine Scholte:
j.m.scholte-1@student.tudelft.nl

General information

1. What is you age?
    a. Less then 20 years old
    b. Between 20-40 years old
    c. Between 40-65 years old
    d. Between 65-80 years old
    e. 80 years or more
2. What is your occupation?
3. Where do you live?
    a. Playa Unión
    b. Rawson
    c. Trelew
    d. Other
4. How long have you been in the area?

The beach

5. How much do you use the beach?
    a. Never
    b. A few times
    c. Once a moth
    d. Every week
    e. Almost all days
    f. Other:

6. Which parts of the Playa do you use most?
    a. Area A
    b. Area B
    c. Area C
7. Whar activities do you do on the beach?
    a. Sport
    b. Leisure or freetime
    c. Work
    d. Walking the dog
    e. Nature
    f. Other:
8. How important is the beach for you?
    a. 1
    b. 2
    c. 3
    d. 4
    e. 5
9. What are the positives of the beach? [open question]
10. What are the negatives of the beach? [open question]

Coastal erosion

Coastal erosion is the process in which soils and/or sand along the coast is worn down or carried away, changing the coastline and making the beach smaller.

11. Do you know about the erosion going on at the coastline?
    a. Yes
        i. 13. Do you experience the effects of erosion? [yes/no]
        ii. 14. What effects do you experience? [open]
    b. No → Continue to next question

15. Do you know about the plans for the expansion of the port? [yes/no]
    a. Yes
    b. No

16. What plans are you familiar with? [open]
17. Do you think the plans benefit Playa Union and Puerto Rawson?
18. Why yes/no?
19. Are there any other questions or comments regarding the points approved in this survey?
20. You can leave your e-mail address so that we can contact you regarding your question or comment if necessary.

H
Brainstorm possible interventions

The first step in designing possible interventions was a brainstorm session. In this session, a lot of possible interventions were considered. However, some of them will not be further investigated since the feasibility and effectiveness of those interventions is questionable or less relevant for the scope. A short overview of the mentioned interventions that did not end up in the report is given below. The grading of the interventions can be seen in section 9.2.

H.1. Groynes

First of all, building one big groyne on the coastline will only translate the erosion problem to another location. Whereas, building multiple big groynes is more expensive compared to multiple small groynes with the same result, as they require more material. See more about this in 8.1.

H.2. Dredging

Another option is dredging, for dredging a location to dredge and a location to disposition the sludge must be considered.

Dredging the area south of the southern breakwater is not desirable since there is an insignificant amount of sediment available, and it will result in an interruption of the current ecosystem. Furthermore, sand in the sedimentation zone at the northern part of the coastline must be avoided. This will result in the interruption of the current sediment balance at the waterline, which is not favourable.

Next to that, it is beneficial that the dredged material is extracted from the surrounding areas, resulting in lower costs.

H.3. Parallel breakwaters

Moreover, there are some parallel breakwaters which could be a possible intervention regarding coastal erosion.

However, a seawall is not considered because it will not solve the erosion problem, a seawall will only prevent the hinterland and not the beach in front of it.

Next to that (partly) disassembly, the short breakwater was also considered. For example, the construction of a longitudinal breakwater offshore from stones of the short breakwater. Nonetheless, this will not be feasible due to the high tidal range, the water depth including waves at a storm. The amount of material is not sufficient to stop the waves from reaching the

shore. Construction of a longitudinal breakwater onshore with stones of the short breakwater will only be a temporary solution requiring a lot of maintenance, see 8.6.
Another possibility was realizing dunes, however, the material needed for dunes is not nearby, making it too expensive. Furthermore, there is not enough space for this intervention.
Some other ideas that were considered, were the usage of old ships as breakwater offshore. But due to the large tidal difference, the environment and the safety it is not advised.

H.4. Redesign current breakwaters

Also, the redesign of the current breakwaters was investigated. The redesign of the southern breakwater will have a negligible effect on the coastal erosion on the south side. However, making a jetty to transfer sediment from the South to North could be favourable. Furthermore, the complete redesign will be too expensive.
The old breakwater is left untouched, due to the possible risk of silting up the waterway.
Next to that, the option of extending the old breakwater and dissemble the northern breakwater is not advised, since it will result in high waves at the port from north-east wave directions.

H.5. Energy interventions

Another intervention could be gaining energy combined with the protection of the coast, but this is outside the scope of this research. It is still in the development phase and is expected to be expensive as well.

H.6. All interventions

All possible interventions that came forward during the brainstorming sessions are listed below:

- Groynes
- Depositing dredged material after the short breakwater
- Destroy short breakwater and use stones as a temporary sea defence
- Shorten the short breakwater
- Reconstruct the short breakwater to follow the beach slope
- Build a seawall at Las Ramblas
- Moving gravel from the south to the north of the short breakwater
- Stones parallel on the beach
- Shortening Northern breakwater
- Breakwaters parallel to the coastline longitudinally
- Redesign the existing big breakwaters
- Dredge inside the harbour and deposit sediment on the erosion zone with rainbowing
- Building a seawall on the south breakwater/ port expansion
- Create a parallel breakwater on the south bank of the river.
- Destroy the old breakwater and recycle the materials for coastal defence
- Extending the old breakwater and deconstructing the new northern breakwater
- Redesign the mouth of the breakwaters
- Floating longitudinal breakwater
- Submerged longitudinal breakwater
- Moving sand from sedimentation zone in the north back to the erosion zone
- Sand engine behind the short breakwater
- Gravel engine
- Planting vegetation onshore and offshore

- Making sediment traps between boat and bridge with constant dredging and coastal supplementation
- Building more breakwaters like the mythic breakwater that is submerged in sediments according to the stories
- Hydroturbines to produce energy
- Wave energy mats
- One single short breakwater
- Foreshore nourishment
- Placing wrecked ships in front of the coast extra benefit is stimulation of tourism
- Creating dunes
- Temporary flood defences in front of Las Ramblas/sandbags
- Redesign of the southern breakwater
- Transport along the breakwaters
- Transporting gravel from the south of the southern breakwater to the north
- Creating a bypass for sediment for the northern breakwater

I

Calculations Groynes

I.1. General design

If the H_s for moderate summer swell wave height is 1 metre with a corresponding period of 10 seconds, the following calculations can be done, see Figure I.1.

What	Dimension	Unit	Remark
Hs,offshore	1	m	to design groyne length
Tp,offshore	10	s	
Hs,onshore	1,404579709	m	
cg,onshore	3,957002847	m/s	group velocity
c0	15,61309992	m/s	=g/2pi * T
cg,offshore	7,806549959	m/s	=n*c=1/2*c,0 = 1/2* g/2pi * T
K,r	1	[-]	
K,sh	1,404579709	[-]	K,sh = root(cg,offshor/cg,onshore)
L,offshore	156,1309992	m	=g*T^2 / (2*pi) assuming deep water
k, with L,offshore	0,04024303527	[m^-1]	=(2*pi) / L
Hb	1,404579709	m	=0,88*waterdepth,onshore
waterdepth, onshore	1,596113306	m	assumed to be at breaking
y	0,88	[-]	breaker parameter

Figure I.1: Summer swell waves

To calculate the breaking depth for the length of the surf zone it is assumed that there is no refraction of waves, only shoaling. Because the angle of incidence of the wave is unknown. The shoaling parameter is calculated according to Bosboom and Stive (2023). Furthermore, the wave direction of the significant waves has a large spread. This calculation can be seen in Figure I.2

What	Dimension	Unit	Remark
Hs,offshore (RP 10 years)	6,29	m	to design groyne length, 10 year return period offshore
Tp,offshore (RP 10 years)	9,4	s	
Hs,onshore (RP 10 years)	5,966478062	m	
cg,onshore	8,155530039	m/s	group velocity
c0	14,67631392	m/s	=g/2pi * T
cg,offshore	7,338156961	m/s	=n*c=1/2*c,0 = 1/2* g/2pi * T
K,r	1	[-]	
K,sh	0,9485656696	[-]	K,sh = root(cg,offshor/cg,onshore)
L,offshore	137,9573509	m	=g*T^2 / (2*pi) assuming deep water
k, with L,offshore	0,04554440389	[m^-1]	=(2*pi) / L
Hb	5,966478062	m	=0,88*waterdepth,onshore
waterdepth, onshore	6,780088706	m	assumed to be at breaking
y	0,88	[-]	breaker parameter

Figure I.2: Wave calculations with return period of 10 years

The wave run-up is calculated by using the Stockdon et al. (2006) formula:
$WaveRun-up_{2\%} = 1,1(0,35\beta_f(H_0 * L_0)^{1/2} + (H_0L_0(0,563\beta_f^2 + 0,004))^{1/2}/2)$.
β_f, is the beach slope. The average upper slope is used
H_0, offshore wave height, 10yr return period
L_0, offshore wavelength, 10yr return period

From Table 4.1 the wave height is obtained as 6,29m and the period of 9,4s for a return period of 10 years. With this, $WaveRun-up_{2\%}$, the start point groyne to prevent outflanking is calculated. The water depth at surf zone is equal to $0.75 * H_b$, this is used to calculate the stop point of the groyne.

The calculations for the groyne are done separately for the M- and S-cross sections. The results of these calculations can be seen in Figure I.3 and Figure I.4.

What	Dimension	if range	unit	Remark	source
Input					
strech of coast prone to erosion	3,3		km		overleaf H3
Strech M-cross section	1,3		km		
Strech S-cross section	2		km		
crest level	0,84		m MOP	between MLW and MHW	coastal book
MLW	-1,84		m MOP	Min low water level	
MHW	3,52		m MOP	Max high water level	
Moderate summer swell wave height	1		m	Hs,offshore	
Lengthe of groyne					
Hb	1,404579709		m		
Waterdepth at start surfzone	1,053434782	1,236030144	m	surfzone starts at waterdepth equal to [0.75-0.88] * Hb	
Stop point groyne in sea	15,80152173	18,54045216	m	only upper slope (length between high water line and end surfzone)	
	263,3586955	309,0075361	m	only lower slope (length between high water line and end surfzone)	
	100		m	estimation ending surfzone based on google earth	
Start point groyne to prevent outflanking	30,93787045		m		
total length groyne	46,73939219		m	beyond breaker line summer	coastal book
	294,296566	339,9454065	m	only lower slope (length between high water line and end surfzone)	
	130,9378705		m	estimation ending surfzone based on google earth	
total length groyne, rounded	47				
spacing between groynes	70,5	141	m	crest levels should be relatively low and spacings in the range of 1.5 to 3 times the length. Or 1:1 ook in hetzelfde boek	
Number of groynes	28,36879433	23,40425532			
Sediment size					
Pebbels d50	13		mm		donini
Sand d50	0,1		mm		
sand medium	0,3		mm		
beach profile					
upper slope	0,06666666667		[-]		donini thesis
lower slope	0,0040		[-]		
Wave run-up					
H_0	6,29		m		
L_0	137,9573509		m		
β_f	0,06666666667		[-]		
H_0*L_0	867,751737				
Brackets part 1	0,6873446096				
Brackets part 2	1,187677842				
Run-up,2%	2,062524697		m		

Figure I.3: Groyne design S-cross section

I.1.1. Low crested groyne

The calculation for the block size of the low crested groyne can be seen in Figure I.5. From van der Bos and Verhagen (2018), formula 6.21 is used to estimate the required size of the blocks for the groyne. This is for surging waves in shallow water at the toe of the structure. $H_{2\%}/H_s = 1,4$ is assumed, as safety, because the breaking waves should not be larger than $0,88 * h_b$, the water depth The validity range for the α, angle of the seaward slope of a structure, is between $1.5 < cot\alpha < 4$. Since the slope of the bathymetry is much more shallow, the upper boundary is used $\alpha = 0,25$. Because for very steep slopes, the formula is not applicable.
To calculate the surf similarity parameter, first, the fictitious wave steepness is calculated. This is done by using formulas 6.15 and 6.16 from van der Bos and Verhagen (2018).

What	Dimension	if range	unit	Remark	source					
Input										
strech of coast prone to erosion	3,3		km		overleaf H3					
Strech M-cross section	1,3		km							
Strech S-cross section	2		km							
crest level	0,84		m MOP	between MLW and MHW	coastal book					
MLW	-1,84		m MOP	Min low water level						
MHW	3,52		m MOP	Max high water level						
Moderate summer swell wave height	1		m	Hs,offshore						
Lengthe of groyne										
Hb	1,404579709		m				0			
Waterdepth at start surfzone	1,053434782	1,236030144	m	surfzone starts at waterdepth equal to [0.75-0.88] * Hb						
Stop point groyne in sea	23,17556521	27,19266317	m	only upper slope (length between high water line and end surfzone)						
	288,6411303	338,6722595	m	only lower slope (length between high water line and end surfzone)						
	100		m	estimation ending surfzone based on google earth						
Start point groyne to prevent outflanking	36,9531902		m							
total length groyne	60,12875541	64,14585337	m	beyond breaker line summer	coastal book					
	325,5943205	375,6254497	m	only lower slope (length between high water line and end surfzone)						
	136,9531902		m	estimation ending surfzone based on google earth						
	60									
spacing between groynes	90	180	m	crest levels should be relatively low and spacings in the range of 1.5 to 3 times the length. Or 1:1 ook in hetzelfde boek						
Number of groynes	14,44444444	7,222222222								
Sediment size										
Pebbels d50	13		mm		donini					
Sand d50	0,1		mm							
sand medium	0,3		mm							
beach profile										
upper slope	0,04545454545		[-]		donini thesis					
lower slope	0,0036		[-]							
Wave run-up										
H_0	6,29		m							
L_0	137,9573509		m							
β_f	0,04545454545		[-]							
H_0*L_0	867,751737									
Brackets part 1	0,468644052									
Brackets part 2	1,058347279									
Run-up,2%	1,679690464		m							

Figure I.4: Groyne design M-cross section

Offshore, wave height	H_0	7,61	50 year return period
Offshore, wave period	T_0	10,2	50 year return period
Mean wave period	T_m	8,67	0,85*T_0 for JONSWAP spectra in deep water
Significant wave height	Hs	1,404579709	maximum onshore wave heigth at the toe of the structure: 0,88*h
fictitious wave steepness	s_0m	0,01196793044	
Surf simularity parameter			
angle of the seaward slope of a structure	α_S	0,25	same as the upper slope for the S-section
angle of the seaward slope of a structure	α_M	0,25	same as the upper slope for the M-section
	ξ_m_S	2,285232966	
	ξ_m_M	2,285232966	
mass density of stone	2400	kg/m^3	reinforced concrete
mass density of seawater	1025	kg/L	
relative mass density	1,341463415		
filter layer			
S damage level	8	SLS	
P notional permeability coefficient	0,6	No core no filter	
N number of waves	29896,19377	In a 72 hour storm	
Hs/ H2%	0,7142857143	since the waves already break at the position of the groyne. The implicit value of 1.4 for H2%/Hs is choosen for safety to allow the posibility for larger waves	
Shallow water van der Meer formula	S-cross section	M-cross section	
Hs/(Δ*D_n50)	2,027914354	2,027914354	plunging
Hs/(Δ*D_n50)	1,46559788	1,46559788	surging
D_n50	0,5163188115	0,5163188115	plunging
D_n50	0,7144185612	0,7144185612	surging
c_pl	8,7		
c_s	1,4		
D50	0,8504982871		surging

Figure I.5: Low crested groyne

J

Port expansion and sediment bypass in the south

J.1. Draft of the new port for different types of ships

It is researched what kind of ships the designed port should be able to accommodate. This is done by looking into different fleets of shipping companies operating in the Argentine sea and by searching on different AIS (Automatic identification system) for ships tracking websites. It can be concluded that there currently operate an insignificant amount of ships of the feeder type with a length from 135-140 metres in the Argentine sea. Bigger ships are operating on the Argentine sea.
The shipping companies currently operating in the Argentine sea make use of container ships that can dock in the major ports in Patagonia. This ports are Puerto Madryn and Comodoro Rivadavia. These ports can accommodate feeder container ships with a length of 200 metres, a beam of $32,3$ metres and a draft of 12 metres. In Figure 8.7a it can be seen that between that the tuba flat lies on approximately $1,5$ to $2,0$ metres SHN. To accommodate feeder container ships with these dimensions at least 14 metres of tuba flat needs to be removed. It is unrealistic to think that a draught of 12 metres can be achieved in Puerto Rawson. A lot of additional research should be performed, including the stability of the existing breakwaters and quay walls.

Although there is currently no market for the feeder ships that Industrias BASS designs for, the design requirements are still looked into. According to the research of IB, the exit channel of the new port needs to be -6 metres SHN and the depth next to the quay wall $-8,50$ metres (Serman y Asociados s.a., 2019). To achieve this depth, excavation works need to be carried out. This results in approximately $10,12$ metres depth of tuff stone flat that needs to be removed to let the ships dock at the new port, depending on the design of the new port.

A more realistic approach for port expansion would be to design the red fleet as the biggest ship in the port. These types of ships have a length of 30 metres, a beam of $7,4$ metres and a draft of at least 3,5 metres according to del Vecchio (2018). In Figure 8.7a it can be seen that between that the tuba flat lies on approximately $1,5$ to $2,0$ metres SHN. To accommodate the ships of the red fleet around $5,5$ to $6,0$ metres of tuff stone need to be removed.

J.2. Design of the breakwater

There are different types of breakwaters. In Figure J.1 eight examples of possible breakwaters are given. For this intervention, a breakwater that can have multiple functions had the preference. The conventional rubble mound breakwater with a crown wall was deemed to be the most suitable because a quay wall to make port operations possible can be added to the crown wall of the breakwater.

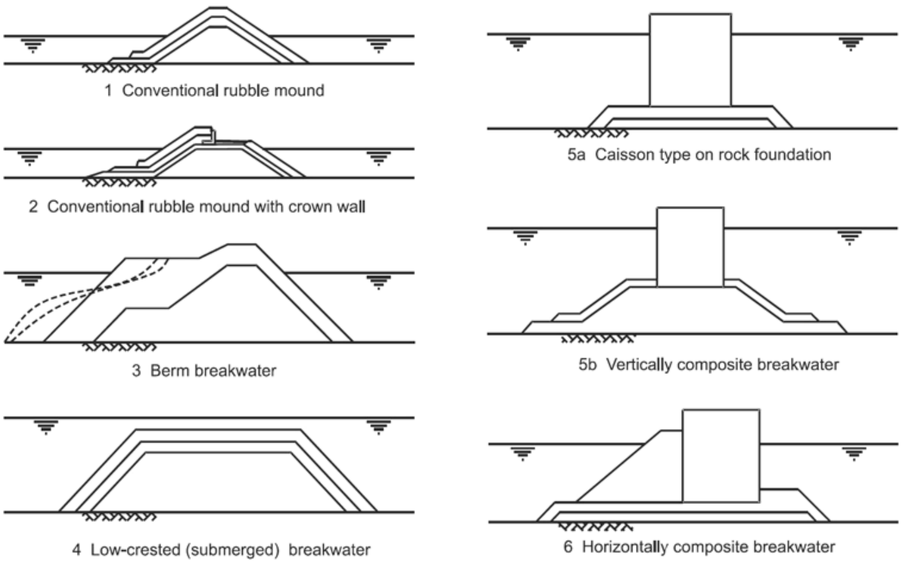


Figure J.1: Different types of breakwaters acquired from De Graauw (2022)

J.2.1. Goda's wave propagation

The significant wave height at the toe of the structure is determined by propagating the significant wave height from Table 4.1 according to Goda's wave propagation formula. Goda's wave propagation formulas that are used together with the calculations made can be found in Figure J.2. As input parameters, the following values are used:

- Water depth at toe of the structure: $= 7,7$ metres SHN
- Offshore wave height: $H_s = 7,61$ metres
- Slope of the foreshore: $1/70$
- $T_p = 10,2$ seconds

$$H_{1/3} = K_s H'_0 \qquad h/L_0 \geq 0.2$$

$$H_{1/3} = \min[(\beta_0 H'_0 + \beta_1 h), \beta_{max} H'_0, K_s H'_0] \qquad h/L_0 < 0.2$$

$$H_{max} \equiv H_{0.4\%} = 1.8 K_s H'_0 \qquad h/L_0 \geq 0.2$$

$$H_{max} \equiv H_{0.4\%} = \min[(\beta_0^* H'_0 + \beta_1^* h), \beta_{max}^* H'_0, 1.8 K_s H'_0] \qquad h/L_0 < 0.2$$

In which

$$\beta_0 = 0.028(H'_0/L_0)^{-0.38} \exp[20 \tan^{1.5}\theta]$$
$$\beta_1 = 0.52 \exp[4.2 \tan\theta]$$
$$\beta_{max} = \max(0.92,\ 0.32(H'_0/L_0)^{-0.29} \exp[2.4 \tan\theta])$$

$$\beta_0^* = 0.052(H'_0/L_0)^{-0.38} \exp[20 \tan^{1.5}\theta]$$
$$\beta_1^* = 0.63 \exp[3.8 \tan\theta]$$
$$\beta_{max}^* = \max(1.65,\ 0.53(H'_0/L_0)^{-0.29} \exp[2.4 \tan\theta])$$

Figure J.2: Formulas for wave propagation by Goda acquired from Bruining (1994)

A Python script is written to make the calculations. This script can be found in Figure J.3.

Goda wave propagation

```
In [25]: h = 5.7 + 2                      # waterdepth [m]
         H0 = 7.61                        # [m]
         g = 9.81                         # [m/s2]
         T0 = 10.2                        # [s]
         L0 = g*T0**2 / (2*np.pi)         # [m]
         theta_deg = 0.818 #0.573 #0.36   # [degrees] (bathymetry)
         theta = theta_deg * np.pi / 180  # [rad]

         def cg(d,T):
             omega = (2*np.pi) / T
             alfa = (omega**2*d)/9.81
             k = (alfa*(np.tanh(alfa)**(-1/2)))/d
             c = omega/k
             n = 0.5*(1+(2*k*d)/(np.sinh(2*k*d)))
             cg = n * c
             return cg

         cgo = cg(200, T0)
         cgs = cg(h, T0)

         Ks = np.sqrt(cgo / cgs)

         def Goda_wave_prop(h, L0, Ks, H0, theta):
             if h/L0 >= 0.2:
                 Hs_toe = Ks * H0
             else:
                 beta_0 = 0.028 * (H0/L0)**-0.38 * np.exp(20*np.tan(theta)**1.5)
                 beta_1 = 0.52 * np.exp(4.2*np.tan(theta))
                 beta_max = max(0.92, 0.32 * (H0/L0)**-0.29 * np.exp(2.4*np.tan(theta)))
                 Hs_toe = min((beta_0*H0 + beta_1*h), (beta_max*H0), (Ks*H0))
             return Hs_toe
```

```
In [26]: print('L0: ', L0)
         print('k: ',2*np.pi/L0)
         print('cgo & cgs: ', cgo, cgs)
         print('Ks: ', Ks)
         print('h/L0: ', h/L0)
         print('Hs_toe: ', Goda_wave_prop(h, L0, Ks, H0, theta))
         print()

         L0:  162.43869153974455
         k:  0.03868034916817988
         cgo & cgs:  7.962726446892075 7.8016281141137
         Ks:  1.0102719050934796
         h/L0:  0.047402499533899585
         Hs_toe:  4.9569515820660115
```

Figure J.3: Python script with the Goda's formulas

J.2.2. Free-board calculations

The breakwater is calculated as being a rubble mound breakwater with a simple armoured slope. It is assumed that the breakwater will have a slope of $1:1,5$. The free-board height of the breakwater is calculated with the design approach equation 6.6 from the EurOtop manual by Van der Meer et al. (2018). The equation together with the calculations made can be found in appendix J.2.2.

$$\frac{q}{\sqrt{9,81 * H_{m0}^3}} = 0,1035 * \exp(-(1,35 * \frac{R_c}{H_{m0} * \gamma_f * \gamma_b})^{1,3}) \tag{J.1}$$

Where:

- $q = 0,001m^3$ Overtopping discharge
- $H_{m0} = 4,96m$ Significant wave height at the toe of the structure
- $R_c =$ Free-board height
- $\gamma_f = 0,38$ Roughness factor for Tetrapods
- $\gamma_\beta = 1$ For oblique waves

The free-board height is calculated with the maths software program Maple. In Figure J.4 the Maple worksheet with the calculations of the free-board height can be found. The calculated free-board of the breakwater is $7,03$ metres.

> restart;

> $eq1 := \frac{q}{\mathrm{sqrt}(9.81 \cdot H\_m0^3)} = 0.1035 \cdot \exp\left(-\left(\frac{1.35 \cdot Rc}{H\_m0 \cdot gamma\_f \cdot gamma\_beta}\right)^{1.3}\right);$

$$eq1 := \frac{0.3192754284\, q}{\sqrt{H\_m0^3}} = 0.1035\, e^{-1.477181633 \left(\frac{Rc}{H\_m0\, gamma\_f\, gamma\_beta}\right)^{1.3}} \quad (1)$$

> $q := \frac{1}{1000}; H\_m0 := 4.96; h := 7.7; gamma\_f := 0.38; gamma\_beta := 1;$

$$q := \frac{1}{1000}$$
$$H\_m0 := 4.96$$
$$h := 7.7$$
$$gamma\_f := 0.38$$
$$gamma\_beta := 1 \quad (2)$$

> sol_1 := evalf(solve(eq1, Rc));

sol_1 := 7.033759219, 0.8478259859 − 6.982475195 I, −6.829370959 − 1.683288760 I, −2.494205393 + 6.576679117 I, 6.228084483 + 3.268750895 I, 3.995630649 − 5.788670353 I, −5.264844375 − 4.664245110 I, −5.264844375 + 4.664245110 I, 3.995630649 + 5.788670353 I, 6.228084483 − 3.268750895 I, −2.494205393 − 6.576679117 I, −6.829370959 + 1.683288760 I, 0.8478259859 + 6.982475195 I (3)

Figure J.4: Maple sheet with the calculation of the free-board height

J.3. Possible nature-based breakwater for the port expansion

If further research about the sediment flow from the south is carried out and the sediment flow seems to be sufficient it can be considered to design a breakwater like the sandbar breakwater at Lekki in Nigeria Spek et al. (2020). This is a nature-based port solution that heavily relies on the natural coastal dynamics of the region. A body of sand held in place by a groyne structure at the tip of the sandbar and oriented towards equilibrium is the central component of the sandbar break idea. The Sandbar Breakwater idea balances the sand and rock quantities: as sand forms the basis of the breakwater. This significantly reduces the amount of rock used in comparison with a conventional breakwater. These pricey, hard building materials must be mined and transported over frequently vast distances and busy, limited highways. Sand is plentiful and easily removed along this beach. It is a desirable building material due to its low price and quantity. To maximise the utilisation of the ongoing sand import and lower the overall amount of construction materials needed, the initial volume of the sand body is limited Spek et al. (2020). In Figure J.5 the sandbar at Lekki in Nigeria can be seen.

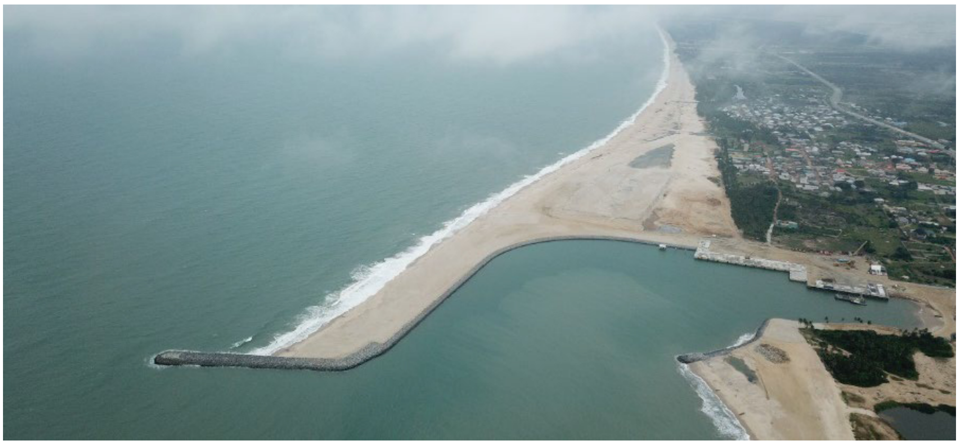


Figure J.5: Sandbar casestudy aquired from Spek et al. (2020)

The concept of the Sandbar breakwater could possibly be implemented in the plans for the port expansion. A new breakwater will be needed to protect the new port. If, after further research, the natural coastal dynamics of the region turn out to be favourable for the project and the sediment flow from the South seems to be sufficient, the sandbar breakwater concept could certainly provide a nature-based solution for the construction of the new breakwater needed for the port expansion. It is important to mention that this concept must go hand in hand with the construction of a new sediment source to the north of this intervention to counteract the coastal erosion, such as a sand motor Spek et al. (2020) because this intervention will capture the entire sediment flow from the south. This will be favourable to counter any coastal erosion South of the Southern breakwater.

J.4. The Sand bypass system on the Gold Coast

The Sand bypass system on the Gold Coast of Australia is being looked into. It was built because the Nerang River mouth kept migrating and this needed to be stopped. A seaway, the Gold Coast Seaway, was built to stop this movement, consisting of two breakwaters. This interrupted the 500,000 cubic metres of sand drift that moved to the north along the coast. The sand Bypass System pumps this sand from the south to the north, using 10 jet pumps installed on a jetty. The sand is pumped under the Seaway, at a depth of 17 metres. Each hour, between 250 and 400 cubic metres of sand is pumped by the system, mainly operating at night.

J.5. Sand-windmill

This concept relies on the natural transportation of sediments along the coast. In this intervention, the windmill could power the pumps on the jetty that suck up the passing sediment. Subsequently, the sediment is pumped through pipes to transport the sediment to the beach. Here the beach will be nourished with the sediment. In Figure J.6 a visualisation can be seen. For this proposed intervention, the sand bypass system could be powered by windmills.

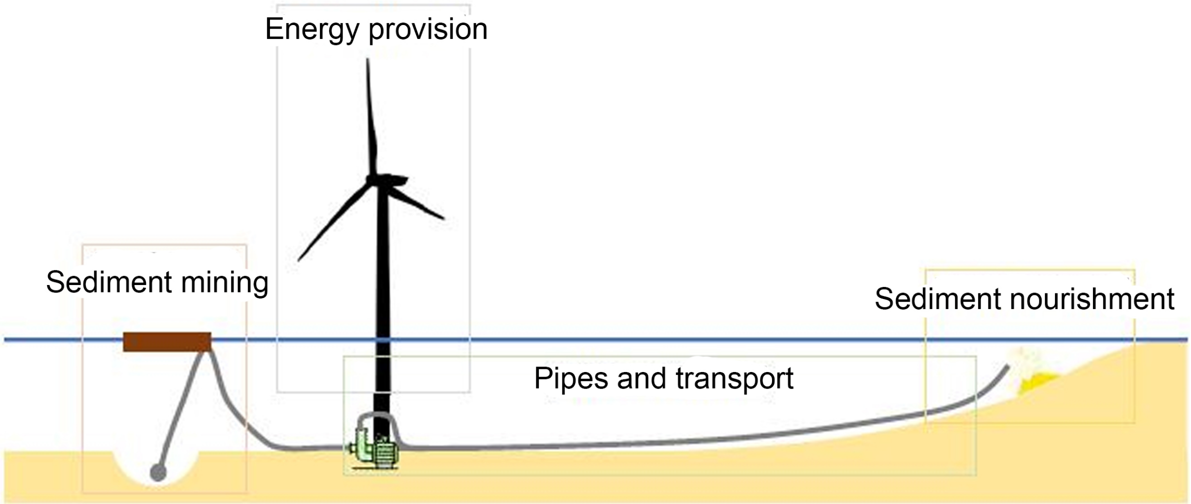


Figure J.6: Sandwindmill (adapted from Rutteman (2021))

K

Temporary longitudinal flood barrier

The following categories of temporary flood defences will be discussed: flood defences filled with soil, filled with water, either by self-filling due to the rising water level or by usage of pumps, and flood walls. In the following paragraphs, each category is discussed and examples are given.

Temporary flood defences **filled with soil** include geobags (shown in Figure K.1: either small or big bags. The advantage of geobags is that any available type of soil can be used to fill the bags made of geotextile. There are three types of geotextiles, non-woven geotextiles, woven geotextiles, and coir geotextiles, depending on the type of usage the best textile can be chosen. One sandbag can give a retaining height of about 15 centimetres, according to Wiki Noodmaatregelen (n.d.). Then with a big group of people, for example, the Prefectura Naval or local residents, the bags can be stacked until the desired height is reached. The disadvantage of this process is that it is very labour-intensive. By using slightly more equipment also big bags could be used. The bags can be filled and thereafter a forklift positions them in the correct place. The geobags can be placed as temporary flood defence by heightening up the beach line or can be stored on the beach as slope protection to protect the erosion. The latter, depending on the weight, may be quickly wiped out by a storm or high water. Heavier geobags are more likely to withstand the force of the water. But according to GEOBAGS, INSIGHTS (2021), geobags are already proven in safeguarding beaches.

Figure K.1: Geobags used in practice (Maccaferri (2023))

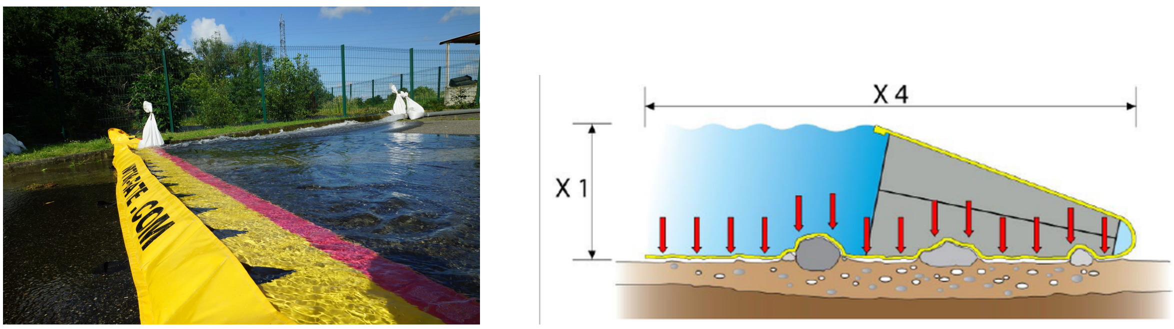
Another category of temporary flood defences can be defences **filled with water**. The system to fill up the barrier can be either by a pump or by using the rising water level due to flooding. An example of boxes that need to be filled by a pump is BoxBarrier (“BoxBarrier, water versus

water", 2021). This system is very simple: plastic boxes are connected with coupling pieces and then a pump is used to fill up the system. In Figure K.2a, an example is visible. 100 metres of barrier can be deployed and filled within one hour by the usage of three men and a pump with a capacity of $30m^3/hr$. The water-retaining height is 0,6 metre, which is sufficient for the amount of overtopping at Playa Unión. However, the system is not tested with waves, therefore the stability along the coastline can be a challenge.
An example of a tube that needs to be filled by a pump is "MOBILDEICH" (see Figure K.2b. The advantages of this system are that only two to four people are needed to install it and 100 metres of tubes can be made ready per hour. The time needed depends on the strength of the pump used. The height of the barrier can be up to 3,5 metres. A mesh net covers the tubes to hold them into place and to absorb great forces. This flood protection has not yet been used at sea. A substantial advantage is that the barriers from "MOBILDEICH" can be used up to a hundred times over a lifespan of ten years (Mobildeich, n.d.).

(a) Boxbarrier (EHS Sales Ltd. (2023)) **(b)** MOBILDEICH (MOBILDEICH (2023))

Figure K.2: Non self inflating temporary flood defences filled with water

An example of a flood barrier that fills up due to the rising water level is the water-gate flood barrier. They are very easy to use because they only need to be rolled out and after that they self-deploy. The flood water lifts the upper part and presses the lower part to the ground. Thus the flood water itself is used as protection. A risk seems that when there is not enough water, the barrier will start floating. This should not happen because the weight exerted by the water is up to four times more (depending on the type) in the vertical direction than in the horizontal direction. This is visualised in Figure K.3b. This ensures the connection of the barrier to the ground.



(a) Water-gate barrier in practice **(b)** cross section

Figure K.3: Water-gate flood barrier (Flood protection solutions (2023))

The other type, **flood walls**, can be compared to a temporary seawall. They could be placed on the street along the coast or on the beach itself. The type of material for this intervention could differ.
An example is Geodesign barrier (Figure K.4a, a flood wall made from metal with a waterproof foil. This barrier gets its stability due to the weight of the water on the inclined barrier, pushing it down. Due to this, it can be less favourable for Playa Unión, since the water retaining height due to floods is usually quite small, thus providing not the needed weight for the system. The maximal water retaining height is 1 m. The advantages of the barrier are that it is simple to install, and the storage volume is very small. The barrier is implemented in real life, but probably not with sea waves. To install 100 metres of the barrier, no less than 20 minutes are needed Geodesign Barriers (n.d.).
Another example is the NOAQ boxwall (from NOAQ Flood Protection AB), a flood wall made from plastic (Figure K.4b). The water-retaining height can either be 0,5 or 1 metre. If the water rises higher, the wall remains standing and is still able to reduce the inflow of water. 100 metres of barrier can be built up within 24 minutes with two persons. The flood water itself anchors the wall. The wall needs to be placed on a hard surface because otherwise, it can topple over, thus it is important to place it on the street and not on the eroding coast (Aquasafe, n.d.-a).
Another possibility for a temporary sea wall can be the use of different materials, such as concrete blocks, steel wall or wall of glass.

(a) Geodesign barrier (Bluepages (2015))

(b) NOAQ boxwall (Aquasafe (2023))

Figure K.4: Floodwalls

L

Plant vegetation with beach nourishment

This intervention uses plant vegetation with beach nourishment to strengthen the coast in a nature-based way. There is not a lot of vegetation along and at the coastline of Playa Unión, see Figure L.1a. In the project area only one small plant on the beach was seen, see Figure L.1b and a line of trees between the road and the beach.

(a) Native plants at Playa Unión

(b) Plant at Playa Unión

Figure L.1: Side-by-side comparison of images

The area prone to erosion is, as mentioned before, a stretch of 3,3 kilometres along the coast. Since this intervention should preferably lie between the mean high water line up to the zone where waves attack during heavy storm conditions ("Shore protection vegetation - Coastal Wiki", n.d.). The resulting width of the beach is roughly 31,25-93,75 metres for the M and 0-62,5 centimetres for the S cross sections, compared to the max high water level of +5,4 metres SHN[1]. Those values are obtained from Figure 4.11a and Figure 4.11b. Furthermore, the distance between the first row of houses and the beach is in some places less than 20 metres.

Due to this limited space, beach nourishment or foreshore nourishment is needed to implement vegetation as an intervention. Beach nourishment does not stop erosion, but provides extra sediment from an external source. Depending on the beach conditions and the type

[1]Max high water level is used instead of mean high water level due to lack of data

of maintenance, the intervals between nourishment range from two to ten years ("Beach and shoreface nourishment", 2023).
Next to that, a dune system can also be considered to prevent the hinterland from flooding. The negative side effect of constructing dunes is that it will hinder sea views and a lot of external soil is needed. Furthermore, dunes must be protected from human interaction, resulting in a disadvantage for the tourism sector of Playa Unión.

Next to the limited space, another difficulty in this area is the big tidal differences and the waves. Those negatively influence the lifespan and effectiveness of the vegetation. According to the article of Massachusetts Office of Coastal Zone Management (2018), areas prone to erosion due to waves, tides etcetera need to have additional site protection. So, for protection beach nourishment can also be an option.

However, vegetation should be considered since in contrast with hard structures, vegetation can absorb and dissipate wave energy. In addition, vegetation gives a natural character and could provide added value for the ecosystem.

For vegetation to be successful, there are a lot of requirements. One is an extensive root system since it will trap the sand and improve the soil structure by adding organic material and moisture. The plants will improve the stability of the dunes in general, but during extreme storm conditions, the vegetation does not have sufficient capacity ("Shore protection vegetation - Coastal Wiki", n.d.). An extensive root system is very important to make planting vegetation successful. But in the beginning, according to Wilke (2023) newly planted vegetation, may even accelerate erosion as a result during a severe storm. This is because the roots are really short in the beginning. Also, in the early stages, it is possible that this intervention needs an irrigation system or planting in a certain season for the roots to flourish.

To protect the root system in the beginning, one could do the following things, according to Massachusetts Office of Coastal Zone Management (2018):

- Installing natural fibre blankets on the ground surface before planting to hold soils in place while roots get established;
- Using temporary baffles of natural-fibre material to shelter plants from the wind;
- Installing sand fencing to help slow wind, trap sand, and reduce erosion;
- Another method to protect the soil around newly planted live vegetation is to plant a salt-tolerant seed mix on the exposed soil.

Next to a proper extensive root system, it is important to monitor the plants throughout their lifetime. Monitoring the plants should be done on a regular basis as well as after every storm. Due to monitoring, maintenance can be applied when needed. For vegetation to be successful it must be a healthy system and human interference as well as storms can alter the quality of the vegetation.

Furthermore, research showed that planting in specific patterns also has benefits. The sand trap around the vegetation is called nebka and Charbonneau et al. (2020) showed, that when the planting is in a staggered pattern the amount of nebka is twice the amount when there is a non-staggered configuration. Also, when the plant size is larger, meaning the width, the amount of trapped sand is also larger.

To select suiting vegetation, Table L.1 is used. However, it is still important to engage an expert when implying this intervention. Non-native plants are excluded and therefore not considered because they could be invasive and thus can potentially harm the existing ecosystem. The plants chosen are endemic and native to the region of Chubut and found in ”El estudio de prefectibalidad” (del Vecchio, 2018) and ”Declara especies protegidas” (Gonzalez et al., 2016). The plants can be seen in Figure L.2. In this table, the plants are compared according to the following criteria.

- **Salt-tolerance:** The plants are at the coastline, consistently subjected to seawater.
- **Soil type:** The plants must be able to grow in sandy soils, or sand and gravel mixed soils.
- **Blooming period:** During storm season, with peaks in the winter, it is beneficial if the plants are blooming o absorb extra energy.
- **Planting period:** According to Massachusetts Office of Coastal Zone Management (2018) in areas exposed to strong wind or waves, like the project area, vegetation should be planted in early spring to reduce the likelihood it will be washed or blown away in winter storms (opposed to ”normal” situations, where the growing season is in early spring).
- **Life-span:** Plants with a long lifespan are preferred, as less replacement is needed. Perennial plants live multiple years, annual plants live a year or less.
- **Root system:** Roots of the plants will hold sediment in place to reduce erosion. Vegetation to prevent coastal erosion should have an extensive root system. Extensive intends large and widely spread roots. The roots of a plant with a tap root system penetrate the ground deeply. A fibrous root system is more shallow and has an extensive and dense root network. This network prevents soil erosion.
- **Plant size:** The size of the plant is interesting for knowing how many plants are needed. Next to that, larger/wider plants trap sediment better. Plants with rhizomes are beneficial because these plants have plant stems growing horizontally above or below the surface and this allows new shoots to grow upwards.
- **Required maintenance:** It is preferred that plants do not need much maintenance.
- **Beach Safety:** Plants should be safe for beach users, thus for example not poisonous.

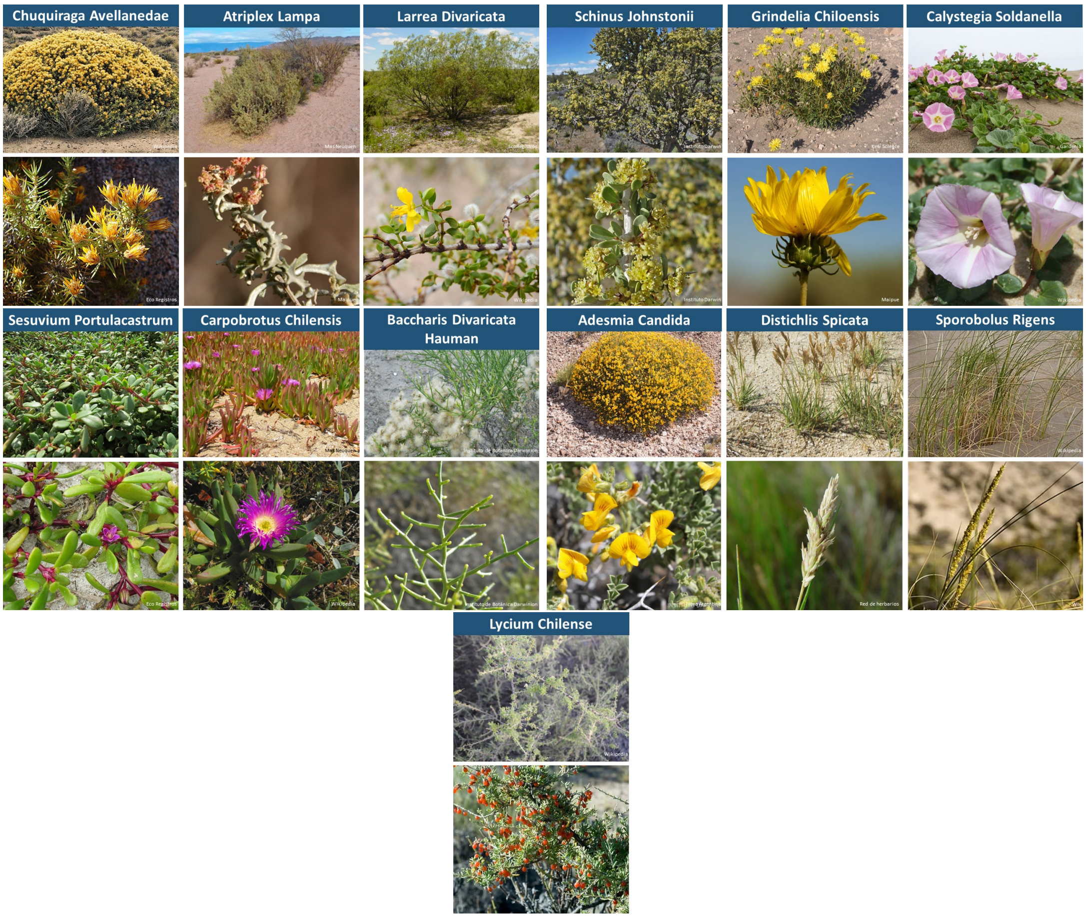


Figure L.2: Plants considered in the analysis

Hardly any information is found about the planting period and the required maintenance, thus these criteria have been left out of Table L.1. Although, some comments can be made about the maintenance. All the plants included in the comparison are native plants living in the steppe climate of Chubut, thus they can survive harsh circumstances. For that, not much maintenance will be needed for any of these plants.

Table L.1: Plants comparison

Plant	Salt-tolerance	Soil type	Blooming period	Life-span	Root system	Plant size	Beach safety
Chuquiraga Avellanedae	Yes	Soft soils, clay	Nov - March	Perrenial	Fibrous root 1-2 m	0,5-1 m	Thorny
Atriplex Lampa	Yes	Sandy soils, arid and poor soils	Spring	Perrenial	Tap root, <3 m	0,6-1,6 m	No specific risks
Larrea Divaricata	Yes	Humid soils	Oct - Nov, evergreen	Perrenial	Fibrous root, >2 m	Up to 3 m	No specific risks
Schinus Johnstonii	Yes	Humid soils	Nov - Dec, evergreen	Perrenial	Fibrous root, >2 m	4-5 m	Thorny
Grindelia Chiloensis	Yes	Sandy soils	Evergreen	Perrenial	Fibrous root	0,3-1 m	No specific risks
Calystegia Soldanella	Yes	Sandy, well-drained soils	Mid-spring to fall	Perrenial	Fibrous root	Rhizomatous, 0,1 m tall, 0,6 - 0,9 m wide	No specific risks
Sesuvium Postulacustrum	Yes	Sandy clay	Evergreen	Perrenial	Fibrous root	Rhizotamous, 0,3 m tall, 1 m wide	No specific risks
Carpobrotus Chilensis	Yes	Poor sandy soils	All-year round	Annual	Tap root, >2 m	0,15 - 0,3 m tall, 0,45 - 0,6 m wide	No specific risks
Baccharis Divaricata Hauman	Yes	Sandy soils	Oct - Dec	Perrenial	Fibrous root	0,3-0,5 m	No specific risks
Adesmia Candida	Yes	Sandy soils	Nov - Dec	Perrenial	Tap root	>0,3 m	Thorny
Distichlis Scoparia	Yes	Saline and humid soils	Dec - April	Perrenial	Fibrous root, >2 m	Rhizotamous, 0,1 - 0,6 m	No specific risks
Sporobolus Rigens	Yes	Sandy soils	Dec -Jan	Perrenial	Fibrous root	Rhizotamous, 0,4 - 2,5 m	No specific risks
Lycium Chilense	Yes	Arid soils	Sep - Nov	Perrenial	Fibrous root	0,5-2 m	Thorny

To conclude, if vegetation is implied to strengthen the coast it must be a native plant to not negatively impact the environment. Also, invasive species should not be planted because it can result in the rapid spread and the obstruction of other plants from growing if the invasive plants have small roots. The advantage of vegetation is that it stabilize the beach surface against erosion and also be of additional value for animals.

All plants mentioned in Table L.1 are tolerant to seawater and can survive in humid circumstances. The Sporobolus Rigens is a good option, especially because it is already used for reinforcing dunes. Plants with a fibrous root system are preferred because it holds the soil together. Thus, that makes almost all plants suitable, except for the Atriplex Lampa, Carpobrotus Chilensis and the Adesmia Candida. The Schinus Johnstonii is less suitable because it is a tree and for that probably too heavy on the coastline. Out of this analysis therefore follows that the following nine plants are suitable for Playa Unión: Chuquiraga Avellanedae, Larrea Divaricata, Grindelia Chiloensis, Calystegia Soldanella, Sesuvium Postulacustrum, Baccharis Divaricata Hauman, Distichlis Scoparia, Sporobolus Rigens and the Lycium Chilense. A combination of a couple of these plants is also possible. It is even beneficial to implement a diversity of plants, to make them less prone to diseases.

Furthermore, one has to make sure maintenance is applied after natural hazards such as storms but also regular maintenance because of human interference with the vegetation. Or even protect the area from pedestrians, so there is no damage to the plants.

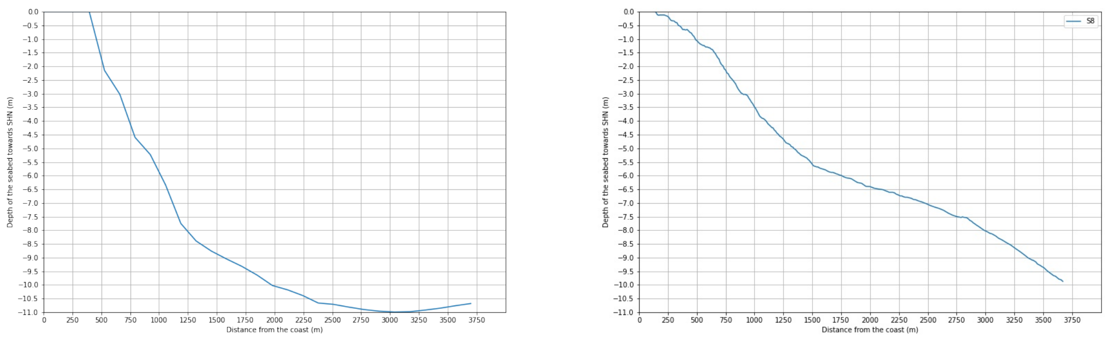
If vegetation is implied, it is advised to consult an expert and to monitor the system well. Monitoring means, making sure the vegetation perform optimal.

M

Sand/Gravel engine

M.1. Bathymetry

The bathymetry between the two locations will be compared to see if it is feasible to construct a similar intervention in Playa Unión. The most important aspects are the water depth and the bed slope. The bathymetry data for the Sand Engine were retrieved from the European Marine Observation and Data Network, an organisation supported by European Commission (n.d.). The data from Playa Unión is the same used in section 4.3. When comparing the two bathymetry profiles in Figure M.1 there are two main things that stand out. The first is that the slope at the Zandmotor is steeper than the one at Playa Unión, but eventually flattens. This suggests that there is more fine sediment at a greater distance from the coast. Looking at the slope of Playa Unión it would suggest that there would be finer sediment near the coast, during the site analysis it was however noted that the sediment on the shore consists mostly of coarse material and gravel. It is possible that under the water the material is finer, but this is not a certainty. The second thing that stands out is the average depth. The average depth for the first 3.000 metres at the Zandmotor is 7,7 metres this is compared to MSL, at Playa Unión this is 4,6 metres. However, this is respective to low tide. It is possible to conclude that the average depths would be pretty similar.



(a) Bathymetry at the Sand Engine in Hoek van Holland

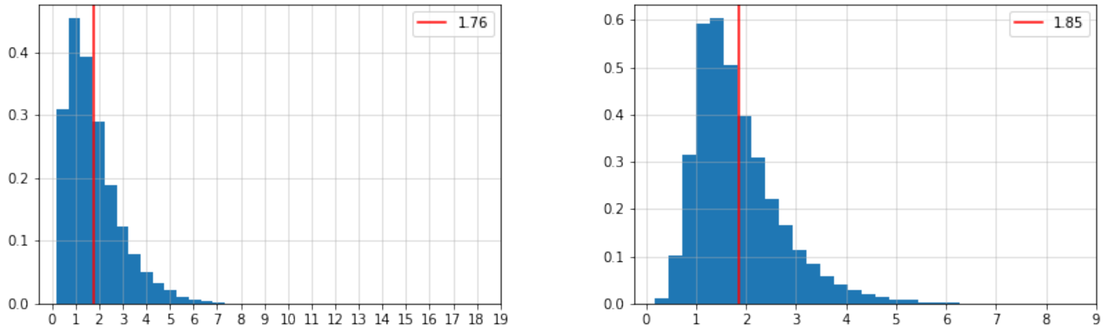
(b) Bathymetry at the small groyne in Playa Unión

Figure M.1: Bathymetry at the Zandmotor and Playa Unión

M.2. Design conditions

M.2.1. Waves

The wave data that will be compared is for the Netherlands that of the the 'Eurogeul' for the period of January of 2020 until July of 2023 from Rijkswaterstaat (n.d.). The data from Savioli et al. (2011) was used to compare wave conditions for Playa Unión. The average wave height at Playa Unión is 1,85 metres which is slightly higher than the 1,76 metres from the Netherlands. However in the Netherlands there are much higher waves recorded. This could be due to the Netherlands data measured is H_{max} and at Playa Unión the measured data is H_{res}. To calculate the real wave heights that shore Goda wave propagation would have been used. However the point of this section is to compare data to see if the region is feasible for such an intervention. For the displacement of sediment in this intervention, the average wave height is most relevant and those are quite similar.



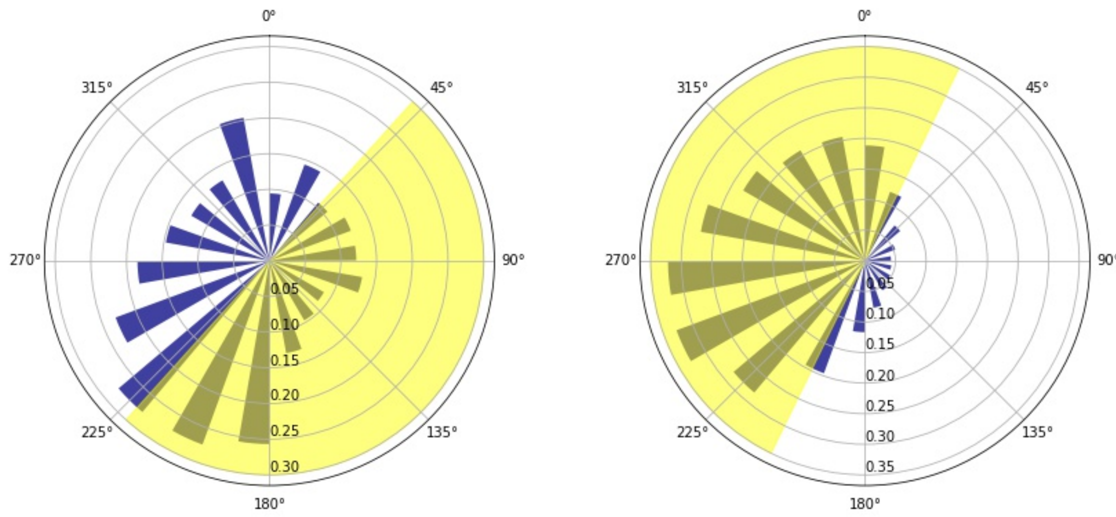
(a) Wave height the Netherlands

(b) Wave height Playa Unión

Figure M.2: Comparison of wave heights between the Netherlands and Playa Unión

M.2.2. Wind

The wind climate from Section 4.1.2 will be compared to data from the KNMI (2023) since the construction of the Sand Engine until now (2011-2023). The measuring station that is chosen is the station at Hoek van Holland. In Figure M.3a a windrose is shown with the percent of wind coming from a certain direction. The yellow area represents the coast, the coastline goes from southwest to northeast. It is clearly visible that the most common wind direction is along the shore in northeast direction. There is still however a considerable amount coming from other directions. Compared to Figure M.3b where it shows that in Playa Unión the majority from the wind comes from the southwest or west what is an offshore wind. The data from Playa Unión is from 1990 until 2010.



(a) Windrose Hoek van Holland

(b) Windrose Playa Unión

Figure M.3: Windroses at the Zandmotor and Playa Unión

From this data the mean is taken to see the difference in wind velocities. In Table M.1 it shows that the average wind speed for the different locations are very similar. In Figure M.4 the two data sets are shown over each other, it shows that in Hoek van Holland there are slightly more often stronger wind conditions.

Table M.1: Average wind velocities

Hoek van Holland	Playa Unión
7,02 m/s	7,12 m/s

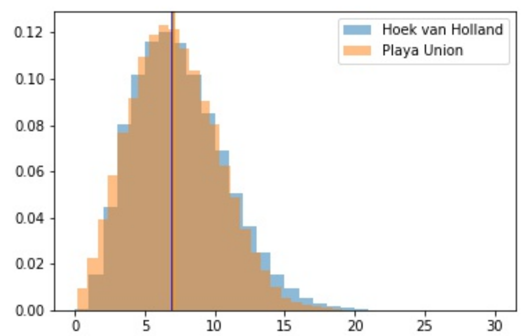


Figure M.4: Comparison of average wind velocities between Hoek van Holland and Playa Unión

M.2.3. Tide

In section 4.1.3 it is shown that there is a tidal range between 2 and 5 metres in Playa Unión. This much larger compared to the tidal range from Hoek van Holland provided by Ministerie van Infrastructuur en Waterstaat (2023). The tidal range measured is between 1 and 2,25 metres. This is considerably smaller than Playa Unión.

M.3. Sediment

The Sand Engine in the Netherlands consists entirely of sand. This sediment was dredged during the construction from the bed of the North Sea. In Section M.1 Figure M.1it is seen that the bathymetry at Playa Unión is still descending. This suggests that there is in contrary to the seabed in the Netherlands larger particle parts. This is based on very little data from 2011 so it is hard to say this for sure. However along the shores of Puerto Rawson and Playa Unión there is a lot gravel accumulation. This could be used as sediment for this intervention.

The Sand Engine in the Netherlands is designed to protect the coast between Hoek van Holland and the harbour of Scheveningen. This is a 16 kilometres stretch of coast. In total 21.500.000 m^3 of sand was used. This is about eight times more than the erosion zone in Playa Unión. When looking at the water depths in Figure M.1, they seem to go to the same depth only at Hoek van Holland this happens at a higher pace. Taking all this into account a conservative rough estimate of the needed amount of sediment would be about 2.600.000 m^3 if it would be constructed the same width away from the shoreline.

M.4. Physical surroundings

At the south end there is a pier stretching into the sea, on the northern end there is the southern breakwater from the port of Scheveningen. These hydraulic works keep most sand between them. Besides these there are not any other significant hydraulic constructions on the beach to interfere with sediment transport. At Playa Unión there are the breakwaters and the small groyne that interfere with sediment transport. The breakwaters stop almost all sediment transport along the coast. The small groyne is a bit more permeable but still stops most the sediment.

Besides the hydraulic structures another important part of the surroundings is the port. Due to the high level of activity during the fishing season it is important that the entrance to the port does not get hindered by this intervention.

N

Multi-criteria analysis

N.1. Scoring

The scores were given on a scale from 1 to 5. Wherein 5 means that the intervention adds positive values and 1 means a negative value regarding the criterion. Since the interventions are on a conceptual level, a range from 1 to 5 is chosen and not greater, since the level of detail of the MCA should correspond with the level of detail of the intervention.

1. Large negative influence
2. Medium negative influence
3. Neutral: meaning the intervention has no effect on this criterion
4. Medium positive influence
5. Large positive influence

N.2. Argumentation scores given to criteria

In this section, the reasoning behind the scores given to the intervention by the authors is given.

Effectiveness

It is expected that the **groynes** accumulate sediment. The groynes are able to restrict the movement of sediments along the coast. They enable the shore to re-orientate perpendicular to the wave direction. The groynes allow sediments to accumulate on the eroded beach. It is also expected that the **low crested groynes** accumulate the sediments faster on the updrift side than the **PPG**, but that also means that the downdrift side accumulates more slowly. Overall, a stabilization of the beach is expected.

Dredging and the **sediment trap** of the port itself will protect the hinterland faster from flooding than the previously mentioned intervention. This is because there is an increment of material in a short time, however, the size of the sediment depends on the dredged area and is uncertain. For the interventions regarding dredging, the beach will erode again because the sediments are not trapped, but with regular dredging and nourishment, the beach can be kept wider. However, the amount of sedimentation from the river is lower than the erosion rate, see 4.2.2 thus it is likely that it will hardly prevent erosion.

The interventions regarding **opening the northern breakwater** will imply the natural flow of sediment from the river towards the coast. These will be mainly fine sediments. This intervention will prevent further erosion, but the supply of sediment is probably not enough to widen the beach.

The **southern port expansion** itself will not protect the hinterland of Playa Unión directly, since the location of this intervention is at the south of the port. However, the sediment bypass will generate an additional flow of sediment toward the coastline, prone to erosion. Namely, the sediments that are now trapped behind the breakwaters. This sediment has a larger particle size than the sediment from the river. Therefore, it is expected to attach better at the steep slopes currently at the coastline. It will take quite some time before this sediment accumulation actively protects the beach.

The intervention **plant vegetation with beach nourishment with beach nourishment**, when maintained properly, can in the long term retain a lot of soil due to the roots of the system. This is in the long term because it takes a long time before the root system is stabilized and the nebka grows. Therefore, this intervention can trap a lot of the sediment flow along the coast resulting in an accumulation of sediment. Also, this intervention needs beach nourishment, providing an external source of sediments at the beginning.

The **gravel engine** will provide an extra great amount of sediment. Therefore, this will result in the biggest accumulation of sediment. But it will take a long time to naturally spread along the coast.

Easiness of implementation

For this criterion, there is no separation in the origin of the investment costs. So, there is no distinction between public or private investments.
For the intervention **plant vegetation with beach nourishment**, the equipment, time and costs of planting the vegetation are limited. Depending on the amount of plants and man-power, it can be fairly short. But, the beach nourishment makes this intervention score less. Since, beach nourishment has a longer construction time and since there is a need for special equipment, the costs are higher. If the nourishment is done onshore instead of on the fore-shore, excavators can be used instead of the more expensive dredging vessels.

Other interventions that need dredgers are **dredging and moving sediment** and the **sediment trap**. Both are simple to implement once there is a dredger available. Currently, in the province, there is no dredger capable of dredging this amount of sediment. Therefore, the current dredger is from Buenos Aires. So, the dredger should be bought or hired during construction, the costs of dredgers are very expensive. The construction time is limited, because dredging in the harbour can only be done during summer, due to the algae and the activities in the harbour. To be able to accomplish it within this timespan, it could be that more dredging machines are needed.

Furthermore, for the **sediment trap**, there must be a pump system available. Once the trap is filled, it pumps the sediment in the trap towards the beach. This happens multiple times during its design lifetime.

Another intervention that needs a special dredger is the **gravel engine**. Since the soil is taken from further away, a different kind of dredging vessel is used. These types of dredgers are more expensive. Making it score lower on the equipment and therefore investment cost. Furthermore, larger sediment is needed, preferably gravel. Which makes the easiness of implementation even harder.

For the implementation of **opening the northern breakwater with tunnels** excavators are needed. The difficult part of this implementation is that the stability needs to be maintained. The **opening with curve** consists of partly disassembling the northern breakwater and constructing a new end, so it could be harder to implement than the interventions which preserve the current breakwater. The easiest to install at relatively low costs is the **opening with sediment bypass**, the hydraulic structure can stay the same but there is a need for an extra investment in a pump.

Interventions that do not necessity need extra nourishment are the groynes. However, in total there is a need for 21 groynes with different lengths depending on the bathymetry. This varying length reduces the easiness of implementation. For the **PPG**, the main material is wood, due to this lightweight material it is easy and quick to install. Furthermore, wood is expected to be cheaper than reinforced concrete. The **low crested groynes** consist of reinforced concrete blocks with a median block diameter of 85 centimetres. To install this, special equipment is needed, like an excavator or crane. This type of material and the need for equipment influence the costs and the easiness of implementation. But also the fact that it includes 21 small constructions is considered.

The southern port expansion is by far the most expensive intervention since it requires the construction of a new port, breakwater and sediment bypass. For the construction of the port, a lot of tuff stone needs to be removed first, indicating the need for special equipment. But also due to the different types of hydraulic structures needed within this intervention, the construction time is longer, the need for different types of equipment is higher and the costs are higher.

Maintenance

The **PPG**'s have a limited lifetime, thus regular maintenance is needed, although the maintenance is not difficult nor expensive. The **low crested groynes** need less maintenance because they are made of rocks, however, if they do get displaced during a heavy storm, the maintenance needed is more complex.

The **dredging** should be done once in a while because the sediments will block the waterway again and to reduce erosion, sediment nourishment is needed again. It is not known how often it should be done. The costs will be equal to the initial investment costs.

The **opening northern breakwater** variants need maintenance multiple times during their design lifetime. The **tunnel** will need more often maintenance than the **opening with curve**, because of the smaller multiple tunnels that will clog faster. For the **sediment bypass**, a permanent system is needed, namely constant pumping. This requires more maintenance than the opening with curve. This last one needs the most maintenance, due to the constant need for a pump.

A permanent pumping system is also needed for the intervention of the **southern port expansion**. The breakwater does not need much maintenance, once built.

For the **sediment trap** if it is not functioning properly any more, the pipes are congested, meaning maintenance is needed. So, the functioning should be checked. Because the pipes are permanent, damage to the pipes will be limited because the pipes do not need to be moved.

Vegetation needs regular checks if the root system is rooting well and maintenance after every storm to check if the plants are still in optimal condition and to plant new ones if needed.

However, the complexity of this maintenance is very low, and the costs are also quite low. But next to that, regular nourishment could be needed for this intervention, which is more expensive and complicated.

The **gravel engine** does not need much maintenance when constructed similarly to the 'Sand Engine' in the Netherlands. If the Dutch sand engine is functioning properly, it does not need maintenance for the first 20 years (Aquasafe, n.d.-b). But when maintenance is needed, the same type of equipment is needed as during installation. However, the amount of sediment needed for maintenance will be less.

Environmental impact

The **groynes** will accumulate sediments on the eroded beach, and thus fewer sediments move to the rest of the beach. So, the rest of the beach could be slightly affected by the decrease in the longshore sediment transport. Furthermore, the groynes are installed as far as the part of the beach where there is enough sedimentation. But since the groynes are permeable and low crested, the transportation of sediments is still possible. However, they do alter the natural shape and sediment balance along the coast. Both groynes must not be lower than the sea level to be efficient. If the sea level rises, they can be adapted. The low-crested groynes can be more easily adapted than the PPG, because extra blocks of concrete can be added and for the PPG the wooden piles need to be replaced. The environmental impact of the PPG is smaller than that of the low-crested groynes because of the materials used.

Dredging and moving sediment might have a negative impact on the natural environment, depending on its location. For example, if the sediments are dredged from the place where the private port will be expanded, the home of the sea lions disappear. They are currently here since it is an easy way to get food however it is not their natural habitat, thus they should be able to relocate. Furthermore, it also has a negative influence on the living organisms at the bottom of the port. Due to dredging, the water is stirred, and the water at the dredge and dump locations becomes murky. Also, the dredging is executed several times and each time dredging is done it interferes with the natural balance and the ecosystem. Dredging is easily adaptable to rising water levels.

The **opening northern breakwater with bypass** will interfere continuously with the small living organisms disturbing their habitat, but both also could restore the sediment flow from the river to the beach. The pump can also generate noise, which can be disturbing. Since the tunnel has a permanent location, it is not adaptable to changes in water level due to climate change. In the intervention with the **curve**, the habitat of organisms is shortly disturbed during the construction, but after that not anymore. However, the breakwater will be disassembled between the highest and lowest point that the waves reach during a tidal cycle. Due to sea level rise, this point will change, and it is hard to adapt the intervention once the breakwater is already disassembled. However, sea level rise could be taken into account when relocating the breakwater.

An intervention like the **southern port expansion** is harder to adapt when needed due to climate change than the other ones. But during designing, the rising seawater level can be taken into account. The port design is planned in an area which is now partly filled with a tuba flat. For that, a lot tuff stone needs to be removed. This will remove the habitat of several flora and fauna and alters the natural balance. In addition, there is a need for a sediment pump for the bypass. On one hand, this restores the natural sediment transport from the south of the breakwaters to the north, but on the other hand, constantly has an impact on the living organisms. However, a benefit in terms of environmental impact is that the power supply of the bypass could be green energy.

The effects of climate change on the **sediment trap** are quite similar as mentioned above for the dredging. A difference is that the pipes of the sediment trap will go overland and are thus not obstructing any flora and fauna in the project area. However, it will negatively influence the Playa Unión and Puerto Rawson. Since the pipes are located there.

The intervention, **plant vegetation with beach nourishment**, will only have direct influence within the boundaries of the project area since it is planted at this location. But, the sediment will eventually be distributed outside the project area. It has a positive impact on the natural environment. The planting of vegetation attracts new fauna and provides a home. The intervention is also easily adaptable to the effects of climate change if needed. Changing the type of plants, amount of plants or anything else is expected to be easy to implement. However, foreshore nourishment is needed and every time this is done the natural balance is disturbed again.

The **gravel engine** can be quite easily adapted by adding extra sediment to the engine. Furthermore, the goal of this intervention is to drop a lot of sediment at a specific part of the coast and due to the natural sediment flow along the coast the sediment will distribute over the whole coast. Resulting in an accumulation of sediment by the use of natural forces. Which can be beneficial for the project area and maybe for a bigger part of the coast, outside the project area. Furthermore, it is a one-time intervention, so the natural balance can be restored, and it can provide additional value for the wildlife.

Recreation

The **groynes** do not provide many opportunities or benefits for this criterion. The condition of the beach does not really improve: the steepness does not mitigate and the fine sediment accumulation will not be substantial. The construction of groynes can result in the feeling of a coast consisting of several parts. This intervention does need to be above sea level to be useful and thus will hinder part of the view like the current groyne also does. They do not reduce but also do not create extra opportunities for tourism and recreation.

Dredging will supply finer sediments, but the dumping of those sediments is visually less pleasant. When the port was dredged in 2023, all the sediment from the river was very dark. The drop location of the sediment is also not accessible, but this is only a small area. Dredging, when sufficient sediment is dredged, can add value to recreation and tourism by widening the beach. It does improve the navigability of the port.

The **opening of the northern breakwater** will improve the condition of the beach because of the supply of finer sediments. The **tunnels** do not change the view. However, the low-cost construction of the **sediment bypass** is by placing the pipes over the breakwater, which will hinder the views. The **opening with curve** extends the breakwater along the coast thus hindering the view partially. The opening with curve makes the northern breakwater inaccessible for walking, mitigating the opportunity to recreate. Lastly, the navigability of the port could increase due to the sediment flow out of the port.

The **Port expansion and sediment bypass in the south** do not improve the condition of the beach because the accumulating sediments will be quite coarse generating a wider but still steep. It will heavily influence the sea views of the few inhabitants living south of the port. North of the port, it will not hinder the view. It could partly be used for a marina, adding value to tourism and recreation. In addition, the pressure on the existing port can be reduced.

For the **sediment trap**, the same applies to dredging regarding the condition of the beach. The view of the sea is not hindered. It does not add or remove opportunities for tourism and recreation.

The **plant vegetation with beach nourishment** will result in an improvement of the condition of the beach because of the accumulation of finer sediments. The vegetation will be planted in sand, placed between the mean high water line and the zone where waves attack during heavy storm conditions. Preferably, this zone should not be entered by beach users since they could destroy the plants. However, due to the improvement of the beach condition, the beach will eventually be more attractive for recreation. The vegetation adds a positive value to the horizon vision, but if the nourishment is too high, like dunes, it could obstruct the sea views.

The **gravel engine** will be the first of its sort thus it could turn into an attraction for ecotourism. The engine can create a lake in the middle and due to the extension of the beach, it can be of additional value for tourism and recreation. This intervention will consist mainly of larger sediments like gravel, this will not improve the condition of the beach. Because gravel at the coast indicates steep slopes instead of sand which has more gentle slopes. The intervention needs to be above sea level to be useful, but the view hindrance will be limited. Also, for this intervention, it is expected that the hindrance will be minimal.

N.2.1. Scoring by externals

To get the most integrated MCA, some experts besides the authors of this report were consulted. However, due to a lack of time, the experts chosen were limited to people already involved in the project. The externals are Pablo Arecco (Argentina, Port Consultants Rotterdam), José A.A. Antolínez (Netherlands, TU Delft) and Rodrigo Bastida (Argentina, Trelew, UNPSJB). The average of the scores determined by the externals equals 50% of the score and the other 50% is the scores given by the authors.

N.3. Results MCA

Two MCAs were conducted, one without weights, thus all criteria have the same importance, and one with weights. Both are methods that minimize biases. Especially the first one completely erases biases. In Figure N.2 the results of the MCA without weights are shown and in Figure N.3 the results of the MCA with weights are shown.

N.3.1. MCA without weights

This subsection shows the results of the MCA without weights. The minimum score an intervention can get is 5 points, the maximum is 25 points.
For the externals, the gravel engine (18[1]) and the sediment bypass (16,7) score the best. Closely followed by dredging and moving sediment (17) and plant vegetation with beach nourishment (16,7).
For the authors, the gravel engine (21) and plant vegetation with beach nourishment (21) scored the best. Followed by the opening northern breakwater with curve (17).
The overall score is obtained by the weighted average. For this, the average of the externals weight equal as much as the authors. From this, the following MCA is obtained, see Figure N.2. From this, it can be concluded that the gravel engine (19,5) and plant vegetation with beach nourishment (18,8) score the best. Followed by opening the northern breakwater with sediment bypass (17) and dredging and moving sediment (16,5).

[1]this number indicates the score

N.3.2. MCA with weights

For the second MCA, the criteria were weighted against each other. The weights were determined by pairwise comparison. If the criterion in the row was more important than the one in the column, it got a 1. If the criterion in the row was of less importance than the one in the column, it got a 0. All criteria were awarded one point for the diagonal where they were compared to themselves. In total, there were 15 points to distribute. The weight per criterion is the sum of the row.
The selection, between giving the criteria a 0 or 1, was done by the authors of this report. The results of the pairwise comparison method can be seen in Figure N.1.

	Effectiviness	Easiness of implementation	Maintenance	Environmental impact	Recreation	Weight
Effectiveness		1	1	1	1	**2**
Easiness of implementation	0		1	0	1	**1,5**
Maintenance	0	0		0	0	**1**
Environmental impact	0	1	1		1	**1,75**
Recreation	0	0	1	0		**1,25**

Figure N.1: Pairwise comparison of the criteria

These weights are multiplied with the previous obtained MCA results in Figure N.3. Therefore, the score is now in the range of 7,5 (low, negative) to 43,75 (high, positive) points.

	Groynes: PPG	Groynes: low crested	Dredging and moving sediment	Opening Northern breakwater: with curve	Opening Northern breakwater: tunnel	Opening Northern breakwater: sediment bypass	Southern port expansion	Sediment trap	Plant vegetation	Sand/gravel engine
Effectiveness	2,8	3,3	3,5	2,8	2,8	3,7	4,0	2,0	4,0	4,3
Easiness of implementatior	4,0	2,3	4,2	2,5	2,7	3,3	1,2	2,8	3,3	2,2
Maintenance	3,0	4,0	2,3	4,2	3,0	3,2	2,7	2,7	3,0	4,3
Environmental impact	3,3	1,7	3,0	2,5	2,7	3,5	2,2	3,5	4,7	4,5
Recreation	1,7	2,2	3,5	2,5	2,3	3,3	3,7	3,0	3,8	4,2
total	14,8	13,5	16,5	14,5	13,5	17,0	13,7	14,0	18,8	19,5

Figure N.2: MCA without weights

Criterion	Weight	Groynes: PPG	Groynes: low crested	Dredging and moving sediment	Opening Northern breakwater: with curve	Opening Northern breakwater: tunnel	Opening Northern breakwater: sediment bypass	Southern port expansion	Sediment trap	Plant vegetation	Sand/gravel engine
Effectiveness	5,0	14,2	16,7	17,5	14,2	14,2	18,3	20,0	10,0	20,0	21,7
Easiness of implementation	3,0	12,0	7,0	12,5	7,5	8,0	10,0	3,5	8,5	10,0	6,5
Maintenance	1,0	3,0	4,0	2,3	4,2	3,0	3,2	2,7	2,7	3,0	4,3
Environmental impact	4,0	13,3	6,7	12,0	10,0	10,7	14,0	8,7	14,0	18,7	18,0
Recreation	2,0	3,3	4,3	7,0	5,0	4,7	6,7	7,3	6,0	7,7	8,3
Total	15,0	45,8	38,7	51,3	40,8	40,5	52,2	42,2	41,2	59,3	58,8

Figure N.3: MCA with weights

The MCA with weights shows no differences in the top 4, only the scores differ. The results can be seen in Figure N.3.

N.4. Sensitivity analysis

For the sensitivity analysis, each criterion is tested on its sensitivity. Per criterion, the weight was increased three times while keeping the weights of the other criteria equal to 1. The weights used were 2, 5 and 10. One should mark the colours and not the scores due to the difference in the weight, the maximum amount of points differs per row.

It can be seen that the alternatives are not really sensitive to different weights. The alternatives gravel engine, vegetation, sediment bypass and dredging are in almost all situations the best options.
But if the criterion easiness of implementation is weighted higher, the top 5 is different. Meaning PPG and dredging and moving sediment are rated higher than the above-mentioned alternatives, making these also interesting interventions if easiness of implementation would be the most important criterion. For the criterion maintenance, the top 4 stays the same (until the weight of 5). However, for this criterion low crested groynes get more interesting as well, but it still scores average. When the other criteria are changed, the top 4 stays the same. The top 4 is the gravel engine, plant vegetation with beach nourishment, the opening northern breakwater with sediment bypass and dredging and moving sediment.

Furthermore, the last line in the Figure N.4 is an analysis without the criterion of easiness of implementation. This was a wish from the client Industrias BASS. They have expressed that they also want to know what the result is when costs and the complexity of implementation are left out. However, if this is left out, the MCA still has the same top 3. But, what is interesting to see is that the southern port expansion goes to the middle, instead of being at the lower half, ending at fourth place.
The result of the sensitivity analysis can be seen in Figure N.4.

Criteria	Weights	Groynes: PPG	Groynes: low crested	Dredging and moving sediment	Opening Northern breakwater: with curve	Opening Northern breakwater: tunnel	Opening Northern breakwater: sediment bypass	Southern port expansion	Sediment trap	Plant vegetation	Sand/gravel engine
Equal weights	**1,0**	**15,3**	**14,0**	**16,0**	**14,5**	**13,5**	**17,0**	**13,7**	**14,0**	**18,8**	**19,5**
Effectiveness	**2,0**	17,7	16,8	20,0	17,3	16,3	20,7	17,7	16,0	22,8	23,8
	5,0	26,2	26,8	30,5	25,8	24,8	31,7	29,7	22,0	34,8	
	10,0	40,3	43,5	48,0	40,0	39,0	50,0	49,7	32,0	54,8	58,5
Easiness of implementation	**2,0**	18,8	15,8	20,7	17,0	16,2	20,3	14,8	16,8	22,2	21,7
	5,0	30,8	22,8	33,2	24,5	24,2	30,3	18,3	25,3	32,2	28,2
	10,0	50,8	34,5	54,0	37,0	37,5	47,0	24,2	39,5	48,8	39,0
Maintenance	**2,0**	17,8	17,5	18,8	18,7	16,5	20,2	16,3	16,7	21,8	23,8
	5,0	26,8	29,5	25,8	31,2	25,5	29,7	24,3	24,7	30,8	36,8
	10,0	41,8	49,5	37,5	52,0	40,5	45,5	37,7	38,0	45,8	58,5
Environmental impact	**2,0**	18,2	15,2	19,5	17,0	16,2	20,5	15,8	17,5	23,5	24,0
	5,0	28,2	20,2	28,5	24,5	24,2	31,0	22,3	28,0	37,5	37,5
	10,0	44,8	28,5	43,5	37,0	37,5	48,5	33,2	45,5	60,8	60,0
Recreation	**2,0**	16,5	15,7	20,0	17,0	15,8	20,3	17,3	17,0	22,7	23,7
	5,0	21,5	22,2	30,5	24,5	22,8	30,3	28,3	26,0	34,2	36,2
	10,0	29,8	33,0	48,0	37,0	34,5	47,0	46,7	41,0	53,3	57,0
Withouth easine	0,0	10,8	11,2	12,3	12,0	10,8	13,7	12,5	11,2	15,5	17,3

Figure N.4: Sensitivity analysis MCA

O

Monitoring techniques

O.1. Wave data

An important part of designing coastal protection or port development is gathering wave data. All designs are based on different combinations of wave data with different wave heights and periods. Buoys are very expensive and could cost up to $170.000 per year (Miros BP, 2023).

There are however cheaper alternatives. A PhD student at the TU Delft developed a cheap alternative to measure wave data using a smartphone(TU Delft, n.d.). After his PhD he started a company named Obscape which produces all different kinds of measuring equipment. The buoys here are priced between three and six thousand euros (Obscape, 2023). They are easy to install and maintain.

To get the most accurate data it would be useful to place a few buoys in a grid pattern in front of the coast.

O.2. Wind data

There are a lot of easy and cheap ways to gather wind data. Most anemometers gather wind data and are available below fifty euros. The most important part of gathering wind data and storing the data is the locations where to place the anemometers. For coastal development, it would be useful to place an anemometer at different heights along the coast. This is to see how much influence the houses in Playa Unión have on offshore wind.

O.3. Bathymetry

Measuring the bathymetry is important for multiple reasons. To start off, for designing hydraulic structures it is crucial to know the water depth. Another important reason is to be able to calculate erosion rate and sediment flow. Most bathymetry tests are done by using a sonar on ships. Sonars send a sound wave and measure the time it takes for the wave to return.

There are multiple cheap sonar systems to measure bathymetry. Most of them range between two thousand and four thousand dollars. These are however not well performing on high waves and might get damaged by the wave conditions at Playa Unión. Another way to manually measure depth is with a RBRsolo depth logger. These are relatively cheap and easy to handle. The only downside is that it is difficult to integrate data since it is hard to remain in the same place to measure the depth (RBR, n.d.). This is however very practical to measure the bathymetry of the Chubut river.

Coastline evolution

”The ability to repeatedly observe and quantify the changing position of the shoreline is key to present-day coastal management and future coastal planning” (Vos, Harley, et al., 2019). Therefore, it is advised to develop the CoastSat analysis as described in section D.2. This can be an effective and cheap manner to monitor the evolution of the coastline.

O.4. River flow data

There are a lot of cheap devices that can be used to calculate flow velocity in a river. Combining this data with the bathymetry from section O.3 it is possible to calculate the river discharge as well. This is useful to get an understanding of the sediment transport in the Chubut river.

O.5. Sediment data

Collecting sediment data is a very complicated procedure to get precise, there are different ways to collect data for a river and sea.

O.5.1. River sediment

There are three different kinds of sediment in a river. In suspension, in solution and rolling over the bed. In suspension, sediment is sediment that is still floating but is making its way to the river bed. In solution, sediment is very fine and almost entirely dissolved in the water. Sediment rolling over the bed is very coarse. No instruments exist that can exactly tell how much of each kind of sediment flows through a river. There are however ways to get an approximation. Sediment in suspension and solution can be measured by collecting water samples and testing them in a lab(Britannica, 2023). In combination with discharge data from section O.4, it is possible to calculate the annual sediment flow.

Sediment rolling over the bed is more complicated to calculate. Kaless et al. (2019) have done this in the past by dredging a sediment trap and measuring how fast this filled up. It would be interesting to perform a grain size analysis on the sediment that gets trapped to see if it could also be suspension and solution sediment.

O.5.2. Marine sediment

Measuring the amount of marine sediment transported is a difficult and time costly procedure. Using open-source models like Delft3D, it is possible to simulate sediment flow along the shore. The most important thing needed to use this program is a lot of data to use as inputs. Using instruments mentioned in this section it is possible to collect the necessary information on waves, wind, sediment, bathymetry and further data.