FINAL REPORT

Multidisciplinary Project

Scheveningen 2100

Water resilience against climate change

An initiative by:

TU Delft | Delta Futures Lab

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- January 2021 -

Final Report

Multidisciplinary Project - Technische Universiteit Delft

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Acknowledgements

We would like to thank our main supervisor, Martine Rutten from TU Delft, who supported us through The Delta Futures Lab along this path. Also, to our supervisors Martijn Onderwater and Yan Liu from TU Delft, who guided us with their expertise. To Henk Nieboer from Ecoshape, our external advisor in nature-based solutions. To the invaluable and continuous presence of Jack Amesz from the Municipality of Den Haag. Finally, we want to thank Marcel Stive, Ronald Waterman, Jessica van Oosten-Däpp, Cees Duvekot, Robbin van Santen, Tom Wilms, and Matthieu de Schipper for their contributions to this project.

Abstract

'The Dutch are not going to lose against the sea', is a commonly accepted quote of the citizens of The Netherlands. Having developed a country below sea level, Dutch people are aware of the challenges of the sea, but are committed in an endless fight against it. Nowadays, with global warming increasing, the challenge for them is even bigger. Sea level rises threateningly, and the estimations about the future conditions are characterized by deep uncertainty. For that reason, the Dutch government identified 13 weak links in the coastal defence system, one of which is the area of interest for this research, the Scheveningen district and its surroundings, belonging to the Municipality of The Hague. Apart from its vulnerable coastal defence position, the area is densely populated and the most popular beach destination of the country.

The aim of this research is to provide water safety solutions in the long term (until 2100), while taking into account the stakeholders demands. Secondly, compare the designs and identify specific aspects in which decision makers in the Municipality of The Hague would be forced to make compromises in order to implement a final solution for the project. Thirdly, investigate on additional measures that can complement and optimize the water safety design. For that reason, a background research was conducted through literature reviewing, interviewing experts and stakeholders, in order to collect information about possible sea level rise scenarios, existing boundaries of the system and stakeholders perspectives.

The water safety issue was tackled with nature-based solutions following the principles of Integrated Coastal Zone Management by Building with Nature a framework that delivers solutions for sustainable infrastructure. Two solutions packages were obtained. The first one uses a Preserve strategy, attempting to maintain the current coastline position with soft (sandy) interventions where possible, keeping construction costs relatively low. The second package uses an Advance strategy, extending land in the seaward direction, and creating a large space for the development of natural habitats and human activities.

To evaluate and compare the resulting designs, a Multi Criteria Analysis was conducted according to five criteria: *Recreation and tourism*, *Social values* , *Ecology*, *Economy and Finance* , *Sustainability*, *Design*. The goal of this part of the analysis is not the selection of a winner option but the assistance to the decision making process by providing strengths and weaknesses of each option, as well as a comparison between the two in terms of the above mentioned criteria. From this point on, this research identified a total of eight aspects where the decision maker, the Municipality of The Hague, would be forced to make some sort of compromises between different interests, in order to implement the project. The evaluation process resulted in a slight preference for the Advance strategy as the most integrated solution package. The optimization of this design was realised and four additional measures were proposed, leading to a more holistic proposal with more chances to bring acceptance among all stakeholders involved.

Keywords: *Building with Nature solutions in coastal landscapes - Integrated Coastal Zone Management for water safety - Climate change resilience in The Netherlands*

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Nomenclature and Acronyms

Here all acronyms and definitions that may be unclear during the report are listed in alphabetic order.

BKL	'Basiskustlijn', which in English means Base Coastline, indicating the minimum threshold for the coastline before having to perform a nourishment
BwN	Building with Nature
IenM	Dutch Ministry of Infrastructure and Environment
Intertidal zone	Beach area with its upper boundary at the water level at high tide and its lower boundary at low tide
JARKUS	Yearly coast profile measurements made by Rijkswaterstaat to monitor the mount of accretion or erosion of the coast. Those measurements are relative to fixed points along the coast called 'raai'
LDS	Lake and Dune System, described in Chapter 5
MCA	Multi Criteria Analysis
MDP	Multi Disciplinary Project
MSL	Mean Sea Level
NAP	Normaal Amsterdams Peil - Dutch reference water level
Nourishment	Applying sand to the sandy structures (beach, dunes, etc) in order to strengthen them or increase them
SLR	Sea Level Rise
SSC	Suspended Sediment Concentration
SWOT and TOWS	Strengths Weaknesses Opportunities Threats
Raai	Division of the dutch coast, along which the morphological coastal profile is measured. There are 1463 raai-sections along the Dutch coast. These raai's are placed within a space of 200 to 250 meter between each other.

Chapter 1

Introduction

Coastal urban areas are put on the spot when facing the global challenges for the 21st century. Although the coastal zone covers less that 15% of the earth's land surface, this is where the majority of the world's population lives and works and where the majority of the world's marine life starts (Bosboom & Stive, 2015). A growing population and global welfare offers many advantages, but often comes together with an increasing social inequality. Furthermore, the consequences of climate change are particularly affecting coastal cities, as they are located in the interface between oceans and land. The *17 Sustainable Development Goals (SDGs)*, adopted by all United Nations Member States in 2015, are an urgent call for action by all countries - developed and developing - in a global partnership.

The Netherlands is not the exception. With large part of its population living near the coast and a third of its land below mean sea level, Dutch inhabitants have been struggling against sea flooding for centuries. Addressing climate change vulnerability with the aim to take measures that makes the country climate-proof and water-resilient, the Delta Program (Ministerie van Infrastructuur en Waterstaat, 2020) has developed a plan on spatial adaptation. Particularly, one of the locations that brings a lot of attention in terms of flood risk is Scheveningen and its surroundings, a 11Km strip of coast in the southern part of South Holland that belongs to the Municipality of The Hague. To deal locally with it on a governance and political manner, The Hague became a member of the 100 Resilient Cities (100RC) network , an initiative of the Rockefeller Foundation, in 2016 . This network helps cities around the world prepare for the physical, social and economic challenges of the 21st century (Resilient Den Haag, 2021).

The Municipality of The Hague has commissioned this Multidisciplinary Project team to research about the necessary measures to be taken in the coastal zone to cope with the challenges of the 21st century, with a particular focus on ***climate change resilience***. From an engineering perspective, current guidelines does not cover the extreme climate conditions acknowledge by the most recent studies, such as the possibility to deal with a sea level rise of up to 3m (Le Bars, 2017) by the year 2100. Moreover, measures should be meant to deliver solutions across the goals for sustainable development. This research embeds in a case study which is approached partly from a scientific view, and partly from a consultancy view. In that sense, the Municipality of The Hague triggers the research questions, but also acts as the client.

Figure 1.1: Photo from the Scheveningen boulevard capturing the seawall. Source: Own picture

Overall, this governmental division wishes to take measures that deliver solutions across all stakeholders involved, by considering their interests and demands:

- Adapt the coastal zone and its infrastructure to guarantee safety against climate change effects, such as sea level rise, change in the wave climate and storm surges levels.
- Reorganization or expansion of the Port of Scheveningen considering current and future demands in port operations and connectivity.
- Protection of the natural habitats within the municipality boundaries.
- Development of recreational areas to increase the economical value of the touristic sector and to make it more attractive to local citizens.
- Protect historical, cultural values, and the identity of the place.
- Improve urban cohesion and the interaction of the city with the port and beach destinations. Moreover, decompress urban pressure in those locations.

Furthermore, a large investment of 75 million euro was destined between 2011 and 2013 to renovate the boulevard of Scheveningen and increase the touristic value of the area. The client requires a more detailed analysis to assess on the current water safety conditions of the Morales Boulevard design, and whether adjustments are necessary to cope with future boundary conditions within the time frame of the research.

1.1 Research Questions

The demands raised by the Municipality of The Hague, together with framework conditions given by overall goals towards a sustainable city in the 21st century, and the strategies proposed by the Delta Program to deal with climate change, compose the set of requirements that need to be met by the *possible* solutions developed in this work. In that sense, the following research questions are posed:

What are the possible solutions for the coastal zone of Scheveningen and surroundings to deal with climate change until 2100? Next, a follow up question: ***What are the balancing factors (trade offs) that can help in the decision making process to choose a final solution?***

The second question triggers an additional important issue, which is related with the intrinsic aspects driving the actions and way of proceeding of the stakeholders involved within the boundaries of the yet-to-be explained study area. The collision of interests between stakeholders revolves around specific aspects, and the identification of these aspects are an essential knowledge decision makers should have in order to come up with an integrated solution i.e. with a high degree of acceptance. It is the objective of this research to:

1. Provide with conceptual design alternatives to deal with climate change in Scheveningen and surroundings.
2. Compare the designs, and by analysing the perception from stakeholders, identify aspects in which compromises need to be made in order to come up with a final solution.
3. With the results of the previous two objectives, provide with more possible measures to complement and optimize the design.

Later on, and beyond the scope of this work, this can be up-taken to select a final solution and conduct a first-order detailed design.

Climate extremes are more or less certain towards 2050, but they include a much higher degree of uncertainty in the second half of the century. Still, recent studies (Le Bars, 2017) (KNMI, 2015) give sufficient information to target uncertainty through an scenario approach of the solutions until 2100, but the predictions become much more diverging beyond that point. In consequence, the research time frame limits to that year in the future.

Chapter 2

Methodology

This chapter describes briefly the general steps followed to answer the research questions. Since this is a research aimed to achieve designs, a theoretical framework to structure the design plays a major role. Additional information about the design method used is also found further in the report, as indicated in the sections to come.

2.1 Theoretical framework

In the previous chapter, the basic requirements to achieve possible solutions for the Scheveningen area were set. Leaving a side the demands from the client for a moment, the focus is put in discovering a method that deliver water safety solutions for sustainable infrastructure. For this project, a choice is made for the option of nature-based interventions with an integrated perspective.

The implementation of nature-based solutions in water-related infrastructure is a relative new paradigm in sustainable development. The aim is to obtain better solutions for societal challenges of the new century, which are addressed in the new global agenda towards 2030 by the *Sustainable Development Goals (SGS's)* (United Nations, 2015). Even though the time scale of the project goes beyond the end dates of those initiatives, they point out the direction to go. A great strength of nature-based solutions is that they are in line with those goals, which is an important reason why it is chosen over traditional engineering methods. There are many widespread similar frameworks using this concept, such as *Engineering with Nature* (USACE), *Working with Nature* (PIANC), or Ronald Waterman's work (R. Waterman, 2010). To structure the design, the ***Building with Nature*** approach by Ecoshape is used (Ecoshape, 2020), since it has been applied several times in the Netherlands with a large stakeholder acceptance. The integrated view of the system is also addressed by Ronald Waterman's work, extending the concept to ***Integrated Coastal Zone Management by Building with Nature.***. This design philosophy aims to create solutions(Nieboer, 2020):

- In harmony with the behaviour of the natural system
- By letting nature do part of the work
- In close collaboration with stakeholders and local communities
- With added value for nature, (local) economy and society

A further description of the theoretical framework and the design method can be read in section 5.1 in Chapter 5.2.

2.2 Analysis of the present system

The first step to design future solutions for the coastal area of Scheveningen and surroundings is to understand the present system. This consists of an analysis of the current coastal protection system (strength), its present and future environmental conditions (loads), and an analysis of the stakeholders (influence), their different interests, attitudes and power towards the project. The first two are described in Chapter 3, and the stakeholder analysis is addressed in Chapter 4.

To collect information about the current coastal protection system and its boundary conditions, an **online research** was done and **experts** from different institutions such as the waterboard of Delftland, Arcadis, Witteveen + Bos were approached via email and/or **interviews**. Additionally, **literature**, such as technical reports, TU Delft reports and calculation guidelines were studied.

What was defined in the research questions as *possible* future design must not only be based on technical grounds but also on the stakeholders in this area, who will be affected by the proposed solution. Therefore, information about stakeholders was collected by means of **literature review and online research**. To find out more about the stakeholders' interests, power and attitude, **interviews** were arranged and **questionnaires** were sent.

2.3 Design of solutions

After understanding the system, including the physical and social aspect of it, different conceptual alternatives were developed in order to protect the coast of Scheveningen against SLR. For the design of these solutions it was of major importance to find technically feasible and nature friendly solutions that would be well-received by the stakeholders. The search of many real life applications of the nature-based approach was inspired by the work of EcoShape, Ronald Waterman, and the course "CIE4301 Building with Nature".

To deal with coastal erosion and flood safety, three different coastal management strategies considered:

- **Retreat**: It implies to accept that certain areas can be flooded if sea level rises. This means that the dike ring protecting Delfland will be shifted landwards (lower left panel of figure 2.1) and the area in front of it will flood more often than in the original situation.
- **Preserve**: Take protective measures to maintain the level of safety, maintaining the coastline in its current position, or as close as possible (upper right panel, figure 2.1). This can be done by constructing a seawall to withstand the hydraulic loads, or supplying sand to the coast in order keep up with sea level rise, wave impact and longshore transport rates.
- **Advance**: In this case, a new shoreline is created and extended seawards (lower right panel, figure 2.1), resulting in a new stretch of land constructed through a mega nourishment, which can accommodate new natural habitats and different types of urban spaces.

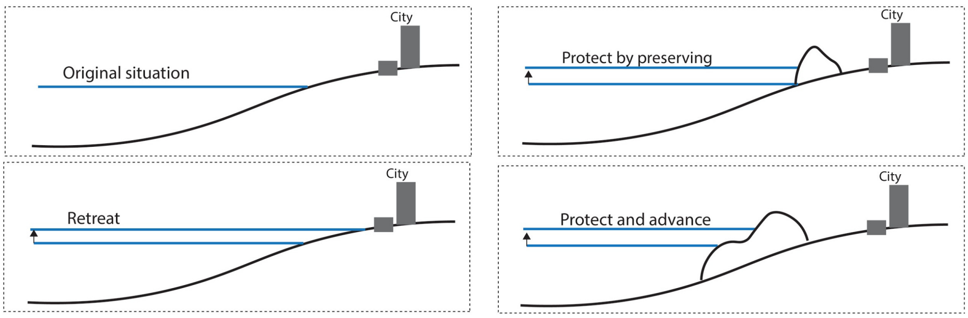


Figure 2.1: Coastal management strategies considered in this study: Preserve, Retreat and Advance.

After a few meetings with the municipality of The Hague (minutes shown in Appendix K), it was concluded that only the 'Preserve' and the 'Advance' strategies would result in a desired solution design. The 'Retreat' strategy is not considered to be attractive enough, once it would transmit a "giving up" mentality, which is against the Dutch nature and history. Besides, The Hague also faces problems regarding urban pressure. A retreat strategy would enhance these problems and create resistance of the stakeholders.

To develop the Preserve strategy, a forward approach is used. This means that the current state of the coastal system is taken as a starting point and adapted by several measures, step by step *forward* in time.

The Advance solution is designed by using a backward approach. In this case, the design attempts to find a final and integral solution, and divide its implementation in partial solution steps by looking *backward* in time, allowing it to be adaptable according to the demands of the system. Both solution packages are fully detailed in chapter 5.2 and Annex N.

2.4 Evaluation of alternatives and optimization

Evaluation by Multi-Criteria Analysis

In order to evaluate the solution packages and conclude in a final solution to propose, a method of assessment is needed. The chosen assessment method for the project is through a **Multi Criteria Analysis (MCA)**. Traditionally the MCA is a tool used to compare different proposed solutions or elements and analyse which one is the best fits for some stated criteria. The strength of this methods, and also the reason to choose it over other assessment methods, is that allows to investigate on the performance of the solutions in terms of such criteria.

During this project, the MCA tool was adjusted in order to fit the purpose of the project. In this case, the most important process element is not which solution package wins or looses, but the knowledge about where the trade-offs lay. In other words, how and when points of struggle between stakeholders will occur, which are related to the compromises the client will have to make to choice a final solution. Therefore the result of the MCA will clarify to the client where the different options stand for, their key elements, as well as their strong and weak points, making it an useful input in the decision making process. The explanation of the different elements of the MCA, and its outcomes, are addressed in the two first sections of Chapter 6.

Optimization by SWOT and TOWS analysis

In order to identify additional measures or interventions that, for some reason, were not included in the design alternatives, a further evaluation is necessary to assess and strengthen the solution proposal. For that reason, a *Strengths-Weaknesses-Opportunities-Threats* **SWOT** analysis was conducted based on collected data collected and own estimations and creativity. These terms are reorganized in a different way, so it was used later as a starting point for a *Threats-Opportunities-Weaknesses-Strengths* **TOWS** analysis. TOWS can prove to be helpful in obtaining a better understanding concerning strategic choices that rise. Additionally, it can assist in the optimization of the solution package, by creating strategies that take advantage of its strengths and eliminate its weaknesses. A further explanation of this methods, and the outcomes from the optimization process are addressed in the last section of Chapter 6.

2.5 Summary of design process and tools

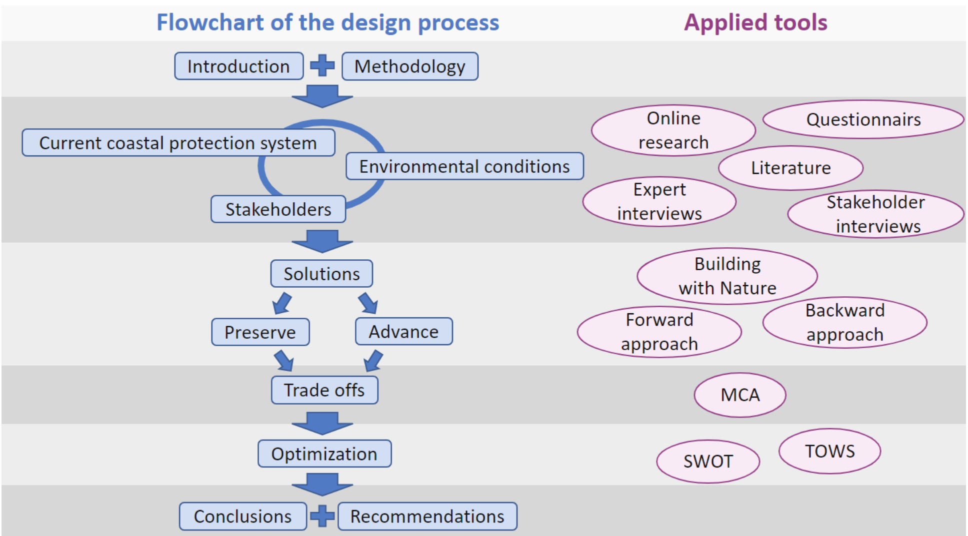


Figure 2.2: Flowchart of design process and applied tools during the design process

Chapter 3

Coastal System

This chapter first provides an overview on how the coast in the area of Scheveningen is protected by dunes, beaches, the port of Scheveningen and the Morales Boulevard. In the second part, the current and future environmental conditions, such as wind, waves and sea level, are presented.

3.1 Coastal Protection in the Netherlands

Since the 17th century, the Dutch government has been strengthening the coastline between Hook van Holland and Scheveningen north locally using seawalls, breakwaters, and wooden or rubble mount groynes. These, however, did not prove to be sustainable solutions, and coastal recession persisted as a result of sediment losses (Stive et al., 2013).

In the late 20th century this strategy started to change, when hard structures were replaced by soft solutions i.e. the application of sand nourishments, both on the beach and on the foreshore (on the seafloor, near shore). Groynes were almost entirely covered with sand and the, dune profiles were heightened and the coastline was shifted seawards until a fixed position called BKL (Base Coastline in Dutch). In the case of the Delfland coast, south of the boundaries of the municipality of The Hague, also a 'mega nourishment' pilot was applied which is called the Sand Engine.

In terms of water safety, different policies and regulations provide a standard for the design of seawalls, dikes and dunes in The Netherlands. According to the Delta Program (Ministerie van Infrastructuur en Waterstaat, 2020), Scheveningen is located in the dike ring area 14, and the design of a seawall within it requires a safety level withstand loads with a return period of once in 10,000 years (a probability of occurrence of 1/10,000).

3.2 Coastal protection system in Scheveningen

The seaward boundary of the Municipality of The Hague is a part of the coastal zone managed by the Water Board Delfland, responsible for the water safety between Hook van Holland and the Scheveningen district. This study focuses on the stretch of coast within the The Hague municipality boundaries, in which the Scheveningen district is the most populated area, associated with the highest flood risk. However, a more extensive area that includes different natural habitats, boulevards, and temporary buildings are also part of the study area. This study area is referred to as the 'System of Scheveningen' even though the extension of the analysis goes beyond the Scheveningen district itself.

The coastal protection system of Scheveningen and surroundings is divided in the following elements according to the type of flood safety structure:

Figure 3.1: Subdivision of the study area into elements according to the type of water structure. Nr 1, 5, 6, and 7 correspond to flexible dune systems. Nr 2 is a fixed dune seawall. Nr 3 and 4 are hard structures (dike-in-boulevard and paved dike, respectively). The different elements are divided by cross-sections following the 'raai' lines defined by Rijkswaterstaat for the entire Dutch coast. Source of the background figure: Google Earth

On the southern edge of the study area, the Sand Engine is present. In this part of the coast, the land extends seaward forming an artificial peninsula that is meant to supply sand to the Delfland coast for about the next 20 years (Stive et al., 2013). However, due to the complexity of the natural processes in this area, the Sand Engine is left outside this preliminary assessment, although it is considered to be a relevant boundary condition for the system.

A characterization of each element helps understanding the system. Furthermore, these elements can be classified into Soft structures (dunes and beaches) and Hard structures (dikes, seawalls and boulevards). Among the latter, there are paved dikes near the Port of Scheveningen, and a special case of a dike-in-boulevard or dike-beneath structure in the Morales Boulevard.

According to the Waterboard of Delfland (van Delfland, 2014) and National regulations (van Verkeer en Waterstaat, 2007) the design water level (associated with a storm) is NAP +5.7 m, and in the case of dunes it is NAP +6.1m. The reasoning behind this is, that other calculation methods and different guidelines are used for the two different types of structures.These aspects are further described in section 3.4.

The next sections will describe these elements not only focusing on water safety, but also describing other ecological and social functions. Particularly, a throughout assessment of the Morales Boulevard was requested by the municipality of The Hague. For an additional description of the dimensions of the coastal elements, see also Appendix A.

3.2.1 Dunes

The coast of Delfland is widely dominated by young (formed 1200-1600 AD) rich-relief dunes, which can elevate up to 30 m high. In the study area of this project, these dunes have a width between 150 and 800 m and all heights are above NAP + 10 m (Actueel Hoogtebestand Nederland, 2020). As these formations are close to the sea, subjected to changing conditions of waves and wind, it is a very dynamic environment with large ecological gradients. As a result, only a few species of vegetation can survive under such conditions (Deltawerken, 2004).

The available sand is used by the wave forcing to shape all kind of 3 dimensional features along the coast. The surf waves throw the sand up onto the beach during flood tide, and during low tide the wind dry up the sand and if wind speed is sufficiently large (from 5 m/s) it moves it further inland. As a consequence, banks can develop, and pioneer plants like marram grass serve as a barrier for the sand transport, resulting in dune development on top of the banks. The larger the complexity of dune strips and valleys, the bigger the chances that natural habitats can thrive. Sand lizards, foxes, birds, and even Scottish cows are examples of species living in these dunes.

Dunes offer important ecosystem services. The most important one is flood safety, as the sea strip can become a strong seawall to function as a dam against storm flood. Another relevant function in young dunes is the storage of freshwater originated by rainfalls. At the Delfland coast, the society has largely seized this possibility of fresh and brackish water supply in Oostduinen (Deltawerken, 2004).

Besides these natural dynamic dunes, there are also fixed dunes in the project area. Fixed dunes are covered by hard structures such as buildings, boulevards, etc. Due to these constructions, the dunes have become static and fixed. They have a smaller width of about 50 to 70 m. This is the specific case of the element *2. Northern Boulevard* (figure 3.1).

More detailed analysis of the dune characteristics in the research area regarding width and height can be found in appendix A. An overview of the dune formation history and coastal features in Delfland can be found in appendix B.

3.2.2 Beaches

Beaches are very important coastal features regarding coastal protection. They are a natural dissipator of waves and decrease their energy before reaching the dunes. Since 1990, the Dutch coastline is maintained with a 'dynamic' approach. This means that a minimum threshold beach width is defined for each section of the Dutch coast. This threshold is called BKL or Base Coastline in Dutch. When the beach width becomes smaller than the BKL, a sand nourishment has to be applied to compensate for the erosion. In case the threshold is not exceeded, nothing has to be done (Hallie, 2017). According to the latest Rijkswaterstaat report on coastline nourishment, the Delfland coastline is healthy and does not show a relatively strong erosion patterns (see figure C.1). In the past 10 years the Delfland coast needed 2.6 million m^3 of sand to be protected. This a relative small amount if compared to other coastal zones (see figure C.2).

Also in the social and recreational aspect does the beach landscape offer many functionalities. The beach in front of the Scheveningen district is one of the most popular destinations for tourists in the Netherlands, with many beach clubs and restaurants. The wider beaches further to the south in Westduinpark and Kijkduin are less affected by buildings and human interventions, offering a more relaxing environment for tourists looking for some more 'naturalness'. This area is also where the majority of the nudist beaches can be found in the Delfland coast.

3.2.3 Port of Scheveningen

Water safety

The primary water protection near the Port of Scheveningen is a paved dike (hard structure) creating a high ground running adjacent to the Scheveningen-Village, protecting it from floods (see black line in figure 3.2 below). Additionally, other complementary elements are part of the flood safety system. The flow of the Verversingskanaal collects surface water and uses a pumping station to transport it to the sea, maintaining a constant water level in the channel. Water excess is pumped to the port basins downstream through a lock that connect the channel with the Second Harbor. As a result, port basins have also a retention function against flood.

With respect to the dike, different buildings, living areas, roads and tram railways are placed along the outer slope (sea side), hence with a lower level of safety than the areas behind it. These vulnerable areas, usually with low economical value and/or no permanent housing, are flooded during design conditions. The areas behind the dike are protected against a 10,000 years recurrence storm, which is the required safety level stipulated by Dutch policies (Rijkswaterstaat). The primary flood defence is connected to the dike of the Morales Boulevard in the north, and to the Westduinpark dunes in the southern edge (figure 3.1 and 3.2).

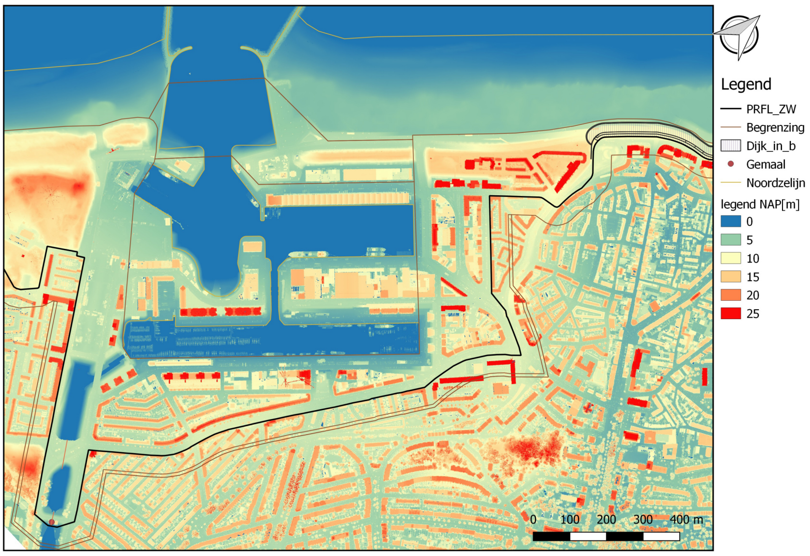


Figure 3.2: Elevation map in the Port of Scheveningen. The black line represents the landward boundary of the water management structure, or 'Boundary profile'. Blue color represent the water areas, and yellow to red represents the elevation in the range NAP + 10-25 meters. Source: (Kreike, B. et al., 2020)

The dike crest is around 3 m wide and between NAP + 6.5 m and NAP + 9 m high. The primary defense is safe for the boundary conditions associated with 50 year lifetime, but not for the 200 year lifetime (see figure E.1) (van Delfland, 2013).

In part of the port areas floods start happening at a water level of NAP + 4.42 m, which is considered as a risk with a return period of 1:1,000 years ((Boers, 2010). Particularly, the weakest part is located in the southern edge of the port, which was flooded several times during the last years affecting the adjacent buildings (Second Harbour near Doctor Lelykade, figure E.2).

Port development

The Port of Scheveningen has a great significance for local residents and is part of the culture and history of the area, creating a sentiment of pride around it (appendix K.3). The main services offered are related to local fishing industry, recreation, research vessels and during the last years also the cruise ship industry. Yachting and small leisure vessels strongly dominate the activities during the summer. Moreover, Scheveningen has international fame for hosting yachting races, like the Volvo Ocean Race or the North Sea Regatta. In addition, the port area is merged and strongly interconnected with the urban space with living and business areas. More information about the functions of the different port areas is provided in appendix E.2.

Looking into the future, the Port of Scheveningen is undergoing a large-scale redevelopment. Priority is being given to the fishing fleet, harbour-related services/off-shore support, water sports and new developments in shipping and water management (Gemeente Den Haag, 2021). As current demands from the port authority, there is a **shortage of the marina** to accommodate small vessels, and there is an **increasing demand of small cruise ships** of up to 160 m large. A potential development, which is not included in the Zoning Master Plan, is the sea farming activities.

In addition, the city of The Hague is facing the challenge to create a better port-city relation. The urban development area is willing to integrate the harbour to the coastal strip. This issue can be approached by constructing a connection for pedestrians and cyclists between the Southern and Northern Harbour heads of the port, as a continuation of the Morales Boulevard (Municipality of Den Haag, 2015).

3.2.4 Morales Boulevard

It was first requested by the municipality of the Hague to make a throughout assessment on the current safety level of the Morales Boulevard. Secondly, to explore for which conditions (SLR, wave climate, storm surge levels) it was designed and when it does not meet the standard of safety anymore.

Description of the Morales Boulevard project

In 2003, the Dutch government defined 13 weak links in the Dutch coastal defence system, that had to be upgraded before the end of 2015 with funds of the government. One of them was the area between the Kurhaus and the port of Scheveningen (figures 3.3 and F.1). To improve the coastal defence in that area, the existing boulevard had to be demolished and rebuild after strengthening the sea defence (Hoogeveen & Veenswijk, 2016).

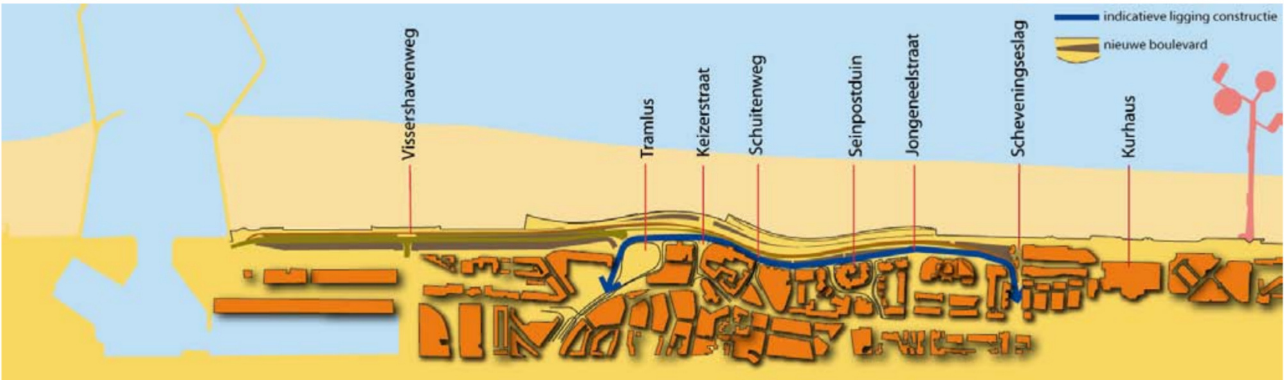


Figure 3.3: Schematic location hard structure dike-in-boulevard. The dark blue line represents the 1 km long stretch of the hidden sea dike, while the dark yellow shaded area shows the location of the 1.9 km long boulevard.

To do so, a plan for a 'hybrid' structure was developed: a combination of a 'hard' dike hidden under an aesthetic boulevard design with a 'soft' beach and foreshore nourishment. The nourished sand volume widens the beach in front of the dike and thus, causes the waves to break earlier. Therefore, the wave heights close to the 'hard' dike structure are smaller and the crest height of the dike could be limited. This ensures an unobstructed view at the sea (Voorendt, 2013).

In order to ensure safety against inundation as a result of floods or break trough, a safe design for the dike-in-boulevard (hard structure) and sand nourishment (soft solution) is needed. The preliminary planning of the dike-in-boulevard was done by Arcadis. All the following information about the Morales boulevard is taken from the preliminary planning report (Arcadis, 2008) and proofed with information from the final planning report of the dike structure made by Witteveen+Bos (appendix G).

On basis of the safety level required by Dutch policies, a design for the dike-in-boulevard construction was done. It consisted of a planning period for the next 100 years assuming a maximum climate scenario with a design water level of NAP + 6.85 m (table 3.1) and a design for the beach nourishment for the next 50 years assuming a middle climate scenario wit NAP + 6.40 m (table 3.1). The reason for the different planning periods and climate scenarios lies in the nature of the two different protection types: the dike-in-boulevard structure is a hard solution, that is difficult to adjust afterwards, while the sand nourishment is a soft solution, that is flexible and can be easily adjusted to the uncertain future demands of climate change.

Table 3.1: Design boundary conditions dike-in-boulevard and sand nourishment. A more detailed explanation for every parameter can be found in appendix F.2.1.

Parameter	**Dike-in-boulevard**	**Sand nourishment**
Design climate scenario	100 year max m	50 year mid
Current design water level w.r.t. NAP	5.20 m	5.70 m
Surcharge sea level rise	0.85 m	0.30 m
Surcharge storm surge	0.40 m	0.00 m
Surcharge dike ring approach	0.30 m	0.30 m
Surcharge bui oscillates	0.10 m	0.10 m
Total design water level w.r.t. NAP	**6.85 m**	**6.40 m**
Offshore wave height H_s	8.6 m	8.6 m
Wave period	14.3 s	14.3 s
Storm duration	35 hrs	35 hrs

Dike-in-boulevard

The height of the sea dike is NAP + 10,10 m. This height results from the existing ground level behind the the hard structure and the spatial requirement to remain a great sea view from all parts of the dike. For a small stretch near the Seinpostduin, the dike height is NAP + 12,0 m to avoid excavation work since the ground level here is naturally higher. At Schuitenweg the ground level is naturally lower (NAP + 8,60 m). To provide a good sea view, the dike has to be lower, which is compensated by a wider beach in front of it. The wider beach causes the waves to break more, so that the wave height at the toe of the dike at Schuitenweg is lower than at the other parts.

The wider beach in front of Schuitenweg results from the shape of the dike-in-boulevard structure, following the original curves of the dunes. At the location of Schuitenweg, the dike arches land inward, which causes the beach to be wider. For more information about technical details of the dike-in-boulevard-structure (dike slope, revetment, toe, design principles and connection), see appendix F.2.2.

Sand nourishment

In order to increase the entire active cross shore profile, the sand nourishment was placed at the seaward side of the dike construction up to approximately 600 m seaward (NAP -5 m line) over a coastal length of approximately 2.5 km.

It was determined that an initial nourishment volume needed for the 50-year medium climate scenario at Keizerstraat should be of 793 m^3/m and at the Jongeneelstraat of 495 m^3/m (table F.1). Without the sand nourishment, the required dike height would have been at least NAP + 11.0 m.

The maintenance nourishment volume to compensate for erosion in front of the Morales Boulevard amounts 384 m^3/m every four years (table F.1). In order to damp the wave energy in front of the Morales boulevard sufficiently with rising sea level, the beach width and height has to be increased with additional future nourishments (see tables F.2 and F.3).

Social and recreational functions

The Morales Boulevard has an important function as an attractive public space for tourists and locals. During high season, the beach in front of the boulevard is a popular destination.

In terms of urban cohesion, it provides a connection between the old seaside resort in the northern Boulevard with the fishing village and the harbour, which allows cyclists and pedestrians to stroll between these areas. In addition, it holds many beach clubs, restaurants and touristic-related businesses with a nice sea view, reflecting also on the high economical value of the boulevard. As mentioned before, the boulevard was designed is such a way that the sea view is maintained from all parts, including the living areas behind the dike, making it an appealing space for living or for temporary accommodation.

Conclusion and possible future design

The current design of the dike-in-boulevard structure assumed a SLR of 0.85 m plus additional 0.40 m in case of an increase in storm surge level due to climate change. As it is demonstrated later on in this report, storm surges are not expected to increase in the future. In light of this, it is more practical to say that the Morales Boulevard is prepared for a sea level rise of 1.25 m. Simultaneously, the beach volume in front of the boulevard was calculated for a SLR of 0.30 m. The beach volume can be increased by beach and foreshore nourishments to also withstand the same SLR of 1.25 m, without compromise the sea view behind the dike. After that, a new solution has to be found.

In the preliminary planning report of the Morales Boulevard, a possible future plan for a maximum climate scenario in 200 years with a maximum design water level of NAP + 7.7 m (using the values from table 3.1 with SLR 1.7 m instead of 0.85 m) is presented. For this plan the dike table height would be raised to NAP + 12.0 m (installation height NAP + 12.4 m taking 0.4 m settlement into account) everywhere and the sand volume in front of the dike would be increased (figures 3.4 and F.2). As a consequence, the sea view from behind the dike would be restricted.

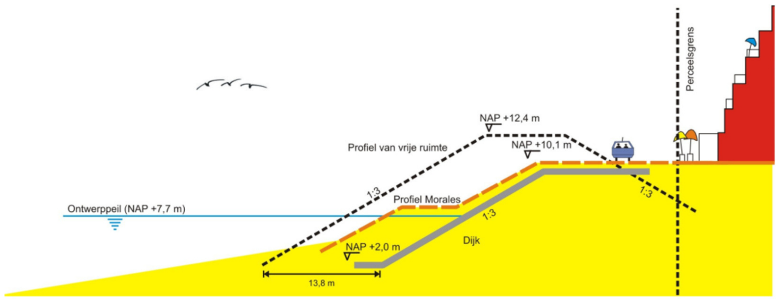


Figure 3.4: Possible future extension of dike-in-boulevard structure in seaward direction for design boundary conditions in 200 years with max. climate scenario.

The beach height elevation for a 200-year maximum scenario will be larger than NAP + 5 m. This would result in a much wider beach, which is not desired because it would reduce the water depth at the entrance of the Scheveningen Harbour. This would cause enhanced sedimentation in the access channel, which leads to a larger maintenance effort. Therefore, it is recommend to either place the sand as a row of dunes in front of the boulevard or apply a hardened dune. A third option would be an extension of the northern breakwater.

Secondly, interventions to preserve or upgrade safety in the Morales Boulevard should try to avoid, in all possible ways, blocking the sea view from all parts in the dike. Also, the access to the beach and related businesses should not be hampered.

3.3 Present and future environmental conditions at Scheveningen

The coast of Scheveningen is dominated by wave action. Its orientation is to NNE-SSW, parallel to the dominant wave direction (see figure 3.5). Near the waterline, a highly dynamic environment is present due to the high turbulence of wave breaking, creating multiple bars in the sea bottom. During storms, waves are responsible to erode and transport large amounts of sand towards offshore. Tidal oscillation create wet and dry areas in the coast. During dry periods, winds are responsible to transport sand landwards, shaping all kind of dune formations.

Global future climate is driven by temperature increase and changes in the air flow pattern, which translates in changes of sea level, wave, and wind patterns. For water safety, sea level rise is the main hazard to be addressed in the coming decades. Slight changes of tide are expected. Storms and wave direction will shift slightly, but the intensity is unlikely to change in the next century.

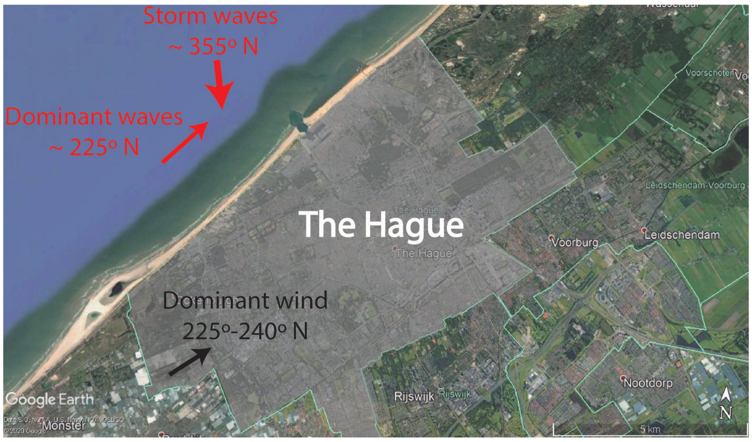


Figure 3.5: Summarize of the relevant wave and wind conditions in the study area. See also Appendix H.

3.3.1 Wave climate and sediment transport

The dominant wave conditions coming from the south-west with a relatively small height (mean wave height H_{m0} between 1.5 and 0.8 m) are the cause of a net longshore sediment transport from south to north. The significant wave period (T_s) at Scheveningen is between 5.4 s and 7.8 seconds (Wijnberg, 2002). Episodic storm waves and surge events come from the north, which result in large sediment transport deeper in the seaward direction. During mild conditions, waves restore part of the sediment to the nearshore. The conjunction of sea level rise and losses to the deeper shore face results in a structural retreating behavior of the coast. The geometry of the North Sea basin is such that Atlantic Ocean and the northern North Sea generated swell waves will always approach the Scheveningen coast from NNE (Wijnberg, 2002).

Recent studies show the extreme boundary conditions of wave height and period will not change significantly. Assuming a moderated climate scenario (the extreme 10,000 year events), which are embedded in Dutch coastal policy, there is no statistically significant change of Hs and Tm for the period between 2071 and 2100 compared to those between 1961 and 1990 (de Winter, 2014).

3.3.2 Tide

Tides along the Scheveningen coast are semi-diurnal, which means there are two high tides and two low tides per day. The mean tidal range (difference between mean high water and mean low water) is 1.4 m. Mean tidal variations can be obtained after processing data from Rijkswaterstaat measurements in the Scheveningen Harbour Rijkswaterstaat (Chotkan, S.A. et al., 2020):

- Mean High Water Spring = MHWS = NAP +1.48 m
- Mean High Water Normal = MHWN = NAP +0.77 m
- Mean Low Water Normal = MLWN = NAP -0.62 m
- Mean Low Water Spring = MLWS = NAP -0.79 m
- Lowest Astronomical Tide = LAT = NAP -1.04 m

Finally, tidal currents vary between +0.5 m/s and -0.5 m/s during the tidal cycle (Wijnberg, 2002)

Regarding the future tidal behaviour, analysis of observation series shows that the flood levels rise 5 cm per century faster than the average sea level, and ebb levels rises on average about 5 cm slower than sea level (TAW, 2002). Giving the level of uncertainty in future water level is in the order of meters, in this study it is assumed the tidal range does not change in the long term.

3.3.3 Temperature

The Netherlands have become warmer during the last 100 years, and temperature is expected to increase even more in the future (figure I.3). The coldest days in winter and warmest days in summer will happen more often. On the other hand, mild days in winter and cool days in summer show relatively modest changes.(KNMI, 2015)

3.3.4 Wind and storm

The predominant wind direction in the area of Scheveningen is south to south west (see also Appendix H). The human-induced changes in wind speed are small in the KNMI'14 scenarios. The changes in the scenarios are within the natural variation range, both for average wind speed throughout the year and for storms in winter. (KNMI, 2015)

With respect to wind direction, northerly winds over the North Sea cause the highest sea surges along the Dutch coast. The scenarios indicate that strong winds from this direction will not change much in the future. Moreover, existing studies on the extreme surge and wind conditions for the Dutch coast, do not show a significant change under a changing climate for the North Sea basin. A recent example of it is the work by (de Winter, 2014), which confirms that the amount of wind from north-west and north-north-west are not projected to change.

3.3.5 Sea Level

The reference value of sea level for NAP + 0.04 m for the year 1995 has been increasing during the last decades at a rate of 2 mm/year, according to KNMI. Currently, it is at NAP + 0.00 m.

Projections of sea level values according to KNMI'14 (appendix I.1) are estimated taking into account different factors including gravitational effects, ocean expansion, melting of ice sheets on a global scale. Land subsidence is not considered but, according to the work by (Kreike, B. et al., 2020), it will be in the order of 1 cm for the area of Scheveningen after one century. Hence, it is safe to say that sea level rise scenarios are relative to the land (SLR equivalent to relative SLR).

Recent signals and insights about possibly additional accelerated sea level rise due to accelerated decomposition and melting of Antarctica, result in two more scenarios for the Dutch coast: RCP4.5 and RCP8.5 (Le Bars, 2017).

The KNMI'14 projections were integrated with socio-economic scenarios in the 'Delta Scenarios' used for the Dutch Delta Program (Deltares, 2018a). According to Delta scenarios (appendix I.2), sea level is expected to be between 0.15 m and 0.4 m by 2050, and between 0.35 m and 1.00 m by 2100. Not only the absolute values are important, but also the rate of sea level rise. The rate along the Dutch coast will increase up to 10-14 mm/yr by 2100. The accelerated scenarios hardly differ until 2050, but they deviate largely after that together with the margin of uncertainty (figure 3.6).

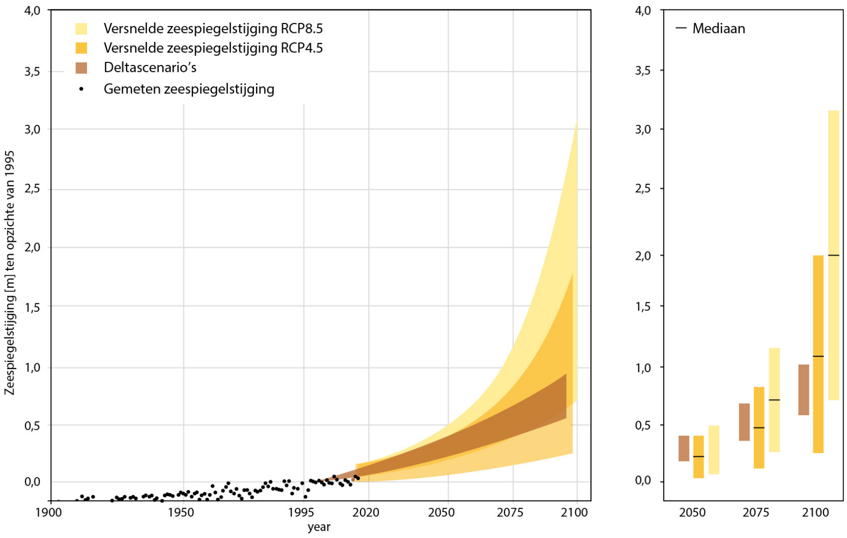


Figure 3.6: Sea level scenarios used according to KNMI14 (Delta scenarios) and the projections of Le Bars et al.2017 (RCP4.5 and RCP8.5), as well as the measurements with respect to 1995 (Baart et al. 2017). The measurements are also relative to the position in 1995. At that time the sea level was 0.04 m compared to NAP. Source:(M. Haasnoot, 2018).

In the new projections a sea level rise from 0.3 m to a maximum of 2.0 m is considered possible for the scenario RCP4.5, provided a maximum 2°C warm-up in this century. With stronger global warming (by 4°C in 2100), this can be as much as 3.0 m. After 2100, this additional accelerated sea level rise can be continue up to 5 and possibly 8 m in 2200. In addition, the speed of 14 mm/year can already be reached around 2050, and it would continue speeding up to about 20-35 mm/year around 2070, to 60 mm/year or more at the end of this century (M. Haasnoot, 2018).

3.3.6 Consequences of climate change in the Coastal Protection Strategy

Nourishing the Dutch coast contributes greatly to protect the coast against flooding and can be seen as a nature friendly solution. But this strategy may face limitations in the future. With SLR, the volume of sand needed to protect the entire Dutch coast will increase. It is estimated that around 2050 around three to four times more sand will be needed than today (table D.1), even without accelerated sea level rise. By 2100 this could rise to 20 times more (table D.1), depending on the rate of rise, which would be a sand volume of twelve times the Sand Engine (12*20 million m^3=240 million $m^3/year$) every year for the entire Dutch coast (Deltares, 2018b).

The Netherlands have the advantage of having a shallow sandy North sea shelf in front of the coast with an ample sand supply. Currently, the reserved area for sand extraction for nourishments amounts 5,200 km^2 (figure D.1). Taking into account existing or future use of space, there are three possible additional areas of another 5,200 km^2 each for sand extraction outside the current reservation area (figure D.1) (Deltares, 2018b).

Until what depth dredging is possible, in other words how much sand in total can be dredged from the North Sea is still unknown. For regular nourishments of the Dutch coast, sand is dredged to a depth of 2 m under sea ground. For the land reclamation of the port extension Maasvlakte 2 in Rotterdam, sand was excavated to a depth of 20 m (de Jong & et al, 2014). Assuming that dredging to a depth of 20 m is possible for all four possible sand extraction areas, this would result in a total sand volume of 416,000 million m^3 (see equation in appendix D.1). Assuming a sand volume of 240 million $m^3/year$ (table D.1), this sand volume would last for more than 1733 years.

As a preliminary conclusion, The Netherlands can be considered to have enough sand to maintain the entire coast even for the most extreme climate scenarios, for a duration that goes a few centuries beyond the time frame of this study. Of course, such a rough estimation does not consider future changes in national and international policies and legislation's, or potential new developments that decision makers are not aware of nowadays, that could restrict the availability of sand in the North Sea.

Besides the availability of sand, also the distance from the excavation site to the placement site matters. The transport costs, and thus the sand price per m^3, increases with the distance from the sand extraction area to the coast. Additionally, the CO_2 emissions increase with distance (de Schipper, 2020). Therefore, more local sources in terms of costs and emissions are preferred. In case this is not possible, it has to be thought of new and innovative technologies.

For more information about the various aspects of future sand nourishments, such as ecological impacts, recreational uses and groundwater considerations, see appendix D.

3.4 Design Boundary conditions for the Scheveningen system

The most relevant hydraulic load to be considered in long term planning of coastal structures is the Sea Level. The reference value, or baseline, is the hydraulic boundary condition derived from the 1/10.000 years probability of failure required by National regulations. The result of such calculation is addressed by local legislation (van Delfland, 2013) and (van Delfland, 2014), which in this report is sometimes called as the 'year 0' design sea level i.e. without considering sea level rise.

Along the coast of Delfland we find soft seawalls (dunes) and hard structures such as the Dike-in boulevard and paved dikes (high ground) protecting the Port of Scheveningen. As a result, the design boundary conditions for the year 0 are different for the two different elements found in the Scheveningen coast: Baseline for dunes: NAP +6.1 meters and Baseline for paved dikes and Dike-in-boulevard: NAP +5.7 meters. For more information about boundary conditions of soft and hard structures, and how this two values are obtained, see appendix J.

Chapter 4

Stakeholders

This chapter refers to and analyses all actors involved both directly and indirectly to this project. Coming from different groups and backgrounds, it is evident that they have different interests, power, attitude and role to this project, the analysis of which will contribute in reaching the most optimal solution.

4.1 Stakeholders Identification

For the identification of the stakeholders, numerous sources were used. First of all, the online research was a useful tool to collect information concerning the area and the people involved in the project. Additionally, the former MDP reports were used as a source of information, but these information were updated to the current situation. Another important input of data were the meetings with the Municipality of the Hague and relevant stakeholders, which provided inside information about the stakeholders themselves, the project and how it should be approached. These meetings were both formal and informal, and led to structured interviews (appendix K), that acted as tools in their further analysis.

4.1.1 Governmental Bodies

The **municipality of The Hague** is a growing municipality of almost 545,000 residents, of whom the 100,000 inhabited the area the last twenty years. It is evident that there is a linear analogy between these numbers and the area's needs in terms of development and welfare. The port and the seaside area along Scheveningen face the extra challenge of remaining safe and flourishing against the gradual sea level rise and the dangers that phenomena like global warming result in. Being the main client, the municipality targets in creating a safe waterfront area and port, while opportunities of economic growth are created for all businesses. It is responsible for the spatial planning and the zoning areas, and for representing the interests of the residents. The intentions and future plans should be acknowledged to the public and the actors involved. In addition, the Westduinpark is managed by the municipality, as a result it must be protected and interventions should always be made according to the Natura 2000 regulations and restrictions (Den Haag, 2021).

Along with the municipality, a plethora of governmental bodies influence and are influenced by the area. The **MRDH - Metropolitan Area Rotterdam - Den Haag** is an organization that consists of 23 municipalities that collaborate in order to increase the economic strength and the well-being of the metropolitan area. Besides the employment and economic boost, ensuring accessibility and adequate transportation are also among their main responsibilities. The organization is the direct recipient of governmental funds for transportation, resulting in direct coordination with the **Transportation Companies** of the plan area, and aims clearly to a more accessible region with frequent and convenient transportation options (MRDH, 2021).

Another local authority that has a strong influence in the area is the **Waterboard - Delfland**. Delfland is responsible for the protection against flooding, the maintenance of dikes and dams, the water level and the water quality control. Particularly, Delfland is responsible for the safety of dike ring structures (both hard and soft) described through sections 3.2.1, 3.2.3, and 3.2.4. Given the wide range of these activities and how they are interwoven, integrated water management is of vital importance, as well as collaboration with various institutions and authorities to achieve common goals or face challenges (Rijksoverheid, 2021).

The **Province of South Holland** is also a governmental body that targets in ensuring the viability of the province, and consequently of the plan area. This body is responsible for transforming the national policies into regional measures, and integrating the design of the provincial spatial planning. Strategic policies and measures are established by the Government to guarantee national safety, and inscribe the water safety standards. This is the reason why the government does not directly influence the project, however if needed, has the right to interfere.

Rijkswaterstaat is the governmental body that is dedicated in the preservation of the coastline, using every tool and method available. Annual reports are created, with detailed information about the coastline, and nourishment activities are realised when necessary. In addition, every four years new nourishment plans are designed, taking into account the Sea Level Rise, to ensure safety and coastal protection (Rijksoverheid, 2021). To summarize, the liability of Rijkswaterstaat restricts to maintaining the coastal profile (beach and seafloor) whereas Delfland is responsible for the dikes, in this case, seawalls. Last but not least, the **Government** is not directly involved in the project, however the project's outcomes have to be in line with the national policies, and to contribute in the achievement of the national goals.

4.1.2 Residents & visitors

Actors that are directly affected by the development of the area are the inhabitants and the visitors of Scheveningen. They can be divided in three different categories, based on their problem perception, their interests and the influence that any change could have in their lives. The **Residents of the Coastal Area (Coastal Residents)** are directly affected, both by the measures and policies concerning safety, but also by the further economic and sustainable development of their area. They want to be part of the decision-making and have set up a local organization, in order to be able to set any questions, advise or request changes throughout the whole process. On the contrary, the **Rest of the Municipality's Residents (City residents)** are indirectly influenced by the changes, resulting in low level of interest and unwillingness to be actively involved in the decision-making process. However, if needed they are capable of requesting changes on decisions that may negatively influence their lives.

Another important stakeholder whose needs and wishes should be taken into account but cannot influence the process during the decision-making, are the **Visitors and Tourists** of the area. Being the most popular seaside resort of The Netherlands, Scheveningen receives millions of tourists every year, and their activities constitute an important source of income for the local economy. It is apparent that any change with negative impact on these actors can lead to change of their recreational preferences or even destination. If that becomes reality, it will be devastating for the economic growth of the area (Be Hague, 2017).

4.1.3 Business owners & the Pier

The economic prosperity of the city is connected to the industry of tourism. Especially for business owners of the beach (as cafes, restaurants, bars, etc.) tourists are the main source of income and consequently, large numbers of visitors are more than welcome. The goal of the businesses is to achieve maximum economic profitability or, in other words, to service the maximum number of visitors possible.

Another goal is to maintain their view to the sea as it is, which is one of the main attractions for the visitors. Of course, they are expected to comply to rules and restrictions that can be imposed, as well as provide services of high quality to the visitors. The same goals apply also for the **Pier**, which is a unique recreational attraction of the region, after its bankruptcy and reopening a few years ago. The Pier aims at providing entertainment for the visitors, while complying with the designated plan. Since the company that manages the Pier is private, economic success and development are its goals, and increase of tourism could be beneficial (De Pier BV, 2021).

Since in this project the Morales Boulevard is studied in a separate section (3.2.4), a corresponding division in stakeholders is appropriate, so we divided Horeca and commercial activities in two different stakeholders, **businesses of the Morales Boulevard** and **businesses of the other areas and the Northern boulevard** of the project.

Figure 4.1: Stakeholder grouped based on their main driver

4.1.4 Harbor industry

Considering the harbor, a few activities take place there. Starting with the first harbor (figure E.2), it is used by the **fishing industry** to produce and transfer quality goods, for unloading and exporting frozen fish, as well as selling fresh fish at the local market. Their responsibilities lay upon paying taxes and costs for occupying space at the harbor. Fishing industry strives for growth of the business and high quality of goods, while maintaining low costs of production and services. The main aim is the accessibility to and from harbors, and having enough space for potential development in the future.

In the harbor area **Water-sports businesses** are also present. As any vivid business, they are eager to achieve maximum economic profits, meaning that they desire the increase of tourism for the area. They intend to provide high quality services to visitors and tourists, while paying taxes and applying to rules and restrictions that could be present.

4.1.5 Buildings of special vulnerability

In the area, Delfland applies a boundary profile to define the maximum allowable dune erosion during storm. Some of the **buildings of the area are more vulnerable** than the other structures to erosion, because they are located in front of the aforementioned boundary profile (for example the famous hotel Amrath Kurhaus). For this reason, these buildings require special defense treatment and they are considered as a different stakeholder. Safety is their main value, especially because they are even more exposed to erosion and sea level rise. Other than observing the plans and providing services to tourists, they don't have any other relative responsibilities.

4.1.6 Environmentalists and Nature Preservationists

In the study area, several locations are environmentally unique, for this reason they are protected by European regulation and designated as part of the Natura2000 network. First of all, Solleveld, located near the Sand Engine, is a dune area that resembles historical agricultural landscapes. Westduinpark, located next to Solleveld and near the Scheveningen Harbor, is one of the largest nature preserves in The Hague, that offers a wide range of flora and fauna (The Hague Marketing Bureau, 2021). Lastly, Meijendel, with a unique structure of parallel rows of dunes, is also a Natura2000 area.

In order to preserve biodiversity as both areas are natural habitat for a plethora of animals and plants, these regions are protected with European regulation (Natura2000) and more specifically, all three of the above areas are under the Habitats Directive Status (Ministry of Agriculture, Nature and Food Quality, 2021). For this reason, special limitations should be applied to construction works in the whole area. Even if the construction works are not inside a preserved area, they could be indirectly affected because of the Natura2000 area restrictions.

Another constraint concerns the permits, as there is a permit policy referring to the level of intervention of corresponding activities. If the activities are interfering with the protected environment, a permit should be granted by the province of South-Holland beforehand.

Figure 4.2: Natura2000 areas of interest

For the dune areas of Solleveld and Meijendel, **Dunea** is the company responsible for their management. Apart from providing water supply to the residents of the area, Dunea also ensures that recreational activities take place, and manages nature, respecting Natura2000 regulations. Their goal is to balance water extraction, nature management and environmental management, having sustainability as their main value (Dunea, 2021).

Omgevingsdienst Zuid-Holland Zuid (OZHZ) is a company in South Holland that has multiple tasks in the area. OZHZ is a consultant of the Province of South Holland in environmental topics, realizes inspections, informs residents about rules that apply in the area, and coordinates the enforcement of permits when needed. They aim at protection of the designated Natura2000 areas and at protection of the living environment in general. Additionally, the company receives reports from the residents considering nuisance and tries to solve the causes of it. The main values that define the company's activities are nature preservation and sustainability (OZHZ, 2021).

4.1.7 EcoShape

Another aspect of sustainability is introduced by **EcoShape**, a foundation that is dedicated in an innovation program of utilizing the forces of nature instead of fighting them. This program is called Building with Nature (BwN) and aims in enforcing sustainable methods in construction. Nature, economy and society are integrated and strengthened. The values that are taken into consideration are, above all, safety and sustainability. For that reason, EcoShape tries to ensure that the outcome of the project will comply with sustainability principles and norms, by providing consultancy services and sharing its knowledge (EcoShape, 2020).

4.2 Interest, Power and Attitude

In order to further analyze the actors involved in the decision-making process, various tools and methods can be employed. The first step is the analysis of their interest, power and attitude, that will provide enough inside and handy information.

<u>The Governmental Bodies</u> are among the most powerful stakeholders. They are in charge of creating, adapting and implementing policies and measures, consequently they have the power to intervene at any point that the process threatens their values and goals. To be more precise, the **Government** that defines strategic policies at national level is not directly involved, as long as the outcomes are in line with these policies. As a result, low interest and high power are the main characteristics of this actor, while the positive attitude makes it a 'Sleeping Giant'.

More engaged in the process is **Rijkswaterstaat**, which has medium to high interest and high power, as a result of the responsibility to annually inspect the coastline and perform nourishment activities when necessary. Given that the project's goals are in line with its goals, the positive attitude constitutes Rijkswaterstaat a 'Saviour'.

The same applies for the **Province of South Holland** and the **Waterboard - Delfland**, since their main responsibility is to transform and implement the national policies into regional and the protection of flooding and good water quality respectively. Consequently they can also be characterized as 'Saviours'.

Figure 4.3: Power Vs Interest grid

The characteristics of **Dunea** are slightly different. Being the one who manages the dune areas of Solleveld, Meijendel and Berkheide, has a medium to high interest concerning the project, but medium to low power in influencing the project, with positive attitude. Based on these characteristics it can be considered as a 'Friend', and should be used as a confidant or sounding board. Another actor without high interest or power is the **Metropolitan Area Rotterdam Den Haag(MRDH)** organization. It is not going to be actively involved, and has a positive attitude because of the development and the protection of the area, so it can be considered as an 'Acquaintance'.

Last but not least, **the Municipality of The Hague**, which is the main client, is one of the 'Saviours'. It has significant power and the highest interest among all stakeholders, and the most positive attitude, aiming to have a very successful outcome.

The Residents & Visitors group of stakeholders has varying interest, power and attitude. Firstly, the **Coastal Residents** are highly interested in the project's outcome, as their lives will be directly affected by it. They also have a relatively high power to influence the process, since they are organized in an association, while their attitude depends on the upshot of the project. If this upshot is in line with their wills, they will be a 'Saviour', otherwise their reactions will constitute them 'Saboteurs', therefore they need to be specially engaged to avoid the change of their role.

Secondly, the **City Residents** are not going to be actively engaged in the process, and they cannot influence the process to a great extent. They have medium to low interest and power accompanied by a positive attitude, they are considered 'Acquaintances', and should be kept informed.

Third, the **Tourists** and day-visitors provide profits for business owners and fundamentally stimulate the local economy with their expenses. Businesses are highly dependent on them for their survival. Their power in the project is considered as medium, because their decision of visiting the recreational area is the driving force of economic growth for the whole region and, consequently, significantly affects the decision-making process about interventions in the landscape. The challenge in this case is that they cannot influence directly the process, however if their preferences are not taken into account, their future reluctance to visit the area will result in huge economic impact. Their interest is also high, as the Scheveningen beach is Holland's most famous seaside resort and is really attractive for visitors, especially during the summer period. In that sense, Tourists and visitors are considered as 'Friends'. Attention should be drawn in the fact that, if visitors lose their interest in the area, for example in the case where the landscape is degraded, and their attitude becomes negative towards Scheveningen, they could turn into 'Irritants'.

Regarding <u>businesses that run in the area</u>, there are several different stakeholders to analyze. Firstly, **businesses of the Morales Boulevard** and on **the other parts of the considered area** have the same level of interest and power. They are directly affected to a great extent of the process, as their prosperity and profitability depend on the number of tourists that are willing to visit the region and spend money and their view to the sea, so the level of their interest is extremely high. As far as their power is considered, its level is rather medium, although in the past they have demonstrated a powerful attitude when their opinions were not heard and their interests were not taken into account. They are positively inclined towards the project, as the area will remain safe in the long-term, attracting tourists for the next several decades. Their attitude can be defined as 'Saviors', consequently their needs should be attended and they should be kept satisfied.

Similarly, the **Pier**'s interest is extended, as the provided coastal safety will protect them and will ensure their financial gain. As a consequence of its bankruptcy in 2013, the power that Pier has is definitely not in its full glory, even if the structure remains one of the most impressive attractions of the area. Pier can be considered as 'Friend' for the project.

Special treatment is required for **buildings of special vulnerability**, since they are more exposed to climate change and coastal challenges. The existence of these buildings is directly dependent on the design of the coast and the measures that will be planned for their protection. These structures have limited power, and combining that with their high interest and their positive inclination, they are stated as Friends.

At the <u>harbor</u>, a variety of activities take place. One of the most important is the **fishing industry** that operates in the area. They aim in having enough space in the harbor to realize their transactions and fishing activities and to potentially develop and expand. They have high interest in the project, especially as far as availability of the harbor and its safety are concerned. They are positive towards the process, as safety is the ultimate purpose, as long as the harbor remains functional and construction works do not hinder their activities. Fishing industry can be defined as 'Saviors', however their satisfaction should be highlighted and taken seriously into account. In case that they feel insignificant and their opinions are neglected, they could decide to move the industry to another area, which could prove harmful for the local economy.

Additionally, the **Watersports businesses**, which are located inside the harbor, are very much interested in the safety of the area that will ensure their profitability in the future. They don't have extended power and they are concerned about hindrance because of the intervention works. They are in general positive towards the project, so they can be identified as 'Friends'.

As advisors of the project, **EcoShape** deserves special attention. Their power is high and it is based on long experience and extended knowledge on the field. As supporters of the Building with Nature method, their contribution to our project is irreplaceable and their willingness to help the project defines their attitude as positive. Their interest is medium to low, as the company is responsible for designing and monitoring numerous projects around the globe and they are not directly involved with Scheveningen 2100 project as an active member. They are defined as 'Sleeping Giants' and their engagement to the project is desired and valuable.

4.3 Critical Actors

Critical are considered the actors that provide important resources to the process and their replaceablity is low. The index that indicates this criticality derives from the combination of these parameters, extracting initially a resource dependency index and consequently the criticality index.

The first actors that are considered critical are the majority of the governmental bodies, namely the National Government, Rijkswaterstaat, the Province of South Holland, the Municipality and the Waterboard - Delfland. Due to their authority and lawmaking nature, they provide resources of great importance and cannot be replaced. On the contrary, the Dunea and the MRDH (Metropolitan area Rotterdam-Den Haag) cannot be considered as critical actors, since the resources they provide are not so crucial for the project.

Secondly, local actors that are critical are the Businesses of the Morales boulevard, the Water sports businesses, the Buildings of special vulnerability, the Coastal Residents and the Fishing Industry. They are part of the local community that is directly affected by the project's outcomes. Important resources are provided by them, such as knowledge and services, with low replaceablity since these actors are organized in associations. The rest of the local community's actors (Businesses of the other areas, City Residents and Tourists, Beach Users - Swimmers, The Pier) provide resources of less importance according to the project's scope and goals. As a result, they are not considered as critical actors.

Furthermore, actors related to environmental issues and green solutions, such as Omgevingsdienst Zuid-Holland Zuid (OZHZ), Ecoshape and the Environmental Organizations are critical, since their knowledge and expertise increases the importance of their resources, and their replacebility is low.

Last but not least, the Transportation Companies are a non-critical actor, given that the resources they provide cannot be considered important for the process.

Table 4.1: Stakeholder map

	Dedicated Actors		Non-Dedicated Actors	
	Critical Actors	Non-critical Actors	Critical Actors	Non-critical Actors
Actors with same perception interests and goals	- Rijkswaterstaat - Municipality of The Hague - Delfland - Businesses of the Morales boulevard - Water sports businesses - Buildings of special vulnerability - Coastal residents - Fishing industry - Omgevingsdienst Zuid-Holland Zuid (OZHZ) - Ecoshape - Environmental Organizations	- Dunea - The Pier	- Government - Province of South Holland - Tourists, beach users	- Metropolitan area Rotterdam-Den Haag (MRDH) - Businesses of the other areas - City residents - Transportation Companies
Actors with different perception, interests and goals	- None	- None	- None	- None

4.4 Co-Creation concept

Co-creation is a concept widely applicable in marketing projects, where development of a new value (concept, solution) is collaborative. Especially nowadays, in a world of continuously increasing competition and innovation-seeking, the urge of stakeholders to collaborate and create together value is rising. Based on this concept, managerial strategies of companies are defined. However, co-creation is yet quite unexplored in the construction field, especially regarding the innovation element of the sector (Smyth, Razmdoost, & Kusuma, 2016).

4.4.1 What is the idea of Co-Creation

The concept of co-creation refers to a value-based, context-driven effort of stakeholders that are collaborating with each other. As an outcome, a product or service is developed. As far as construction is concerned, that outcome can be a building or even a coastal safety design. The cornerstone of co-creation are values like respect among the stakeholders, transparency of activities and methods, trust and mutuality of stakeholders (Akhilesh, 2017).

Co-creation is a collaborative process where stakeholders work together in order for value to be created. The outcome of the collaboration is often more valuable than the individual produced outcome of each actor. Studies have shown that, when certain stakeholders have an open relationship with positive attitude to each other, the process of developing an outcome can be benefited significantly. These stakeholders can be management-related, local stakeholders, contractors, consumers, specialists and more (Mijnheer & Gamble, 2019).

One of the most important aspects of the aforementioned collaboration is the comprehension of the objectives and goals of the users as well as the owner, and integrate them into the development of functional products, buildings (or coastal safety design, in the case of this project) (Haddadi, 2016).

4.4.2 How it can be applied

As far as the context of this project is concerned, co-creation can be observed with local residents and more specifically coastal residents on the one side and the municipality on the other, as the stakeholders who join forces. These stakeholders have different objectives and points of view upon the area. At the end, the outcome of the design should be appealing for the local residents and tourists visiting the area, in order for the economy to grow further. For that reason, it is vital that the opinions and interests of residents are taken seriously into account throughout the whole design process.

The idea is to actively involve stakeholders that live in the area and utilize their input in the decision making process. A joint table can be created where different opinions are present and each stakeholder tries to approach or at least understand the others' interests (Savolainen, 2015). In more depth, representatives of coastal residents of the area can be appointed and collaborate with municipality members to discuss possible interventions in the area that fulfil the interests and goals of every involved. Of course, this joint action must follow some rules and requirements. Transparency is one of the main elements of this collaboration, in addition to mutual trust and respect for different perceptions. A display of the concept of co-creation concerning our project can be found in figure 4.4.

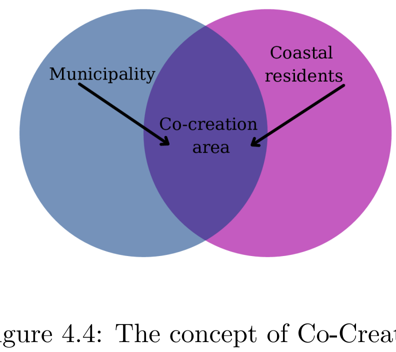


Figure 4.4: The concept of Co-Creation

Chapter 5

Solutions

5.1 Design method

5.1.1 Dealing with uncertainty

In order to deal with uncertainties in the long term, it is necessary to create a scenario-based design of the interventions in the coastal zone of Scheveningen. In this case, the scenarios largely depend on the influence of climate projections according to Delta Scenarios and Accelerated SLR scenarios, which were described in section 3.3. The occurrence of one or the other scenario will remain uncertain, although the solutions need to include action plans to deal with these uncertainties. In that sense, **adaptability** is a main requirement, and it has been dealt with through a phased design. To define clear and quantifiable design objectives for each phase, this study uses two points of view: a forward and a backward approach.

Forward approach

This approach starts based on the current state of the coastal system and then looks **forward** in time. The system is analysed and internal SLR thresholds (weak points) from different elements are defined (figure 5.1), and their timings. Before each of the thresholds is exceeded, a measure has to be taken to ensure safety. In total, 5 critical values were identified for dunes and hard structures along the current system, which are all concentrated within the Scheveningen district. The dunes seawalls in Oostduinen, Westduinpark, and Kijkduin-Solleveld areas offer a sufficient protection (appendix A) which can be maintained with regular nourishments.

A difference is drawn between: **physical boundaries**, which are elevations of the weak spots in the defense system; and **design boundaries**, referring to the design values of a specific infrastructure (e.g. Morales Boulevard design dike-in height). If a physical type of threshold is exceeded by sea level, certain (urban) areas are flooded when measures are not planned in Advance. If a design threshold is exceeded, it means the structure no longer meets the minimum requirements it was build for.

To identify when the above-mentioned critical values will be reached, sea level rise scenarios were applied to the local system and its different elements (see figures 5.1). It is important to clarify that new thresholds are created after an intervention to the system take place, by upgrading the safety in the area or covering weak spots. Overall, the current and new thresholds are included in four different phases, as will be explained in the next section.

Backward approach

In this case, the design attempts to find a solution for the overall goal of the project, and then propose partial solutions (phases) by looking **backward** in time. In order to define such phases in a simple way, the concept of adaptive pathways was applied (M. Haasnoot, 2018). Each pathway is a major solution itself to cope with a final Sea Level Rise value in the year 2100. The difference with the Forward approach resides in the view to the system. While the first one looks at its internal characteristics to define design values, the second one creates a new design goal for the overall system. The next section elaborates more on how such pathways are defined.

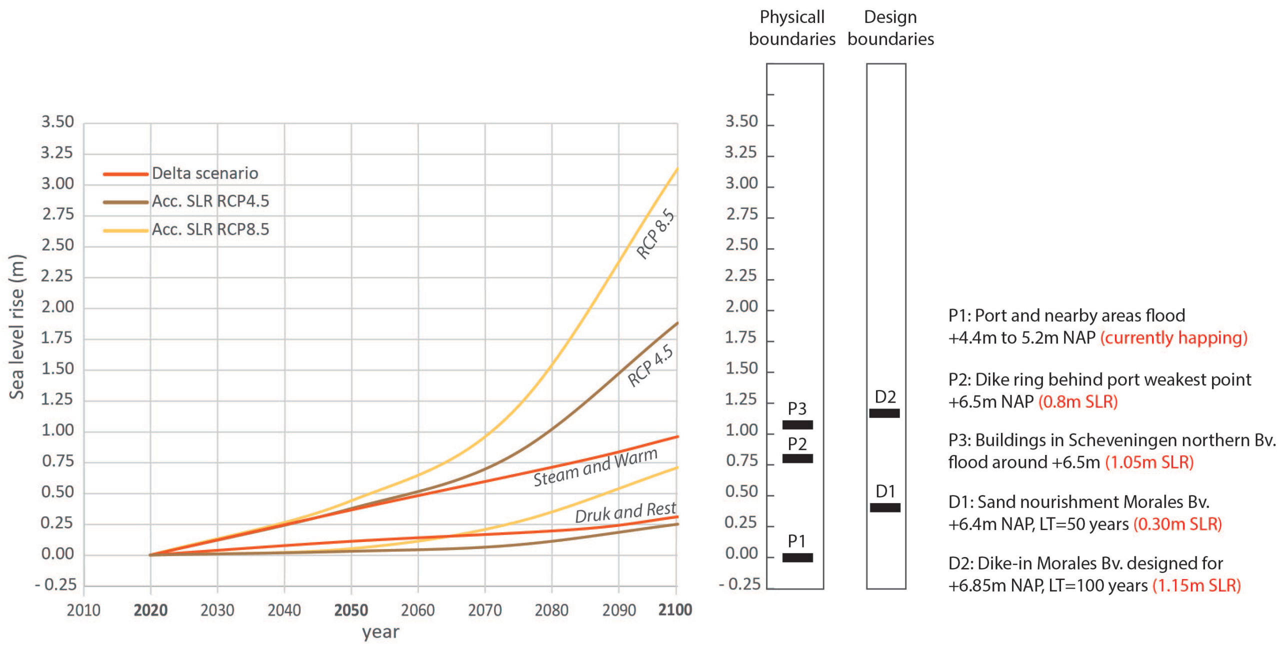


Figure 5.1: Internal thresholds in the study area in a plot of SLR (meters) vs time (years). The dike ring in P1 is exceeded with the current situation; P2 will be exceeded between 2060 and 2080; P3 between 2070 and after 2100. Design conditions in D1 will be exceeded between 2040 and 2050, and D2 between 2075 and after 2100.

5.1.2 Strategies

Coastal management strategies to deal with coastal erosion and flood safety can be to **Retreat**, **Preserve** or **Advance** the present coastline (as explained in section 2.3). As mentioned in earlier chapters, "Retreat" is not an attractive option, so it is decided to only design solutions for the "Preserve" and "Advance" strategy.

To create future solutions for the coastal area under consideration (shown in figure 3.1), the **Preserve** strategy is developed by using a **Forward** approach. In other words, the interventions are limited to solve weak spots as soon as they became an issue for water safety, and as a result preserving the coastline as it is. On the other hand, for the **Advance** strategy a **Backward** approach is preferred, since it seems more logical to plan an intervention that creates land seawards through the definition of a global SLR goal for the entire system.

Both solutions result in an adaptive design and an implementation plan consisting of four phases. The different phases will be activated depending on the SLR (as shown in figure 5.2), which is regularly monitored in order to find out when in time which measure has to be taken. It is important to point out that if after monitoring SLR seems lower than expected, the plan can stagnate at each phase, which will be enough to properly defend Scheveningen from the sea exerting its function.

Three pathways were necessary to cover the entire range. These are defined in 0.5m and 1m SLR sequences, and focusing on the expected final 2100 sea level for each of the above mentioned scenarios. Then, it is possible to understand what sea level rise means for the design strategy. Specifically, it is useful observe the time span available for the planning and execution of possible interventions. The latter is relevant for the post 2050 strategy, above all.

Phase 1 comprehend measures for a Sea Level Rise from 0 m to 0.5 m and will most likely end sometime between 2052 to 2058. Phase 2 covers all measures for a SLR between 0.5 m and 1 m of SLR and may start between 2052 to 2058 and ends sometime between 2070 to +2100. Phase 3 reaches from 1 m to 2 m of SLR, which according to the RCP 8.5 and RCP 4.5 scenarios, will happen approximately between 2070 and 2080, taking the most pessimistic boundaries into account. Phase 4 is only necessary when a SLR of 2 m is exceeded. It is most likely that phase 4 will not be needed until the end of 2100, but in order to be prepared for a worst case scenario, as shown in figure 3.6 where phase 4 may start in 2085, coastal protection measures for a SLR of up to 3 m or more are developed.

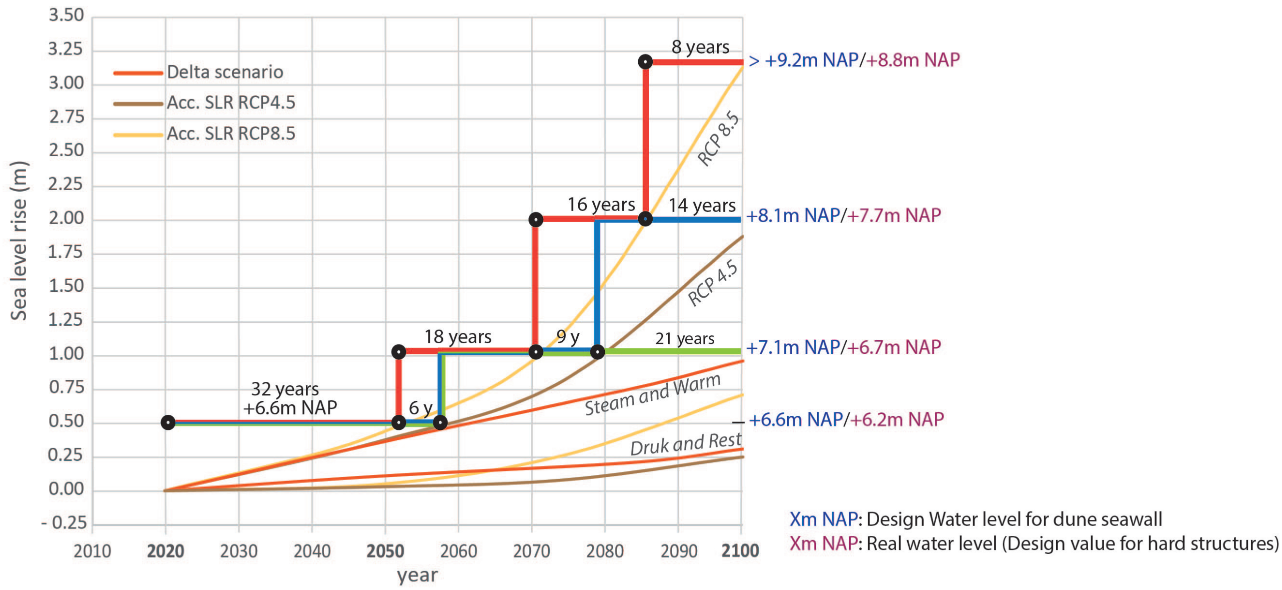


Figure 5.2: Adaptive pathways approach inside Municipality of Den Haag boundaries. Three goals are defined towards 2100: +1m for Delta Scenarios *Steam and Warm*, +2m for *RCP4.5 maximum scenario*, and +3.2m SLR for *RCP8.5 maximum scenario*. An intermediate scenario is set at +0.5m SLR for the year 2050. On the right side vertical axis, the plot shows the values referenced to NAP. The real water level is written in magenta, which gives information on the design level for hard structures. The values written in blue are adjusted to design dune seawalls.

5.1.3 Integrated Coastal Zone Management by Building with Nature

An integrated perspective is the basis for each solution. This is achieved through the Building with nature concept (Ecoshape, 2020) to obtain measures that increase the value of the area, responding to the stakeholder demands identified in chapter 4.1.

Building with Nature

As mentioned in Chapter 2, a great strength of nature-based solutions is that it delivers across the global and local sustainability goals, which is an important reason it is chosen over traditional engineering methods. To structure the design, **Building with Nature** approaches by used and described by **EcoShape** were used (Ecoshape, 2020), as most of the strategies has been applied in the Netherlands with success.

The Building with Nature approach typically follows five steps of development (Ecoshape, 2020):

- **Step 1:** Understand the system in terms of physical processes, ecology, and society, and identify values, services, and benefits they can deliver to both nature and humans. Chapters 3 and 4 address these aspects.
- **Step 2:** Identify alternatives that provide value for nature and humans. In other words, that enhance the values, services, and benefits acknowledged in the previous step.
- **Step 3:** Evaluate each alternative to select an integral solution. Each alternative should prove to be a business case that includes all natural and human co-benefits.
- **Step 4:** Refine the selected solution, considering the conditions and restrictions that come from the practicability and governance of the project.

- **Step 5:** Prepare the solution for implementation by making key elements of the solution explicit to facilitate further uptake, funding, and stakeholder involvement. The goal of this study is to provide with design alternatives on a conceptual level, with a clear indication of where the trade offs between the two lay. This can be up-taken by the client to select a final solution and conduct a first-order detailed design.

EcoShape has developed and shared a package of many Building with Nature concepts (Ecoshape, 2020), which is one of the sources used in the design of the interventions. The second source and inspiration is the Waterman Plan, described further in the next section. Thirdly, interviews with experts in the matter (Henk Nieboer, Martijn Onderwater, Marcel Stive and Ronald Waterman) provided more tools in the application of nature-based solutions (appendix K). The complete list of nature-based measures applied for this project are listed and described in appendix N.1.

Waterman Plan

The pioneering work by Ronald Waterman's plans (R. Waterman, 2010) (R. E. Waterman, Misdorp, & Mol, 1998) acknowledged many years ago the concept of integrated coastal zone management by Building with Nature. A big part of this work is applied to different points along the Dutch coast, and particularly, one of the plans is a long term development of a large land reclamation between Oostduinen and Hook van Holland (Plan 1). Another plan, which is already executed, is located in the entrance of the port of Ijmuiden where a new marina was created (Plan 3).

In general terms, Waterman's plans exploit natural wind and wave processes, to develop complex dune and beach systems delivering a number of services and functions to humans and nature, such as safety, erosion protection, fresh water supply, transport, habitat quality, among many others. The underlying concept behind Plan 1 in Delfland is to restore the habitat back to the situation in the 17th century, before large hard structures were affecting coastal dynamics. In order to do it, a careful historical research provided him with the necessary knowledge to obtain designs in such a way that historical values are respected. Those historical aspects are briefly explained in Appendix B.3.

The expertise from Ronald Waterman is considered one of the bases to develop the designed solutions in this project, as his plans are well known to reflect the desires and expectations of stakeholders in South Holland. On the one hand, several elements of the two above-mentioned plans were taken to develop interventions which then build up into the two overall alternatives of this study. On the other hand, a presentation plus 3 hours of interview with R.W. (appendix K) was useful to capture broad Building with Nature concepts into practical design applications in the Scheveningen area.The layouts of R. Waterman's Plans number 1 and 3 can be found in Appendix B.3.

5.2 Solutions

5.2.1 Solution 1: Preserve

This section presents the four phases of the Preserve strategy. After a brainstorming session and looking at the pros and cons of different alternatives (appendix M), this final design was developed. For a more elaborated explanation on how the different measures work and what benefits are expected from them, the reader is referred to appendix N.

Phase 1

Starting in 2021

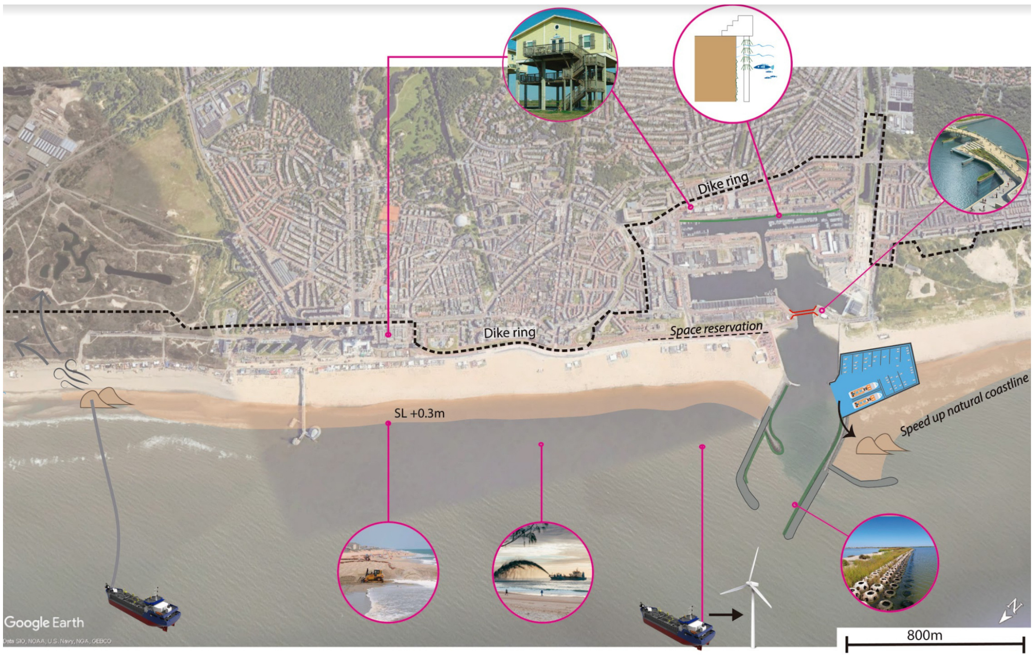


Figure 5.3: Conceptual sketch of Preserve strategy, phase 1: creation of urban resilience, textures sea walls and hanging structures, cyclist and pedestrian bridge, new marina, breakwaters with rich revetments, test site for continuous nourishment. Furthermore, the current nourishment strategy of Rijkswaterstaat will be continued and extended to an additional dune reinforcement nourishment every 10 years.

The weakest part of the project area is the Port of Scheveningen, where certain areas can be flooded several times a year (as described in section 3.2.3). To avoid that, the **quay wall in the 2nd harbour needs to be heightened** to a crest level of NAP + 3.65 m, following up the results from a former Multidisciplinary Project ((Chotkan, S.A. et al., 2020)). To help marine life to thrive and increase the ecological value inside the harbour, **textured walls** and additional **hanging structures** will be implemented.

As mentioned in section 3.2.3, currently large parts of the entire port area and nearby living areas start to flood at NAP + 5.2 m. The probability of this event will increase largely by a SLR of 0.5 m. In order to preserve the attractiveness of the port space, it is recommended to not increase the quay wall even more but to prepare the buildings in that area (restaurants, business, fishery industry, sheds for the support of wind farms activity, yacht sheds) by creating a plan for **urbanistic resilience**.

Furthermore, issues such as a shortage of marina area, a demand from the cruise ship activity, and space for recreation is identified. Together with the necessary interventions to maintain the same level of water safety, the port needs to increase values in the social aspect, and offer space for the increasing cruise ship activity. To do so, a **new marina** for yachts, small vessels, and cruise ships up to 160m will be built. The dredged sediment will be used as a **sand fill**, to speed up a natural sand accumulation process in the southern breakwater. The new port basin will have an estimated surface of 9 has.

Besides that, the **breakwaters will be extended** to keep the sand fill in place and to prevent sedimentation of the access channel. **Rich revetments** will be used to create a substrate for marine vegetation, which could develop into new fish and shellfish habitats. In addition to the added ecological value, scuba diving activities could be developed near the breakwaters in certain spots far away from vessel activity.

To connect the northern and southern part of the port for cyclists and pedestrians, a **bridge** will be constructed in one go with the new marina and breakwater. According to the city Zoning Plan, this measure would encourage social cohesion between the southern areas with the Morales Boulevard (Municipality of Den Haag, 2015).

Simultaneously, it is recommended to start in phase 1 researching about sustainable dredging methods, for which a test site for **continuous nourishment** will be implemented. If this test site is successful, continuous nourishment in form of “**sand showers**” every few hundred meters will replace the current nourishment technology of dredging vessels. Such new methods could be fully powered by offshore wind energy.

The last measure of this phase will happen before SLR exceeds 0.3m, level reached by 2050 in all climate scenarios. The **width and height of the beach** in front of the Morales Boulevard **have to be increased** in order to ensure safety of this hybrid structure. According to the calculations made by the engineering company Arcadis, it should be around 130m wider and 3m higher (Arcadis, 2008). This will be also done in front of the Northern boulevard to create a safe morphological whole for the entire touristic area of Scheveningen, while beach and sea view is maintain from all parts of the boulevards.

Phase 2

Starts in 2052-2058

Figure 5.4: Conceptual sketch of Preserve strategy, phase 2: creation of salinity gradient and storm surge barrier in the port area and dune reinforcement in area just north of the port.

In the second phase, several measures in the port area will take place. The population behind the dike is at a higher risk for a SLR of 0.8 m because the elevation near the pumping station in the Verversingskanaal (NAP +6.5 m) will then be equal to the design water level. The elevation of the dike surrounding the port will also be in a critical situation, since it is not more than 0.5m higher than the weakest point (as shown in Appendix E.1). To solve this issue, a **storm surge barrier** near Voorhaven will be build with enough height to secure safety for a SLR up to 2 m. However, an increasing sea level implies an increasing closing frequency, which creates obstructions to shipping. Thus, the barrier is designed for 3 closures per year when it reaches 2m of SLR. In addition, the design should be adaptable, such that it could be rebuild into a lock when this threshold is exceeded.

Once the storm barrier is finished, it is safe to restore the connection between Verversingskanaal and the 2nd harbour by removing the lock between the channel and the 2nd harbour. This will give back a **salinity gradient** to the habitat, which improves the ecological conditions for vegetation and marine life. Additionally, the walls in the other harbours (1st and 3rd) will be textured to enhance the ecological value of the area.

Besides that, there are missing links in the dike ring parallel to the coast, just north of the port area. The dunes in this area became too narrow for a SLR of 1 m. Thus, the dune front in the Strandweg street will be widened and linked to the existing ring.

Phase 3

Starting around 2070

Figure 5.5: Conceptual sketch of Preserve strategy, phase 3: heightening of Morales boulevard and creation of dunes in front of Morales boulevard and northern boulevard.

When SLR exceeds 1.15 m, the design conditions of the dike-in boulevard structure would be exceeded for the design load (max overtopping volume of 1 l/s/m is exceeded). Therefore, the **dike height will be increased in more or less 2m, up to NAP +12.4 m** and the current basalton **revetment will be changed** into a two layer quarry stone revetment that will damp the wave energy more efficiently (Arcadis, 2008). This design is assumed to be safe for a SLR of 2.5 m (2 m due to increase of height + 0.5 m due to change of revetment). This measure will restrict the sea view from behind the Morales boulevard, which is against the stakeholder demands as presented in chapter 4.

In order to ensure safety of the areas behind the northern boulevard and Morales boulevard, the beach width in front of the boulevards has to be increased by another 130m and the height by 3 more meters. Such values are estimated considering a similar intervention as in the previous phase. This will lead to a very high beach that also will block the sea view. Thus, it is decided to create an **appealing dune landscape with a multi-functional design** (shown and further described in appendix N.2.5) including underground services as parking (similar to the dunes in Katwijk). The dune on top is an artificial habitat that resembles the natural ecosystem and provides pathways for visitors to enjoy the sea view from top of the dunes. This measure can be implemented at the same time as the reinforcement of the dike-in-boulevard. The new dune landscape will be connected to the Oostduinen dune seawall in the north, and to the existing dune front in the Strandweg in the south.

Phase 4

Starting around 2085

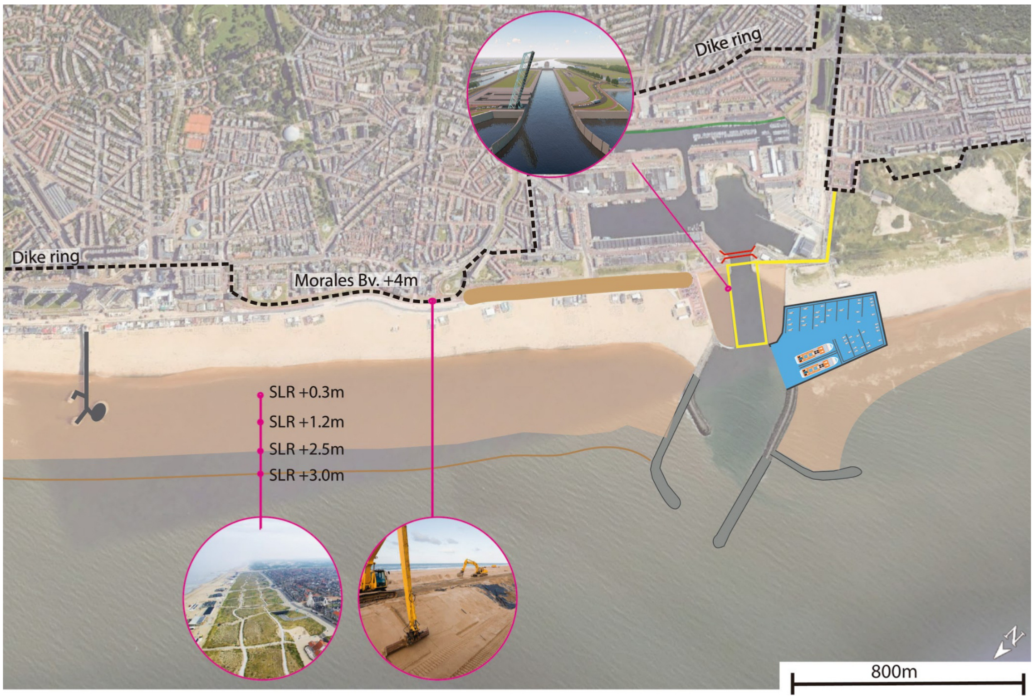


Figure 5.6: Conceptual sketch of Preserve strategy, phase 4: adjustment of storm surge barrier into lock, heightening of Morales boulevard, reinforcement of dunes.

For a SLR of more than 2 m, it is estimated that the storm surge barrier will exceed a closing frequency of 3 times/year, hampering shipping to an unacceptable level for port users. Therefore, the storm surge barrier will be adjusted to a **sea lock** that should be safe for a SLR of 3 m and more.

Before SLR exceeds 2.5 m, the **Morales boulevard has to be reinforced** again by increasing its height, in approximately 4m, depending on the sea level rise. Following with same criteria as in the previous stages, the **dunes** in front of the Morales and the Northern boulevard have to be **strengthened** in a third expansion of approximately 130 meters width and 3 meters height, through sand nourishments. If SLR continues to higher values, the same strategy of dune strengthening should be continued.

Nourishment strategy to preserve the coastline position

For all four phases, the current nourishment strategy of Rijkswaterstaat as described in section 3.2.2 will be continued to compensate for erosion. Besides that, every 10 years, an additional nourishment, sand-feeding the intertidal zone as described in the timeline of figure N.1.1 in the appendix. Natural processes (wind and waves) will transport this sand towards the existing dunes, strengthening them gradually enhancing the dune landscaping concept from EcoShape (Ecoshape, 2020)).

5.2.2 Solution 2: Advance

For the Advance strategy two concepts have been selected to be developed further: the Lake and Dune System (LDS) and the Scheveningen Wadden System (SWS). After a preliminary analysis on both the SWS and the LDS plan it has been chosen to keep only with LDS. This concept is presented in the following section. For more information about the SWS plan, the reader is referred to appendix R.

The LDS system is divided into 2 separate systems by the Port of Scheveningen. LDS-South which corresponds to the area of Westduinpark, Boulevard of Kijkduin and Solleveld-Kijkduin and LDS-North, corresponding to the area of Scheveningen Port, Morales Boulevard, Northern Boulevard and Oostduinen.

The proposed measures for the LDS solutions are shortly explained here. For more elaborate explanations on how the different measures work the reader is referred to appendix N.

Phase 1

Starting in 2021

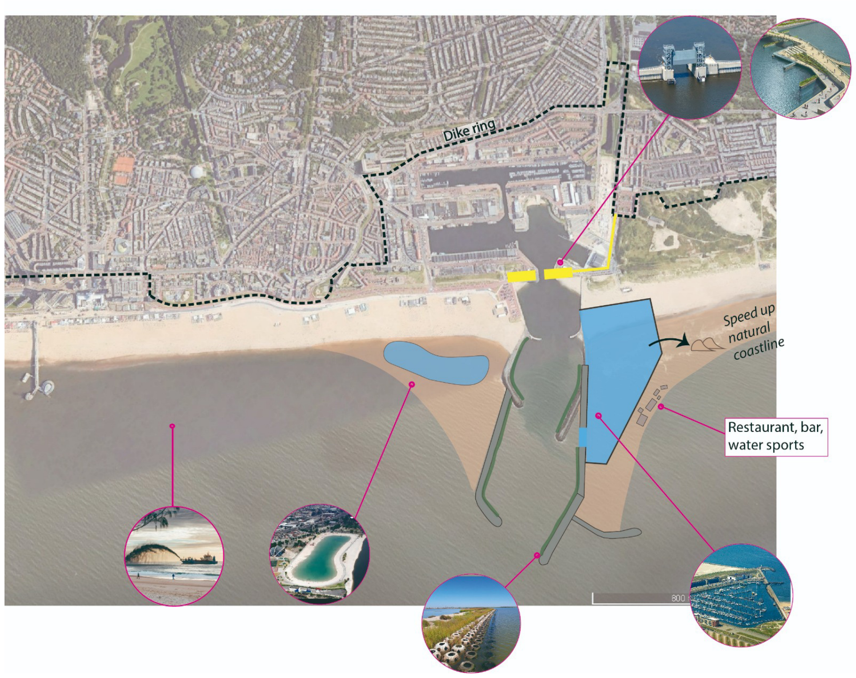


Figure 5.7: Conceptual sketch of LDS plan, phase 1. Construction of a breakwater extension with a rich revetment, a port expansion, land reclamations, an adaptable storm surge barrier and implementation of a pilot for artificial lakes.

LDS-South
In the first phase most of the measures will take place in the port area.

The idea is to **expand the port breakwaters seawards**, approximately 1 km from the shoreline. With that, accretion will occur naturally on the south side of the port. To accelerate this process, nourishments will be done in order create reclaimed land which will be formed in the same shape as the Van Dixhoorn-Triangle near Hoek van Holland at the Port of Rotterdam (R. E. Waterman et al., 1998).

On this triangle, on the water side, some small removable **recreational businesses** (as beach bars and restaurants, and water sport offices) are allowed to be constructed and used only during the summer months, when chances of a storm event is lower.

Inspired by the Seaport Marina of Ijmuiden, a **port expansion** will be constructed within the newly created triangle in order to accommodate more fishing activities, recreational vessels, supporting vessels for the wind parks, and others needing extra space in the Port of Scheveningen. The new port basins will have an estimated surface of 23 has (around 2.5 times bigger than the Preserve port expansion).

As discussed before, the Port of Scheveningen is considered the weakest link of the sea defense system of Scheveningen. In order to prevent flood events inside the port, an **adaptable storm surge barrier** will be constructed.

Together with the construction of the storm surge barrier, its building pit (that will be already there) will also be reused for the construction of a **cycle bridge** that will connect the area from south of the port to the north.

LDS-North
North of the port, there will be another **land reclamation** in the shape of the Van Dixhoorn-Triangle. Differently from the triangle on the southern side, this reclaimed land will not come naturally due to accretion, but on the contrary it will be very prone to erosion, once it is located on the lee side of the port's breakwater. For this reason it will be necessary to severely maintain this new area with frequent nourishments. Inside the northern triangle a pilot of one of the **thematic lakes**, as described in appendix N.2.7, will be constructed. A pumping system will be installed on the lake to ensure a salt water exchange with the sea.

Phase 2

Starting between 2052 and 2058

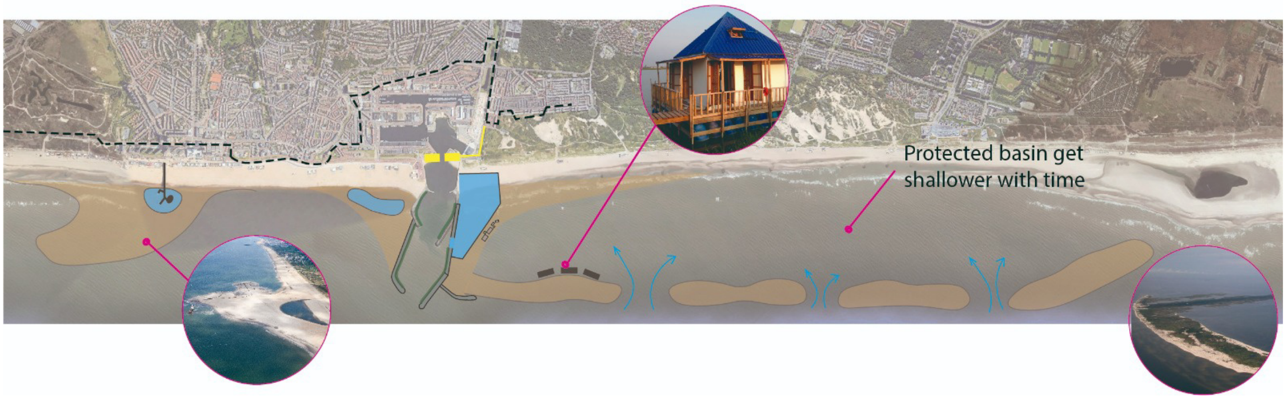


Figure 5.8: Conceptual sketch of the LDS plan, phase 2. Construction of barrier islands on the southern side of the port, implementation of a few floating structures for recreation and monitoring and construction of a second Sand Engine (SE-2) on the northern side.

LDS-South
The second phase consists of the creation of **4 barrier islands** extending from the southern arm of the port breakwater until the Sand Engine, at approximately 800 m from the previous coastline. Between the barrier islands there will be breaches letting water and sediment flow in and out.

Due to uncertainty and safety issues there will be limited activity at the barrier islands. Only on the island closest to the southern breakwater, a **few floating structures** (inspired by Fintch Floating Homes (Homes, n.d.)) will be constructed to serve as water sport offices and monitoring stations. Those structures would only be allowed to be used during summer months when storms are less likely to occur. The old beach bars, restaurants and water sport offices would still be able to perform their activity in the basin behind the islands.

LDS-North
In front of the northern boulevard and Oostduinen, a mega-nourishment called **"Sand Engine 2"** (SE-2), equal to the Sand Engine between Monster and Kijkduin, will be constructed. Its southern boundary will be placed at the northern boundary of the Morales Boulevard, and it will extend until the border of the research area of this project, with approximately a total length of 2 km.

The SE-2 will be extended almost 800 m seawards, which is more than originally planned for the width of the total LDS-North project. The reason for this is that it is supposed to react in the same way as the original Sand Engine: extend to both sides and lower in width (Stive et al., 2013), protecting the surrounding area. A **lagoon** should be formed at the northern boundary, also as happened with the original Sand Engine. This lagoon will later become one of the thematic lakes designated for natural ecology and environment.

Phase 3

Starts in 2070 at the earliest

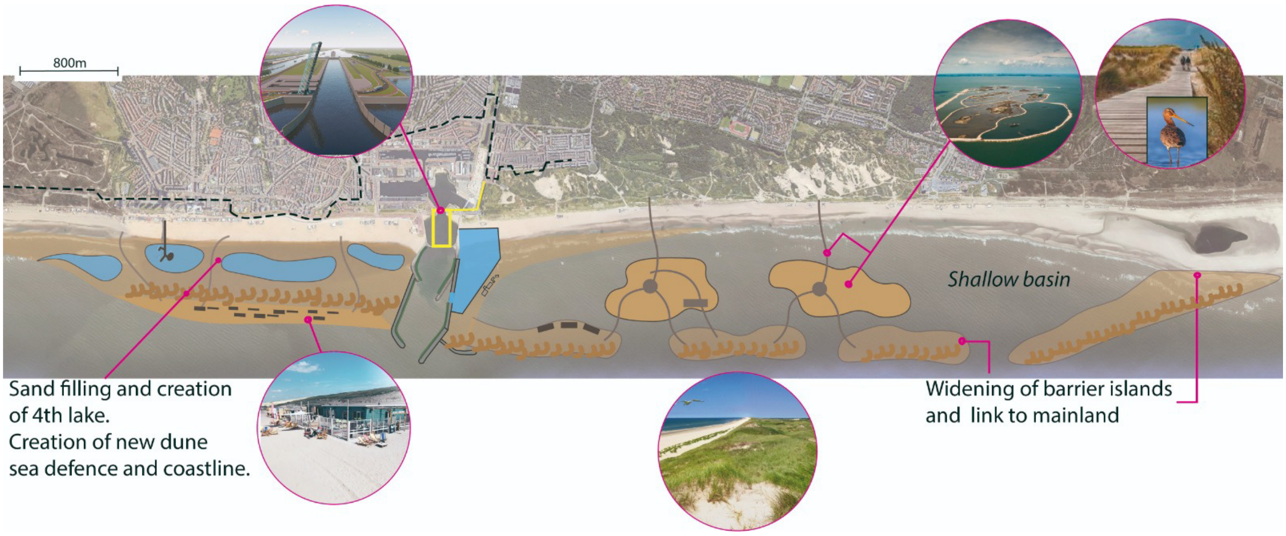


Figure 5.9: Conceptual sketch of the LDS plan, phase 3. LDS-South: creation of two islands, dune enhancement as sea defence and adaptation of the storm surge in the port for a sea lock. LDS-North: land reclamation, creation of a new dune system and thematic recreational lakes.

LDS-South

Due to natural processes of sediment transport, the created basin behind the barrier islands and the breaches between them are expected to become shallower with time. Inside the shallow basin four **nature islands** will be created to enhance the ecological value of the area.

On those new islands inside the basin, the water will be very shallow, therefor a few elevated **hut structures** would be created for bird and sea life watching during low tide. Those high structure would also work as cafes/bars and monitoring stations, only accessible during the day and normal weather conditions.

To protect the hinterland, the barrier islands are made wider and a **dune system** is created in order to protect the area behind from storm surges. As behind the dunes there is no real area of flood risk, the design criteria for these dunes are not that rigorous as the ones protecting the hinterland, at the old shoreline.

To connect the old shoreline to the new islands, the elevated huts and the barrier islands, **wooden deck pathways** will be constructed. These decks could also be used by bikes.

Around the islands the water will be shallow and silted, but deep enough to perform water sports, as done in the lagoon of the Sand Engine now a days. The old shoreline would continue functioning as before. In front of the shoreline there is still water form the basin's lagoon.

LDS-North

The third phase of the LDS-North plan is designed with extra safety measures and is therefore already the last phase of the LDS-North plan. The measures implemented in this phase are able to withstand a sea level rise of at least 3 m. This extra safety measure is made because Scheveningen, as being a very populated area, is very sensitive to SLR and large disasters can happen in case of flood events.

This phase consists of **creating a whole new shoreline seawards** at approximately 400 m from the previous shoreline. In this phase the space between the northern triangle at the breakwater and the SE-2 would be filled, a lake would be place at the old shoreline and a new dune system created near the new shoreline. This dune system would be responsible for the primary sea defence of Scheveningen.

For the beach users to approach the new coastline, the same **decks** as at the LDS-South project will be constructed.

Phase 4

Starts in 2085 at the earliest

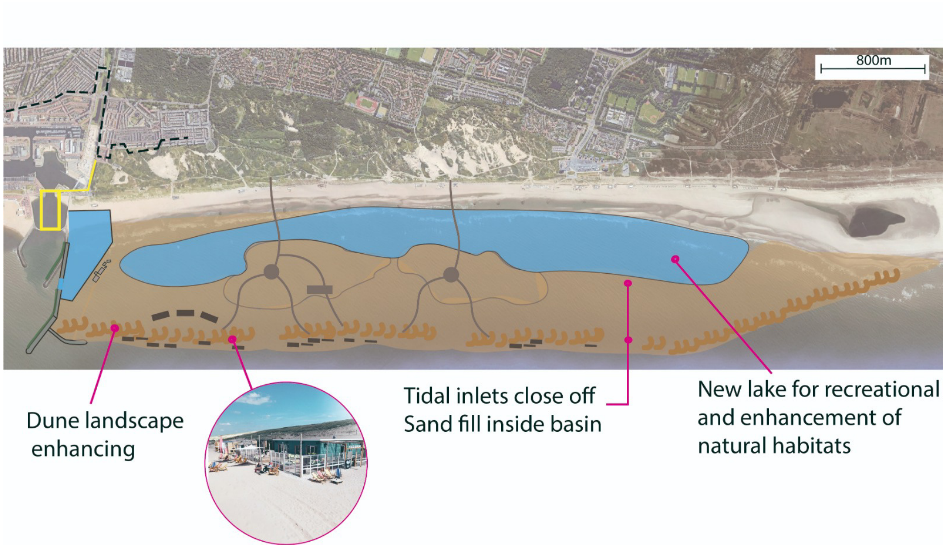


Figure 5.10: Conceptual sketch of the LDS plan, phase 4: filling in of the rest of the basin behind the barrier islands, creating a one extended lake and enhancing the dune landscape to defend the hinterland.

LDS-South

The last phase of the southern part starts with closing the remaining basin area behind the barrier islands, in order to **extend the new dune system**. In front of the old shoreline a long stretched lake will remain, which could be used for water sports, recreation and bird watching.

Some restaurants, cafes and water sport offices will be allowed to place removable structures at the new shoreline during summer months. In order to reach the new shoreline the decks constructed in the previous phase will still be used.

The newly created area will be used as a national natural park and will have to be preserved in order to fulfill its coastal defense function and to enhance the ecology in the area.

5.3 Time and cost comparison of solutions

For both strategies, different measures are implemented at different points in time. Due to the uncertainties resulting from the scenario approach, it is hard to estimate when each phase is activated, specially for the second half of the century, as can be seen in the timelines in the figures below (figure 5.11: Preserve, and figure 5.12: Advance).

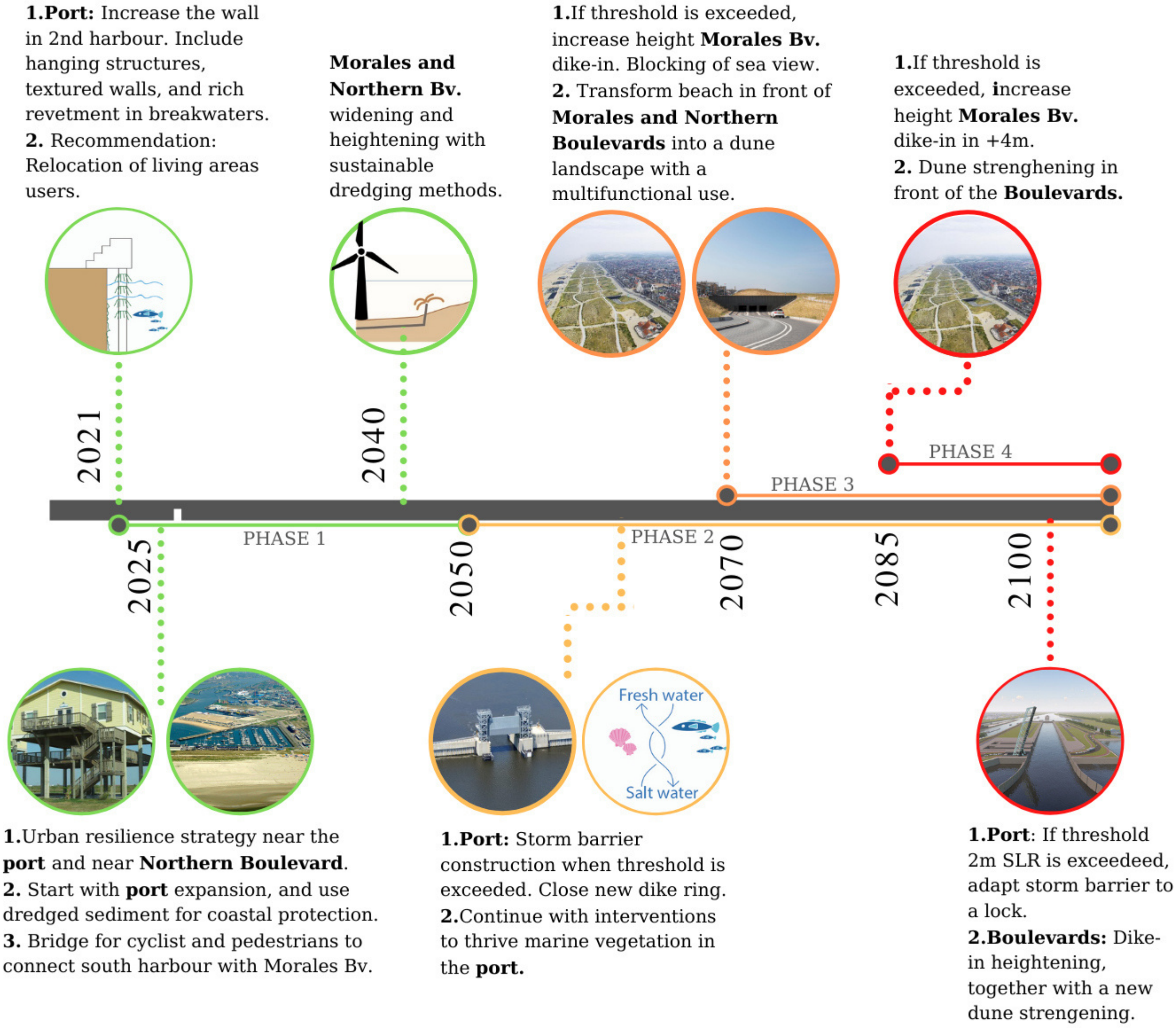


Figure 5.11: Timeline and description of the main features of the Preserve solution. The 4 Phases are symbolized with different line color (green, yellow, orange, and red).

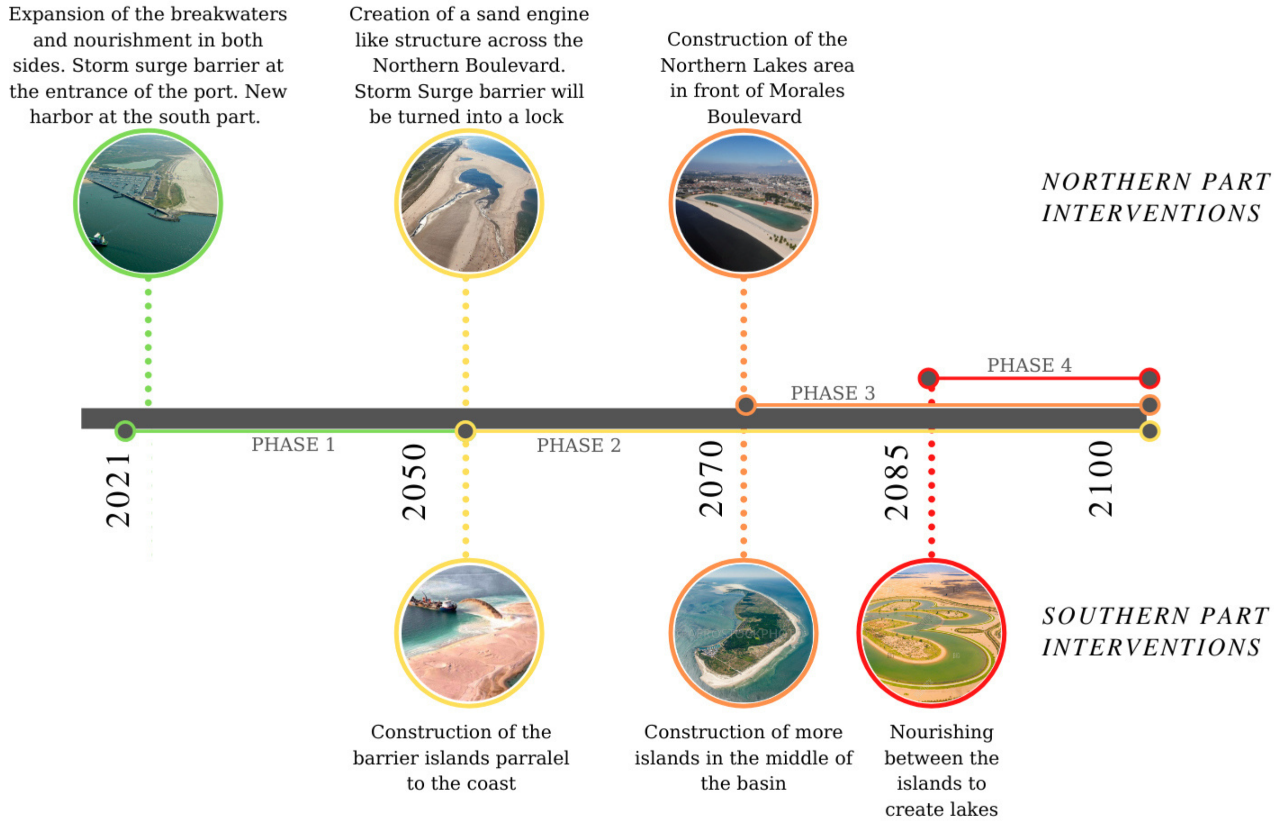


Figure 5.12: Timeline and description of the main features of the Advance approach. On the upper part the are north of the port is represented, and on the lower part the area south of the port is represented

Besides the different implementation of different measures, also the costs are different. All cost are estimated based on comparable projects or unit prices such as € 5 per m^3 of Dutch sand (see appendix O). The total cost for the Advance solution are about 2/3 higher than for the Preserve solution (as can be seen in table 5.1, appendix O and appendix P). The costs of the Preserve solution are estimated per phase, while the costs for the Advance solution are estimated per area (LSD-South and LSD-North) based on cross sectional profiles of the final design after phase 4 as shown in appendix Q.

Table 5.1: Cost comparison of Preserve solution (appendix O) and Advance solution (appendix P).

Cost category	**Preserve costs**	**Cost category**	**Advance costs**
Maintenance nourishments	€ 500,000,000	Maintenance nourishments	€ 500,000,000
Phase 1	€ 303,450,000	LDS-South all phases	€ 997,000,000
Phase 2	€ 307,000,000	LDS-North all phases	€ 881,800,000
Phase 3	€ 136,300,000	-	-
Phase 4	€ 175,000,000	-	-
Total	**€ 1,421,750,000**		**€ 2,378,800,000**

5.3.1 Monitoring

As mentioned earlier, both strategies require monitoring. The most important monitoring objective for the project is **SLR**, in order to be able to determine whether it is necessary to implement the next stage of the project or not. The implementation of every design stage should start being implemented every 5 years before a certain sea level threshold is expected to be reached, based on the most recent monitoring and prediction data, in order to be able to have the project finished at each threshold itself. In this way it is possible to prevent a potential flood disaster with a sea level for which the dunes are not resistant to.

The other monitoring objectives are **the hydro-sedimentary evolution, suspended sediment concentrations (SSC) caused by dredging, the quality of the dredged sand, added social and economical values and ecology.** It is important to keep track of these objectives to assess the added value of the implemented measures for nature, (local) economy and society. In case certain measures are not successful, this has to be identified by monitoring and counter acted by improvements or changes of the implemented measures.

A detailed monitoring plan explaining the methods used for every monitoring objective can be found in appendix S.

Chapter 6

Multi Criteria Analysis

Since the aim of the research is to enable a decision making process to the client, an evaluation technique is essential in order to assess the two designed solutions (section 5.2), concerning aspects that are important for the project (Dodgson, Spackman, Pearman, & Phillips, 2009). Multi Criteria Analysis (MCA) is a framework that assists complex decision-making procedure with conflicting objectives (Saarikoski, Barton, & Keune, 2016). Moreover, attention is paid on how stakeholders perceive each solution, who supports and who opposes each one of them, and what is the impact of the solutions for every stakeholder. The main purpose of the research is not to pick a "winning solution" and discard the other, but their comparison to each other, based on the criteria chosen for the project. The comparison of the solutions that have been developed can provide helpful feedback about their design, highlight their strong elements and point out the trade offs that occur. The MCA method offers effective tools to deal with objectives, and this is the reason why it was selected over other methods that compare alternatives (such as a cost-benefit analysis).

Firstly, the choice of the criteria and their ranking is presented. Then the two solutions are compared according to the different criteria, and trade-offs are identified. This comparison is displayed from the point of view of the writer, since the technique is highly subjective. The chosen solution of the MCA is further investigated at the end of this chapter by using the SWOT and TWOS analyzes, in order to achieve its optimization.

6.1 Choice of criteria and their ranking

6.1.1 Categories of criteria

For the definition of the criteria that really fit the project, a brainstorming session was held, where the team discussed possible indicators and how they could be applied in the project. Apart from the team's brainstorming, the selection of criteria and their ranking is according to the preferences of the client, as they were indicated in the interviews and during online discussions (appendix K). The participation of team members from both disciplines in the MCA process was essential. In this process two major elements emerged: firstly the management aspect and secondarily the hydraulic element. Of course, the personal point of view of the group is a determining factor for the design of the MCA, as the method is characterized by subjectivity.

As a result, a plethora of elements was collected, and consequently grouped to create general categories (Table 6.1). By comparing and ranking the categories, a weight was defined for every category, with all together resulting in 100 % in total.

Table 6.1: Categories of criteria and their weights in MCA

Category	**Weight**
Recreation and tourism	30 %
Social values	25 %
Ecology	15 %
Economy and Finance	15 %
Sustainability	10 %
Design	5 %

Firstly, the **recreational and tourism** aspect holds a major role in the future of Scheveningen. This is reflected in the Scheveningen zoning plan (Municipality of Den Haag, 2015), and it was confirmed by the interviews mentioned above. The most important interventions in this coastal area, such as the Morales Boulevard, aim to make Scheveningen a touristic landmark of The Netherlands. As a consequence, there is a desire to increase the space dedicated for marina's, attract international yachting challenges, and offer a unique beach experience. For these reasons, a weight of 30% is given to this criterion.

Another important aspect of Scheveningen is related to its history and identity. Starting in the late 19th century as a fishing town without a direct link to The Hague, it evolved around the Harbour area as a more complex urban space with its own traditions. The district grew along the coast, while more and more tourism-related buildings were created, until becoming the most popular beach destination of the country. In that sense, a weight of 25% is given to the **social values** to acknowledge the importance of protecting the historical values, the old port areas, and the beach life identity.

The proximity of Scheveningen to important Natura 2000 areas create awareness about the importance of protecting the species living there, but also offers the opportunity to enhance their intrinsic natural values through a large-scale intervention. The weight for **ecology** in this case is 15%, slightly lower than the social aspect. This decision is motivated by the fact that the area has already a healthy natural habitat, but unsolved social issues are still present.

In fourth and fifth place, "**Economy and Finance**" and "**Sustainability**" are ranked, with weights of 15% and 10% respectively. Given the ethical dilemma behind them, it is hard to decide upfront which category is more significant. For this study, it is considered that economic development is slightly more important as it involves people's welfare and quality of life. Moreover, as both solutions are based on the Building with Nature philosophy (section 5.1.3), it is safe to say that environmental quality will not decline as a result of economic development. As the construction phase includes extensive dredging activities, it is important to acknowledge sustainable methods to prevent the next generations from bearing the burden of the damage made today to the environment. In the same line, solutions should include some level of adaptability to cope with the large uncertainty around climate change scenarios.

Finally, "**Design**" aspects of the solutions were weighted with 5%. After the interviews conducting with the client (appendix K), it was clear that innovation is a desired element in this research. Although measuring innovation is quite subjective, a solution that is planned, designed and constructed by combining nature-based techniques can break into the society with a meaningful impact, and be useful for the climate change issue in decades to come.

The vast categories are further studied and they are divided in several sub-criteria (third column, figure 6.1), which focus on more precise and detailed aspects that were observed to be the most relevant. Since the solution packages were developed having Safety as the main design driver, the two solution packages are equally safe. For that reason, the criterion of safety was excluded from the MCA, as it would not add any value.

6.1.2 Grading system, criteria and weights

Having identified the criteria, their weights and the sub-criteria, the next step is the definition of corresponding sub-criteria weights within each category. The weight range is set from 0 to 100 percent, same as for the main criteria.The total weight (fifth column, figure 6.1) is calculated by multiplying the criteria weight number (second column, figure 6.1) with the sub criteria weight number (fourth column, figure 6.1). All sub-criteria's scores accumulated to 1 (last row, fifth column, figure 6.1).

After agreeing upon criteria, the solution packages are ready to be scored in each category and receive a final score. The scores that are used range from 1 to 5, with 5 being the best score. The solution package with the highest score is the one that fits best the chosen criteria. The total score of a solution (seventh and tenth column, figure 6.1) is determined by multiplying the total weight (fifth column, figure 6.1) with the score (sixth and ninth column, figure 6.1). The maximum grade a solution can get is 5 points. The total score of the Advance solution is 3.92/5, while the Preserve solution scores slightly worse with a score of 3.4/5.

Criteria	Weight (%)	Sub criteria	Weight (%)	Total weight	Grading					
					Advance	Advance total	Advance per criterio	Preserve	Preserve total	Preserve per criterio
Recreation - Tourism	30		100	0,3	4	1,2	**4**	3	0,9	3
Social values	25	Sea view-Aesthetics	40	0,1	4	0,4	**3,7**	3	0,3	3,3
		Historic value-Education	30	0,075	4	0,3		3	0,225	
		Provision of services (fisheries, local markets, fresh water)	30	0,075	3	0,225		4	0,3	
Ecology	15	Impact to the ecosystem (Natura2000)	60	0,09	4	0,36	**4,4**	4	0,36	3,6
		Expected added ecological value	40	0,06	5	0,3		3	0,18	
Sustainability	10	Methods used	60	0,06	3	0,18	3	4	0,24	**4**
		Adaptability	40	0,04	3	0,12		4	0,16	
Economy and Finance	15	Construction costs	30	0,045	3	0,135	**4**	5	0,225	3,8
		Maintenance costs	20	0,03	3	0,09		4	0,12	
		Expected added economic value	50	0,075	5	0,375		3	0,225	
Design	5	Accessibility	30	0,015	4	0,06	**4,7**	4	0,06	3,3
		Innovation	70	0,035	5	0,175		3	0,105	
Total	100			1		**3,92/5**			**3,4/5**	

Figure 6.1: Grading of criteria for Advance and Preserve strategy

6.2 Scoring of Preserve and Advance solution in different criteria

Based on the criteria stated and ranked, the two solutions were evaluated and weighted. The two packages scored similar in almost all the categories, without significant deviations. A notable difference can be found in the "Economy and Finance" criterion, where Advance scored much higher for "Expected added economical value" but lower for costs, especially "Construction costs". As far as "Expected added ecological value", Advance strategy scored better than Preserve, as it contains the development of a whole new ecosystem in the landfill. Additionally, considering the sub-criterion of "Innovation", Preserve strategy scored lower than Advance by 2 points out of 5, as it is mostly a conservative approach.

6.2.1 Recreation-Tourism

Businesses and Tourism industry: The Preserve solution keeps the business and the services in the area running, while it offers the opportunity to implement new recreational elements in the port areas to attract cultural events, provides more space for a new marina, and leads to a wider beach to accommodate more restaurants. Currently, the recreational areas near the Kurhaus do not have the minimum required level of safety, a condition that will remain if the project is executed with the Preserve strategy. The Advance solution offers a much wider variety and extension of recreational spaces where businesses can expand. The lakes and the islands will add value and will be aesthetically pleasing, offering opportunities for tours through the wooden paths, bird watching, and ecotourism, while in the northern part thematic lakes with different recreational businesses and water sports around them will contribute to the economic development. The large land created seawards offers more space for huts and temporary structures.

Attraction for tourists: The Preserve solution focuses on maintaining the existing touristic values concerning the beach and water sports. Even though large interventions take place from 2050 on, the beach width is not expected to increase more than 500m, which gives a relatively accessible sea front. The Advance approach will attract many groups of tourists, interested in lake landscape and bird watching activities, thematic lakes for different types of visitors (families, young people, elderly, etc.) while at the same will create more place for water sports and yachting. Overall, the Advance strategy is more tourism-appealing than the Preserve strategy, and it is expected that the tourism flux will increase largely with more land to exploit. However, in this case the seafront can be around 800m from the boulevards and city center, so it is likely that tourists with a strong preference for a quick-access seafront will not be attracted.

6.2.2 Social values

Sea view: Both alternatives face the issue of providing water safety at the expense of blocking the sea view from the city buildings and boulevards. This is expected to occur around 2075. The Preserve solution attempts to create an artificial dune landscape that separates the city from the sea, and hence creating an appealing view in concordance with the natural habitats. On the other hand, the Advance solution includes four large lakes near the boulevards and rows of dunes next to the sea front. In both solutions the interventions are executed in phases, giving a sufficient period of time to people to get familiarized with the change. However, the Advance strategy offers a more appealing view from the boulevards and the coastal buildings, that is closer related to the previous seafront aesthetic.

Historical values: Both solutions protect the cultural heritage, the old port and the lighthouse among all the relevant buildings that characterize the local identity, except of the Kurhaus. In the case of the latter, these buildings of special vulnerability remain unprotected in the Preserve strategy. On the contrary, this complex of buildings with the interventions included in the Advance solution remains behind the sea defense after 2050. Another landmark in Scheveningen is the Pier, a place that will lose its attractiveness after the sea bottom underneath is covered by sand. However, in the Advance strategy this aspect is partly compensated by a lake surrounding the jetty.

Educational values: Advance solution provides an area for bird watching in the southern part, whereas the Preserve provides a high point for astronomical observation in the port bridge. However, the potential of the Advance solution is much higher in terms of development of scientific research within nature related disciplines, such as engineering with Building with Nature.

Fishery activity: In this case there is no clear difference between the solutions. Both maintain the fishery operations in the port as it is considered to be part of the Scheveningen identity. Nevertheless, neither of the two lead to an expansion of this activity.

Freshwater supply: The Preserve strategy focuses on enhancing the current dune system, leading to more fresh water storage in dune valleys. On the other hand, the Advance strategy does not increase the groundwater storage.

6.2.3 Ecology

In general terms, both solutions follow the **Building with Nature** philosophy, which means that the natural habitats are enhanced. However, the scale of the Advance intervention is much larger, and so it is the added ecological value to the area. In the latter, more dynamic ecosystems are created, supporting species biodiversity and abundance (birds, dune vegetation, marine life), while at the same time it is expected to protect the existing natural habitats. The Preserve strategy adds some ecological value to the system by increasing the plethora of the already existing land and marine species.

Adaptation period for the new natural habitats: The big scale of the Advance solution's interventions implies that a much longer period is required to let species populate the newly created islands and dune systems. On the contrary, the Preserve solution's interventions are attached to the current dune habitats and gradually improve it, with faster results. All in all, even though the Advance solution offers more ecological added value, it will be visible in the long term.

Impact to existing natural habitats: Since the Preserve strategy focuses on maintaining the coastline position by introducing more sand to the system, it will eventually affect the Natura 2000 areas (Westduinpark, Solleveld-Kijkduin) by making the dunes higher and wider, enhancing the current natural habitats. In that sense, the negative impact is considered to be minimum, and it even allows for more space for nature to thrive.

In the case of Advance strategy, a new type of ecosystem is introduced consisting of an intertidal zone, mud flats and islands. Although it is expected that the newly created tidal system can complement the existing natural habitat, there is a large uncertainty on how this process will develop. To summarize, less impact is expected by the Preserve strategy than with by the Advance. Under any condition, legal restrictions regarding the Natura 2000 areas must be taken into account.

6.2.4 Economy and Finance

Construction costs: The Advance solution in this case is much more expensive because of the amount of material required. The barrier and basin islands, the sand engine and the new dikes are large scale interventions that increase the costs exponentially, while on the contrary the Preserve solution minimizes this type of costs.

Maintenance: The concept behind the Preserve Strategy is to conduct a gradual maintenance. As a result, there are continuous maintenance costs, which however are similar to the costs of the current policy. The Advance solution maintenance deviates from this policy, given that it will require frequent maintenance, making use of large amount of material, leading to greater maintenance costs. Especially across the barrier islands and the new coastline, maintenance nourishment will drastically increase the costs.

Expected added economic value: The Advance strategy is more advantageous in this case, because it will create a plethora of new options and activities that will add value to the area and will rejuvenate the ambition of becoming northern Europe's resort. Islands and lakes will increase services provided, while beaches will be still accessible both to the north and to the south. Coastal restaurants and bars will have the chance to provide their services both in their existing place and in the temporary structures by the beach. Concerning the Preserve strategy, it will result in retaining the existing businesses, however it will minimize the vision of added value. With respect to the port development prospects, both alternatives boost marina and cruise activities after the harbour expansion. However, the Advance strategy has a larger port basin with additional berthing areas to accommodate new terminals dedicated to wind farm support, shellfish activity, or to deal with trade adaptation.

6.2.5 Sustainability

Methods used: Sustainability is addressed to deal specifically with the methods used during the construction. That being said, both alternatives aim to minimize the construction of new hard structures, except for the breakwaters, the storm surge barrier and its future transformation into a lock. The rest of the planned interventions are nature-based. The Preserve solution package can be considered better in terms of sustainability, considering less volumes of sand are extracted, transported, and dumped in the coast. On the other hand, it is evident that the Advance solution, even if it follows the BwN principles, requires large amount of materials, especially in the barrier islands where coastline has to be moved to a more offshore location, requiring more dredging equipment, and resulting in more emissions to the environment.

Adaptability: The solution packages are adaptable and gradually implemented. As far as Advance solution is concerned, being a more drastic plan results in the need for more effort, in case of changes that deviate significantly from what planned are preferred.

6.2.6 Design

Accessibility: Creating areas accessible to all visitors was one of the main parameters taken into account while designing both solution packages. The Advance solution includes the construction of wooden paths across the lakes and up until the beach, constituting it accessible even by bike. All points of interest are accessible, while the south and the north part of the city will be connected with a bridge in the port, solving the existing connectivity problem of the port area. The same applies in the Preserve solution, providing access to all points of interest, and solving the connectivity issues at the port.

Innovation: The Advance strategy is the winner between the two solution packages in terms of innovation, since it consists of very innovative and creative solutions, whereas the Preserve is more conservative. The new harbor with the marina and the storm surge barrier and the lock are quite modern, but not as revolutionary as the barrier and basin islands and the lakes that the other solution offers.

6.3 Trade offs identified

As mentioned at the beginning of this chapter, the Multi criteria Analysis is highly subjected to the expertise and fields of knowledge from the team members. Although the team counts on two different disciplines such as Construction Management & Engineering and Hydraulic Engineering, the team must be aware about the level of subjectivity in the weighting of the criteria, and provide tools to come up with an integrated and impartial solution. Ultimately, the subjectivity is better transferred to the wishes of the Municipality of The Hague, the driver of the project. In that sense, specific points of debate were identified, where the client is being forced to make some sort of compromises between criteria, and translate it to the solution choice, in order to implement the project. The next bullets explain each one of them:

- **Tourism Vs. Local residents**: If the area turns into a very touristic place (like an international resort), this will probably lead to a high opposition from the local citizens that desire a calm place to live. In the Advance strategy, where the economic activity is expected to flourish, the business owners will be satisfied, but the local residents will have more complaints for nuisance, lose of their identity and other related issues. Decision maker is forced to make compromises with Recreational, Economic & Finance criteria vs Social values criteria.

- **Sea view Vs. No sea view**: In both solutions the sea view is blocked by interventions occurring around 2075, although the Advance strategy partly compensates for this by creating lakes and moving beach restaurants to temporary structures next to the sea. On the other hand, the Preserve strategy replaces the sea view with a dune landscape and relocates beach restaurants. It is expected the Advance would be supported by the tourism and real estate industry placed near the beach, and also by local beach users. However, residents living in the first row of beach houses have already paid a significant amount of money to have sea view, and would oppose both solutions strongly. Decision maker is forced to make compromises with Recreational, Economic & Finance criteria vs Social values criteria.

- **Wide beach Vs. Large landfill**: Beach users do not find it very pleasant to walk long distances to reach the seafront, which negatively affects the touristic attractiveness of the area and raises complaints from nearby local users (citizens). In the Preserve solution, such distance is kept as short as possible (below 500m) by using only the necessary sand volume and securing a safe design. Otherwise the beach would have disappeared after a few big storms. In the Advance solution, the beach will become a large landfill, and people who want to go to the seafront will have to walk around 400m in the north and 800m in the south part of the beach. However, in this solution, visitors will have many more recreational options apart from swimming. Decision maker is forced to make compromises with Recreational criteria vs Economic & Finance criteria.

- **Investment costs and expected revenue** have a political perspective too. In the Advance solution, the investment costs are way higher, but the added economical value (as a result of the touristic boost to the area) is also very high. This solution package is an investment with high chances to build up as a business case. On the other hand, the Preserve strategy is more conservative in terms of costs, however does not create any significant added economic value. At a governance scale, it is possible that a lack of financing options for the project (by the Municipality, National Government, etc.) could eliminate the Advance solution, as the lack of investment makes the option unfeasible. For that reason, a bigger share of stakeholders needs to be convinced and enhance the support to the business plan. Because of the magnitude of investment costs, this decision refers to a broader, governmental approach.

  Another friction point that needs to be handled by the Municipality is the **different interests between different types of citizens**. In the Advance, investment costs are remarkably higher and revenues will come true in the long term, which could raise many complaints from part of Den Haag or other regions citizens (tax payers) that do not live near the beach nor use it frequently. The Preserve strategy requires a much lower investment, possibly bringing more acceptance from the Advance-opponents at the expense of dissatisfaction of 'beach' type of stakeholders.

- **Influence on Natura 2000 areas**: The Preserve strategy, given that it will have no negative influence in the Natura2000 areas, will have Dunea and Nature preservationists as supporters. On the other hand, the Advance strategy is highly intervening to the current natural environment, so there is deep uncertainty about what the consequences to the area will be. If Natura2000 areas remain uninterrupted, the aforementioned stakeholders will support this strategy too, otherwise they will oppose it, even by appealing to

European courts. Apart from this, the increase of tourism will also affect the Natura 2000 areas, especially where there is no control of the visitors entering the areas. Decision maker is forced to make compromises with Recreational, Economic & Finance criteria vs Ecology criteria.

- **Limitations of the dredging industry**: The application of sustainable dredging methods could become a constraint during the construction phase, especially in the case of the huge amount of sand needed for the Advance strategy. Compromises will have to be made in the future if the dredging industry is not capable of meeting policies and regulations regarding sustainability, or if those regulations lead to economically unfeasible projects. This could lead to limit the options to only the Preserve strategy, or that none of the solutions are feasible. Decision maker is forced to make compromises with Sustainability criteria vs Economic & Finance criteria.
- **Scheveningen Northern Boulevard buildings included vs Not included in the water safety solution**: The Advance solution ensures the safety level required by Dutch legislation for the northern boulevard area, which includes important landmarks that enhance local identity, such as the Kurhaus and the Pier. On the opposite, the Preserve solution protects this stretch with a lower safety level i.e. maintain the current level. Local residents may want to keep this area more safe than it is nowadays. On the other hand, some stakeholders that prefer the Preserve strategy would struggle with locals (for instance, the Municipality could prefer Preserve due to budget constraints). In the specific case of the Pier, it will lose its function as a jetty when sand nourishments or landfills cover the sea bottom. In principle, opposition from this stakeholder is expected in either of the two strategies, but at least in the Advance solution a lake is created as a compensation measure, which could tip the scale in favour of the latter. Decision maker is forced to make compromises with Social values criteria vs Economic & Finance criteria.

6.4 Optimization by using SWOT and TOWS

Based on the MCA, the two solutions, Preserve and Advance, resulted in similar grades, with Advance strategy prevailing with a small difference of 0.52 out of 5. For that reason, the focus in the optimization is laid only on the Advance strategy, but a similar approach could be done for the Preserve strategy.

The goal of this project is to provide a solid proposal to the client, where stakeholders are satisfied as much as possible, and their opinions are taken seriously into account. The Advance solution scored better in the MCA but is still not perfect. To optimize this solution, to be more acceptable by stakeholders and to ensure fewer complaints, a SWOT(Streghts Weaknesses Opportunities Threats) analysis and, consequently, a TOWS(Threats Opportunities Weaknesses Strenghts) analysis is performed. After these analyses, the key elements of the project are highlighted, as well as challenges that the project may have to face. Strengths and weaknesses of the project are assessed, while opportunities and threats are pointed out. All the aforementioned are then combined, in order for the Advance solution to be optimised and possible negative aspects are eliminated. This allows the creation of a holistic design, with the improvement of the solution with interventions towards achieving the final goal.

Before starting the analysis and after having identify the trade-offs, a useful tool can be employed to identify potential changes in the attitude of the stakeholders, by comparing their initial attitude (section 4.1) to the one against the Advance solution that is the one proposed. Stakeholder Role diagram is used to reach that goal. As it can be observed in the diagram (figure 6.2), the majority of the stakeholders will have a positive (or neutral to positive) attitude towards the proposed strategy. Problematic may be the attitude of two stakeholders, the city residents and the Pier, since they will be negatively affected by the strategy. On the one hand, the city residents that may consider the strategy too costly, may raise their concerns, being turned into Trip Wires. On the other hand, while the Pier will be partly compensated for the loss of its current glamour, it will potentially still oppose to this solution.

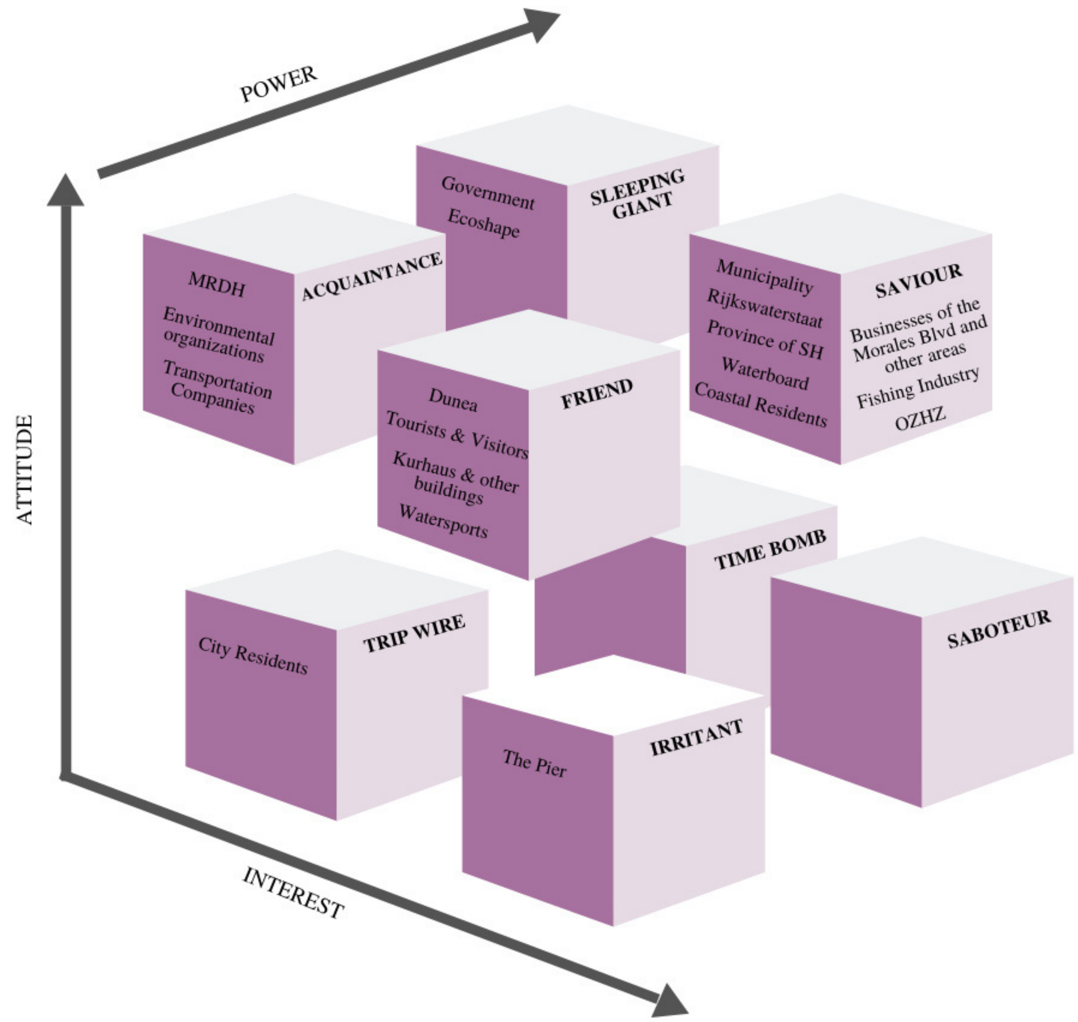


Figure 6.2: Stakeholder Role

6.4.1 Description of method

SWOT (Strengths Weaknesses Opportunities Threats) analysis is a tool that helps define the weak spots, the qualities of the project, favorable circumstances that may occur and can lead to increased value, as well as menaces for the project which can cause the decrease of the project value. The first two elements are internal factors of the project, while the latter two concern the external environment. After defining all these elements, the objective is to manage and combine them in such a way that the project becomes more fitted to the purpose of satisfying as much as possible the stakeholders. More specifically, the aim is to build on strengths, eliminate weaknesses, exploit opportunities and mitigate threats that could occur. For that reason, a table with 4 quadrants was created, each representing one letter of SWOT (appendix T). The table contains one part with the strong elements of the project, one part with the weak spots, one part with possible opportunities and one part with threats that the project could face (Dyson, 2004).

As an extension of the SWOT analysis framework, TOWS(Threats Opportunities Weaknesses Strenghts) analysis was also conducted. After the identification of the aforementioned elements, TOWS allows the coupling of them, in order for the project to be optimized. Strengths are coupled with Opportunities and they are the most advantageous elements of the project, as strengths enable stakeholders to grasp opportunities. Weaknesses are coupled with Threats, consisting one of the most dangerous issues that need to be taken care of. More specifically, weaknesses will make the project vulnerable towards threats of the environment, and stakeholders will not be able to deal with them. Additionally, the matching of Strengths with Threats enables external threats to be dealt with strong aspects. The coupling of Weaknesses with Opportunities points out how certain weak points can prevent stakeholders from exploiting favorable circumstances. These combinations can lead to interesting results that could prove beneficial in the optimization (Weihrich, 1982).

6.4.2 Result of TOWS analysis: TOWS Matrix

Strengths - Opportunities	**Strengths - Threats**
• The new variety of different recreational options not only provides activities for all, but also contributes in the social and economical development through the new job offerings and the new businesses. • The protected port and boulevards in Scheveningen offer the ability for development and expansion of port activities, as well as touristic-related businesses. • The enhancement of the yacht racing activities and the use of the area as a worldwide meeting point can be combined with the local identity of the port and turn the port into a new-age landmark, where past and future meet. • Increased biodiversity and abundance of species in natural habitats inside Delfland increase the chances for regional nature enhancement in adjacent habitats. The development and spread of nature can be a motive for connecting Rotterdam and Den Haag with a large environmental park. At the same time, it creates more motivation for further scientific research regarding ecology conditions of the area. • A phasing-design approach allows citizens to adapt to large interventions, engaging them even more to the development of thematic lakes. This is beneficial, as it is a political decision and stakeholders must be convinced to support it. • Since the government wants to comply with the Paris Agreement, the use of sustainable techniques and methods is a key advantage for the project. • Maintaining local identity helps citizens to have a larger sense of belonging to the city, and obtain a more positive approach towards the project, feeling part of it.	• The great variety of options will cover a very wide range of preferences (e.g. thematic lakes that address children and are safer). For that reason, the business plan is more likable to succeed. • The new tidal system will be carefully implemented, gradually (phases) and by using sustainable methods, giving the opportunity to nature to adapt to the new conditions and achieve balance to the maximum. • The increase of tourism will be coupled with the significant increase of facilities provided. As a result, a wider area and more choices will bend potential reactions from local citizens, as the opportunity to use the facilities can compensate for their complaints. • The variety of the attractions offered reinforce the fact that Scheveningen is the most popular beach destination in the Netherlands. This can be the match point/win the competition among the other 12 weak points of the country. • The weak point of the area can be considered as one of the most important, given that the high historical and cultural value of the Scheveningen, results in it being one of the government's priorities to allocate resources to protect the area.

Weaknesses - Opportunities	Weaknesses - Threats
• The phases of the project are designed in a way that the expected return on investment can be evaluated before the initiation of the next one. Potential downturn can indicate the need for changes or even cancellation of some phases, so cost overruns will be prevented. • The maintenance costs can be partly self-covered by the taxation of businesses that will be based in the newly constructed area. Indirect boost of the local economy will also allow for the covering of these expenses. • The loss of sea view will be realized at a point that there is no other option against safety, but the size of the lakes and the new landscape will compensate for this old sense. • The involvement of politics in the project can attract new investors and make the large investment costs more manageable.	• An unbalanced new natural system will decrease the return on investment, and potentially increase the maintenance costs (e.g. need for more nourishment), which will further increase the total costs of the project. As a result, cost overrun can occur. • Significant increase of tourists, combined with the longer beach and the loss of sea view will infuriate the local citizens.

6.4.3 Interventions to optimize the Advance solution

After performing the TOWS analysis, there is a clearer view of the key elements of the project and possible situations that the project may have to deal with. The next step is to find the link to specific interventions as modifications of the Advance Solution and how they can be applied. The main interventions proposed in this study are the following:

Modify Phase 4 of the project to decrease investment costs

- Do not fill the inner water basin with sand, and restrict the intervention to only widen the barrier islands, closing the inlets (gaps between islands), and the sandy seawall. This way, safety requirements are met with a smaller landfill, resulting in a much larger inner lake compared to the original proposal. This would decrease the construction costs, where at the same time would secure a strong and successful development of flora and fauna in the area. Jointly, the same recreational activities can still take place: bird watching, beach tourism, water sports etc. Lastly, less dredged material is needed, so the project becomes more independent from the possible limitations of the dredging industry i.e. have more chances to comply with legislation and policies regarding sustainability.

Create more access infrastructure to key locations within the Municipality boundaries

- Improve the accessibility from the boulevards to the seafront by constructing more wooden decks, cyclist paths, and certain zones of the beach for buggies. Users of the beach will be able to reach the seafront more easily and, consequently, will be more satisfied.
- Create infrastructure that provides easy access from the Scheveningen northern part of the district to the Oostduinen and Rijnland beaches, so tourists or local citizens with a strong preference for narrow beaches (nearby seafront) are less reluctant to the project.

More compensation for loss of sea view

- The municipality should find ways to compensate for building users that lose the sea view. Options: Free parking near the lakes, restaurant coupons, benefits in renting a beach house (huts).

Strengthen the attractiveness of historical values in the city

- First, bring a concept addressed in the Preserve solution. In order to raise the attention and public involvement with the historical Harbour, buildings like a concert stadium or amphitheater can be constructed here.

- Rebuild the pier in the new (seaward) seafront, with more recreational and hospitality functions included. This can help building the business case for the required investment (use pier project TU delft master thesis as a reference).

Add more ecological value

- Apply concepts from the Preserve solution in the Port of Scheveningen to increase the ecological value of the area, like constructing hanging structures and textured walls. Additionally, restoration of salinity gradient can prove ecologically beneficial for the habitat.

Chapter 7

Conclusions and discussion

An extensive research was carried out to identify possible integrated solutions for the coastal zone in The Hague to deal with water safety in the 21st century. Afterwards, different designs were compared in terms of a multi criteria, resulting in the identification of certain aspects in which compromises need to be made. This is crucial information that the decision maker needs in the process of choosing a final solution. The first section of this chapter gives a first overview of the preliminary conclusions of the research. In the second part, the research questions are answered. The third section provides some recommendations and limitations that can be up taken for future research.

7.1 Preliminary conclusions

Coastal protection system
The coastline within the boundaries of the municipality of The Hague is currently protected by dunes, beaches, the port of Scheveningen and the dike-in-boulevard construction hidden under the Morales boulevard. Dunes and beaches are soft coastal defence structures, that protect the coast with their sand volume determined by their height and width. A special case of a fixed dune is found in the Scheveningen northern boulevard. In this case, buildings, roads, and landmarks such as the Kurhaus placed on top of the sandy dune have a lower level of protection than the area behind the seawall.

Beaches along the entire coastal zone are dissipators of waves, decreasing their energy before reaching the dunes. In a storm event, the erosion profile determines the safety of a sandy coastal section. To maintain a sufficient sand volume in front of the coast, nourishments with offshore dredged sand are the current practice. It is found that even with an increased sand demand in the future for the entire Dutch coast, the availability of sand in the North Sea will not be a problem. Hence, future solutions that require a lot of sand are a possibility. The port of Scheveningen protects the hinterland mainly by means of a paved dike (hard coastal defence structure), having its weakest part in the southern edge of the port, which was flooded several times during the last years. Outside the limits of the Scheveningen district, complex dune systems form a protection against the sea, and were proved to be safe to withstand hydraulic loads providing the current maintenance strategy.

Morales boulevard
The dike-in-boulevard structure of the Morales boulevard (hard structure) works in combination with an increased beach volume (soft solution) in front of it, that dissipates the incoming wave energy. Such a combination is called hybrid structure. It is found that the current dike-in-boulevard structure is designed for a SLR of 1.25m, while the beach volume in front of the boulevard is calculated for a SLR of 0.30m. The beach volume can be increased by beach and foreshore nourishments to also withstand the same SLR of 1.25m, without compromising the sea view behind the dike.

Hydraulic boundary conditions
It is expected that the wave climate, the tide and wind and storm conditions will not change significantly until the end of the century. However, temperature will increase, which causes the ice at the poles to melt faster and thus, sea level to rise. The predictions of SLR until the end of 2100 are very uncertain, ranging between 0.3m for the most optimistic scenario to 3.0m for the most pessimistic one.

Stakeholders
The stakeholders of the area can be grouped based on their main driver: recreation (residents, visitors), safety (governmental bodies), profitability (business owners, the pier, harbor industry) and environment (environmentalists, nature preservationists). All stakeholders are in favour of the project because they all want safety in the future. However, depending on the design of the solutions and whether the solutions fulfill their other demands, they either support or oppose the project. The most critical actors are the majority of the governmental bodies, local business owners, tourists and residents of the area. Actors related to the protection of the environment can also proof critical, mainly because of their knowledge and power.

7.2 Final conclusions

Regarding the first research question:

What are the possible solutions for the coastal zone of Scheveningen and surroundings to deal with climate change until 2100?

Based on the current coastal protection system, the future boundary conditions in the area and the stakeholders' interests, two different future solutions for the 11 km of coastline within the boundaries of the municipality of The Hague have proved to be possible: with the **Preserve** solution, the dike ring is kept in the same position; and with the **Advance** solution, the shoreline is shifted between 400m and 800m in seaward direction. Both solutions follow the guidelines of Integrated Coastal Zone Management by Building with Nature, which means that both solutions add value for nature and humans, while complying with safety requirements. Furthermore, both solutions are adaptable in a way that the different measures are implemented in four different phases depending on SLR (which is monitored) in order to deal with the large uncertainty regarding this issue.

In the first phase of the Preserve strategy, the quay wall of the 2nd harbour will be increased, hanging structures, textured walls and rich revetments will be implemented, and the port will be extended with a new marina. Besides that, parts of the beach will be heightened and widened and an urban resilience strategy will be realised. In the second phase, a storm surge barrier will be constructed at the port entrance and a salinity gradient will be given back to the system. In the third phase, the height of the dike-in-boulevard structure will be increased and a multi-functional dune landscape will be created. In the last phase, the storm surge barrier will be adapted to a lock and the height of the dike-in-boulevard will be increased as well.

In the first phase of the Advance strategy, the current port breakwaters will be extended and a nourishment will be executed on both sides. Additionally, a storm surge barrier at the port entrance and a new harbour will be build. In the second phase a nourishment inspired by the sand engine will be placed in front of the Northern boulevard, barrier islands with dunes parallel to the coast south of the port will be formed and the storm surge barrier will be adapted to a lock. In phase three, thematic lakes protected by seaward dunes in the area north of the port and islands behind the barrier islands in the southern part will be constructed. In the last phase, additional nourishments will be done to connect the barrier islands and to create one big lake behind the barrier islands protected by dunes on top of it.

Also, regarding the second research question:

What are the balancing factors (trade offs) that can help in the decision making process to choose a final solution?

To enable a decision making process to our client, five different criteria were defined: 1. Recreation and tourism, 2. Social values, 3. Ecology, 4. Economy and finance, 5. Sustainability and 6. Design. After evaluating the solutions, specific trade offs between the criteria were identified.

First, a point of conflict is expected between the growing touristic sector and a part of the local residents suffering the disruption of their way of living (1 and 4 vs. 2). **Second**, maintaining the sea view as required from local citizens and the touristic sector will not be technically feasible for certain climate scenarios, and it could lead to unnecessarily expensive solutions (1 and 4 vs. 2). **Third**, long distances from the city to the seafront could raise complains from beach users and related business. Quite long distances will happen for a seaward expansion (landfill), but relatively short distances are possible for a beach widening aimed to preserve the coastline (1 vs

4). **Fourth**, large investments to build a seaward expansion comes with a significant added value to humans and nature in the long run, but a strategy to preserve the coastline needs a lower investment, it has immediate results, but with little added value to humans and nature. Following up with the last one, a **fifth** trade off lays between different types of citizens. The revenues of a large scale project benefit only a certain share of the population, the citizens related to coastal activities, but without any significant benefit to other non-related tax payers that are indirectly paying off the large investment coming from state resources (2 vs 4). **Sixth**, the legal implications of affecting Natura 2000 areas, even if it is with the aim to enhance its natural values, could stop the project execution. While a conservative Preserve solution hardly affect the natural habitats, the creation of a large scale new ecosystem is associated to a large level of uncertainty surrounding nature development in the interface with Natura 2000 areas (1 and 4 vs. 3). **Seventh**, considering the large amounts of sand necessary to execute the project, the application of sustainable dredging methods could become a constraint during the construction phase if the project becomes non profitable when considering sustainability as a requirement (4 vs 5). **Lastly**, a decision has to be made whether to increase the level of safety in the buildings in the northern boulevard, were important landmarks of the district are placed. Whereas local citizens may want to keep the identity of the area, the Municipality should define to what extent is willing to invest in more infrastructure to protect these (2 vs 4).

The final conclusion is related to the optimization of the design. The starting point is the Advance solution, as it performs slightly better in the multi criteria analysis than the Preserve. The following additional measures are recommended to minimize threats and weakness, and maximize strengths and opportunities of the project: **A)** decrease the investment costs by not filling the basin behind the barrier island with sand; **B)** create more beach access infrastructure to key location within the municipality boundaries; **C)** compensate for the loss of sea view with governance measures during the operation stage; **D)** strengthen the attractiveness of historical values in the city in the port and the Pier; and **E)** take measures to enhance marine life in the port water areas.

7.3 Discussion

Limitations

While conducting our research, a few limitations concerning our project have surfaced. These limitations were hindrances for the smooth outcome of the project, and obstacles that were not exceeded and caused deceleration of the group productivity.

First of all, it was observed that the stakeholders were not reacting to our requests during the research. Despite approaching different stakeholders and the willingness to add value to the report by using their own opinions as an input, the communication was most of the times unilateral. This is a logical consequence of the COVID19 pandemic situation, as priority for citizens and business owners is now health and economic survival. Additionally, as communication was merely online, there was a lack of physical contact that could engage stakeholders even more and increase their interest towards our research. As a result, the stakeholder part is not targeted and tailormade to the project, but a general overview of the stakeholders involved, based mainly on online research.

Another obstacle the MDP encountered was the uncertainty of certain fields that were touched upon. As some future aspects are uncertain, assumptions were made, in order to overcome bottlenecks. Based on a very simplified calculation, we concluded that the sand volume required to execute the project will not be a problem in the future. This is a rough assumption and it does not consider future uncertainty in policies and legislation, such that a modification of the current legal frame neglects the possibility of sand mining in the North Sea, and as a result dredging industry will not be able to obtain these huge amounts of sand needed in the future.

A final aspect that is not strictly defined, is the research of sea level rise. Studies concerning sea level rise are being continuously updated, resulting with a plethora of assumptions and scenarios been taken into account. This creates a deep uncertainty on the field, as there is not one and only right option, and a limitation to our MDP.

Recommendations

Evaluate a retreat strategy

In the present report, two solution packages were developed; the Preserve and the Advance strategy. A third approach that could potentially compliment the project is the Retreat strategy, which implies to do nothing and accept the flooding possibly of the study area. Even if this option is not developed in this report, a decision based on client's preferences and demands, a further investigation in this alternative would enrich the evaluation of designs. The development of such alternative could provide innovative measures that could be implemented in the former two solution packages, Preserve and Advance. For instance, to accept the port of Scheveningen is not protected from sea level rise and storms anymore. In that sense, it would be useful to investigate the trade-offs concerning economy, the preservation of local identity, and the necessary measures to deal with stakeholder reactions.

Involve expertise from more disciplines
By combining the two disciplines of the group members, Construction Management & Engineering and Hydraulic Engineering, the project focuses mainly on these aspects. A recommendation would be to also involve experts from other disciplines, such as Architecture and Urbanism. This way, a more detailed strategy could be developed by taking into consideration land-use planning, urban revitalization and citizens' welfare. Another way to look at our project could be from a more exhaustive economic and financial point of view, where Economists study in depth the design of the business plan of the proposal, creating a detailed cost-benefit analysis and conducting research about investment and financing options. A third field of knowledge that was not included is transport and logistics. Currently, the Scheveningen district faces important issues related to the hinterland connections to the port and touristic destinations. Looking at different transportation means and infrastructure in a sustainable way, and relate them to the solutions proposed in this report, could also be a follow up of this research.

Investigate on the application of the co-creation concept
A proposal for further research is the concept of co-creation, which is firstly introduced in Chapter 4. After touching upon the concept briefly, it is possible that a more elaborated analysis could provide useful results and help the decision making of the client. A possible alliance of coastal residents and the municipality can solve issues of miscommunication and reduce complaints coming from the local community. Other combinations of involved parties can be proposed, as well as how the concept can be applied and under what conditions. Additionally, the pros and the cons of the co-creation implementation can be registered in detail. Consequently, the concept of co-creation invited for a deeper exploration.

Look at a broader scale
Another recommendation for future research could be a regional study of the Scheveningen area. The integration of the present proposal to a more regional planning addressed by different division within the National Government can result in an innovative proposal. There are two options that worth to be mentioned. One line of research is to investigate how the solutions proposed by this study can be integrated into a Dutch National Park between Hoek van Holland and Ijmuiden. Certain natural habitats included in the solutions could be expanded to enable the attachment of other adjacent green areas, building up into a single national park along the coastal strip. A second option is the infrastructure connection between Scheveningen and Rotterdam through a sea corridor. This is particularly applicable in a seaward expansion where new transport infrastructure could be executed.

References

Actueel Hoogtebestand Nederland. (2020, March). *Ahn viewer.* Retrieved 18-11-2020, from `https://www.ahn.nl/ahn-viewer`

Akhilesh, K. (2017). *Co-creation and learning. in: Co-creation and learning.* SpringerBriefs in Business. Springer, New Delhi.

Amesz, J. (2020). *Friday lunch webinar - delta futures lab: Dutch coastal resilience.*

Arcadis. (2008). *Waterbouwkundige rapportage - achtergronddocument bij projectnota en verbeteringsplan versterking zeewering scheveningen; arcadis rapport 110403.001485.*

Arrieta, X., Almeida, E., Silva, R., Hewageegana, H., & Marinov, K. (2016). *CIE4061-09 MULTIDISCIPLINARY PROJECT: Coastal and Marine Engineering and Management Master - Final Report.*

Be Hague. (2017). *Scheveningen.* Retrieved 13-11-2021, from `https://www.behague.com/en/wijken/scheveningen-en`

Boers, M. (2010). *Atlas 13 kustplaatsen.*

Bosboom, J., & Stive, M. (2015). *Coastal Dynamics I - lecture notes CIE4305.* Delft University of Technology).

B.V., S. N. (2018). *Beheerplan bijzondere natuurwaarden westduinpark en wapendal - beheerplan 2018-2023.*

Chotkan, S.A. et al. (2020). *4th harbour scheveningen masterplan.*

Chu, J. (2013). *Fast company.* Retrieved 17-11-2020, from `https://www.waterstudio.nl/tag/koen-olthuis/page/25/`

College van dijkgraaf en hoogheemraden. (2014). Tussennotitie Kust. Hoogheemraadschap van Delfland.

Dave Berman. (2021a). *Pedestrian bridges: Connecting people with communities.* Retrieved 15-01-2021, from `https://ced.sog.unc.edu/pedestrian-bridges-connecting-people-with-communities/`

Dave Berman. (2021b). *Seaport marina ijmuiden.* Retrieved 15-01-2021, from `https://eu.floridatoday.com/story/news/local/2018/09/27/port-canaveral-awards-contracts-153-million-cruise-terminal-project/1436060002/`

De Pier BV. (2021). *About us.* Retrieved 14-11-2021, from `https://www.pier.nl/over-ons/`

de Jong, M. F., & et al. (2014). Impact on demersal fish of a large-scale and deep sand extraction site with ecosystem-based landscaped sandbars. *Estuarine Coastal and Shelf Science 146:83-94.* doi: 10.1016/j.ecss.2014.05.029

Deltares. (2018a). Delta scenarios for the 21 century; update 2017. , 34.

Deltares. (2018b). *Mogelijke gevolgen van versnelde zeespiegelstijging voor het deltaprogramma. een verkenning.* (No. 11202230-005-0002).

Deltawerken. (2004). *The dune landscape.* Retrieved 08-12-2020, from http://www.deltawerken.com/Dunes/103.html

Den Haag. (2021). *Fun on scheveningen beach.* Retrieved 31-07-2019, from https://www.denhaag.nl/en/in-the-city/leisure/fun-on-scheveningen-beach.htm/

de Schipper, e., Matthieu A. (2020, November). Beach nourishment has complex implications for the future of sandy shores.

de Winter, R. (2014). *Dune erosion under climate change* (Unpublished doctoral dissertation). Department of Physical Geography Faculty of Geosciences.

Dodgson, J., Spackman, M., Pearman, A., & Phillips, L. (2009). *Multi-criteria analysis: A manual.*

Dunea. (2021). *De duinen van Dunea.* Retrieved 15-11-2020, from https://www.dunea.nl/duinen.html

Dyson, R. G. (2004). Strategic development and SWOT analysis at the University of Warwick. *European Journal of Operational Research*, *152*(3), 631–640. doi: 10.1016/S0377-2217(03)00062-6

Ecoshape. (2020). *Building with Nature: creating, implementing, and upscaling Nature-based Solutions.* nai010.

EcoShape. (2020). *Pilots.* Retrieved 13-11-2020, from https://www.ecoshape.org/en/pilots/

Ecoshape. (2021a). *Creating hanging and floating structures.* Retrieved 15-01-2021, from https://www.ecoshape.org/en/concepts/creating-hanging-and-floating-structures/

Ecoshape. (2021b). *Creating rich revetments.* Retrieved 15-01-2021, from https://www.ecoshape.org/en/concepts/creating-rich-revetments/

Ecoshape. (2021c). *Restoring salinity gradients.* Retrieved 15-01-2021, from https://www.ecoshape.org/en/concepts/restoring-salinity-gradients/

Gemeente Den Haag. (2021). *Scheveningen harbour.* Retrieved 19-01-2021, from https://www.denhaag.nl/en/in-the-city/getting-there-and-around/getting-to-scheveningen/scheveningen-harbour.htm

Gil Vicente de Andrade. (2021). *Piscinão de ramos.* Retrieved 15-01-2021, from https://www.pinterest.de/pin/457748749612418255/

Haddadi, A. e. a. (2016). A conceptual framework to enhance value creation in construction projects. *Procedia Computer Science*, *100*. doi: 10.1016/j.procs.2016.09.196

Hallie, F. (2017). Basiskustlijn 2017 - Herziening van de ligging van de basiskustlijn. In *Dir. Algemeen Waterbeleid en Veiligheid.* Minitery of Infrastructure and Environment.

Homes, F. F. (n.d.). *Floating architecture: The future for tropical flood plains.* Retrieved 10-12-2020, from https://www.finchfloatinghomes.com/

Hoogeveen, R., & Veenswijk, M. (2016). *Coping and constructing: A narrative perspective on project dynamics.* Retrieved 15-11-2020, from https://www.scirp.org/journal/paperinformation.aspx?paperid=65044 doi: 10.4236/jbcpr.2016.41006

KNMI. (2015). KNMI'14 climate scenarios for the Netherlands; A guide for professionals in climate adaptation. , 34.

Kreike, B. et al. (2020). *MDP Project; Future Coastal Protection of Scheveningen.*

Le Bars, D. e. a. (2017). A high-end sea level rise probabilistic projection including rapid Antarctic ice sheet mass loss. *Environmental Research Letters*, *12*(4). doi: 10.1088/1748-9326/aa6512

marinas.com. (2021). *Port canaveral awards contracts for 153 million dollars cruise terminal project.* Retrieved 15-01-2021, from https://marinas.com/view/marina/

Mark Voorendt. (2021). *The netherlands - katwijk aan zee.* Retrieved 15-01-2021, from https://www.flooddefences.org/katwijk-aan-zee.html

M. Haasnoot, e. a. (2018). *Mogelijke gevolgen van versnelde zeespiegelstijging voor het Deltaprogramma; Deltares rapport 11202230-005-0002.*

Mijnheer, C. L., & Gamble, J. R. (2019). Value co-creation at heritage visitor attractions: A case study of gladstone's land. *Tourism Management Perspectives*, *2019*(32). doi: 10.1016/j.tmp.2019.100567

Ministerie van Infrastructuur en Waterstaat. (2020). *Deltaprogramma 2020 - Doorwerken aan de delta: nuchter, alert en voorbereid.* Retrieved 22-01-2021, from https://deltaprogramma2020.deltacommissaris.nl/

Ministry of Agriculture, Nature and Food Quality. (2021). *Natura 2000, solleveld and kapittelduinen.* Retrieved 17-11-2020, from https://www.natura2000.nl/index.php/gebieden/zuid-holland/-kapittelduinen.html

MRDH. (2021). *What are we doing.* Retrieved 28-11-2020, from http://mrdh.nl/doen.html

Municipality of Den Haag. (2015). *Bestemmingsplan scheveningen haven (vastgesteld).*

Navionics S.r.l. or its subsidiaries. (n.d.). *Navionics.* Retrieved from https://www.navionics.com/fin/

Netherlands Board of Tourism and Conventions. (2021). *Marker wadden.* Retrieved 15-01-2021, from https://www.holland.com/de/tourist/reiseziele/provinzen/flevoland/marker-wadden-3.htm

Nieboer, H. (2020). *Introduction to building with nature - lecture of the course cie4301.* Retrieved 18-01-2021, from https://brightspace.tudelft.nl/d2l/le/content/210699/viewContent/1651892/View

Onderwater, M. (2008). *Tweede fase versterking zeewering scheveningen randvoorwaarden en uitgangspunten voor veiligheidsaspecten en de morfologische studie.*

Oorschot, L. (2012). *Spaanse temperamenten en haagse vindingrijkheid: de scheveningse boulevard van manuel de solà-morales.* Retrieved 15-11-2020, from https://www.archined.nl/2012/11/spaanse-temperamenten-en-haagse-vindingrijkheid-de-scheveningse-boulevard-van-manuel-de-sola-morales/

Oranjewoud, I. (2013). *Achtergronddocument water MER Scheveningen-Haven - Projectnr. 250854.*

OZHZ. (2021). *Natuur en biodiversiteit.* Retrieved from https:///www.ozhz.nl/themas/natuur/.html

Resilient Den Haag. (2021). *Resilient Den Haag.* Retrieved 22-01-2021, from https://resilientthehague.nl/

Rijksoverheid. (2021). *Waterbeheer in Nederland.* Retrieved from https://www.rijksoverheid.nl/onderwerpen/water.html

Rijkswaterstaat. (2020, December). *Kustlijnkaarten 2020.*

Roos, A. (1971). Scheveningen uit de branding.

Saarikoski, H., Barton, J., D.N.and Mustajoki, & Keune, H. (2016). *Multi-criteria decision analysis (mcda) in ecosystem service valuation.* Potschin, M. and K. Jax (eds): OpenNESS Ecosystem Services Reference Book.

Savolainen, e. a., J. (2015). Stirring the Construction Project Management with Co-creation and Continuous Improvement. *Procedia Economics and Finance*, *21*, 64-71. doi: 10.1016/S2212-5671(15)00151-3

Scheveninger, D. (2017). *Nieuwe trappen voor de morales-boulevard.* Retrieved 17-11-2020, from `https://www.de-scheveninger.nl/2017/12/20/nieuwe-trappen-morales-boulevard/`

Sector, D. W. (2013). *Official opening boulevard scheveningen adds new icon to modern coastal landscaping.* Retrieved 16-11-2020, from `https://www.dutchwatersector.com/news/official-opening-boulevard-scheveningen-adds-new-icon-to-modern-coastal-landscaping`

Smyth, H., Razmdoost, K., & Kusuma, I. (2016). Innovation and the co-creation of value in construction. , *2016*.

Stive, M. J., Schipper, M. A. d., Luijendijk†, A. P., Aarninkhof, S. G., Gelder-Maas, C. v., Thiel de Vries, J. S. v., ... Ranasinghe, R. (2013). A new alternative to saving our beaches from sea-level rise: The sand engine. *Journal of Coastal Research*, *29*, 1001-1008.

TAW. (2002). *Leidraad zandige kust.* Technische Adviescommissie voor de Waterkeringen (TAW).

The Hague Marketing Bureau. (2021). *De duinen van dunea.* Retrieved 13-11-2020, from `https://denhaag.com/nl/westduinpark.html`

United Nations. (2015). *THE 17 GOALS.* Retrieved 19-01-2021, from `https://sdgs.un.org/goals`

van Delfland, H. (2013). *Berekeningen ten behoeve van de tussennotitie kust en de legger zeewering.*

van Delfland, H. (2014). *Tussennotitie kust.*

van Verkeer en Waterstaat, M. (2007). *Hydraulische randvoorwaarden primaire waterkeringen.*

Voorendt, M. (2013). *The Netherlands - Scheveningen.* Retrieved 22-11-2020, from `https://www.flooddefences.org/scheveningen.html`

Waterman, R. (2010). *Integrated coastal policy via building with nature.* Delft University of Technology.

Waterman, R. E., Misdorp, R., & Mol, A. (1998). Interactions between water and land in The Netherlands. *Journal of Coastal Conservation*, *4*(2), 115–126. doi: 10.1007/bf02806503

Weihrich, H. (1982). The TOWS Matrix-A Tool for Situational Analysis. *Long Range Planning*, *15*(2), 54–66. doi: 10.1016/0024-6301(82)90120-0

Wijnberg, K. M. (2002). Environmental controls on decadal morphologic behaviour of the holland coast. *Marine Geology*, *189*, 227–247.

Appendix A

Coastal defense characteristics

	Length	Type of defense	Dimensions	Remarks
1. Oostduinen	1.4 Km	Soft, dune seawall	Foredune elevation NAP +16 m high and 200m wide + back dune NAP +10m to +3m high.	Located in a Natura 2000 area Meijendel & Berkheide. Adjacent to Rijnland in the north. The lower-lying dune area is a water extraction area.
2.a Northern Boulevard of Scheveningen	1.1 Km	Buildings and roads built on top of dunes.	Beach elevation NAP +4m, boulevard NAP +6.6m. Dune varies between NAP +10 and +11m.	Several buildings on the dune are in front of the dike ring exposed to storm erosion. Also, this boulevard is currently under construction works.
2.b Morales Boulevard	1.9 Km	Partly as a dune and partly as dike-in-boulevard.	Elevation from NAP +8.6m to +12m. Width for Dike-in 40-70m and foredune 50-70m	Dike beneath the boulevard. In case of storm, the boulevard is damaged but the dike protect the areas behind. The beach also offers protection from waves.
2.c Port of Scheveningen	0.9 x 0.8 Km	Paved dike (High ground) and other structures (pumping station, sluices)	Elevation between NAP +6.50m and NAP +8.5m	The entire port and living areas are located in front of the high ground, thus exposed to a lower level of safety
3. Westduinpark	3.5 Km	Soft, dune seawall	Foredune elevation NAP +12-20m, inner dune NAP +2.5-3m. Width 400-800m.	Natura 2000 designated nature reserve “Westduinpark & Wapendal”.
4. Kijkduin Boulevard	0.9 Km	Soft, dune seawall with buildings on top	Foredune elevation NAP +12-15m and width 150-300m	Natura 2000 area “Solleveld & Kapittelduinen”.
5. Solleveld - Kijkduin	1.2 Km	Soft, dune seawall	Foredune NAP +10-14m and width 150-300m	Natura 2000 area “Solleveld & Kapittelduinen”. Part of the ZandMotor is in front of the beach.
TOTAL 10.9 Km of coast				

Figure A.1: Detailed description of the elements in the Scheveningen coastal defense system mentioned in Chapter 3. The descriptions were obtained from official sources (van Delfland, 2014). Information about dune elevations was also verified with maps from the Current Altitude File Netherlands (Actueel Hoogtebestand Nederland, 2020)

Appendix B

Coastal Dunes use and functions in Delfland

B.1 Coastal Protection

Dunes are found along the whole coast of the Netherlands area of research, from Oostduinen to Solleveld they are applied as soft and dynamic coastal structures or fixed dunes.

At Oostduinen, Westduinpark, Boulevard van Kijkduin and Solleveld-Kijkduin, soft dunes can been identified. This means that the dune system is permitted to dynamically change, and drifting, carving and parboiling foredunes are allowed in order to meet safety requirements. In other words, soft sandy interventions can be implemented without restrictions.

For the Scheveningen Northern Boulevard area (element Nr. 2, figure 3.1) the dunes have been covered by buildings and revetment. Due to this constructions, the dunes have become static and fixed. A more flexible system is found at the Boulevard of Kijkduin (element Nr. 6, figure 3.1), where the dune system is very close to where a town area is situated, decreasing the dynamical aspect of the dune. This causes the dune to become whether fixed behind the dunes, but still allowing for soft interventions in the front of the dune.

Concerning the dune heights, it has been observed that all dune heights in the study area were above NAP +10 m (Actueel Hoogtebestand Nederland, 2020). To check whether this height is sufficient according to current legislation, the minimum allowable water level is determined according to the 'Waterwet', in which a storm of once in 10,000 years is allowed. This results in a minimum foredune height of NAP +6 m for a 50 year lifetime. According to the Waterboard of Delfland (College van dijkgraaf en hoogheemraden, 2014), for a 200 year lifetime, this height should be increased by 1.8 m (getting to a design height of NAP +7.8 m). In figure B.1 the dune design height and zoning is illustrated.

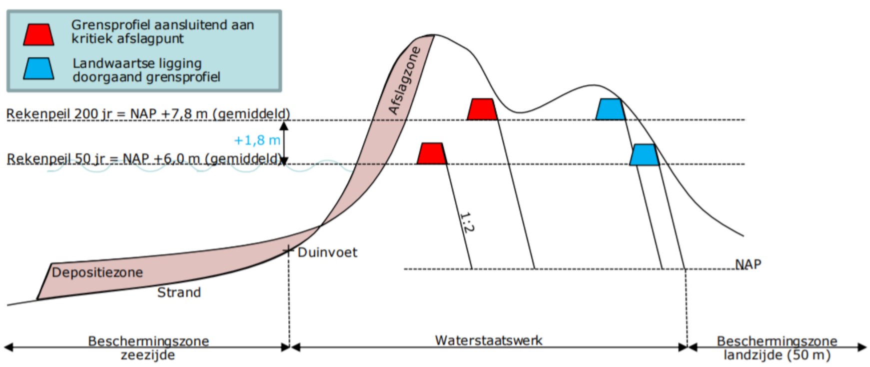


Figure B.1: Zoning of dune and definition of design height (College van dijkgraaf en hoogheemraden, 2014)

B.2 Historical evolution of the dune landscape

The coastal morphology in the dry areas on the landward side are characterized by dune systems. In the coast of Defland, two types of dunes can be identified clearly. First, old dunes formed 4000 BC are fixed and stable formations, relatively low (below 10 m high), and covered by a dense vegetation that resulted after thousands of years of development of root structures and plant diversity. However, after the sea level started rise again around 500 BC, river outflow and sea breakthrough started to erode (partially) these formations. As a consequence, large old dunes areas are only found several kilometers away from the coast of Delfland. A special case of a remaining old dune formation is the Natura 2000 Solleveld & Kapittelduinen, near the southern edge of The Hague boundaries. The area is not very relief-rich and consists of dunes, dune forests, grasslands, struwels, roughs and puddles. On the inner dune edge are a number of old estate forests with a rich stinzeflora (B.V., 2018).

Secondly, young dunes formed 1200-1600 AD on top of the remaining old dunes after large amounts of sand were released to erosion processes as described above. The available sand is used by the wave forcing to shape all kind of 3 dimensional features along the coast. The surf waves throw the sand up onto the beach during flood tide, and during low tide the wind dry up the sand and if wind speed is sufficiently large (from 5 m/s) it moves it further inland. As a consequence, banks can develop, and pioneer plants like marram grass serve as a barrier for the sand transport, resulting in dune development on top of the banks. As a consequence, the coast of Defland is widely dominated by younger rich-relief dunes, which can elevate up to 30 m high. This is the case of Westduinpark, Oostduinen, and the original land where the Municipality of Den Haag is located. As this formations are close to the sea, subject to changing conditions of waves and wind, it is a very dynamic environment with large gradients. As a result, only a few species of vegetation can survive under such conditions, for instance sand oats and blue sea thistle (Deltawerken, 2004).

B.3 Recent history of the coastal zone evolution - Underlying concepts behind Ronald Waterman's work

The young dune system covers almost the entire area of study, and are present mostly in from Oostduinen to Westduinpark (see figure B.2). From the general pattern of dune ridges it can be observed that they oriented according to the South-South West dominant wind direction, and the extensions of historical dune ridges can still be recognized in the basic street pattern of The Hague (R. E. Waterman et al., 1998).

On the other hand, the coastline orientation is the result of wave and water level action, accompanied by human interventions. The dominant wave conditions coming from the south-west with a relatively small height (below 2m) are the cause of a net longshore sediment transport from south to north. Episodic storm waves and surge events come from the north, which result in large sediment transport deeper in the seaward direction. During mild conditions, waves restore part of the sediment to the nearshore. The conjunction of sea level rise and losses to the deeper shore face results in a structural retreating behavior of the coast.

For the sake of simplicity, a starting point for human actions can be set around the 17th century, when the first large interventions took place to prevent coastal erosion. Strengthening the coastline locally with seawalls, breakwaters, and wooden or rubble mount groynes was carried out between Hook van Holland and Scheveningen north. These, however, did not prove to be a sustainable solution, and coastal recession persisted (Stive et al., 2013) as a result of sediment losses due to rip currents. A proof of this fact is found when comparing against the coastline of the area north of Scheveningen, where no strengthening of the coast was developed. As conclude from the work by (R. Waterman, 2010), despite being subjected to the same wave and surge forcing during the last 300 years, this stretch of coast has remained relatively stable. On the contrary, the southern stretch has retreated in the other of 1 to 5 kilometers since year 1611 (see also figure B.2).

The strategy started to change in the 20th century by the application of sand nourishment, both in the beach and in the shoreface. It was not until the 1990s that the method became a governmental issue in the Netherlands, and as a result groynes were almost entirely covered with sand, the coastline shift seawards until the year 1990 position, and dune profiles were heightened. In the case of the Scheveningen coast, also the 'mega noursihment' concept was applied in what is called the 'Zand Motor' located south of the Municipality boundaries, a project that was completed by 2011.

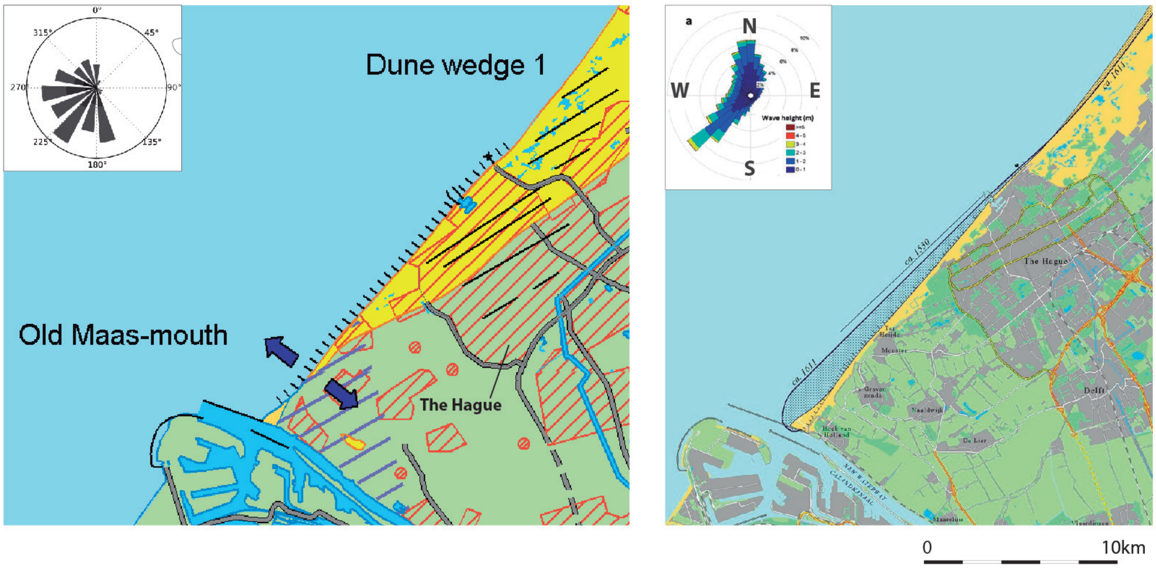


Figure B.2: LEFT: The wind rose in the upper-left shows the predominant wind direction is from the South-west. The dune orientation, represented by orange lines, gives insight on how this force of nature drives a dune wedges landscape. The grey line represent the Municipality of The Hague boundaries. RIGHT: The wave rose in the upper-left shows the dominant wave direction follows the dominant wind. These waves have a lower height than the ones coming from the north, which occur less frequently (during storm conditions). The black line shows the coastline position in the year 1611. The current coastline is located around 4Km landwards of the 1611 coastline near Hook van Holland (river mouth), and it has been maintained stable near Oostduinen (north of The Hague). Source: (R. Waterman, 2010)

B.4 Ecosystem services in young dunes systems

All small dunes eventually form a closed dune row. When they are large enough to form an elongated dune ridge with high plains, dune rows can offer important ecosystem services. The most important one is safety, as the sea strip can become a strong seawall to function as a dam against storm flood. A particular morphological feature called primary dune valley develops when a sea strip settles a little further away from an existing one. As a result, sea water trapped between both sea strips may become fresh, and eventually a layer of peat or clay will originate ((Deltawerken, 2004)).

Dune valleys host a fauna and flora biodiversity. An important function in young dunes is the storage of freshwater originated by rainfalls. In Delfland, the society has largely seized this possibility of fresh and brackish water supply in Oostduinen.

Appendix C

Nourishment plan

Since 2017 the BKL of Scheveningen and surrounding area is moved seawards by 30 to 130 m. This is in line with the commitment made by the Minister of Infrastructure and the Environment (IenM) in 2013 to change several BKL of coastal sections that were too much landwards (not safe enough) or seawards (not fulfilling its function of efficient alarm threshold) (Hallie, 2017).

According to the latest Rijkswaterstaat report on coastline nourishment, the Delftland coastline is healthy and does not show a relatively strong erosion pattern as can be seen in the picture below.

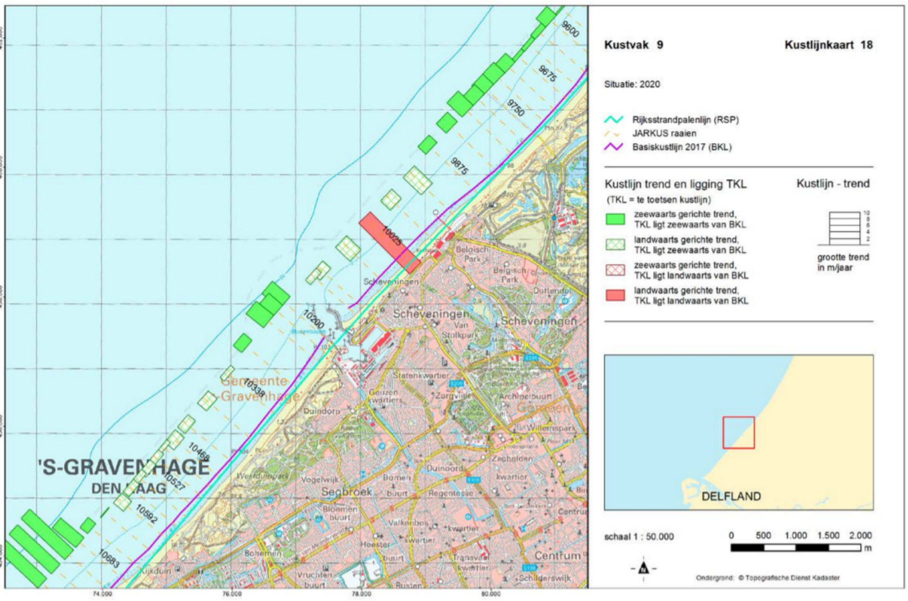


Figure C.1: Result of 2020 JARKUS survey (Rijkswaterstaat, 2020)

Here it is possible to identify an overall sea ward coastline trend, except for section 10025 in the middle of the Scheveningen beach (between the port entrance and the pier). It was found that a retreat of 22 m was taking place. This big difference is probably due to the seaward move of BKL that took place there.

Figure C.2 shows the total amount of nourishments done in every coastal section of the Netherlands.

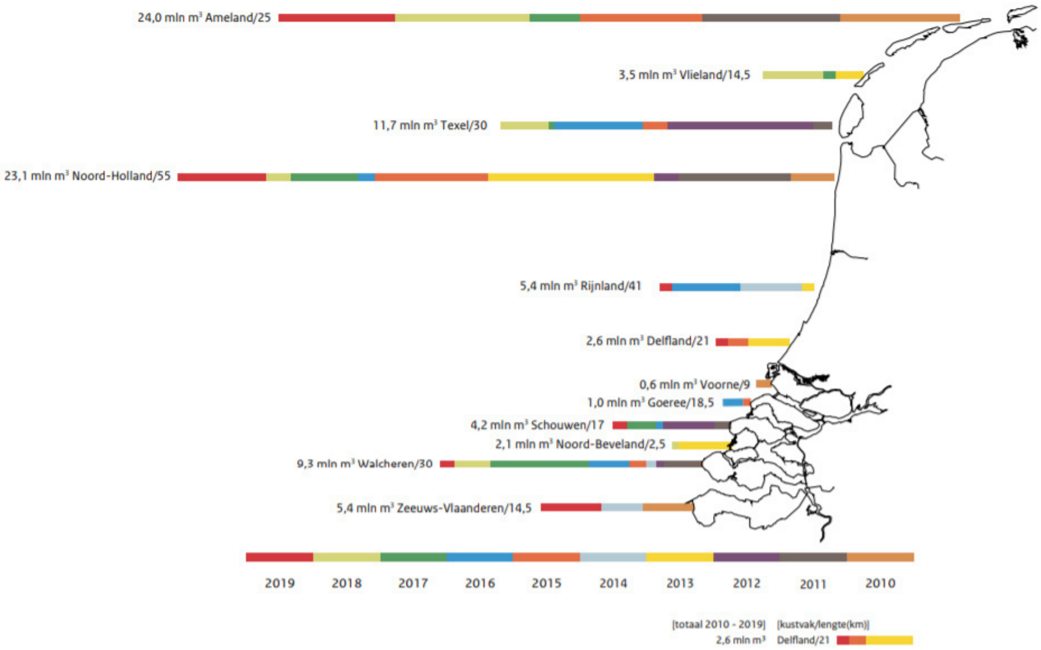


Figure C.2: Map with last 10 year nourishment volumes along the Dutch coast (Rijkswaterstaat, 2020)

As can be seen the Delfland coast needed in the past 10 years 2.6 million cubic meters of sand nourishments to be protected. This a relative small amount if compared to other coastal zones. According to this figure, approximately 125.000 m^3/km was needed in this area.

Appendix D

Future sand nourishment

As explained in subsection 3.3.6, nourishing the Dutch coast contributes greatly to protect the coast against flooding. But besides that, various other aspects play an important role and should be taken into account when considering nourishments as a coastal protection solution in the future. Such aspects can be the sand mining considerations, recreational uses, ecological impacts, and groundwater considerations(de Schipper, 2020). All aspects are elaborated in the following.

Sand mining

With SLR, the volume of sand needed to protect the Dutch coast will increase. Using a simple calculation based on a total Dutch coastal nourishment area of 4,000 km2 and assuming that sea bed has to grow with SLR (which is the current strategy of the Dutch government), the following volumes are calculated (Deltares, 2018b):

Table D.1: Future nourishment volumes and costs for the Dutch coast for different SLR scenarios (Deltares, 2018b)

SLR [mm/year]	**Sand volume [mio $m^3/year$]**	**Nourishment costs [mio €]**
2	8	28-40
3	12	42-60
5	20	70-100
12.5	50	175-250
30	120	420-600
40	160	560-800
60	240	840-1200

The estimated costs (table D.1) might be larger. The costs are based on the construction costs for the sand engine (ca. € 3,50 per m^3) and the current costs for doing smaller noruishments along the Dutch coast (ca. € 5,00 per m^3). In the future, sand might have to be extracted further away or from larger depths, which can result in increased costs (Deltares, 2018b).

Not only more sand is needed in the future , also the availability of sand will become more difficult. There is a global shortage of sand due to high demand for concrete, land reclamation and coastal nourishments, which will increase the competition for sand. However, compared to other countries, the Netherlands have the advantage of having a shallow sandy North sea shelf in front of the coast with an ample sand supply. (de Schipper, 2020) But also this sand source has its limitations. First, not all sand in the North Sea is suitable for nourishments. Usually, sand with native properties is preferred. Coarser sand would increase the retention of the nourishment but may impact the ecology negatively. Finer sand can be advantageous for dune growth through wind-blown transport but it can also be easier washed away. Second, room occupation due to other functions such as wind farms (which number is expected to increase in the future), Natura2000 areas and pipelines, limit the available area for dredging activities.(Deltares, 2018b)

Currently, the reserved area for sand extraction for nourishments amounts 5,200 km^2 (white area, figure D.1). Taking into account existing or future use of space, there are three possible additional areas of another 5,200

km^2 each for sand extraction outside the current reservation area (different grey areas, figure D.1). (Deltares, 2018b) Assuming that dredging to a depth of 20 m is possible for all four possible sand extraction areas (figure D.1), this would result in a total sand volume of

$$4 * 5,200\ km^2 * 20\ m = 416,000\ mio\ m^3 \tag{D.1}$$

Looking at the most extreme scenario from table D.1 with 240 mio $m^3/year$, this sand volume would last for more than 1733 years. This calculation has to be considered with care and might be too optimistic, since it is not guaranteed that a dredging depth of 20 m is possible everywhere (sand properties might not be perfect, better dredging technology is needed). But it shows that despite the room occupation in the North sea, the demand for sand will most likely not become in problem the closer future.

Figure D.1: Possible additional areas for sand extraction outside the current reservation area, taking into account existing or future use of space. The transport costs, and thus the sand price, will increase with the distance from the sand extraction area to the coast.(Deltares, 2018b)

Recreational uses

When beach nourishments are executed, sand is often pumped on the beach and distributed by bulldozers. For safety reasons, the beach has to be closed for visitors. That decrease the recreational value of the beach for a certain period of time. (de Schipper, 2020)
At the moment, this only happens every few (4 to 5) years and is therefore not a problem. In case beach nourishments become more frequent due to accelerated SLR (e.g. 4 times a year), the recreational use of the

beaches might decrease.

Also the beach width plays an important role for beach visitors. When the beach becomes too wide, people who want to go for a swim have to walk much further, which might decrease the recreational value of the beach as well.

Ecological impacts

Sediment properties (texture, size, moisture, organic matter), topography (slope elevation, width relief), hydrodynamic forces (waves, currents, tides) and biological interactions (productivity, carbon subsidies and predation) shape the structure of an ecosystem.(de Schipper, 2020)

Beach species are adapted to high energy environments with rapidly changing conditions but that does not mean that they are resilient to habitat changes and physical forces caused by nourishments. During nourishment constructions, a loss of ecological features (reduction of number of species and individuals) can often be observed. Living beings are buried under the new sand layer or mechanically crushed by the used machines.(de Schipper, 2020)

Furthermore, water turbidity increased as a consequence of dredging and releasing sand, which can cause plumes that have a negative impact on corals or seagrass meadows. Additionally, the turbid water causes limited prey detection and clogging of feeding structures of filter feeders. Besides that, the altered cross shore profile after nourishing can be disadvantageous for nesting, spawning, foraging. (de Schipper, 2020)

The recovery times of different species in different environments vary widely. Hence, the design of nourishments and monitoring is important. A mega nourishment, such as the sand engine, slowly feed the adjacent coasts with sand and may thus minimize ecological harm. But it also buries organism under larger depths of sand, so that other nourishment designs such as mosaics or very thin sand layers might be a possibility to reduce mortality and therefore enhance the ecological value. (de Schipper, 2020)

Groundwater consideration

Accelerated sea level rise from 2050 in combination with storms can cause an increase in salt intrusion via rivers and groundwater salinization.(Deltares, 2018b) (de Schipper, 2020)

Beach nourishments increase the coastal elevation of beach and are therefore likely to reduce probability of land-surface inundation, infiltration of seawater and salinization. Additionally, nourishments increase the terrestrial extend of coast, which leads to an increased trapping of precipitation and thus, an enhanced groundwater recharge and increased freshwater resources. However, during storms beach and dunes absorb sea water, which can result in a groundwater bulge, that increases in magnitude with storm period. After a storm, the groundwater from under the dune exfiltrates onto the beach, which potentially enhances erosion or reduces onshore blowing sand, that could contribute to rebuild the dune. Furthermore, the groundwater bulge moves inland and may cause flooding in low lying areas behind dune. Therefore, the impact of noruishments on the groundwater is two sided. (de Schipper, 2020)

Summary

Aspects	Advantages	Disadvantages	Mitigation
Sand mining	-protection of coast against flooding -Netherlands have shallow sandy North Sea shelf in front of the coast with an ample sand supply -> no sand limitations in close future	-costs might increase in future (sand from further away and larger depths, global shortage of sand due to high demand for concrete, land reclamation and coastal nourishments, which will increase the competition for sand)	-development of new, sustainable dredging technologies -continuous dredging with robots and underwater pipeline
Recreational uses	-nourishments maintain beaches and avoid retreat of the coastline -> recreation possible with SLR	-during construction, beach is often closed for visitors -> decrease recreational value of the beach for a certain period (e.g. 4 times a year for accelerated SLR) -beaches may become too wide	-foreshore nourishment instead of beach nourishment -continuous dredging with robots and underwater pipeline -beach cars, beach lakes
Ecological impacts	-preservation of habitats when sea level is rising in a rather nature friendly way	-loss of ecological features during construction (buried under the new sand layer or mechanically crushed) -increased water turbidity -> negative impact on corals or seagrass meadows; limited prey detection and clogging of feeding structures of filter feeders -altered cross shore profile -> possible disadvantageous for nesting, spawning, foraging.	-ecological design of nourishments -monitoring
Groundwater considerations	-reduced probability of land-surface inundation, infiltration of seawater and salinization -increased trapping of precipitation -> enhanced groundwater recharge, increased freshwater resources	-groundwater bulges possible -> potentially enhanced erosion or reduced onshore blowing sand after storm; flooding of low-lying areas behind dune	

Figure D.2: Aspects of future sand nourishment

Appendix E

Port of Scheveningen

E.1 Flood safety

The primary defense of the Port of Scheveningen is safe for the boundary conditions associated with 50 year lifetime, but not for the 200 year lifetime (van Delfland, 2013). This can be concluded from figure E.1, because the ground level line (blue line) is lower than the required height of the water barrier for a 200 years scenario (green line).

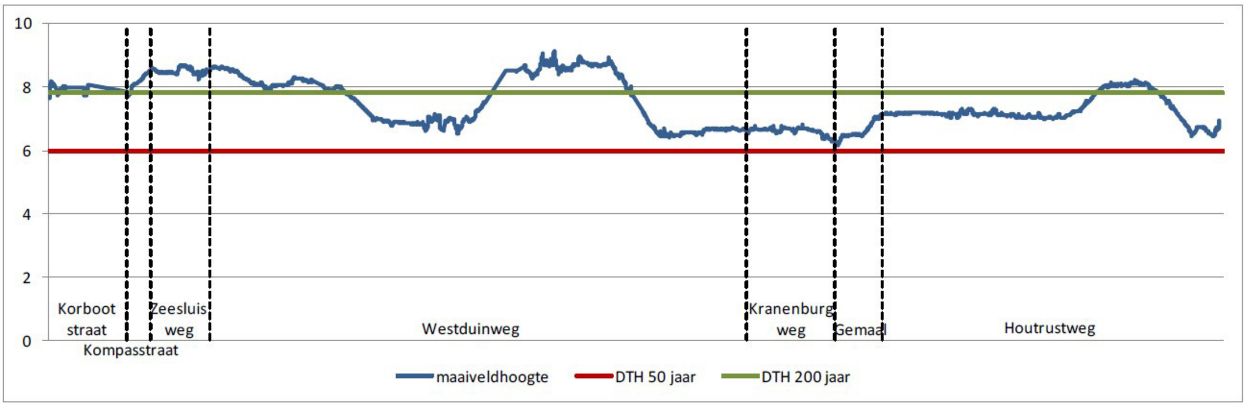


Figure E.1: Length profile with the minimum required height of the water barrier (50 year = red line and 200 years = green line) and ground level height = blue line. The vertical axis shows the elevation in meters, the horizontal axis indicated the location.

E.2 Port infrastructure

The Port of Scheveningen is located in a strategic position in the Dutch coast, with a direct, deep water access to the North Sea. The main services offered are related to local fishing industry, recreational, research vessels, and during the last years also the cruise ship industry. In addition, the port area is merged and strongly interconnected with the urban space with living and business areas.

The water infrastructure consist of four harbour basins: the First Harbour, Second Harbour, Third Harbour, and Front Harbour (Voorhaven). Just seaward of these basins the Outer Harbour is located, which has two different parts surrounded by the breakwater arms.

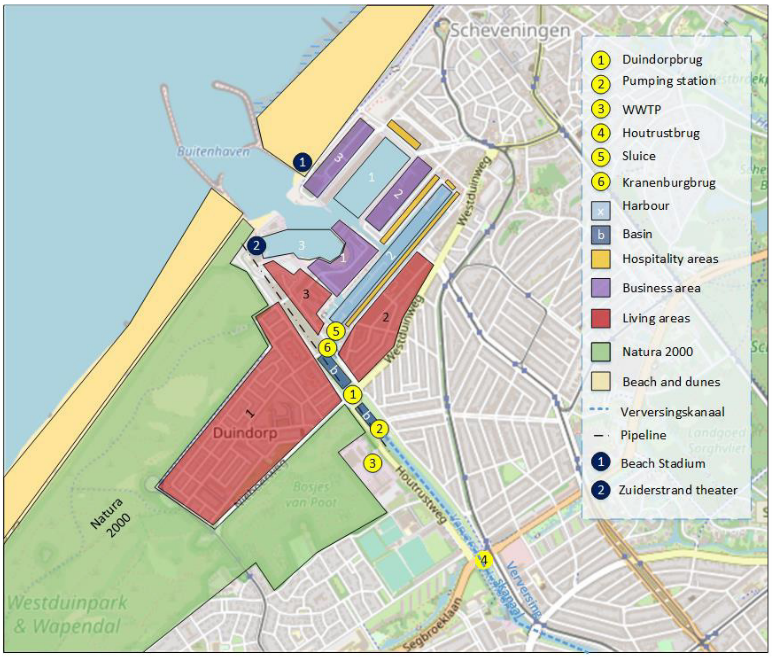


Figure E.2: Overview of the subareas in Scheveningen Harbour (Chotkan, S.A. et al., 2020). Source: OpenStreetMap contributors, 2017.

First Harbour: fisheries

The First Harbour is the oldest part of the Scheveningen harbour dating from 1904. It is mainly used for unloading fresh fish at the fish auction on the northern quay wall, and for (supply) and loading (export) of frozen fish on the opposite quay wall. There is also space for off-shore vessels, large commercial vessels, the towing services and the coast guard rescue services (KNRM). During the last years, the southern quay wall has also received small cruise ships up to 165 meters. The entire water basin is 400m long and 135m wide, and guarantees a maximum vessel draught of 7.5 meters (Municipality of Den Haag, 2015).

Second harbour: recreation

The construction of the second harbour started in 1923. It is connected to the rest of the water areas though a narrow channel called "De Pijp". This harbour started accommodating fishery, but since 1965 changed its function to tourist activities and recreational. The use of this harbour is very mixed. It has a marina in the southwestern half of the harbor basin, that also have a slipway for ship maintenance or repair. Along the eastern quay the sport fishing vessels and other vessels for tourist-recreational use dock, while along the peninsula quay between Second and First Harbor berth of a varying number of cutters (inshore fishing) and a museum ship is (Municipality of Den Haag, 2015). It is the largest basin in the port with a length of 800 meters and a width of 80 meters, although it is shallower than the rest of the water areas in the port (5-6m below MWL).

Third harbour: special vessels

Due to the upcoming transport ships, in 1973 a third harbour "3e Haven" was constructed to accommodate a Ro-Ro terminal for transport company Norfolk Line, together with an expansion of the breakwaters. In 2005, Norfolkline decided to leave Scheveningen, after which the dry areas were re-functionalized to storage, business, the Zuiderstrandtheather, parking, living areas, and a the seawater heat plant "Duindorp". The northern berth is used for the boats of Rijkswaterstaat, but it can also be used for commercial and research vessels, and is also suitable for larger sailing boats. Part of this harbour will be developed as a harbour for seagoing vessels. The third harbour basin dimensions are 100m per 120m and the water goes from 6m below MWL at the western quay wall to 7.5m below MWL at the boundary with the Front Harbour.

Front Harbour

The outer harbour is connected to other harbour basins on three sides: the Outer Harbour, the Third harbour Port and the First Port. On the fourth side there is a small sloping beach, containing a concrete ramp used for launching small boats into the water for recreational and professional purposes. During the last years, the Port has been accommodating small cruise vessels (120m) in the eastern berthing area (Adriaan Maaskade).

Outer Harbour
The outer harbour is divided in two parts. The landward part extends until the original harbour breakwaters, and has a length of 300m perpendicular to the shoreline. It lies between old, brick sheet piling structures. The seaward par extends around 350m from the old heads until the tip of the new breakwater arms. The armour of the new structure is built with irregularly placed concrete cubes.

The access channel extends from the offshore end of the coastal shoreface, at a water depth of around 8.5m below MSL, until the entrance of the Front Harbour with a water depth of 8m below MSL (values obtained from (Navionics S.r.l. or its subsidiaries, n.d.)). The width in the offshore part is 110m, decreasing down to 75m in the part between the old breakwater heads and the Front Harbour.

Appendix F

Morales Boulevard

F.1 Background of Morales Boulevard

In 2001, the municipality of The Hague formulated their ambition to upgrade the boulevard of Scheveningen and assigned internationally well-known Spanish architect Manuel Sola de Morales. The municipality of The Hague lacked the financial means to carry out his vision so the plan came to rest. In 2003, the Dutch government defined 14 weak links in the Dutch coastal defence system, that had to be upgraded before the end of 2015 with founds of the Dutch government. One of them was the area between the Kurhaus and the port of Scheveningen (figure F.1). (Hoogeveen & Veenswijk, 2016)

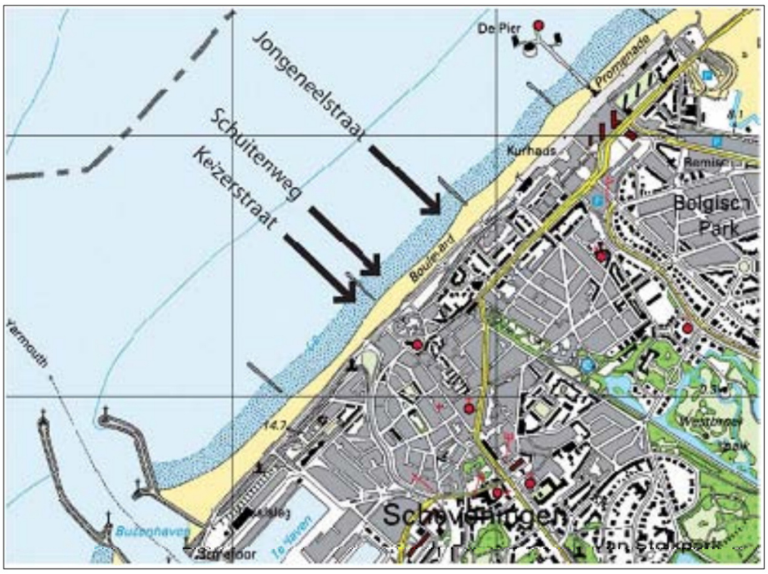


Figure F.1: Map of the coastal area of Scheveningen with indication of the locations of the weak link in the coastal defence system

To improve the coastal defence in that area, the existing boulevard had to be demolished and rebuild after strengthening the sea defence. The city of The Hague saw this as an opportunity to realize their vision to build an entire new, attractive boulevard. For this, Morales' plans came back on the table. (Hoogeveen & Veenswijk, 2016)

The main design phase of the structure took place between 2007 and 2009 (Oorschot, 2012). The most important task of the design was to solve the dilemma of a high flood defence structure that provides safety for the next 50-100 years against the vision of an attractive public space that attracts tourists (Amesz, 2020)

To enhance the attractiveness of the boulevard as public space even more, some other aspects were included in the design. The beach clubs were designed into clusters to provide a nice beach view in between. A colour concept with appealing blue colours for street furniture and art objects was created. Strips of native dune grass were included to connect the boulevard with the adjacent dunes. (Amesz, 2020) To increase the visual drama and merge the boulevard naturally into its surroundings, the shape of the boulevard is dominated by horizontal and vertical curves following the original undulating course of the dunes which make visitor interested in what is over there or what is beyond that bend. To create a relaxing and safe environment, different height levels to separate a pedestrian area, a cycle path in both directions, a one-way street for cars were applied (Chu, 2013)(Sector, 2013)

The construction of the boulevard started in 2010. In 2013, the boulevard was opened with a big opening ceremony. The total costs for the boulevard including the sea dike were 75 million €. The boulevard finally connects the old seaside resort to the fishing village and the harbour and allows visitors to stroll between these areas. (Oorschot, 2012) Optimisations in the area of the Morales boulevard are still going on to make it more attractive. In 2018, for instance, the municipality of The Hague improved the beach access by building wide stairs with a ramp for prams, wheelchairs and benches in front of boulevard as part of 'De Kust Gezond' development program (Scheveninger, 2017).

F.2 Coastal protection function of Morales Boulevard

F.2.1 Design boundary conditions

The surcharge sea level rise describes the relative expected sea level rise, which means that also land subsidence is taking into account.

The surcharge 'dike ring approach' results from the fact that one dike ring consists of several elements in one line. Therefore, it can be considered as a series system with many single elements. If one element fails, the whole system fails. To take an increase in failure probability of such an series system into account, an extra 30 cm surcharge is included in the design to add some safety and compensate for the dike ring effect.

To account for a possibly higher water level in the future caused by tubular gusts and storm oscillations, a surcharge of 10 cm is used.

The offshore wave height is expected to increase by 5% compared to the present value for all future scenarios, which causes the wave period to increase by 2.5%. The consequences of an increased wave period were unknown during the planning of the sea dike, which was taken into account by adding extra safety to the dune erosion calculations to determine the sand nourishment volume.

The storm duration of 35 hours was assumed to be on the low side of the maximum storm duration for an extreme event. Coastal storms result from large scale pressure fields and might be up to 200 hours. Therefore, a sensitivity analysis was done for different storm durations. The storm duration is important since it influences the scour process in front of the hard structure. The longer the storm takes, the greater the size of the scour hole in front of the structure can become. After some time, the scour can lead to failure of the hard structure.

F.2.2 Coastal protection function of dike-in-boulevard

The boulevard has a length of 1.9 km. The hidden sea dike is 1 km long and located between Scheveningse Slag and the ream loop on the south side of Keizerstraat. The sea dike was needed in order to ensure safety at the three weak links identified by the national government. From a safety point of view, a continuous construction was preferred over local improvements at the three locations.

All the dike heights mentioned in subsection 3.2.4 are the installation heights, which 20 cm higher than the table heights to take settlement for a design period of 100 years into account.

Dike slope and revetment

At the land side of the dike, the ground level has the same height as the boulevard at almost all locations. Therefore, the inner slope is below ground level and no visual slope with a revetment exists. At some locations, the ground level behind the sea dike is lower. and a relatively short slope exists. In these cases, a slope of 1:3 is applied with the same revetment as at the sea side of the dike, that extends 1 m below ground level. The theoretical slope of the dike can not intersect with the foundations and cellars of the existing buildings. Using a maximum possible slope of 1:3 determines the minimum distance from the dike-in-boulevard construction to the buildings.

At the sea side of the sea dike, a revetment is applied to cover the slope and crest. The slope (1:3) and crest width (5.5 m) follow from a minimal profile principle, which allows the dike to be as small as possible. A bigger construction (e.g. flatter slope or applying a berm) would reduce the spatial quality of the area, which is tried to be avoided as much as possible. As revetment type, it is decided to use basalton, which provides visual attractiveness of the boulevard (spatial integration). At locations, where the height revetment coincided with the surface height of the boulevard, the boulevard material is used.

Having the dike height set based on the desire for spatial quality, with the maximum overtopping flow rate being set at 1.0 l/s/s, the maximum allowable wave height H_s at the toe of the structure was calculated.

The maximum allowable wave height H_s determines the dimensioning of the revetment and the amount of sand to be applied. For a more extreme climate scenario, the allowable wave height is smaller, since the design water level is higher. Hence, more sand has to be applied for a more extreme climate scenario in order to create a wider beach that breaks the waves more efficiently. Therefore, the maximum allowable wave height, for which the strength of the revetment is planned, results from the 50-year medium climate scenario with NAP + 5.9 m. For a slope of 1:3, a crest width of 5.5 m and a basalton revetment, the calculated wave height at the toe of the structure is $H_s = 1.38$ m.

Beside basalton, other revetment types such as one and two layer quarry stone were considered. For these revetment types, the maximum allowable wave heights at the toe of the structure were higher, which results in a smaller requires sand nourishment volume.

Toe

The toe of the structure is assumed to be free of settlement, so the toe is at NAP +2.0 m at the sea side of the dike. The width of the toe is 2.5 m to prevent sliding of the stone revetment. The concrete sheet piling at the toe reaches up to NAP 0 metres.

Design principles

Under design storm conditions, the boulevard is designed in such a way that it can be fully damaged. Only the sea dike has to remain in order to protect the hinterland. Therefore, during a wave attack, all objects in front of or on top of the flood defence must fall apart in order to prevent damage to the flood defence.

Northern and Southern connection

At the southern and northern end of the sea dike, diaphragm walls are used as a connection with the existing coastal protection measures. They prevent lagging (water behind dike-in-boulevard).

The diaphragm walls are considered to be free of subsidence. The top of the diaphragm walls is graduated. To the north from NAP +10.1, to NAP +10.0, to NAP +9.5 and NAP +9.0. metres and in the south of NAP +10.1, to NAP +10.0 and NAP +9.0 metres.

F.2.3 Coastal protection function of sand nourishment

Dimensions of the sand nourishment

To increase the sand volume in front of the Morales Boulevard as part of the hybrid coastal defence solution, sand was pumped from offshore into a trailing suction hopper dredger (TSHD), which than sailed closer to the shore from where the sand was pumped via pipelines towards the beach. At the beach, bulldozers distributed the sand to the final locations.Between Scheveningseslag and the tram loop (Tramlus, figure 3.3), part of the nourishment was used to build a sand bank against the boulevard with a height of NAP + 4.5 m and a width of 75 m. The beach pavilions are placed on top of this.

The volume of the initial nourishment follows from the maximum allowable wave height at the toe of the dike and was calculated with computer models. It was determined that for the 50-year medium climate scenario, at Keizerstraat a volume of 793 m^3/m and at Jongeneelstraat a volume of 495 m^3/m was needed (table F.1). To create a responsible morphological whole, it was decided to also nourish the part in between the two locations with an average volume of 644 m^3/m.

Table F.1: Beach nourishment

RSP [km]	Safety volume $[m^2/m]$	Maintenance volume $[m^2/m]$	Widening of beach $[m]$	Beach elevation $[m]$
99.00	0	384	35	0.7
99.25 (the Pier)	0	384	35	0.7
99.50	248	384	50	1.3
99.75 to 100.10 (Jongeneelstraat)	495	384	70	1.6
100.2 to 100.40 (Seinpostduin)	644	384	80	1.9
100.4 to 100.75 (Keizerstraat)	793	384	90	2.1
101.00	397	384	60	1.5
101.25 (Visserhavenweg)	0	384	35	0.7
101.50	0	384	35	0.7

The maintenance nourishment volume before the construction of the Morales boulevard to compensate for erosion was about 200,000 $m^3/year$ for the coastal stretch between Scheveningen harbour and Kurhaus.Due to the seaward shift of the coastline as a consequence of the initial nourishment, an increase of the nourishment volume of 20% is assumed. The strategy of the Dutch government is to not nourish the coast every year but in a period of about four years. Therefore, after four years, the total maintenance nourishment volume is about 960,000 m^3/m. Placed over a coastline of 2.5 km this results in 384 m^3/m every four years.

Future sand nourishment

The beach will gradually increase in the coming period.

Table F.2: Beach nourishment 50-year scenarios

	50-year medium climate scenario		50-year maximum climate scenario	
	Jongeneelstraat	**Keizerstraat**	**Jongeneelstraat**	**Keizerstraat**
Safety volume m^3/m	495	793	1,275	1,511
Maintenance volume m^3/m	384	384	384	382
Height increase m	1.6	2.1	2.9	3.3
Width increase m	70	90	120	140

Table F.3: Beach nourishment 100-year scenarios

	100-year medium climate scenario		100-year maximum climate scenario	
	Jongeneelstraat	**Keizerstraat**	**Jongeneelstraat**	**Keizerstraat**
Safety volume m^3/m	738	960	ca. 2,000	ca. 2,100
Maintenance volume m^3/m	384	384	384	382
Height increase m	1.9	2.4	4.0	4.0
Width increase m	80	100	160	160

F.2.4 Robust and durable future design

A robust and durable design takes future developments and uncertainties into account. That was done for the Morales Boulevard by considering a maximum climate scenario in 200 years with a maximum design water level of NAP + 7.7 m (using the values from table 3.1 with SLR 1.7 m instead of 0.85 m). A possible solution for this scenario would be to raise the dike table height to NAP + 12.0 m (installation height NAP + 12.4 m taking 0.4 m settlement into account) everywhere and to increase the sand volume in front of the dike. Raising the dike height means that more space for the structure either in seaward or landward direction (figures 3.4 and F.2) is required and that the sea view from behind the dike is restricted.

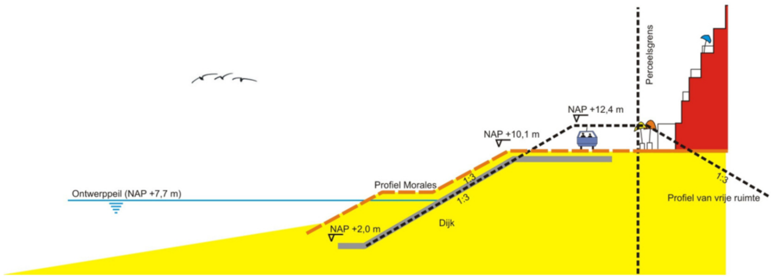


Figure F.2: Possible future extension of dike-in-boulevard structure in landward direction for design boundary conditions in 200 years with max. climate scenario.

The required land, which is needed for the reinforcement for a 200-year maximum scenario, is owned by either the water boards, the national government or the municipality of The Hague.

Appendix G

Design Boundary conditions of dike-in-boulevard

Tom Wilms <tom.wilms@witteveenbos.com> 20 Nov 2020, 14:08

to me

Dear Charlotte, Sebastian, Jan, Anastasia and Lefketi,

At the municipality of The Hague you can ask for the final report for the design of the dike including appendices. The document code is GV892-1_094, according to the filing system at Witteveen+Bos.

The design fulfills the safety standard for the probability of exceedance of 1/10,000 years.
The division of the dike sections is:

dijkvaknummer	RSP (van ... – tot ...) [km]	kruinhoogte [m + NAP]	dijktafelhoogte[1] [m + NAP]
dijkvak 1	99,85 – 100,00	10,10	9,90
dijkvak 2	100,00 – 100,35	12,00	9,90
dijkvak 3	100,35 – 100,45	8,60	8,40
dijkvak 4	100,45 – 100,70	10,10	9,90

1) Conform het verbeteringsplan [ref. 1.].

dijkvaknummer	RSP (van ... – tot ...) [km]	teenhoogte [m + NAP]	kruinhoogte [m + NAP]	talud helling [-]	bekleding [-]
dijkvak 1	99,85 – 100,00	1,50	10,10	1:3	betonzuilen
dijkvak 2	100,00 – 100,35	1,50	12,00	1:3	betonzuilen
dijkvak 3	100,35 – 100,45	1,50	8,60	1:3	betonzuilen / asfalt (kruin)
dijkvak 4	100,45 – 100,70	1,50	10,10	1:3	betonzuilen / asfalt (kruin)

The hydraulic boundary conditions are stated below. They are at RSP 100.65 and the Hoogheemraadschap van Delfland stated it is applicable for the entire dike. These conditions are nearshore:

parameter	waarde
significante golfhoogte, H_s	1,38 m
piek golfperiode, T_p	14,3 s
spectrale golfperiode, $T_{m-1,0}$	13,0 s
ontwerppeil	NAP +5,8 m (exclusief buioscillatie van 0,10 m)

Wave overtopping is 1 l/s/m and for the 50 year midden klimaat scenario.
The storm duration I could not find. We used the values as stated in the standard design manuals at that time.

Does this information help you?
When you need more information, please contact me.

Best regards, Tom

Figure G.1: Design Boundary conditions of dike-in-boulevard from final report of Witteveen + Bos as response to our email. We asked for them to compare them to the design conditions from the preliminary report from Arcadis. They turned out to be the same.

Appendix H

Environmental Conditions at Scheveningen

This appendix shows figures of the current tidal, wind and wave conditions close to the project area in Scheveningen.

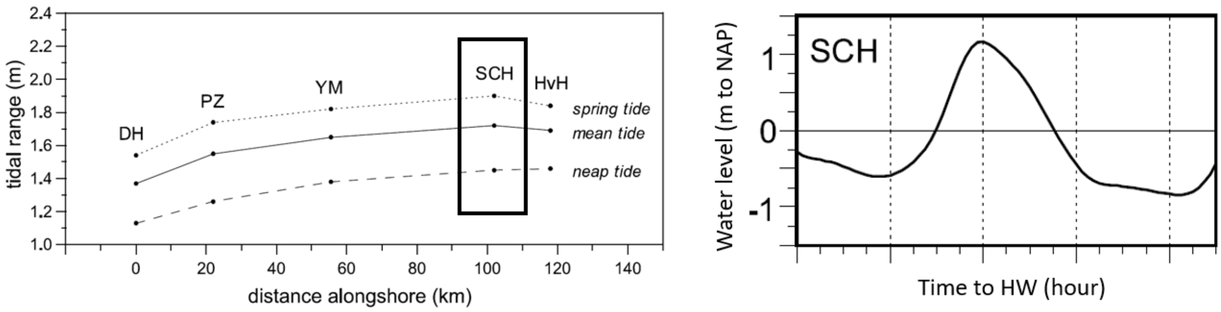


Figure H.1: Tide along the Holland coast with focus on Scheveningen (Wijnberg, 2002)

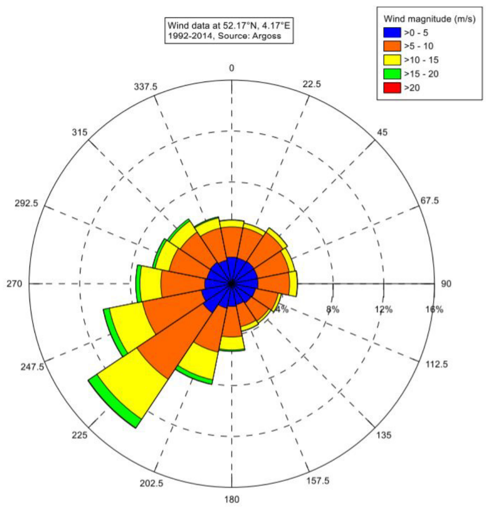
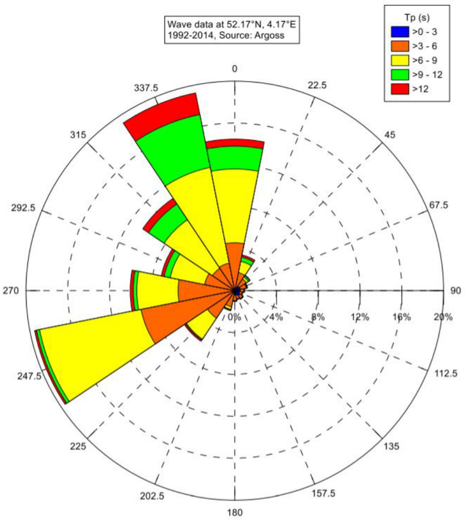
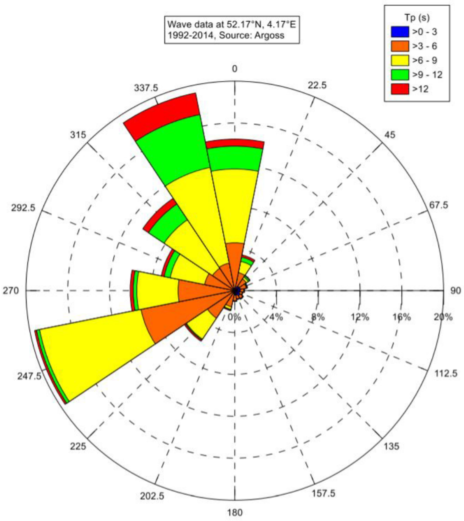


Figure H.2: Offshore wind rose at 52.17°N, 4.17°E, from 1992 to 2014 (Arrieta et al., 2016). The predominant wind direction in the area of Scheveningen is south to south west.



(a) Significant wave height



(b) Peak wave period

Figure H.3: Offshore wave rose at 52.17°N, 4.17°E, from 1992 to 2014 (Arrieta et al., 2016). The dominant wave conditions come from the south-west with a relatively small height (mean wave height H_{m0} between 1.5 and 0.8 m). The significant wave period (T_s) at Scheveningen is between 5.4 s and 7.8 seconds (Wijnberg, 2002). Episodic storm waves and surge events come from the north. The waves are higher and have longer peak periods.

Appendix I

Climate scenarios for the Dutch Coast

The likely changes in the climate conditions have always certain level of uncertainty. For The Netherlands, the guide provided by the Koninklijk Nederlands Meteorologish Instituut (KNMI, 2015) offers the opportunity to evaluate changes in the climate according to the newest insights, based on the continuous updates from the Intergovernmental Panel on Climate Change (IPCC). The current governmental strategies to combat climate change are based on the KNMI'14 scenarios, as the latest update of this guideline. Moreover, they have an official status since they were integrated with socio-economic scenarios in the 'Delta Scenarios' used for the Dutch Delta Program (Ministerie van Infrastructuur en Waterstaat, 2020). This section walks through the future environmental conditions that characterize the climate in The Netherlands during the time span of this project.

I.1 KNMI'14 scenarios

The KNMI'14 climate scenarios are defined by four combinations of two possible values for the global temperature increase, 'Moderate or G' and 'Warm or W'. In addition, two possible changes in the air circulation pattern, 'Low value or L' and 'High value or H' (see Figure I.1). In the H scenarios more frequent westerly winds occur in winter. This leads to mild and more humid weather compared to the L scenarios. In summer, high-pressure systems have a greater influence on the weather in the H scenarios. Compared to the L scenarios these high pressure systems cause more easterly winds, which implies warmer and drier weather for the Netherlands ((KNMI, 2015)).

Finally, there are two different time horizons for which the possible values are defined: around 2050 and around 2085, relative to the reference period of 1981-2010.

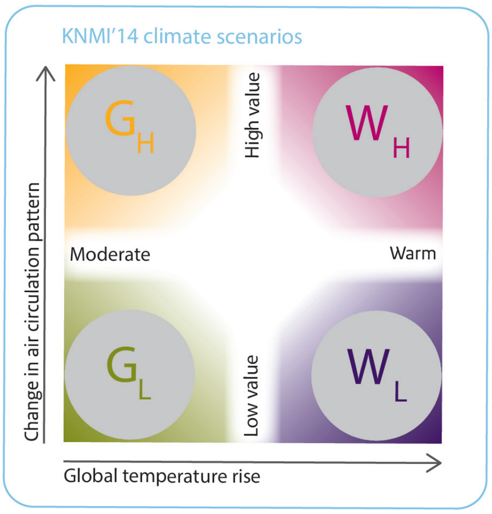


Figure I.1: KNMI'14 scenarios (KNMI, 2015). The capital letter indicates de increase in temperature (G to W). The second smaller letter indiactes the increase in change of the air circulation patter (L to H).

I.2 Delta Scenarios

In total, four scenarios are proposed by the Delta Program, which represent lower and upper values, related to a 2°C and 4°C global temperature increase in 2050 and 2100. In addition, two possible socio-economic scenarios are presented. As a result of the assessment of KNMI'14 scenarios, values of the key climate parameters for the NL are obtained for each Delta Scenario (Deltares, 2018a). For "Rest" and "Busy", KNMI'14 GL is used. For "Steam" and "Warm", KNMI'14 WH is used. In other words, for Delta Scenarios only the lower and upper KNMI'14 boundaries are used to define climate conditions (figure I.2).

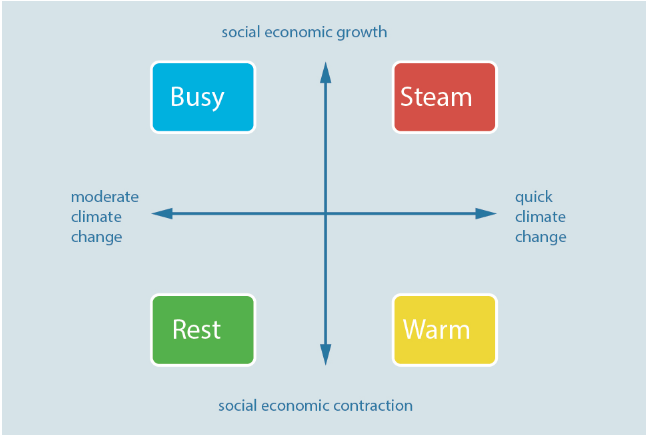


Figure I.2: Delta scenario scheme (adapted from (Deltares, 2018a)). BUSY ("Druk") is the result of moderate climate change and strong growth of economy and population. STEAM ("Stoom") is the result of rapid climate change and strong growth of economy and population. REST ("Rust") is the result of moderate climate change and low growth of economy and population. Finally, WARM is the result of rapid climate change and low growth of economy and population.

I.3 Temperature

Results from (KNMI, 2015) show the mean winter temperature can increase from 3.4°C (reference period) up to an uncertain value between 4.5°C and 6.1°C by 2050, and this range diverges up to 3.6-7.5°C by 2085. On the other hand, mean summer temperature can increase from 17°C up to 18-19.3°C by 2050, and up to 18.2-20.7°C by 2085. In both cases, the temperature keeps growing towards 2100 (figure I.3).

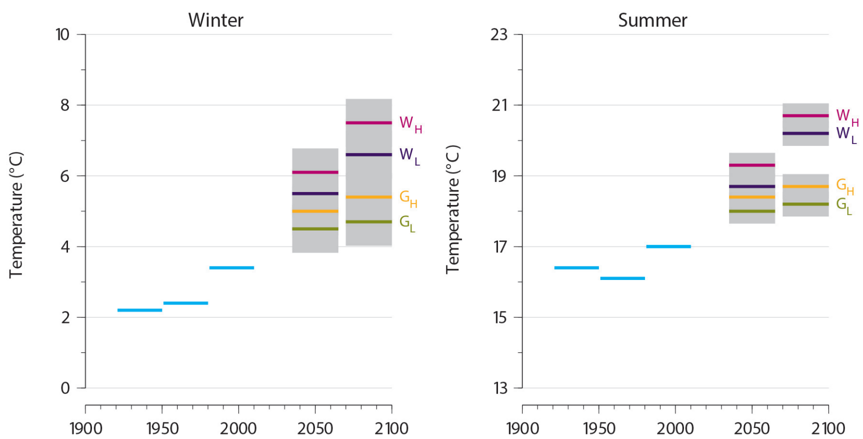


Figure I.3: Winter and summer temperature in De Bilt (Netherlands): observations (three 30-year averages, in blue), KNMI'14 scenarios (2050 and 2085, in four colours) and natural variations (in grey). These are natural variations for 30-year averages ((KNMI, 2015))

Appendix J

Boundary conditions for the Scheveningen area

J.1 Boundary conditions for Dunes

In this case, HR2006 defines a level of NAP +5.7 m for the 1 in 10,000 year design water level. On top of it, two surcharges are applied: length effect compensation takes into account the increase in the probability of failure of a dike ring if there are several relatively weak spots present. Secondly, a 0.1 m surcharge to consider storm oscillations in a time scale of 10 seconds that cause temporary raising in the water level. The former two assumptions are obtained from the Engineeering design of the Scheveningen wall for the Morales Boulevard (see also (Onderwater, 2008)).

With respect to the wave climate, the northern dune system Oostduinen (Jarkus raai 9750-9875) is associated with a wave height of 8.35 m and a peak period of 13.9 sec. It varies linearly until the southern edge of the domain in Solleveld-Kijkduin (Jarkus raai 10773), where wave height is 8.05 m and the period is 13.2 sec (table J.1).

Boundary Condition	Value
Design water level (HR2006)	NAP +5.70 m
Length effect	+ 0.30 m
Localize storm surges	+ 0.10 m
Calculation water level for year 0	**NAP +6.1 m**
Wave height	8.35 m (North of Port of Sch.) to 8.05 m (South of Port of Sch.)
Wave period	13.9 sec (North of Port of Sch.) to 13.2 sec (South of Port of Sch.)

Table J.1: Boundary conditions for Dune systems in Delfland coast. It includes the dynamic dunes systems of Oostduinen, Westduinpark, and Solleveld-Kijkduin. Also, the fixed dune systems in Scheveningen northern boulevard and the Kijkduin boulevard.

J.2 Boundary conditions for hard structures

In the case of boundary conditions for the Dike-in boulevard, the reader can refer to section 3.2.4, which are based on the design calculations documents for the Morales Boulevard Project (Onderwater, 2008).

For the protection system around the Port of Scheveningen the baseline is built from the value NAP +5.20 m associated with the 1 in 10,000 year storm water level. The over-topping requirement results in 0.30 m (van Delfland, 2013), together with additional local surcharges of 0.20 m. At the inner water areas of the port, waves hardly play a significant role (van Delfland, 2013); the significant wave height varies between 0.31 m and 0.48 m. In contrast, outside the breakwaters the calculations values are 5.85 m for the wave height and 11.5 sec for the peak wave period, but these conditions are not applicable to the paved dike surrounding the port.

Boundary Condition	Value
Design water level (HR2006)	NAP +5.20 m
Local surchages	+ 0.20 m
Overtopping requirment 0.1 l/m/s	+ 0.30 m
Calculation water level for year 0	**NAP +5.7 m**
Wave height	0.31 - 0.48 m

Table J.2: Boundary conditions for paved dikes. The most relevant structure of this type is the high ground surrounding the Port of Scheveningen.

Appendix K

Interviews

In this chapter the interviews conducted with some of the stakeholders are provided. The stakeholders are Mr. Jack Amesz on behalf the Municipality, Mr. Cees Duvekot on behalf of Scheveningen Port and a specially organized series of interviews for the rest of the stakeholders' point of view, conducted with Mr. Jack Amesz. Last but not least, the group's discussion with Mr. Ronald Waterman was perceived as an open interview that led to useful knowledge and in depth understanding of the advance strategies.

K.1 Municipality of The Hague

Jack Amesz, 07/12/2020

Mr. Amesz was one of the project's advisors and was present in its total. As a result, he was well informed about the object of study, the methodology and the strategies followed. The present interview is the formal structured interview conducted via email.

General questions

Question: What is the biggest challenge you can identify in our project?
Answer: By exceeding SLR expectations maintaining the combination of resilient coastal defense and public/urban space and an unobstructed view at sea.

Question: Could you prioritize the following: safety, economic development, protection of the environment, tourism, recreation, port development.
Answer: Safety, tourism/recreation, protection environment, economic development, port.

Question: What do you think could go wrong with this project?
Answer: The project solution is a true balance between (I) people, planet, profit and (II) content/process/network & relations & organizations and it goes wrong not finding this balance.

Question: What historic issues exist related to the project, the stakeholders and the location?
Answer: (1) Own identity of Scheveningen and to be respected, (2) on- and off development port fishing, housing, industry, sports, marina, cruise, (3) on- and off development Pier.

Stakeholders

Question: Is the municipality responsible for the Westduin park?
Answer: Yes, within regional (Province), national and EU regulations and coastal defense (Delfland).

Question: How would you feel about a collaboration of the municipality with local residents and business owners?
Answer: Essential and for us not always easy; preference and opinion of residents and business owners may vary quite a bit; secondly, interaction quite often including media debate.

Question: From 1 to 10 how powerful would you say Dunea is?
Answer: Depending on role: in general, responsible for drinking water, extremely 9-10 (in Holland, a national pride issue: 'we can drink from the tap'); nature (Meijendel): strong position 7-8; as a cable owner in the city, one amongst many 4-5.

Question: From 1 to 10 how powerful would you say the Metropolitan area of Rotterdam Den Haag (MRDH) is? Are the transportation companies totally managed by the MRDH?
Answer: MRDH is only responsible for regional mobility and general economic development; for public transport grantor towards HTM for instance; say 5. Much more influence by the region (Province) and municipalities.

Question: Are there any interest conflicts between the governmental bodies?
Answer: Not that I know off, however, there are quite a few conflicting interests

Question: What is the procedure of acknowledging the process to the public?
Answer: This question needs a bit of clarification first.

K.2 Stakeholders

Jack Amesz, 30/12/2020

This is a special series of interviews, aiming at understanding the preferences and point of views of various stakeholders. The questions are designed for the Amrath Kurhaus, the Business owners of the Morales and the Northern Boulevards, the local residents, the fishing industry, the Waterboard, the Rijkswaterstaat and the Nature organisations, and were answered by Mr. Amesz on behalf of them.

K.2.1 Amrath Kurhaus, Business owners of the Morales and the Northern boulevard:

Grade the following aspects (using a X in the respective cell)

Not at all	-4	-3	-2	-1	0	1	2	3	4	Totally
How safe do you feel with the existing situation? (in terms of water safety)										
(Kurhaus)								x		
(Businesses)						x				
How important is the seaview for the hotel/business?										
(Kurhaus)									x	
(Businesses)									x	
How would you feel if the seaview is lost but the hotel/business will remain in front of the beach										
(Kurhaus)					x					
(Businesses)		x								

Preserve Strategy:
Question: How would you feel if the beach is a) 200m, b) 500m, c) 1000m wider than that it is now?
Answer: 200 m would be more or less okay; 500- 1000 m would be too much and a too great distance to the

water.

Question: How does that affect your business?
Answer: Difficult question; a lot will stay probably the same; a part of the guests would bring their own drinks to the beach if they want to stay close to the water/sea.

Advance Strategy:
Question: What is your opinion on having initially the sand engine and then the thematic lakes constructed in front of the north beach?
Answer: Interesting solution, keeping in mind the experience at the existing sand engine; interesting for surfers etc, maybe a bit dangerous for swimming, however, lively coast/beach conditions, including water nearby (lakes).

Question: Would the business owners like the idea of having extra temporary structures on the new coastline, in front of the dune system?
Answer: If this is hazardous for swimming better not.

Both strategies:
Question: Which one would you prefer and why?
Answer: With a beach width of about 250 m maximum, the preserve option, next the advance strategy.

K.2.2 Local Residents:

Grade the following aspects (using a X in the respective cell)

Not at all	-4	-3	-2	-1	0	1	2	3	4	Totally
How safe do you feel with the existing situation? (in terms of water safety)								x		
How important is the seaview for you?								x		
How would you feel if the seaview is lost?		x								
Do you agree with the increasing tourism in the area?			x							
How bonded do you feel with the port and its history?					x					
How much would you agree with the option to close the port?			x							

Preserve Strategy:
Question: How would you feel if the beach is a) 200m, b) 500m, c) 1000m wider than that it is now?
Answer: A wider beach is fine, especially when it helps to remain an open view at sea, including a sunset. And more space on the beach in general is also fine.

Question: How does that affect your activities?
Answer: Not really.

Question: In a very high level of SLR would you compromise the sea view for safety?
Answer: Yes. However, a discussion will follow on urgency and proposed solutions.

Advance Strategy:
Question: What is your opinion on having initially the sand engine and then the thematic lakes constructed in front of the north beach?
Answer: A dynamic and uncertain situation might be unfavourable and dangerous. And short construction periods are better.

Question: Would you like the idea of having extra temporary structures on the new coastline, in front of the dune system and around the lakes?
Answer: A more natural looking situation is favourable.

Question: Would you agree with the idea of constructing the barrier islands and the basin islands in the long-term to protect the south beach?
Answer: Long term will be hard to judge and depending on urgency.

Question: Will the new activities (bird watching, watersports, cafes etc) be appealing for you to visit the area?
Answer: In principle yes, and also interesting to have more choice in activities, including all four seasons.

Both strategies: Question: Which one would you prefer and why?
Answer: Hopefully SLR will be limited and the preserve strategy will do. No preference to have to think about more serious measures.

K.2.3 Fishing Industries:

Grade the following aspects (using a X in the respective cell)

Not at all	-4	-3	-2	-1	0	1	2	3	4	Totally
How safe do you feel with the existing situation? (in terms of water safety)							x			
Fishery cargo is unloaded to the port partly from vessels and partly from trucks. How important are the vessel-related operations compared to whole fishery activity in the port?					x					
Assuming all land fishery operations in the port are maintained (truck unloading, processing, transfer shed, auction hall, etc.) would you agree if the fishery-related water areas are lost to give place to other activities like marina's or wind farm support?				x						
Do you agree with the construction of the barrier and (later) the lock to protect the port from flood?						x				
Do you agree with the expansion of the harbor?						x				
How much would you agree with the option to close the port?		x								

K.2.4 Waterboard:

Grade the following aspects (using a X in the respective cell)

Not at all	-4	-3	-2	-1	0	1	2	3	4	Totally
How safe do you feel with the existing situation? (in terms of water safety)								x		
How much would you like the idea of having extra temporary structures on the new coastline, in front of the dune system and around the lakes?			x							

Preserve Strategy vs. Advance Strategy:
We propose two solutions that cope with the required water safety. The first solution preserves the protected area as well as the current social and ecological values. The second solution extends the protected area and at the same time creates a large area that enables many new social and ecological functions, but for a much larger cost and effort.

Question: Do you prefer a smaller investment with a short return period that mainly focuses on safety or a bigger investment that provides additional ecosystem and social services but has a longer return period? Why?
Answer: A smaller investment with a short return period that mainly focuses on safety fits much better with the purpose of the Waterboard. However, a bigger investment can be interesting to make together with other parties (Municipality, Dunea (drinking water production), Province).

Question: Do you think nourishing the Dutch coast to keep up with SLR is a feasible strategy in future? Or do you think other, non-sandy solutions would be better?
Answer: In the coastline itself sandy solutions are best; however, we also need 'hard' solutions at our ports and water outlets. Land inwards we also might think of making ground level elevations or inundations for certain areas.

Question: Do you think continuous dredging would reduce the maintenance effort of the area and could be a good solution for the future when a lot more sand is needed?
Answer: Yes, especially when combined with windmills and actually, the variety in wind is in this case not a problem.

Question: What is your opinion on having initially the sand engine and then the thematic lakes constructed in front of the north beach?
Answer: This would be a good solution, and maybe worthwhile to investigate if these lakes could become brackish or even sweet over time to reduce salt groundwater intrusion.

Question: Would you agree with the idea of constructing the barrier islands and the basin islands in the long-term to protect the south beach? Will the new activities (bird watching, water sports, cafes etc) be appealing for you to visit the area?
Answer: We would be most interested in the long-term safety aspect of this solution.

K.2.5 Rijkswaterstaat:

Grade the following aspects (using a X in the respective cell)

Not at all	-4	-3	-2	-1	0	1	2	3	4	Totally
How safe do you feel with the existing situation? (in terms of water safety)									x	
How much would you like the idea of having extra temporary structures on the new coastline, in front of the dune system and around the lakes?		x								

Preserve Strategy vs. Advance Strategy:
We propose two solutions that cope with the required water safety. The first solution preserves the protected area as well as the current social and ecological values. The second solution extends the protected area and at the same time creates a large area that enables many new social and ecological functions, but for a much larger cost and effort.

Question: Do you prefer a smaller investment with a short return period that mainly focuses on safety or a bigger investment that provides additional ecosystem and social services but has a longer return period? Why?
Answer: From a perspective of the national government a more long-term view is favourable, creating a strategy that will reach long term goals step by step, aligning and starting with the short-term strategy.

Question: Do you think nourishing the Dutch coast to keep up with SLR is a feasible strategy in future? Or do you think other, non-sandy solutions would be better?
Answer: Similar answer as waterboard.

Question: Do you think continuous dredging would reduce the maintenance effort of the area and could be a good solution for the future when a lot more sand is needed?
Answer: Yes, however, a constrain can be the availability of sufficient sand from the near shore coast.

Question: What is your opinion on having initially the sand engine and then the thematic lakes constructed in front of the north beach?
Answer: Similar answer as waterboard.

Question: Would you agree with the idea of constructing the barrier islands and the basin islands in the long-term to protect the south beach? Will the new activities (bird watching, watersports, cafes etc) be appealing for you to visit the area?
Answer: Similar answer as waterboard.

K.2.6 Nature Organizations:

Grade the following aspects (using a X in the respective cell)

Not at all	-4	-3	-2	-1	0	1	2	3	4	Totally
How safe do you think the natural values in Natura 2000 are? (in terms of water safety)							x			
How important is the preservation of Natura2000 for you?									x	
How untouchable would you say the Natura2000 areas are?									x	
In a very high SLR, would you agree to sacrifice a part of Natura2000 areas for the coastal safety of Scheveningen?					x					
How important is the use of sustainable methods in the construction works of the area?									x	

Question: Would you agree with the idea of constructing the barrier islands and the basin islands in the long-term to protect the south beach? Will the new activities (bird watching, watersports, cafes etc) be appealing for you to visit the area?
Answer: Interesting plan to potentially expand the Nature 2000 area, and the new National Park 'Hollandse Duinen', with a kind of Waddensea.

K.3 Port of Scheveningen

Cees Duvekot, 08/12/2020

This interview was conducted online as an open interview with the whole group. In order to structure the answers, notes taken during the meeting where then transformed into a structured interview.

Question: How ''untouchable" would you say is the port area? (because of local identity and stakeholders operating there).
Answer: Current stakeholders (e.g. residents, business owners) are strongly bonded to the port and are not eager to relocate in the near future. However, the changes that sea level rise will force, will make it possible for bigger changes in twenty or more years. More vulnerable are considered the buildings in front of the harbor,

which are not protected by the dunes, and given that the second harbor already faces some floodings on a yearly basis. Port's operations are not causing any big problems to the locals, only some recreational ships and/or bigger ships that have strong lights and are quite noisy, or producing large amounts of smoke. This is partly managed by the fact that loading and unloading are not allowed during the night.

Concerning relocation: the option of relocating the port seawards has never been discussed, mainly discussed of making an extra harbor seawards (e.g. for the cruise ships). Locals are very proud of the port and don't want to lose it. Thinking of making a way of 'closing' the port to protect it from high water, results in two alternatives (1) between first and second harbor and (2) a barrier in front of the beach – parallel to the current coastline.

Concerning the option of relocation compared to closing: The locals would like a new port, and to be taken into account that watersport activities are extremely important. Additionally, Natura2000 area is located next to it, consequently at the moment relocation is not welcomed. In the long-term relocation to facilitate development (e.g. residential buildings) would be possible if current activities were moved in a new harbor, and sailing activities are retained (e.g. olympics sailors).

Question: How important would you say the fishing industry is for the local economy? And is relocation of the fishing activities an option?
Answer: The importance of the fishing industry could be graded by 7 or 8. Fish comes partly by trucks and partly by boats. The port has logistics facilities to operate, with storage and export spaces but they are not enough. The fact that not all fish are coming by boats could be an incentive of relocating the fishing industry, however total relocation is very difficult for the fishing companies.

Question: New developments of port areas proposed by the zoning plan: where can we find more info? Is there a project already going on?
Answer: The zoning plan of 2015 is currently followed. Concerning the idea of the bridge, it should be able to open in order to allow high ships -must allow ships with free board 20m-, also there are thoughts about a tunnel until the beginning of the Morales Boulevard.

Question: Is there any current development for potential future activities (cruise ships, shell-fish farms, offshore wind farms support)? We didn't observe any dedicated area in the zoning plan.
Answer: Works under construction containing offshore wind farm support started being built at the south part of third harbor (current use of the north part: fishing industry and cruise ships, while wind farms currently berth in the first harbor), seaweed farm, shellfish, cruise ships: there are some thoughts for a new harbor, while initially there was a thought of constructing them in the third harbor but finally residential use was selected for this harbor. In addition, the theater of 3rd harbor will be demolished and built next to the offshore farm support terminal.

Question: Are there any Dredging activities in the port?
Answer: Dredging activities take place 2 times per year (in April and in September/October), and checking for dredging needs takes place every 2-3 months. The locations are right in front of the harbor and outside the port/breakwaters and the channels (longshore transport south to north). There is no dredging in the second harbor -the north part has a sluice- only taking the sediment from the canal to the first harbor. Additionally, since the creation of the sand motor it is observed that more dredging in the outer part is needed.

Question: Where can we obtain a bathymetry of water areas including the access channel?
Answer: In the document provided there are all related depths.

K.4 Ronald Waterman

Ronald Waterman, 04/12/20, Delta Future Lab lecture

This interview was conducted as a very interesting open discussion after the lecture. The parts that are mostly related to the project are listed here.

Question: What created that coastline orientation between sand engine and port of scheveningen?
Answer: Waves orientation! And for the dune orientation responsible are the north east winds.

Question: What is the natural evolution of the coast south of the breakwater?
Answer: It is going to accumulate sand near the breakwater until the equilibrium profile. Solution could be to speed up this process, the same procedure as the one followed at the Ijmuiden case study.

Question: How do you solve the problem north of the breakwaters? And what would be the best position for the fourth harbor?
Answer: With nourishment. The fourth harbor should be located in the southern part, while the southern breakwater has to be larger, and not linear, to prevent siltation in the channel.

Question: What is your opinion about the project's BwN solutions and what parameters should be taken into account?
Answer: Studying the history of the coast is very important. BwN is a very flexible approach, ''an elegant instrument in wrestling with the sea". However, maintenance costs should not be neglected as they can be high in some cases.

Question: What could the drawbacks of an island BwN solution be?
Answer: There are several drawbacks, for instance the SLR all around the island and the need of infrastructure to link the land to the new island. In addition, a stage approach is difficult when islands are planned.

Question: Is closing the harbor an option?
Answer: A very strong opposition is expected by locals, fish industry and everyone around it. The port is really important for the local community. Really disapprove closing the harbor, a suggestion could be making a sluice at the port entrance.

Appendix L

Waterman Plan

L.1 Plan 1 (R. Waterman, 2010)

Plan 1 is a wedge-shaped land reclamation between North Scheveningen (coastal area of The Hague) and Hoek van Holland, circa 21 km in length and its width is gradually increasing from a few metres near North Scheveningen to approximately 4 km near Hoek van Holland. The plan includes a primary range of dunes with a new beach in front, parallel to the new coastline, and secondary ranges of dunes at an angle to the coast, as it were, extensions of historical dune ridges which can still be recognized in the basic street pattern of The Hague.

This land reclamation has two parts: a smaller part with a short new hollow coastline from North Scheveningen to the extended northern harbour mole of Scheveningen, and a much larger part with a new hollow arched coastline between the extended southern harbour mole of Scheveningen and the adapted existing northern harbour mole of Hoek van Holland.

The first segment of Plan 1 has already been created, the so-called Van Dixhoorn-Triangle near Hoek van Holland. The plan aims at restoring a former coastal configuration (16th century), which was washed away by river outflow and sea breakthrough. The position of the new coastline is among others determined by the northern harbour pier of Hoek van Holland and the coastal segments inside this land reclamation plan are planned to be in alignment with the old coastal barrier system on which the city of The Hague was built.

The new land has an area of circa 3,250 hectares and the volume of sand required, amounts to approximately 360 million m3. This amount of sand can be obtained by widening and deepening the Euro-Maas Channel and by dredging from the seabed of the North Sea beyond the 20 m − MSL depth line, thereby keeping intact the coastal seabed foundation up to this 20 m − MSL line.

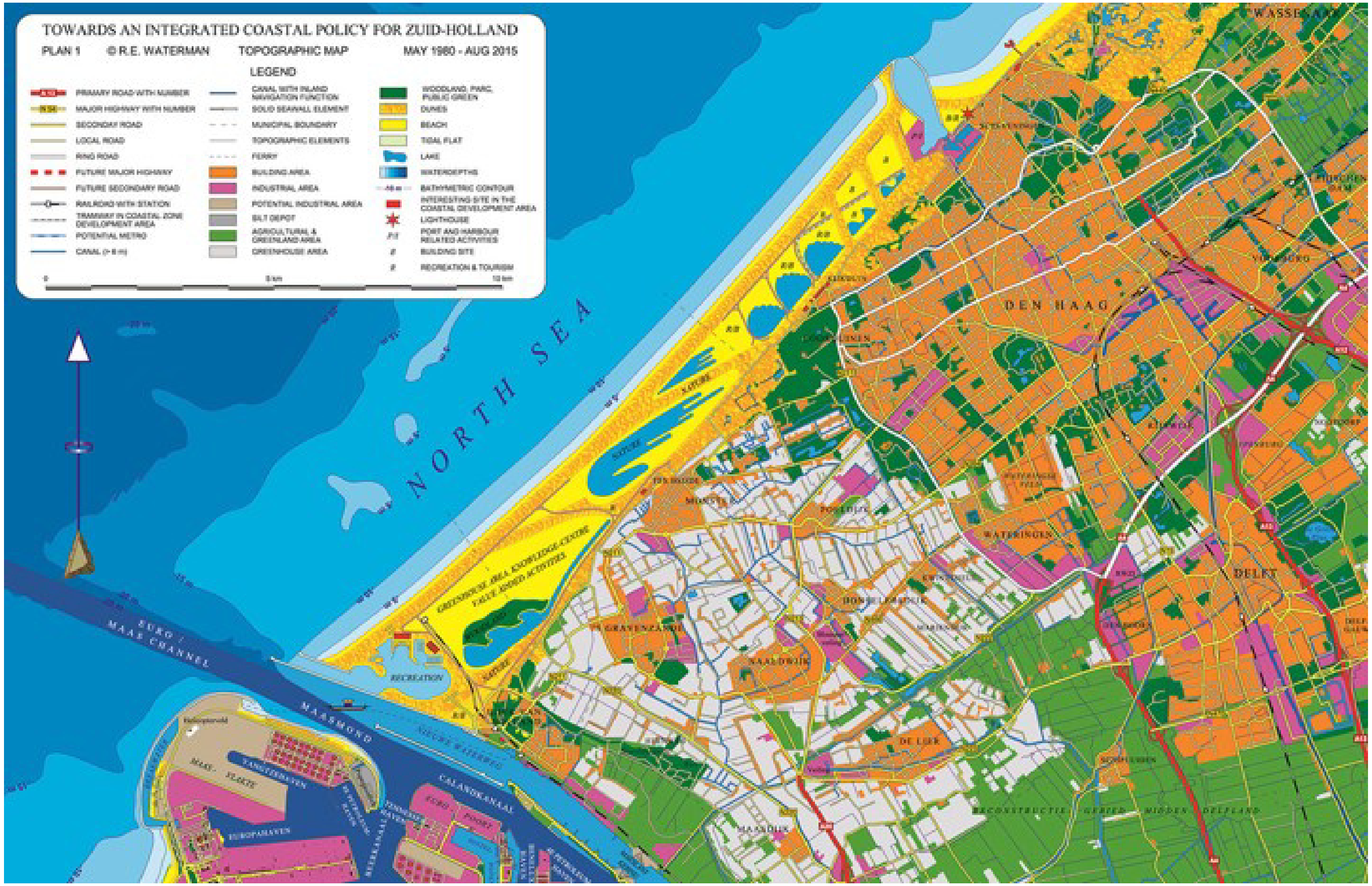


Figure L.1: Plan 1 Waterman between Hook van Holland and Oostduinen

L.1.1 Plan 3 (R. Waterman, 2010)

Dredging material from the marina is used to help speeding up the accumulation process in the southern breakwater. Once the coastline stabilize once it reaches the equilibrium orientation.

The newly created land is triangle-shaped and consists of a primary range of dunes with a marina, double boulevard, apartments, restaurants and shops, hotel capacity, infrastructure, intensive recreation and tourism; transition zone with a lake (Kennemer Lake); a nature reserve area linked to an existing nature reserve area (Kennemer Dunes).

The developments are continuing. Nature extented itself on three sides of the lake, resulting in a larger nature reserve area in connection with the national park South Kennemer Land. A footbridge will be constructed at the entrance of the marina, while a new nautical centre will be situated at the eastern corner of the marina.

Along the West-Boulevard, at it's northern tip, a complex of high-rise apartment buildings will be realised. The total number of apartments will then reach 500. Attractive bicycle and footpaths will be provided for and of course adequate transport facilities together with 3300 parking places. In locations for police and rescue aid is foreseen and in space for five beach pavilions. In conjunction with a South-Boulevard an entrance square and a central square for leisure activities will be realised.

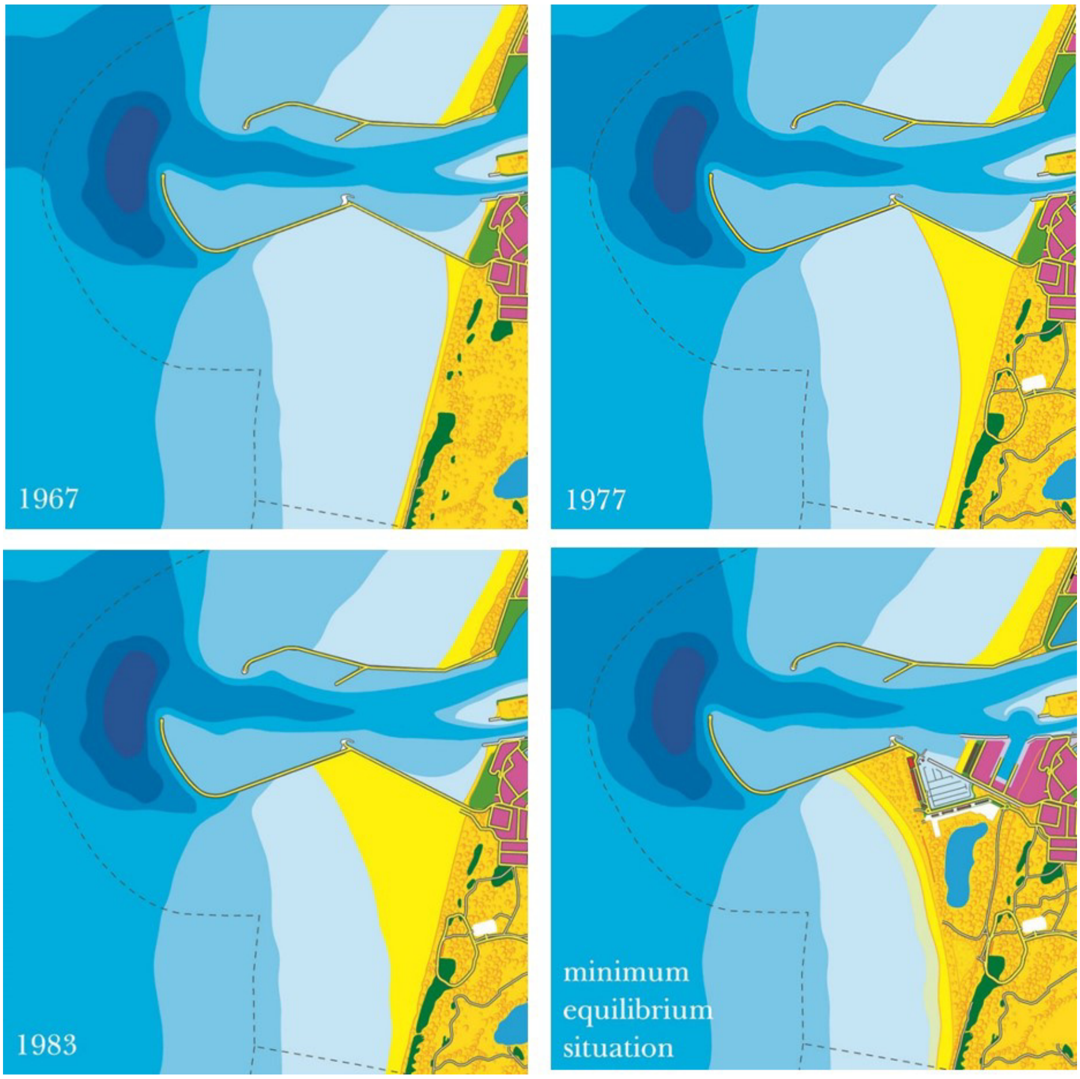


Figure L.2: Plan 3 Waterman near in Ijmuiden port entrance

Appendix M

Brain storming Preserve strategy

This appendix shows ideas from our brain storm session while developing the Preserve strategy. After making a list of the pros and cons of each measure, we decided for measures that we wanted to have in our final solution. These measures are highlighted in green in the following.

Based on this we developed the measures in more detail and added more ideas how the final picture should look like. Additionally, we looked at the internal thresholds of the system, to make a decision when which of the measures becomes necessary.

Possible measures for the port

Measure	Pros	Cons
Storm surge barrier	Adaptability, does not disturb operations too much	Costs, for extreme SLR it has to be closed too often
Lock	Adaptability, port always open	Disturbs operations (more time), costs
Gradual increase height of quaywalls and land	Not disturb port operations, safety of buildings around port, adaptability	Restriction of view, increase adjacent land, costs, can become unfeasible (when houses are affected), loose touristic attraction
Partially increase quay wall + allow for flooding, relocate housing and high value industries	Keep port and sea view	No adaptability for very high sea level rise scenarios
Flood basement of buildings during extreme conditions	Costs	Create nuisance, loss of private property, relocate
Close the port	Costs, sea view	Damages cultural value, loss of economic growth
Floating quaywalls, floating port	Keep port operational	Does not solve safety issue of nearby areas
Reconnect channel to port basin to connect fresh and salty water which enables certain vegetation to grow	Good for ecology	Only works with storm surge barrier or lock
Tidal park: allow retreat for a higher part that tide only partly floods that part	Good for ecology	Relocate, much space needed, destroying identity
Rise hinterland (second dike)	Area close to the sea keeps its value	Higher flooding probability in front of hinterland, costs
Relocate port and only keep recreational aspects (e.g. sailing)	Local identity (fish market), recreational aspects continue	Loose economical value of fisher boats, has to be combined with safety measure

Possible measures for Morales Boulevard

Measure	Pros	Cons
Rising the dike-in-boulevard	Safety	Costs, not flexible, sea view
Nourishment/Dunes in front of the boulevard	Flexible, ecological values, costs	Sea view (maybe later loss than dike), new dredging technology, dredging emissions
Glass wall behind of existing boulevard to allow more overtopping	Avoid water in hinterland, sea view	Not solution on its own, only in combination with hard solution for very extreme SLR scenarios
Vegetation	Catching overflow water, ecology	Needs a lot of space, maybe not efficient enough
Allow for more overtopping	Dike height can remain relatively low, sea view	Limit when this is not possible anymore, combination with other solution needed
Change revetment of dike	Lower crest height temporary possible (higher porosity), create greater ecological value	Costs, not a solution forever (only effect once but not adjustable
Creating rich revetment by replacing parts of the beach	Good for ecology, preventing of erosion	Recreational value decreases, less attractive for tourists
Offshore wave breaker e.g. sand banks, oyster reefs	Wave height decreases, lower dike height possible	Maybe not very efficient, water depth during design conditions much larger so that breakers so not work efficiently

Possible measures for Northern Boulevard and Kurhaus area

Measure	Pros	Cons
Allow flooding during extreme conditions, building resilience (allow basements to be flooded, construction on piles) + relocate any activity that includes housing and high value industry	Low costs, sea view	Protest of residence (but only a small part)
Beach nourishment	Flexible, relatively cheap, nature based, current system stays intact	Emissions during dredging, destroying nature offshore, limitations of dredging capacity in future, wider beach
Dune landscape in front of the boulevard with dike underneath the dune (hybrid structure)	Ecology, recreation	Loss of sea view
Build a dike (hard solution)	Safety	Not flexible, ugly, loss of sea view, no recreation
Creating rich revetment by replacing parts of the beach	Good for ecology, preventing of erosion	Recreational value decreases, less attractive for tourists
Rise hinterland	Area close to the sea keeps its value	Higher flooding probability in front of hinterland, costs

Possible measures for Dunes

Measure	Pros	Cons
Continuous nourishment, sand showers at several places	Not very intervening to the existing environment, ecology (natura2000), flexible	Not very drastic and problem-solving maybe?
Nourish entire profile to have enough sand in the foreshore	Flexible, good for ecology	Costs, high maintenance costs
Hard structure as second dike ring	Sea view, coastal area does not have to change much, low maintenance costs	Costs (as we relocate buildings and create a second ring), not flexible at all, natura2000 areas do not allow hard structures

Appendix N

Measures of Preserve and Advance solutions

In section 5.2 of the report, the Preserve and Advance strategy are shown. Several measures are presented, how to improve the coastal safety of the project area. This appendix provides more elaborate explanations how the different measures work and what benefits we expect from them.

Most of measures are nature-based solutions following the BwN philosophy. Other measures are implemented just to improve safety or to increase the economical or toruistic value of the area.

N.1 Building with Nature measures

N.1.1 Beach and dune nourishments

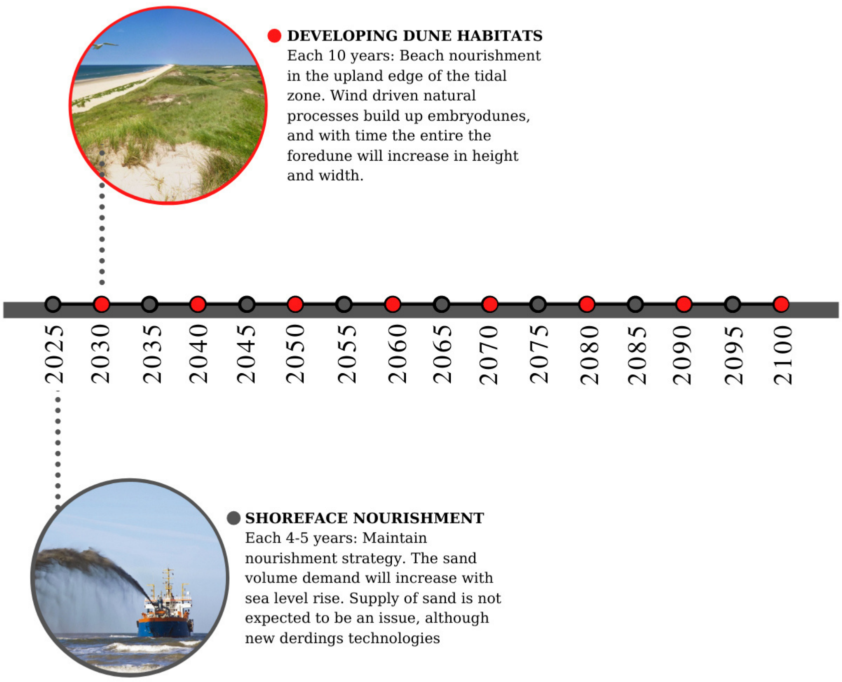


Figure N.1: Timeline of the nourishment strategy to keep up with sea level rise towards 2100. The seawall protecting Oostduinen, Westduinpark, and Kijkduin-Solleveld use the concept of dune enhancement

N.1.2 Continuous nourishment and "sand showers"

While working on the project and having meetings with our supervisors, we came up with the idea of continuous nourishment. The idea behind this is to have offshore dredging robots (operated with green wind energy from offshore wind farms), which dredge sand from offshore locations in the North Sea. This sand is then pumped via long pipelines all the way to the shallow foreshore, close to the beaches, that have to be nourished.

To not disturb the beach visitors by dredging activities, the sand will not be pumped on the beach but in the shallow foreshore, underwater in front of the beach. A distribution mechanism, that stops to create just one sand hill at the end of the pipeline has to be invented. Waves and currents will then transport the sand from the foreshore towards the beach.

This method seems very promising to compensate for the disadvantages of present nourishment method, which uses dredging vessels. The new method would have almost no CO_2 emissions. In future, when much more sand is needed than currently, the CO_2 emissions of the dredging vessels could become a serious problem. Additionally, continuous nourishment would not create one big sand layer once every 4 to 5 years as it is common for the current nourishment practice. Instead, a relatively small amount of sand is continuously added to the beach, so that less fauna and flora would be buried or damaged.

One continuous nourishment site, including the offshore robot, the pump, the transportation pipeline, and a sand distribution mechanism at the end of the pipeline can be understood as a "sand shower". The idea is to apply several sand showers every few hundred meters in the future. A system of sand showers could be enough to supply the coast with all the sand needed to compensate for erosion and keep up with SLR.

N.1.3 Textured walls and hanging structures

Hanging structures add variation to otherwise smooth underwater environments and provide artificial substrates for habitat creation. These installations promote settlement to enhance the population of filterfeeders and provide fish habitats, thereby improving biodiversity. Filterfeeders contribute to improved water quality, often a significant motivation for action in cities. Two further benefits are new opportunities for recreational fishing and the potential for wave attenuation where structures have grown heavy with marine life. The structures are relatively easy to apply and offer opportunities for added services even when physical conditions or design constraints require hard solutions and/or provide little space for Building with Nature.(Ecoshape, 2021a)

Figure N.2: Example of a hanging structure (Ecoshape, 2021a).

N.1.4 Breakwater extensions and rich revetments

In order to stop the port entrance channel to silt up from additional sand nourishments, the breakwaters have to be extended in offshore direction. The costs for this measure are estimated to be around 120,000,000 €. This number is based on the cost of an earlier breakwater extension in Scheveningen between 1969 and 1971 (Roos, 1971).The idea is to use this measure as an opportunity to also enhance the ecological value of the area by applying rich revetments.

Enriching revetments comprises small adaptations in texture, form, and material of hard structures in intertidal and underwater landscape that create habitat and support biodiversity. Even with limited space, rich revetments can enable algae, seagrass, corals, and other organisms to settle and grow, becoming a food source that attracts shellfish, fish, and birds. Varied concrete surfaces and specialized seawall tiles offer cracks and spaces that become protected habitats. Tide pools or "eco-basins" can be constructed at the toe of coastal dikes or estuary edges. At scale, these enhancements and their marine life can contribute to improved water quality, become an important educational tool and create a hotspot for divers (Ecoshape, 2021b).

Figure N.3: Example of a rich revetment (Ecoshape, 2021b)

N.1.5 Restore salinity gradient

Estuarine environments and river outflows naturally contain mixing gradients of fresh and salt water that cause sediment to be imported along with salt water from the coast. In many urbanized environments, transitional zones have been eliminated in favor of constructed shorelines with pumps and locks. Restoring freshsalt transitions with diverted streams that meet the coast in wetland zones enhances and diversifies habitat conditions. Introducing gradients creates opportunities for flora and fauna with varying salinity tolerances, from migrating fish to plant ecosystems. In ports, eliminating sharp transitions by restoring salinity gradients affect the stratified flow, reducing the inflow of sediment and along with it, dredging requirements.(Ecoshape, 2021c)

N.1.6 Nature islands

In the third phase of the Advance strategy, nature islands will be created in the shallow lagoon in the area of LDS-South. These islands will be constructed with a design inspired by the Markerwadden (figure N.4). As on the Markerwadden, those islands would be reserved mostly for the enhancement of the ecology

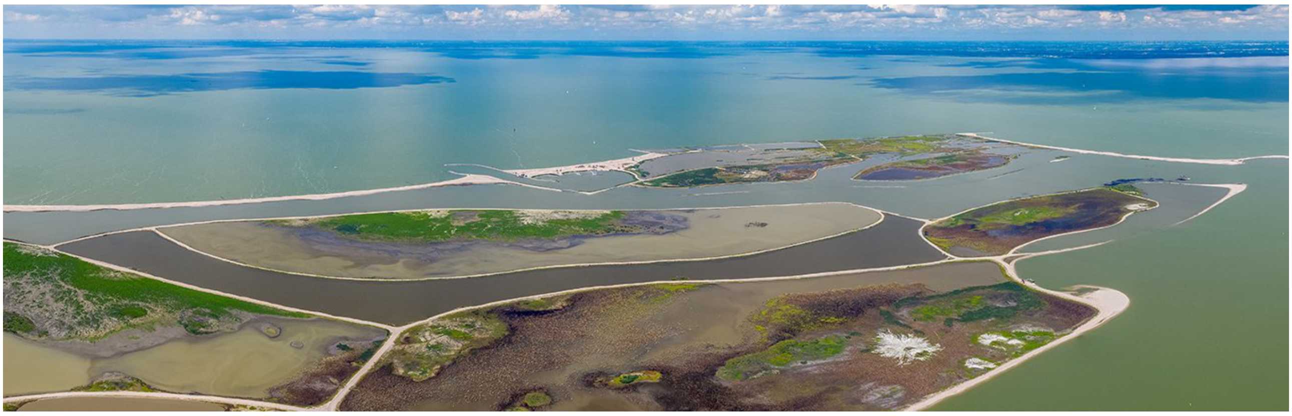


Figure N.4: Markerwadden islands, Netherlands (Netherlands Board of Tourism and Conventions, 2021)

N.2 Safety measures and measures with added value

N.2.1 Urbanistic resilience

Some buildings in front of the primary flood defence line are protected with lower failure probability than 1 in 10,000, what only applies for the buildings behind that line. To minimize the damage and loss of lives during a flood event, the buildings in front of the primary flood defence have to be adjusted. Options to adjust these buildings and make them more resilient could be to apply deep foundation with piles or soil improvements, so that houses do not collapse or only the piles will be flooded but not the building itself. Furthermore, it can be thought of adjusting the function of the basements of the buildings, e.g. making garages out of it instead of living areas.

The advantage of this measure is that the sea view can be kept for a longer period of time and less other measures need to be applied.

N.2.2 Port expansion and sand fill

Inspired by the Seaport Marina of Ijmuiden, a port expansion will be constructed within the newly created triangle in order to accommodate more fishing activities, recreational vessels, supporting vessels for the wind parks, small yachts, cruise ships and others needing extra space in the Port of Scheveningen. In the case of the Advance solution, this expansion is 2.5 times bigger, hence it can accommodate other activities such as support for offshore wind farm vessels. The basin needs a water depth of +/- 4-5m for small vessels and +/- 8m in the deepest parts to accommodate cruise ships and offshore vessels.

Figure N.5: New marina Ijmuiden (marinas.com, 2021)

The costs for this new marina are estimated to be around 150,000,000 euro. This estimate is based on the costs for other new cruise ship terminals, such as one of similar size in Florida for instance(Dave Berman, 2021b).

Soil properties were verified. The soil in Scheveningen consists mainly of sandy deposits up to a great depth (more than 30 meters), and layers of clay are almost completely absent from the coastal strip, where the excavations will take place. More information about soil properties can be obtained from (Oranjewoud, 2013).

N.2.3 Cyclist and pedestrian bridge

The idea behind the cyclist and pedestrian bridge is to solve the connection problem of the southern and northern end of the harbour. Currently, people who want to strive along the coast, have to walk big detours to pass the port area. Especially, when a cruise ship terminal is created, more tourists will arrive at the port. Therefore, a proper infrastructure is necessary, so that visitors can easily walk in the area.

The costs of the new bridge are estimated based on unit prices for pedestrian bridges ($ 150 to $ 250 per square foot, (Dave Berman, 2021a)).

N.2.4 Storm surge barrier and lock

In the second phase of the Preserve strategy or in the first phase of the Advance strategy, a storm surge barrier becomes necessary. For a SLR of more than 2 m, it is estimated that the storm surge barrier will exceed a closing frequency of 3 times/year, hampering shipping to an unacceptable level for port users. Therefore, the storm surge barrier will be adjusted to a lock. The technical requirements to do so will be already considered in the planning of the storm surge barrier. In this case, the costs for the lock, are minimized. The lock is safe for a SLR of 3 m and more.

The estimation of the closing frequency of the storm surge barrier and when the lock becomes necessary is based on calculations made by Hydra-NL for the Maeslant barrier in Rotterdam ((M. Haasnoot, 2018), page 51), which determines the 3 closures per year frequency is reached when sea level is above 1m with respect to the reference level in 1995. The same document indicates a frequency of 1 closure per year as cut-off point in connection with the obstruction of shipping. However, in our case the Scheveningen Port is of less importance for trade as compared to the Port of Rotterdam, thus a value of 3 seems reasonable.

N.2.5 Multi-functional dune landscape

The figure below shows an example of a multi-functional dune landscape. The sketch of the 'wall-in-dunes' with a parking garage combined in the flood defence was developed as an alternative to the design of dike-in-dune solution, that was finally chosen in Katwijk.

Figure N.6: Katwijk: sketch of the 'wall-in-dunes' alternative, with a parking garage combined in the flood defence (Mark Voorendt, 2021)

When dunes have to be build in front of the Northern boulevard and Morales boulevard, a design similar to this, could be used. Such a design ensures safety but also provides additional services, that can compensate for the loss of sea view. In this way, the stakeholders get an attractive alternative, with a landscape that resembles natural dunes.

N.2.6 Floating structures

In phase 2 of the Preserve strategy a few floating structures will be constructed to serve as water sport offices and monitoring stations. The idea is based on pilots of Fintch floating homes (Homes, n.d.) developed by a TU Delft initiative (figure N.7).

Figure N.7: Example of floating structures, pilots of Fintch floating homes (Homes, n.d.).

N.2.7 Thematic lakes

This idea of the thematic lakes is based on a project in Brazil called Piscinão de Ramos (figure N.8. It is a salt water lake that exchanges water with the ocean and offers a great recreation opportunity for many people.

Figure N.8: Piscinão de Ramos, Brazil (Gil Vicente de Andrade, 2021).

Appendix O

Costs for Preserve strategy

This appendix shows a cost estimate for all measures of the Preserve strategy. For every phase, the costs are estimated based on comparable projects or unit prices such as € 5 per m^3 of Dutch sand. The total estimated costs for all measures together are approximately € 1,421,750,000.

Maintanence Nourishment Costs until 2100		
Measure	**Costs**	**Source/Calculation**
nourish coastline with maintenance volume of approx. 140 m^3/m per year along 9 km sandy coast (80 m^3/m to compensate for erosion and addtional 60 m^3/m to keep up with SLR assuming a SLR rate of 15 mm/year on average within the next 80 years)	**€ 500,000,000.00**	~ 140 m^3/m*80 year*9 km * 5€/m^3

Costs for Phase 1		
Measure	**Costs**	**Source/Calculation**
Increase the quaywall to +3.65m NAP	€ 6,150,000.00	MDP Scheveningen october 2020
Textures sea walls and hanging structures	€ 1,000,000.00	
Building and urbanistic resilience. Includes: Restaurants, business, fishery industry, sheds for the support of wind farms activity, yacht sheds.	€ 10,000,000.00	
Build a new marina for small yachts and cruise ships. It is expected worldwide sailing competitions to happen in the port	€ 150,000,000.00	https://www.portbris.com.au/cruise/ https://eu.floridatoday.com/story/news/local/2018/09/27/port-canaveral-awards-contracts-153-million-cruise-terminal-project/1436060002/
Extend breakwaters and reinforce them with rich revetments	€ 120,000,000.00	https://kennisbank-waterbouw.tudelft.nl/breakwaters/details.php?id=029
Build a bridge for pedestrians and cyclists (length ~ 150 m, width ~ 2.5 m = 375 m^2 -> 800,000€)	€ 800,000.00	https://ced.sog.unc.edu/pedestrian-bridges-connecting-people-with-communities/#:~:text=The%20Federal%20Highway%20Administration%20estimates,%245%20million%20per%20complete%20installation.
Increase width and height of beach	€ 15,500,000.00	3,1 mln m3 sand * 5 €/m3 = 15,5 mln €
Total costs phase 1	**€ 303,450,000.00**	

Costs for Phase 2			
Build a storm surge barrier with a closing frequency of 3 times/year	€	300,000,000.00	https://en.wikipedia.org/wiki/Maeslantkering Smaller than Maeslantkering (450 mln €)
restore the connection between Verversingskanaal and the 2nd harbour. Remove pumping station, lock between channel, 2nd harbour and small dredging tasks if needed.	€	2,000,000.00	
Dune reinforcement north of port area	€	5,000,000.00	
Total costs phase 2	**€**	**307,000,000.00**	

Costs for Phase 3			
Increase height of Morales boulevard, increase width and height of beach and dunes	€	75,000,000.00	approx. same cost as total costs for Morales Boulevard
Increase the width and height of the beach, and start creating a dune landscape with a multifunctional design. Include underground service, like parking (for instance, case Katwijk beach). The dune on top is an artificial habitat that resembles the natural ecosystem.	€	61,300,000.00	https://climate-adapt.eea.europa.eu/metadata/adaptation-options/adaptation-or-improvement-of-dikes-and-dams http://landezine.com/index.php/2015/02/katwijk-coastal-defence-by-okra/ 45 mln € + 6.3 mln € + parking garage 10 mln €
Total costs phase 3	**€**	**136,300,000.00**	

Costs for Phase 4			
Build a lock with a design that can be adaptable for large values of sea level	€	100,000,000.00	
Increase height of Morales boulevard, increase width and height of beach and dunes	€	75,000,000.00	approx. same cost as total costs for Morales Boulevard
Total costs phase 3	**€**	**175,000,000.00**	

Total costs	**€**	**1,421,750,000.00**

Appendix P

Costs for Advance strategy

This appendix shows a cost estimate for all measures of the Advance strategy. The costs are estimated per area (LSD-South and LSD-North) based on comparable projects or unit prices such as € 5 per m^3 of Dutch sand and cross sectional profiles of the final design after phase 4 as shown in appendix Q. The total estimated costs for all measures together are approximately € 2,378,800,000.

Maintanence Nourishment Costs until 2100			
Measure	**Costs**		**Source/Calculation**
nourish coastline with maintenance volume of approx. 140 m^3/m per year along 9 km sandy coast (80 m^3/m to compensate for erosion and addtional 60 m^3/m to keep up with SLR assuming a SLR rate of 15 mm/year on average within the next 80 years)	**€**	**500,000,000.00**	~ 140 m^3/m*80 year*9 km * 5€/m^3

Costs for measures south from Port			
Measure	**Costs**		**Source/Calculation**
Build a new marina for small yachts and cruise ships. It is expected worldwide sailing competitions to happen in the port. Approx. 23 ha	€	375,000,000.00	https://www.portbris.com.au/cruise/ https://eu.floridatoday.com/story/news/local/2018/09/27/port-canaveral-awards-contracts-153-million-cruise-terminal-project/1436060002/
Construction of floating structures at the first barrier island closest to the southern breakwater	€	500,000.00	
construction of walking and cycling paths infrastructure to access the new shoreline	€	1,000,000.00	
construction of recreational huts	€	500,000.00	
meganourishment	€	620,000,000.00	geometry of cross-section

Costs for measures north from Port			
Build a storm surge barrier with a closing frequency of 3 times/year	€	300,000,000.00	https://en.wikipedia.org/wiki/Maeslantkering#:~:text=The%20ball%2Dshaped%20joint%20is,barrier%20cost%20450% Smaller than Maeslantkering (450 mln €)
Build a bridge for pedestrians and cyclists (length ~ 150 m, width ~ 2.5 m = 375 m^2 -> 800,000€)	€	800,000.00	https://ced.sog.unc.edu/pedestrian-bridges-connecting-people-with-communities/#:~:text=The%20Federal%20Highway%20Administration%20estimates,%245%20million%20per%20complete%20installation.
extend length of port breakwater (use BwN friendly material to create habitat for certain species)	€	120,000,000.00	https://kennisbank-waterbouw.tudelft.nl/breakwaters/details.php?id=029
meganourishment	€	250,000,000.00	geometry of cross-section
Construction of 3 recreational lakes (as the Piscinão de Ramos in Rio de Janeiro)	€	100,000,000.00	http://est.uff.br/wp-content/uploads/sites/200/2020/03/tese_doutorado_2015_moni initial investment + maintenance of 6 lakes
Build a lock with a design that can be adaptable for large values of sea level	€	100,000,000.00	
construction of walking and cycling paths infrastructure to access the new shoreline	€	1,000,000.00	
Building and urbanistic resilience. Includes: Restaurants, business, fishery industry, sheds for the support of wind farms activity, yacht sheds.	€	10,000,000.00	

Total costs **€** **2,378,800,000.00**

Appendix Q

Dune cross section and calculation of sand volume from Advance strategy

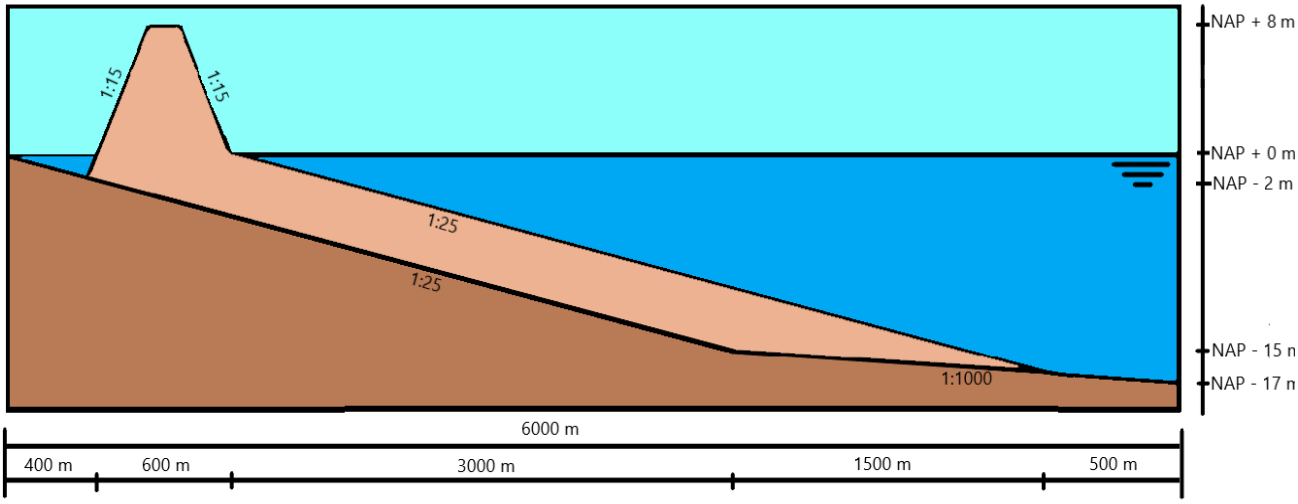
In this appendix the sand volume of the Advance strategy is roughly calculated using an estimation of how an average cross-section of the southern dune profile and the northern dune profile should look like.

This sand volume is used to calculate the costs of the mega nourishment. Finally this volume is compared to the volume of Maasvlakte 2 in the Port of Rotterdam, and the result is that their volumes are of the same magnitude. This is an acceptable estimation as their areas are comparable as well.

Sand volume and costs south of the port

Area trapezium dune	3600	m2
Area trapezium under dune	1800	m2
Area 1:25	10800	m2
Area 1:1000	2812.5	m2
total area nourishment cross-section	19012.5	m2
longshore length	6500	m
total volume	1.24E+08	m3
cost per m3	5	euro/m3
total costs	**€ 617,906,250.00**	

Southern dune profile cross section



Sand volume and costs north of the port

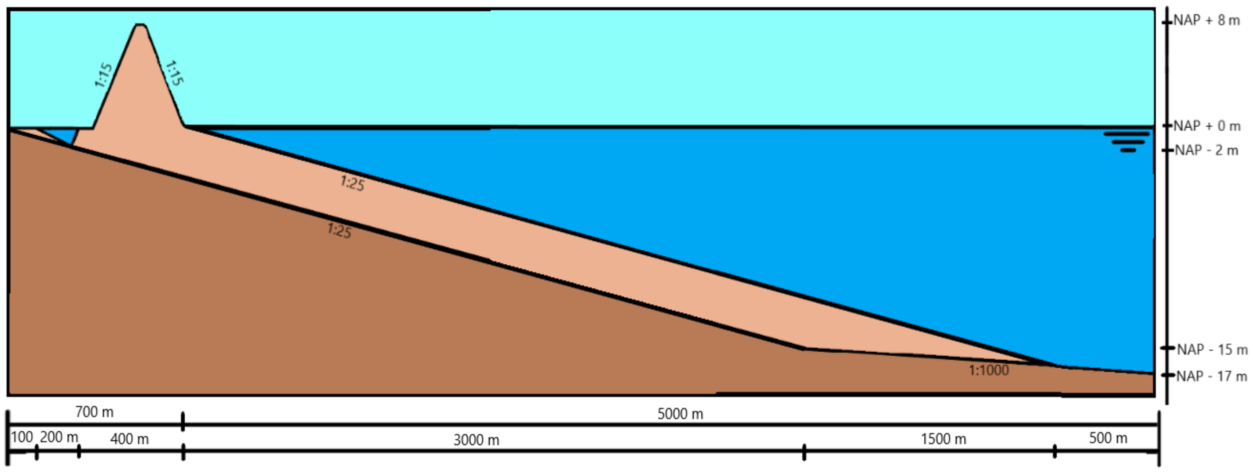
Area trapeziuem dune	1600	m2
Area trapezium under dune	1200	m2
Area triangle shore	100	m2
Area 1:25	10800	m2
Area 1:1000	2812.5	m2
total area nourishment cross-section	16512.5	m2
longshore length	3000	m
total volume	4.95E+07	m3
cost per m3	5	euro/m3
total costs	**€ 247,687,500.00**	

Total volume of sand needed	1.73E+08	m3
Sand Engine equivalent volume	8.7	
Total costs of the nourishment	**€ 865,593,750.00**	

Size of maasvlakte 2: 210 mln m3

https://magazine.boskalis.com/issue01/maasvlakte-milestone

Northern dune profile cross section



Appendix R

Scheveningen Wadden System (SWS)

In the SWS plan a whole new barrier island system will be created in order to protect the coast of Scheveningen and surroundings. The Islands would serve as breakwaters, preventing storm surges of causing damage in this area.

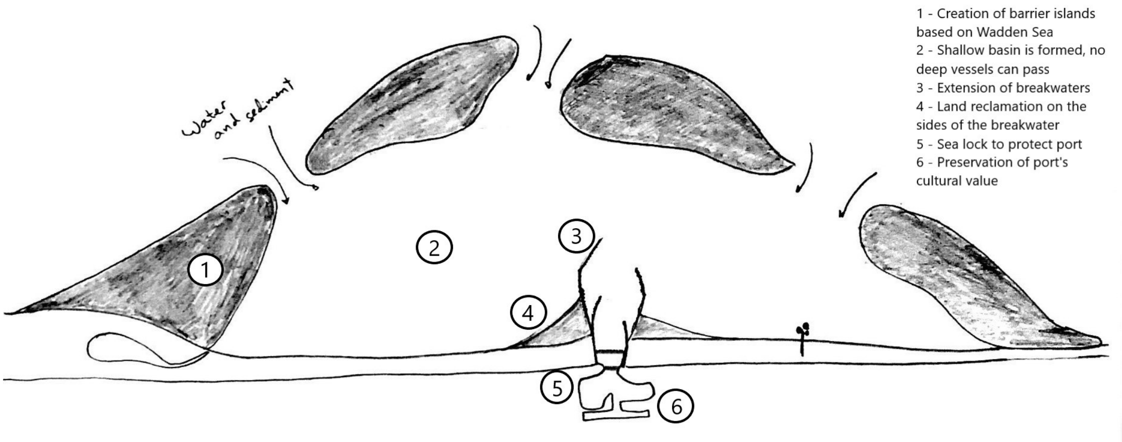


Figure R.1: Conceptual sketch of the SWS plan

The idea is that the SWS islands would create a shallow basin behind it, and the sand that gets trapped into that basin would continuously nourish the coast. The basin would have insufficient depth for deep fishing vessels to visit the Port of Scheveningen. For that reason the port would have to be permanently closed for the entrance of these vessels. The port will be protected with a sea lock, to prevent the port area to be flooded.

To prevent the cultural and socioeconomic value of the port to be lost, the fisheries will be preserved and the fish markets will keep at the same location. The difference is that the fish would have to be shipped with trucks to the port, instead of the vessels. According to an interview with the port authority of Scheveningen (see interview with Cees Duvekot in appendix K), the majority of the fish is already transported by truck because the fisherman prefer to unload their cargo at the nearest port (North Holland, Belgium or France), and have a truck transport it to the fishing company, instead of having to come all the way back to Scheveningen.

After a quick analysis on both the SWS and the LDS plan it has been chosen to keep only with LDS. This can mainly be reasoned with two arguments: first, the barrier islands are very effective preventing storm surges of causing floods in Scheveningen, but less effective against SLR as the islands are permeable and let water through. Secondly, for the creation of this kind of islands offshore an unprecedented amount of sand would be needed, which will increase the costs dramatically. Therefore, due to mainly these two reasons, the SWS approach will be discarded.

Appendix S

Monitoring plan

In this appendix the monitoring plan is presented in the form of an table. In blue the SLR monitoring strategy is represented, in orange the dredging and SSC strategy is shown, in purple the social monitoring is approached and finally in green the ecological monitoring is shown.

Monitored objective	Objective	Method
Sea level rise	Keep track of the evolution of SLR to validate the most recent predictions made and to be able to evaluate whether it is needed to get into the next stage of the project.	Satellite images and other measuring equipment are used multiple times a month, in order to avoid seasonal and episodic changes to influence the monitoring results.
Hydro- sedimentary evolution and nourishment volume	Measure the possible erosion and/or accretion to investigate how the coastline will develop and when maintenance nourishment is necessary	Using satellite images and cross section profiles which are taken once per year, the development of the shoreline can be assessed and the nourishment volume can be estimated.
Suspended sediment concentrations (SSC) due to dredging	During dredging increased SSC can occur, which can have a negative influence on ecology. Therefore, high levels of turbidity caused by the dredging activities have to be detected that an adaptive management approach can be adopted to implement mitigating interventions in the project when a certain threshold is exceeded.	SSC will be measured at a location around the dredging processes, around mega nourishments, around sediment extraction areas, far up north from these areas (near Wadden-Islands) and far down south from these areas (near Zeeland and Belgium). Control measurements are needed at least 1 year in advance to identify the SSC before the start of the project and to take out different seasonal effects on the control and identify different components in the system that might also compromise the control measure. During and after dredging, the amount of light entering until a certain depth to compute the SSC will be measured and sensitive receptor species around the area will be monitored. Three thresholds of SSC will be created and transposing each threshold will have the following consequence: • Caution trigger level 1: a sediment screen will be implemented to trap suspended solids at the dredging site. This is a light mitigation measure and will not have big influences on the project. • Caution trigger level 2: a sediment screen will be implemented, and equipment will work at a lower production rate to decrease suspended solids during dredging. This measure is more drastic and will result in a longer project duration. • Stop trigger level: dredging must stop until SSC drops to acceptable levels.

Legend: Sea level rise | Dredging and nourishment | Added social and economic value | Ecology

Quality of dredged sediment	To ensure that the dredged material is pollution free and is suitable for nourishments	Take samples once every year to see if heavy metals, contaminants, pesticides or other harmful material are present in the sediment, assess sediment size
Jobs	Evaluate the increase in the number of jobs in fisheries and tourism sector	Research the number of companies using the Scheveningen area for business by performing an online research and distributing surveys in the area and city. This is done once a year.
Stakeholders opinion and transparency in the communication	Evaluate the degree of stakeholder engagement. Early identification of changes in perception.	Conduct periodic surveys, organize workshops, presentations, and any type of method to obtain feedback from stakeholders.
Return on Investment	Evaluate the business plan and the return on investment	Make detailed cost benefit analysis, register costs and benefits from tourism and comparison.
Fishery	Evaluate the increase in the number of fish and species	Analyse the amount and types of food available for fish by means of taking samples and laboratory research four times per year. Assess the totaö number of fish and species diversity by obligating local fishermen to , for example, fill in a form eight times per year
Biodiversity evolution	Evaluate the evolution of the number of species that are using the new area or leaving the new area	Once every year fieldwork is performed in which biologists will identify vegetation, birds, insects and other identifiable organisms. Additionally, the new textured walls and hanging structures will serve as a test area to monitor marine vegetation growing.

Legend: **Sea level rise** **Dredging and nourishment** **Added social and economic value** **Ecology**

Appendix T

SWOT analysis of Advance strategy

Strengths ("I want to exploit")	**Weaknesses** ("I want to remove")
• Offers a variety of different recreational options in old and new places. Scheveningen Northern Boulevard buildings are totally protected. • Harbour activities are protected during the lifetime of the project, first with a storm barrier and afterwards with a lock. • Increased biodiversity and abundance of species in natural habitats. Compensate seaview loss with lake landscape. • Maintain local identity values in place (port, Kurhaus,...) • Phasing makes it more acceptable for the stakeholders (citizens) • Sustainable solutions using soft construction methods have a wide social acceptance, and are inline with the Government goals to meet the Paris agreement conditions. • It is an innovative solution with meaningful impact setting a precedent to deal with climate change.	• Very high investment costs, especially if phase 3 is activated between 2070-2080. • High maintenance costs since, including nourishment costs, especially after the large seaward expansion in phase 3. • Revenues are possible in the long term (estimated in 20-30 years after construction). • Beach width is too large, making the seafront difficult to access. • Loss of seaview at some point, dissatisfaction of local stakeholders

Opportunities ("I want to take advantage of them")	**Threats** ("I want to reduce them")
• Political decision: opportunity to create a national integrated plan. For instance, green areas integration towards a Dutch National Park. • The creation of jobs and tourism-related businesses will contribute to the development of the city and nearby areas. • Boost of the logistic sector through expansion of port activities: wind farm support, fishery, and others. The new landfill could provide a new connection between Rotterdam and Scheveningen. Newly created natural areas offer the right opportunities for more flora and fauna to thrive. • The use of the area as a world wide meeting point for yacht racing, kitesurfing and other water sports will be enhanced through the expansion of the marina and the creation of lakes. • Engagement of different types of citizens after creating thematic dedicated lakes (example: lake for kids) • Motivation for further scientific research in the newly created natural areas.	• Lack of tourists visiting the area because they do not find the area, and its activities, as appealing. (failure of the business plan) • The project cannot continue due to restrictions imposed by Natura2000 legislation, as a consequence of a negative impact to natural habitats. • The newly created tidal natural system does not complement successfully with the current natural habitat. • Cost or time overrun • The construction cannot continue because the dredging industry is not capable of meeting legislations and policies regarding sustainability. • If tourism increases significantly, maybe citizens raise complaints about hindrance to their normal way of life. • Political decisions regarding allocation of resources could pass over this project, considering there are other 12 more weak points along the Dutch coast (in terms of safety).