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Dutch stakeholders perspectives on adaptation measures caused by a sea level rise in 2150

A case study about the future of the Delta Works

(Ian Watson, 1992)

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PREFACE

I am an International Land and Water Management master student at the university of Wageningen. This thesis report has been composed on behalf of the university of Wageningen over a period of approximately half a year time. I have a technical background and studied civil engineering as my bachelor. This thesis process and its approach have been a relatively new experience for me, which allowed me to gain more knowledge and experience regarding stakeholder analyses, water management and the Delta Works along with many different topics.

I would like to thank both Gerardo van Halsema and Raffaele Vignola for their support and supervision during this entire process. Both supervisors have frequently provided me with feedback or inputs regarding the thesis process. I would also like to thank the representatives of the provinces of Zeeland and Zuid-Holland, the waterboards of Hollandse Delta and Scheldenstromen, the Deltacommissie and Rijkswaterstaat. These representatives have all been interviewed, which has been an essential part of this thesis report. Without those representatives the main research question could not have been answered. I would also like to thank my family, friends and others that have supported me during this research process.

I hope you find this report informative.

Wouter Heijmans

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ABSTRACT

Originally the delta project was intended to raise existing dikes, construct the storm closure of all main tidal inlets and estuaries, while maintaining shipping access to both the port of Rotterdam as the port of Antwerp *(Watson, I & Finkl C.W., 1992)*. While the function of the Delta Works has not changed, many other factors have. A sea level rise of nearly 2 meters in 2100 *(Haasnoot et al., 2020)* decreases the lifespan of the Delta Works significantly and requires immediate evaluations of possible adaptation strategies. The protect-closed, protect-open, advance and the retreat/accommodate strategies are currently explored as options to adapt to sea level rise *(Deltares, 2021)*, which are based on six responses to sea level rise in IPCC reports *(IPCC, 2022)*. While the clock is ticking no final decision has been made regarding the implementation of one of these strategies. There is a need to analyse the different strategies and determine stakeholder perspectives regarding these approaches.

This report considers a selected group of stakeholders that have the biggest influence and/or dependence on the different adaptation measures, namely the Deltacommissie, Rijkswaterstaat (not included into MCA), waterboard Scheldestromen, waterboard Hollandse Delta, both the provinces of Zeeland and Zuid-Holland. Representatives of these organizations have analyzed the different adaptation approaches based on four criteria, being economic and environmental factors, future adaptation possibilities and the reliability of these approaches.

This report indicates that organizations which are significantly impacted and influential in adaptation change have different perspectives on the approaches, which limits the ability for decisive decision making in order to provide protection against sea level rise. The lack of for example statistic data regarding the effects of adaptation strategies limits decisive decision making even further. However climate change data suggest that the available timeframe for implementation of adaptation strategies is limited, meaning that difficult choices have to be made rather sooner than later. Even when a certain adaptation approach is selected, political, funding, (conceptual)design, preparation and construction processes will still require a lot of time before an approach becomes fully operational. Considering these adaptation strategies are implemented on a national level, this will take many years. The time to critically consider and compare all adaptation strategies is now. The executive summary is located in the appendix.

KEYWORDS

Adaptation strategies, Climate change, Delta Works, Flood risk management, Sea level rise (SLR), Stakeholders perspectives.

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1. INTRODUCTION

1.1 INTRODUCTION TOPIC

Globally floods are considered the most common type of disaster *(CRED, 2023)*. Regardless of the risks human tend to live in disaster prone areas *(Askman J, et al., 2018).* In the Netherlands a high percentage of people live either close to the coast or below sea level. Currently almost 4 million people within the Netherlands live below sea level. A sea level rise of 1 meter would further increase this number to 6,6 million residents *(Hut, R & Hoes O., 2015)*. While these regions are prone to flooding from either rivers or the Sea this did not stop people from settling here. Most of the land is ideal for agriculture and cattle breeding. The Netherlands has always been in a 'battle' against coastal floods from the North Sea. During this battle multiple parts have been lost and reclaimed over again. Many areas next to coast where quite vulnerable to flooding, which means measures had to be taken. In the province of Zeeland the Delta Works function as the main protection measure against coastal flooding.

Due to climate change the poles and glaciers are melting, which results in a rising sea level. Climate change also increases the severity and amount of storms and extreme weather in many areas *(Ralf Weisse, 2010)*. Multiple low lying areas across the world that are close to the coast are becoming more vulnerable to coastal flooding, including the Netherlands. As result of the expected sea level rise in 2150, the Delta Works need to be improved or replaced. This is necessary to ensure the safety of civilians and reduce economic and environmental damages. This is easier said than done, the Delta Works are located in a populated area and also function as a bridge between the different parts of Zeeland *(Rijkswaterstaat, 2022)*. There are many stakeholders that are dependent on the Delta Works and have their own economic, environmental and technical perspectives. For example changes in the Delta Works could have significant impacts on both birds and aquatic life incubation areas. This already occurred when the Delta Works where originally constructed.

Climate models indicate a significant sea level rise *(Bezem, 2021)*, which will challenge the current water management approach within the Netherlands. The Delta Works are reaching the end of their lifespan *(Deltacommissie, 2008)* and new adaption approaches are required. However these approaches will have significant impacts on the Netherlands in multiple sectors *(Deltares, 2021)*. This is why it is important to ensure that stakeholder perspectives are taken into account when new solutions are being assessed. The thesis is divided into multiple sections, the introduction, 4 research questions and the conclusion/discussion. The introduction exists out of the situation and problem description, conceptual framework and the methodology.

1.2 RESEARCH TOPIC

1.2.1 SITUATION

In the year 1953 the south-western part of the Netherlands was heavily affected by coastal floods *(Rijkswaterstaat, 2022)*. This lead to much economic and environmental devastation and casualties. Since this event, projects like the Deltaplan took place to protect the Netherlands against such a coastal flood in the future *(Ronald Rietveld, 2017)*. The first Deltaplan consisted of dikes, sluices and storm surge barriers across the western parts of the Netherlands that are exposed to the North Sea *(de Haan et al, 1984)*. These measures have proven to be a successful method of flood protection in the past *(Ian Watson, 1992)*. In the provinces of Zeeland and Zuid-Holland there are multiple of Delta Works to protect against floods, these are shown in figure 6.

Figure 6: Delta Works. (Rijkswaterstaat, 2022)

Between 1901 and 2010 the sea level rose between 17 and 21 centimeters, which is an average of 1.5 to 1.9 millimeters a year *(IPCC, 2013)*. Climate predictions from 2014 indicate that the sea level will increase by minimum 0.4 meter and maximum 1.2 meter in 2100 *(Horton, 2013)*. In 2021 IPCC published the expected sea level rise for the year 2150 according to different climate scenarios. SSP8.5 (the most extreme climate scenario) predicts a sea level rise of 1.90 meters in 2150 compared to 2000 *(Bezem, 2021).* However RCP8.5[A] suggest a sea level rise of 1.90 meters might already occur as early as 2100 *(Haasnoot et al., 2020)*, which is an significant difference. Even a sea level rise of 5 meter within the next century cannot be ruled out *(Tol R, et al., 2006)*. These different reports indicate there are a lot of uncertainties regarding the predicted sea level rise. Figure 7 indicates the model that has been used for this report.

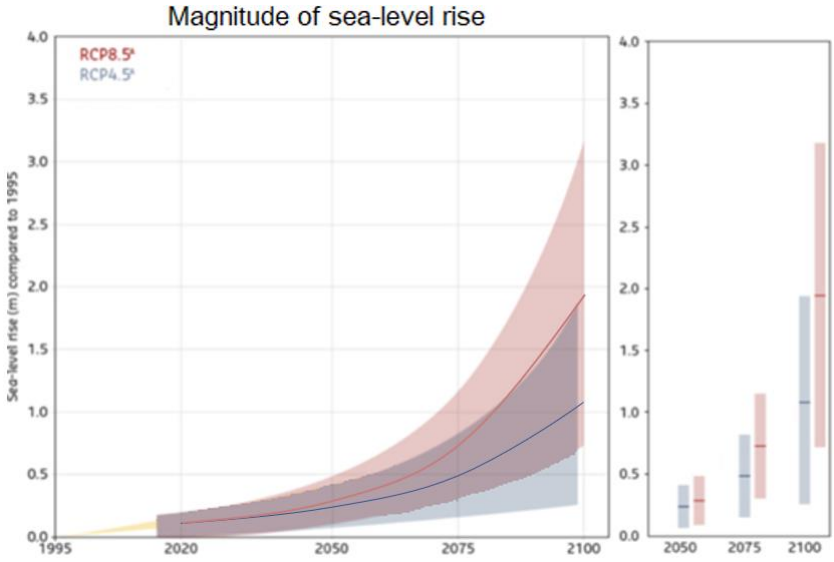


Figure 7: Magnitude sea-level rise compared to 1995. (Haasnoot et al., 2020)

The Dutch Flood Protection Program DFPP is an alliance of regional water authorities that face an enormous task, since about 1500km of dikes and 500 civil-engineering structures have to be strengthened before the year 2050 *(Deltares, 2022).* This while new solutions are usually designed to have life expectancy of 100 years. It takes time before a structure is completely designed, financed, communicated with stakeholders and implemented, especially for huge project like the Delta Works. A life span of 100 years indicate that these measures have to be able withstand the sea level rise until 2150. This indicates the significance of the year 2150 and why it should be used for long term design and calculations for the Delta Works.

There are multiple stakeholders who should be considered before new solutions can be implemented to protect the Netherlands against coastal flooding. These stakeholders each have their own view on the economic, environmental and technical aspects of the solutions. The main stakeholders discussed within this report are:

- Deltacommisie
- Province Zuid-Holland
- Province Zeeland
- Rijkswaterstaat
- Waterboard Hollandse Delta
- Waterboard Scheldenstromen

1.2.2 PROBLEM

Since around a quarter of the Netherlands is located below sea level and a significant amount barely above it, flood protection measures are only expected to get more severe and expensive, since the water level is expected to rise. This results in an increase of areas that are located below sea level, which would become more prone to costal floods, see figure 8. Not only the sea water is rising, some parts of the Netherlands are also subsiding, which further increases the risks of flooding.

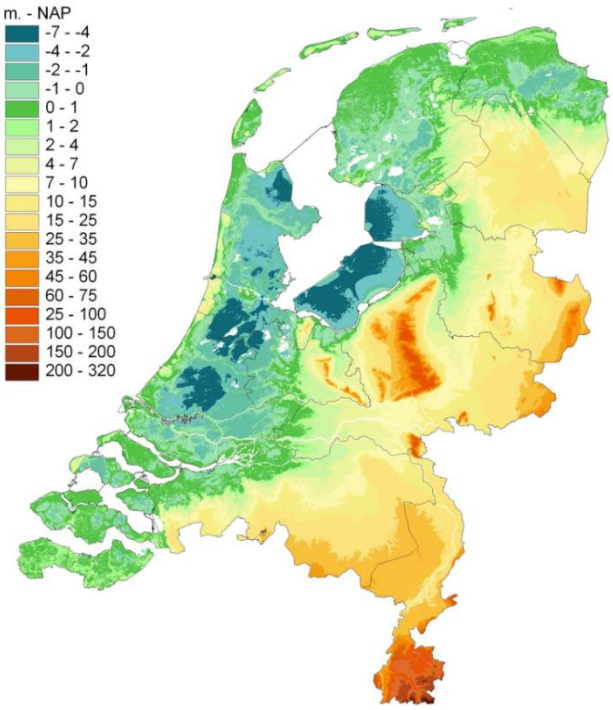


Figure 8: Heightmap of the Netherlands. (Blom-Zandstra, et al., 2009)

Most of the current Delta Works where designed to withstand an anticipated sea level rise from around 1950 until at least 2050 *(Ruessink M, et al., 2019)*. Yet climate change is accelerating compared to earlier predicted models. Since a significant sea water level increase is predicted in the 22th century, the current Delta Works won't be able to provide their original intended protection. Not only the predicted water level has increased, but also risk management practices have changed over the years *(Klijn F, et al., 2012)*. The areas that are relying on the Delta Works have increased in population but also in economic importance. In combination with a predicted increase in water level, the possible economical damage due flooding becomes even more significant. For example if all current dikes where to fail the damage would be around 190 billion euro. A water level increase of 1,5 meter in 2100 would mean a potential economic damage of up to 3700 billion euro *(Aerts et al., 2008)*. This would affect risk management and could result in a stricter exceeding frequency, which is lower than 1/10.000. This will result in an even bigger need for new adaptation measures.

It is important to look at the possible adaptation measures to be able to ensure the safety and protection of the Netherlands and its citizens. If the Delta Works fail and the sea level rises, it will not only affect Zeeland. It will effect a huge part of the Dutch river system. Fresh water will turn salt, what will heavily impact the ecosystem within and around the rivers. Most of the current measures are quite old and should be adjusted to modern day or future proof standards. The current Delta Works are listed in appendix 2.

The Delta Works effectively shorten the Dutch coastline that is directly exposed to the North Sea and thus the increasing sea level. If the Delta Works would be removed completely, the dikes that are currently not fully exposed to the North Sea would require significant improvements, since they don't meet the required standards. This would be incredibly costly, but so would improving all the Delta Works. In the past the choice was made to build the Delta Works instead of improving a lot of dikes along the rivers. Yet this doesn't mean that this will still be the best option for 2150. Neither of these options is a small task and both will be expensive. However there are more adaptation approaches to consider.

Figure 9 shows the results of safety test that has been conducted in 2006. This figure indicates that a lot of dikes within the delta area already don't meet the current requirements regarding flood risks. This does not mean that the dikes are not safe, yet probability of flooding or failure is higher than the national norms.

Figure 9: Results second safety tests primary water barriers 2006. (Deltacommisie, 2008)

For example the storm surge barrier within the Eastern Scheldt is sufficient enough to ensure flood protection for a long period after 2050 according to current predictions. Unfortunately there are only limited possibilities in terms of modification to improve the existing structure *(Deltacommisie, 2008).* This is a problem since all of the Delta Works are designed to be able to function until a certain water level. Once this water level is reached, the structure is no longer able to provide the same level of safety as intended. After that a new solution is necessary to meet the future requirements. There is a need for an adaptive and modular approach where measures could be updated over time as result different factors like an increase in sea level.

Not every adaptation measure is suitable for every area within Zeeland or South-Holland. Different stakeholders might disagree on the implementation of certain measures, due to disagreements on environmental, economic or technical aspects. The different views should be taken into account to asses which adaptation measure is best suitable for an certain area. An example is the Western Scheldt, which is crucial for the harbor of Antwerp. This mean that it has to remain open and different solutions have to be implemented to secure the safety of civilians.

An increase in sea water level would result in the Maeslantkering (Maeslant barrier) being forced to close more often. When the Maeslantkering is closed this will limit the possibility for ships to either leave or enter the Port of Rotterdam, which is of significant importance for the Dutch Economy. Another problem is an increase in the discharge of the Meuse and the Rhine. When the surge barriers are closed on a more frequent basis, a big quantity of fresh water has to be stored or the rivers will overflow. The increase in winter discharge in combination with the more frequently closed surge barriers makes this problem more urgent. Currently the Rhine has a maximum discharge of 16.000 m^3/s, which is expected to increase to 18.000m^3/s in 2100. The winter discharge of the Meuse will also increase from 3.800 m^3/s to 4.600 m^3/s in 2100. *(Deltacommisie, 2008)*

While an increase in winter discharge will require a bigger water storage, the opposite happens during summer. During the summers the discharge will decrease which could lead to increased salt intrustion within the water. The combination of an increased sea water level and lower freshwater levels will result in the infiltration of salt water within the freshwater. This happens both through the groundwater and the rivers itself. This will have disastrous consequences for example farmers, the availability of drinking water and the environment. *(Deltacommisie, 2008)*

The Delta Works comprise of one systemic flood protection system that provides flood protection to the entire estuary. This means that changing one of the flood barriers will have impacts on the other measures but also the rivers and the environment. As the Delta Works come under threat it is thus important that not only individual works are assessed and discussed, but also the systemic flood protection approach. The flood protection strategy which was adopted in the 1950s might not be feasible for future climate change, which implies that the Netherlands need to shift towards another strategy.

There are also opportunities for the new solutions, like for example generating electricity. Energy can be generated by the currents or by the charge difference between salt and fresh water *(Meng Ye et al., 2019)*. While this is not necessary part of this report, it is still important to keep in mind the possibilities in combination with the suggested flood defense measures. Since both depend on the Delta Works and the distribution and flowrate of fresh and salt water.

All the possible solutions have both positive and negative effects on the environment and stakeholders. Some solutions are preferable compared to others, but it is unlikely that all stakeholders agree on their ideal solutions. One solution might be beneficial for transport ships and ports, while another solution is beneficial for the environment. Construction on one of the Delta Works will limit the infrastructure and increase traveling time for people traveling within Zeeland, since the Delta Works also connect the different parts of Zeeland by road. of This is why a MCA (Multi Criteria Analysis) is crucial to determine which solution is deemed most desirable by the stakeholders, while also meeting the requirements for a significant water level rise. This report considers four adaptation approaches, which could be implemented within the Netherlands.

1.2.3 MAIN QUESTION/OBJECTIVE

The current Delta Works are not robust enough to withstand the sea level rise in 2150 according to climate scenario RCP8.5[A]. However most of the Delta Works are expected to fail their initial design requirements significantly earlier. The current adaptation approach needs to be assessed and compared with alternatives. To provide a solution to the earlier stated problem, the following question should be answered:

What are different stakeholder perspectives regarding adaptation measures to ensure the safety against coastal floods caused by sea level rise in 2150 based on environmental, economic and technical aspects?

Before an answer can be provided for the main question, multiple sub questions have to be answered first. Firstly the expected sea level rise has to be determined, followed by an assessment of the current Delta Works. This is necessary to be able to determine the needs and limitations of certain approaches. Lastly stakeholders indicate their perspectives on these approaches.

- How much will the sea level rise till the year 2150 according to different projections?
- Which current coastal flood protection measures are not robust enough to ensure the safety and protection of the Netherlands and its citizens in the year 2150?
- What are possible adaptation measures to ensure the safety and protection of Netherlands and its citizens in 2150?
- What are different stakeholder perspectives on the possible adaptation approaches?

Flood risk management

Absolute protection is not achievable because of high costs and uncertainties. Flood risk management is more suitable within flood research. Flood risk management deals with a wide array of tasks and issues which are ranging from predicting water levels and flood hazards, through their societal consequences to measures and instruments for risk reduction (Schanze, 2006). This concept fits well with this case study, since absolute protection isn't necessarily a goal. The goal is to improve or change the current Delta Works in Zeeland and South Holland, based on the perspectives of different stakeholders. Surely protection against flood is one of the main goals, but other factors also need to be taken into account. For example environment and economic aspects. While the goal is not to provide absolute protection, it is crucial to reduce the risks of flooding. This conceptual framework is based on Nafari's *(R. H. Nafari, 2018)* description, however it further incorporates stakeholders perspectives regarding flood risk. It is deemed essential to include stakeholders within flood risk management, since they have different interests and concerns regarding flood risks management. Stakeholders vary on their perspectives on multiple factors, like technical, economic and environmental aspects, these differences lead to different perspectives regarding flood risk management as a hole, see figure 10.

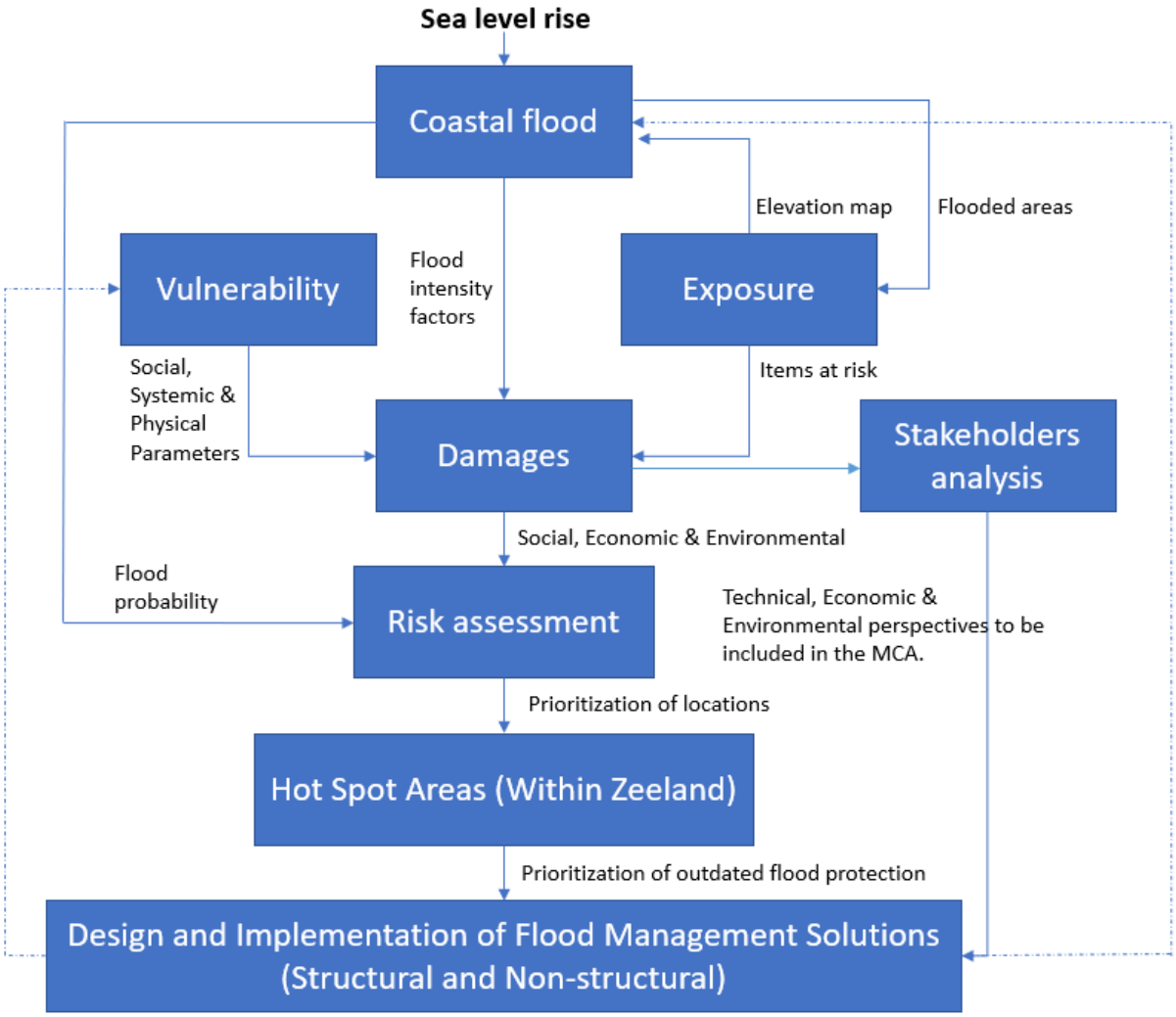


Figure 10: Altered flood risk management.

1.2.5 METHODOLOGY

This study looks through the lenses of multiple stakeholders in order to get a better understanding regarding different adaptation approaches. The research question and the sub questions are partly answered by a literature study, in which scientific papers and articles function as the main source of information. Different stakeholders have been interviewed to get additional information that is used to determine which adaptation approaches are preferable. This report has been constructed over an approximated span of half a year. The research is specific for the context of ILWM (International Land & Water Management) which the main focus is on WSG (Water Systems and Global Change Group), while using a civil engineering background. The nature of knowledge will be social but also technical constructed. For this case study interdisciplinary research is required, in which different disciplines are integrated. Which involves different frameworks and perspectives. It requires a combination of social science, applied science, natural science and humanities.

Sub question one includes information from climate scenario models obtained from literature research, which predict the rise of the sea level till both the year 2100 and 2150 due to climate change. Within this chapter sea level rise projection based on the Deltacommision 2008 findings, are compared with more recent projections. Time periods have been determined which indicate when certain sea levels are reached according to each projection. The differences are compared and used for the second question.

The second question provides more clarity about the current state of the Delta Works. The different projections from question 1 indicate different years in which a certain Delta Works will no longer be functional. These are listed to ensure this information can be used for question 3.

The third question analyzes four different approaches regarding protecting against sea level rise. Each of those approaches has been explained in order to create a clear picture about the pros and cons regarding these strategies.

The fourth question describes the main stakeholders and determines their perspectives related to these approaches and four criteria.

- **Literature:**

All of the sub question required some sort of literature study. This was required to verify information and achieve the desired results. The main source of information regards published reports about sea level rise and the effects on the Netherlands. This regards comparing different data on subjects like climate change, sea level rise, the Delta Works but also the impacts on different sectors like the environment or the Dutch economy. Both scientific articles and public data from stakeholders have been used. In order to ensure the used data is reliable, it is important to analyze the source of the information.

- **Interview experts:**

Different experts have been interviewed since not all information can be found online about the specific technical aspects of the different flood protection systems. These interviewed experts mostly include stakeholders. Experts have been questioned for very specific topics in which they are specialized. Most of the data from experts has been collected simultaneously during the stakeholder interviews. Yet specific questions have been asked that are not directly part of the MCA but rather other topics regarding this report.

- **Interview stakeholders:**

Some information is available online about the stakeholder, yet this is limited. It is important to interact with the different stakeholders in order to use this information for the MCA. Different perspectives are required regarding environmental, economic and technical aspects. Information is required about the perspectives of the provinces, Rijkswaterstaat, waterboards and the Deltacommissie.

- **MCA:**

A MCA is an useful approach which incorporates a mixture of quantitative and qualitative information while taking the preferences of different stakeholders into account (*Qureshi M.E et al., 1999).* Four different categories are included into the MCA. The environmental and economic criteria are important to analyze vulnerabilities and opportunities due to climate risks *(UNFCCC, 2022)* like sea level rise. The economic criteria is required on almost all stages of the assessment of adaptation needs, like identifying desired adaptation actions, compiling them or determining the capacity or finance regarding them. The technical criteria is also essential to determine the capacity and to determine how realistic certain approaches are *(UNFCCC, 2022)*. The main goal of the adaptation strategies is to provide protection against flooding, which requires solutions to be reliable. Since this concerns solutions which have to be efficient and reliable for a long period of time and there it impossible to accurately determine the needs and opportunities within the Netherlands in the year 2150, it is essential to also include the future adaptation criteria.

It is possible to include an endless amount of criteria however this would become chaotic and difficult to analyze considering there are still a lot of uncertainties regarding the actual impacts of adaptation strategies. One criteria that can be linked with all of the earlier described ones, are future proof/future adaptation possibilities. Stakeholders have different perspectives regarding the four criteria this has been taken into account by connecting different numbers to each criteria. Each number represents their own factor, the higher the number the more important a criteria is. This number will be multiplied by a number from 1 to 5 which indicates how well an adaptation measure scores on a certain criteria. This range is relatively small, since there is still a lot of uncertainty regarding the adaptation approaches and their impacts *(Infrastructure Australia, 2021)*. It would be unwise to use a bigger score range since stakeholders are unable to link statistical data to most of their choices. Referring to these scores in words, such as negative, neutral or positive decreases the change of different interpretations of these factors *(Infrastructure Australia, 2021)*.This process is essential to determine the weights of different criteria while taking stakeholders perspectives into account *(Infrastructure Australia, 2021)*. Different weights are crucial since it leads to different outcomes *(Odu G, 2019)* and there are clear differences between the importance or impacts of certain criteria. Finally the total scores are compared and the highest score represents the most suitable adaptation measure. However the MCA does also indicate the different stakeholders perspectives regarding different adaptation approaches, which is the main goal of this report.

2. THE EFFECT OF CLIMATE CHANGE ON EXTREME EVENTS AND THE SEA LEVEL.

Within this chapter the predicted sea level rise of the Deltacommisie (2008) is compared with other projections. The Deltacommissie has been appointed in 2007 by the Dutch parliament. This commission came with a program to ensure the water safety and freshwater availability of the Netherlands.

According to the Deltacommissie a sea level rise between 0,65 and 1,3 meters in 2100 will occur. This includes the effects of land subsidence (0,1m) and represents the possible range of the future sea level. It is important to take those into account, to ensure that the measures will be efficient for a longer period of time *(Deltacommisie, 2008)*. This is based on a combination of information from KNMI 2006 *(KNMI, 2006)* and the IPCC 2100 scenarios from 2007. Figure 11 indicates the sea level rise at the Dutch coast excluding land subsidence according to the Deltacommissie in 2008.

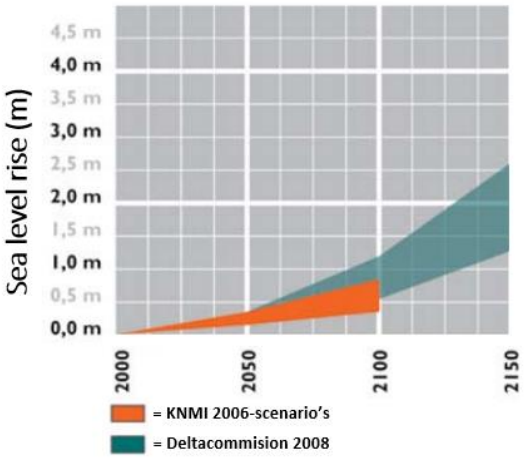


Figure 11: SLR (Deltacommsie, 2008)

This information is no longer up to date and the KNMI will provide new information in 2023 *(KNMI, 2023)*. This is necessary since climate models and thus sea level rise predictions become more reliable every year *(Räisänen J, 2007)*. These models are based on measurements from previous periods in terms of for example sea level rise or temperature change *(Räisänen J, 2007)*. This can provide a more accurate indication about future sea level rise factors. Another reason why current models tend to be more reliable is that the period between 2008 and 2022 can be based on measurements instead of predictions. This makes the jump to 2100 or 2150 smaller and thus decreases the uncertainties in the models, which increases the further the model predicts the future.

The sea level rise is influenced by multiple factors, which can be correlated with temperature rise. Just like sea level rise, temperature changes are also influenced by multiple factors. Natural events can cause changes in the temperature, but so does human interference. The emission of greenhouse gasses play a significant role in the temperature around the world. It is important to decrease the amount of greenhouse gasses in the atmosphere to reduce climate change. Multiple climate summits have taken place in which promises have been made to battle climate change, yet almost none of the promises are actually fulfilled. 14 years have passed since the Deltacommision released their data in terms of the sea level rise. This period of 14 years has been included in newer climate models as reference and indications for predictions. There is more information available about climate policy and the effects of greenhouse gasses. All these factors contribute to more accurate models with less uncertainties.

There are recent reports about the expected sea level rise that differ from the one used by the Deltacommissie. Figure 12 *(Haasnoot et al., 2020)* indicates the increase in sea-level at the Dutch coast. Blue indicates RCP4.5^{A}, while red indicates RCP8.5^{A}, both are based on Le bars *et al (2017).* RCP stands for Representative Concentration Pathway. These range from 1.9 until 8.5 in which the numbers indicate the concentration of greenhouse gases in the atmosphere in 2100 *(Coastadapt, 2017)*. Regarding this report a higher RCP number indicates a more significant sea level rise.

RCP 8.5 indicates that emissions will continue to increase during the 21st century and is considered the worst-case scenario in terms of climate change. The 4.5 RCP scenario is considered the intermediate scenario which predicts a peak emissions between the years 2040 and 2050 and a decline from that point. These are high-end SLR scenario's for the Netherlands that assume a rapid ice sheet loss *(Haasnoot et al., 2020)*. Regional redistribution of ocean water due to changes in ocean currents, winds and local steric effects are taken from the CIMP5 models *(Jackson L. P. and Jevrejeva S, 2016) (Haasnoot et al., 2020)*. A Monte Carlo method is used to the uncertainties that occur between individual sea level rise contributors *(Kopp R E et al., 2014).*

Until the year 2050 the RCP^{A} scenarios are considered high-end SLR projections, which are similar compared to currently used scenarios regarding the Delta Program *(Haasnoot et al, 2020)*. However from 2050 onwards they start to deviate sharply, due to the incorporation of models regarding significant icesheet instability *(Nauels et al., 2017) (Wong et al., 2017)*. The bandwidth ranges from 5th until 95th percentile. Due to uncertainty in ice-sheet processes a 5 meter sea level rise cannot fully be ruled out in 2150. The dark red and blue lines indicate the median SLR, which will be used in this report. The median has been used since there is a lot of uncertainty about the future sea level rise. For example in 2100 RCP8.5^{A} indicates a SLR between roughly 0,75m and 3,15m, which is a huge difference and would result in different approaches in terms of solutions to protect the Netherlands against coastal floods.

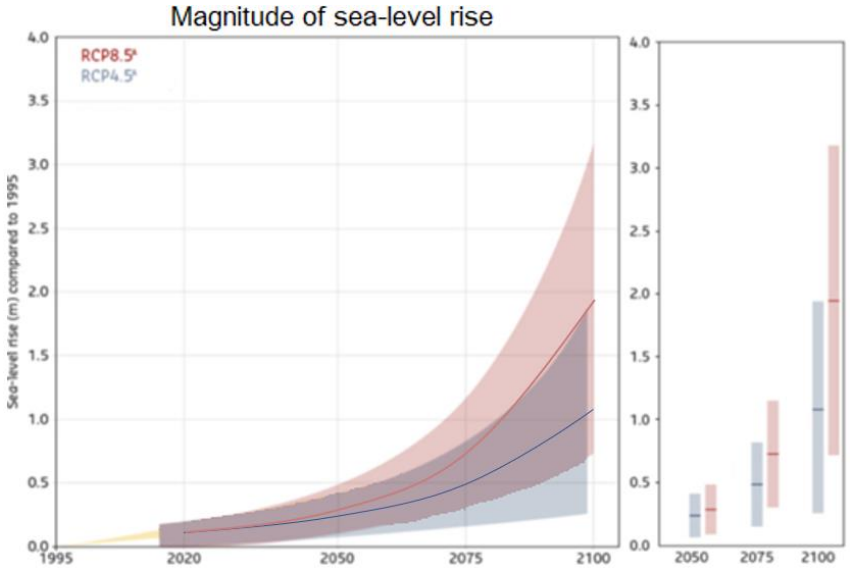


Figure 12: Magnitude sea-level rise compared to 1995. (Haasnoot et al., 2020)

Since RCP8.5^{A} is already the most extreme scenario, the maximum sea level rise is also considered to be the most significant in this projection. A 3,15m SLR in the year 2100 seems to be unlikely and would cause to take drastic designing actions that are not likely to be necessary. Using the most extreme uncertainty for RCP8.5^{A} could likely result in over engineering and overspending. However this can result in the construction of robust measures which will be able to withstand sea level rise in the years beyond 2150. The minimum SLR according to the RCP8.5^{A} in 2100 is significantly lower. However this could lead to under engineering which can lead to failures or to a significantly lower life expectancy of the new solutions. The same arguments can be made for RCP4.5^{A}. This is why the median of both the RCP4.5^{A} and RCP8.5^{A} scenario will be used for within this report.

Coastal flood defense systems in the Netherlands like the Delta Works are designed based on certain life expectancy of usually 100 years, during which this structure must be able to withstand storms with a return period of once in 4.000 or 10.000 years (depending on the location and structure). This results into certain design requirements, yet the structures are always designed to withstand even more extreme situation to protect against uncertainties. Even if the sea level rise tends to be more extreme than anticipated, structures would be able to provide protection until a certain point. Yet this is not desirable for most of the structures. The Oosternscheldt barrier is capable to withstand an significant sea level increase, however this would result in a permanent division between the delta area and the North Sea. While this civil structure would still provide protection, it would come at the costs of its other functions.

Table 3 is based on figure 11 and 12 and compares the sea-level rise according to *(Deltacommisie, 2008)* to *(Simonovic, P et al., 2022)*. Each projection is marked in its own colour. These colours also indicate the uncertainty of different values according to these scenarios. A dark colour indicates a relatively small uncertainty, while a lighter colour means increased uncertainty.

Table 3: SLR per projection based on figure 11 and 12.

SLR	0,5m	0,75m	1,0m	1,25m	1,50m	2m	2,5m
Deltacommision 2008	2060	2075	2088	2105	2113	2128	2146
RCP4.5^{A}	2075	2087	2097	2106	2112	2125	2135
RCP8.5^{A}	2065	2075	2081	2085	2091	2103	2110

The table indicates that the projections become more uncertain over time. This is due to the fact that uncertainty about climate change and policy making increases over time. It is nearly impossible to accurately predict the determination of different actors regarding the reduction of climate change and thus sea level rise.

During the 2022 climate summit it became clear almost none of the countries reached their goals and little where willing to refine their climate objectives *(Arora, P & Arora N K., 2023)*. Although there were some positive aspects about the climate summit, no real changes have been made that would indicate a significant reduction in emissions and thus sea level rise. In fact climate scientists are becoming more pessimistic about the future aspects and expect a higher maximum temperature compared to the increase of 1.5 degrees Celsius agreed up on by the United Nations *(Nordgren A, 2021)*. During the summit there were also calls for removing the earlier agreed max temperature of 1.5 degrees Celsius and a suggestion to use a max temperature increase of 2 degrees Celsius *(Arora, P & Arora N K., 2023)*.

The Deltacommision expects the sea level to increase to 0,50 meter as early as 2060 *(Deltacommisie, 2008)*. This threshold will be reached earlier compared to the other climate models, yet the RCP8.5^{A} scenario agrees on a 0,75 meter increase in 2075 *(Haasnoot et al., 2020)*. From that point on the RCP8.5^{A} becomes more extreme compared to the data used by the Deltacommissie and rapidly increases the need for new solutions to provide protection against the SLR. The RCP4.5^{A} predicts the SLR to increase slower compared to the Deltacommision until 2110 *(Haasnoot et al., 2020)*. This increases the amount of time that is available to create new solutions to battle the SLR. The current Delta Works would also be able to function for a longer period of time. However this changes after 2110, since the model projects a higher SLR compared to the Deltacommision.

An increase in the sea level also results in an increase of the water level within the rivers that are connected to the delta area. Figure 13 indicates the increase in water levels at certain point upstream due the changing sea water level.

This figure uses an average Rhine discharge of 2200m^3/s. The top figure indicates water levels in mNAP at different locations upstream of the Waal as result of different sea water. The bottom figure indicates the change in water level within the river according to different sea level increases.

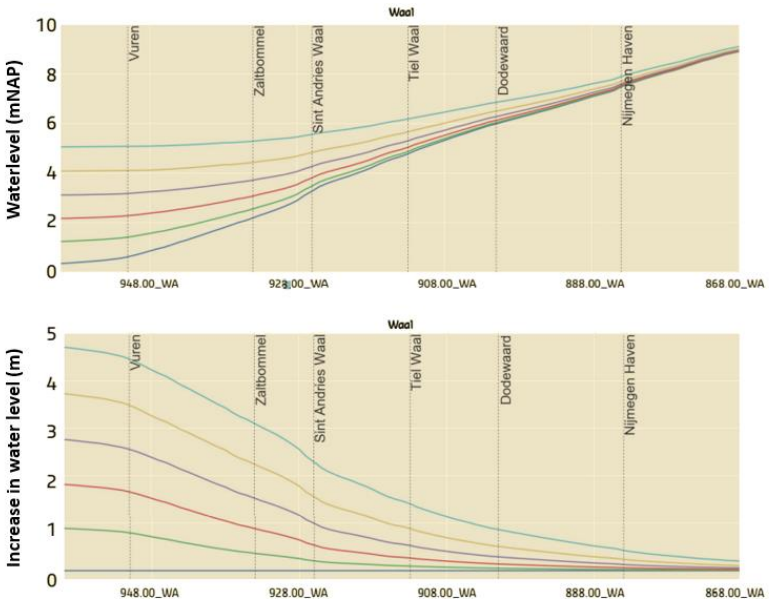


Figure 13: River water level due to SLR (Deltares 2018).

3. THE LIMIT OF THE CURRENT DELTA WORKS

Before analyzing the different adaptation strategies, it is important to analyze the current Delta Works first. In this chapter the biggest risks caused by sea water level rise are described.

3.1 CLOSING FREQUENCY

The Eastern Scheldt Barrier and the Maeslant Barrier are some of the complex structures that divide the North Sea from the Dutch delta. These structures have to be able to open and close when necessary. This is dependent on the water level of the North Sea.

The Maeslant Barrier closes when the surrounding waters close to Rotterdam reach a sea level of 3 mNAP. The closing progress takes around two hours *(Rijkswaterstaat, 2022),* yet this does not include the reopening of the structure. When the Maeslant Barrier is closed, ships will not be able to pass the Maeslant Barrier. The duration of this period is dependent on the duration of the high water levels. This is highly variable, but even if the barriers only have to be closed for a short period of time, it will limit transport for the entire day. This is due to the fact that the Maeslant Barrier has to be closed well before an extreme event occurs. It would be unsafe to close the barrier just before this extreme event, because their might be possible issues or miscalculations. The closure reliability of the Maeslant barrier is considerably low, there is a 1/100 probability of failure each closing *(Retico, J., 2017)*. An increase in average sea level will not only result in an increase of the frequency in which the Maeslant Barrier has to be closed, but also the duration of this process. It is reasonable to assume that the barrier would be forced to close for multiple days in a row if the sea level has risen significantly. A sea level rise of 1,5 meters would result in a closing frequency of 30 times a year. However the difference between the regular sea level and the maximum sea level which requires the closure of this civil work is sharply decreased. There is 1,5 meter less leeway before extreme heights are achieved resulting in longer closer periods as well.

In addition to providing protection against floodings, it is also essential for the Maeslant Barrier to ensure that the harbor of Rotterdam is accessible for ships and thus trade can continue. This is extremely important for the Netherlands. The port of Rotterdam had an added value of 23,8 billion in 2020 *(Havenmonitor, 2021).* In the first 9 months of 2022 351 million tons of goods passed through the port of Rotterdam. This indicates that an average of 1,3 million tons of goods pass through the Maeslant Barrier on a daily basis. On average the amount of transported goods through the port grows on a yearly basis. The quantity in tons of goods has increased with an average of 0,25% per year since 2016 *(Port of Rotterdam, 2022)*. This growth will be used to determine the effect of the closing frequency in the future.

Yet the goods can differ a lot depending on multiple factors, since the needs of the Netherlands, Europe and its citizens/industry are variable. For example in 2022 the amount of natural resources that pass through the port of Rotterdam significantly increased, while other goods saw an decrease in quantity. The reason for this change is due to the conflict between Russia and Ukraine and shows that the port of Rotterdam is dependent on many things. *(Port of Rotterdam, 2022)*

However an increase in goods that pass through the port of Rotterdam is still likely to increase over the years. Meaning that the average of 1,3 million tons per day will likely become higher over time. Being able to receive and ship these goods is critical for the Dutch, but also other European companies. Since a lot of companies in Europe are dependent on the port of Rotterdam is impossible to accurately indicate the economic effect of closing the port during different periods until 2150, this would be a thesis on its own.

Closing the port would in most cases cause a delay in delivery, but the goods will not simply cease to exist. This makes it increasingly difficult to determine the economic impacts as result of closing the barrier. A relevant indication regarding the importance of the port of Rotterdam is the fact that in 2021 565.000 jobs within the Netherlands where directly dependent on the port of Rotterdam *(Port of Rotterdam 2021).* Limiting the access to the port of Rotterdam would impact a lot of companies in a big variety of sectors. This could also mean that other European ports could use this opportunity to grow significantly at the cost of the port of Rotterdam. The direct and indirect added value of the Port of is 63 billion euro, which is 8,2% of the GDP of the Netherlands *(Port of Rotterdam 2021).*

Table 4 indicates the closing frequency and the yearly costs in tons of goods that are caused by a certain increase in the sea level rise.

Table 4: Closing frequency Measlant barrier, based on (Haasnoot et al., 2020)

Maeslant Barrier						
SLR	**0,0 m**	**0,5m**	**0,72m**	**1,0m**	**1,25m**	**1,5m**
Closing frequency (times per year)	1:10	1:3	1:1	3:1	10:1	30:1
RCP 8.5a	2022	2065	2074	2081	2087	2092

Figure 14 and 15 indicate how many million tons of goods will be delayed every year. This graph takes a yearly growth of the port in Rotterdam into account. Yet this is dependent on a lot of factors and could lead to a significant increase or decrease in the amount of delayed goods. It should also be noted that the barrier might be closed for longer periods due to an higher base level of the sea level. In combination with extreme events this could lead to moments in which the barrier is closed for a longer period, while the graph only takes closing period of 1 day into account.

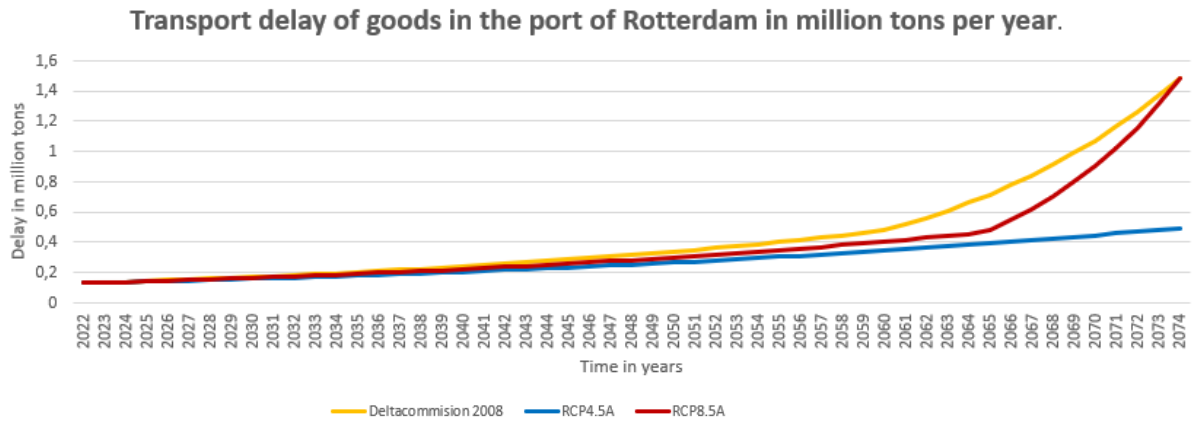


Figure 14: Transport delay of goods in the port of Rotterdam in million tons per year (2022-2074).

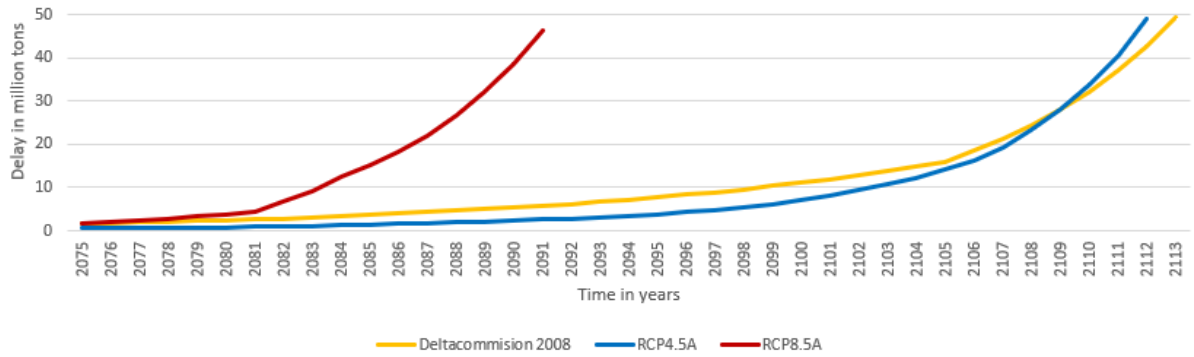


Figure 15: Transport delay of goods in the port of Rotterdam in million tons per year (2075-2113).

The construction phase of a new water barrier will also cause a shipping delay in the port of Rotterdam. However this is heavily dependent on the type of construction. Maintaining the current structure will likely cause a bigger shipping delay compared to the construction of a new sea barrier. It is desirable to construct a new barrier or a different approach before this period. This is important because delaying the construction of the new solution due to transport delay concerns would be counteractive at this point, since the amount of delay in tons would be the same in both situations. It would still be necessary to construct the barrier resulting in a delay in tons that would be double compared to immediately constructing a new solution.

A delay of 10 million tons of goods per year would impact little over 2 percent of the current goods in the port of Rotterdam *(Port of Rotterdam, 2022)*. This would mean that the delay of goods in the port would have increase more than 75 fold. Before reaching this value it could be argued that the costs of constructing a new solution are not worth the delay in million tons of goods. However depending on the projection, this would significantly increase every year from this point on. Table 5 indicates that on short term the delay does not seem that significant but it increases significantly. For example in a period of 19 years, the RCP8.5[A] model projects an increase in delay which is 40 times higher compared to 2071, while this only increases exponentially at this point until the port becomes unusable. It is not a question if but at what rate the sea level rise would negatively impact the transport within the port of Rotterdam. It is simply not sustainable to maintain the current method over a longer period.

Table 5: Transport delay in millions tons within the port of Rotterdam as result of SLR.

Maeslant Barrier transport delay in million tons						
Tons in millions	**1**	**1,5**	**5**	**10**	**20**	**40**
Date in years						
Deltacommissie 2008	2069	2074	2089	2098	2106	2111
RCP 4.5[a]	2082	2085	2097	2102	2107	2111
RCP 8.5[a]	2071	2074	2081	2083	2086	2090

The main reasons why the Eastern Scheldt Barrier has the ability to open and close is to ensure fish migration and create a more natural transition between salt and fresh water. If these structures are closed for longer periods during the year, it will have negative effects on these factors. However the Eastern Scheldt Barrier in combination with other barriers have already significantly decreased the amount of possibilities for migratory fish to migrate from

salt to freshwater and back and forth *(Kamermans et al., 2013).* Permanent closure of the Eastern Scheldt Barrier would have significant impacts on the ecology within this area. If the Eastern Scheldt Barrier is permanently closed, this means that an alternative solution is required in order to be able to maintain or improve the possibilities for fish to migrate from salt to fresh water and back and forth.

Closing the Eastern Schledt Barrier for a longer period would also result in a surplus of fresh water which could lead to river flooding if no measures are taken. Realistically this problem could be countered by the usage of pumps, which would mean that the Eastern Scheldt Barrier would still be functional. But this would require a big pumping station which needs to be active all the time. Another problem occurs if these structures are forced to close more frequently, their failure probability will increase due the frequent movement of technical parts. Yet it is possible to significantly decreased these risk by having regular checks.

Table 6: Closing frequency Eastern Scheldt Barrier, based on (Haasnoot et al., 2020)

Eastern Scheldt Barrier					
SLR	0,0 m	0,50 m	0,75 m	1,0 m	1,3 m
Closing frequency	Closed 1 time a year	Closed 5 times a year	Closed 15 times a year	Closed 45 times a year	Almost permanently closed
RCP8.5a	2022	2065	2075	2081	2087

3.2 RETURN PERIOD

Coastal barriers have been designed to withstand an extreme events that occur once every 4.000 years, while river barriers have a norm of 1/1.250 years. Increased sea level results in an increase in extreme events *(Rijkswaterstaat, 2022).* The Delta Works where designed on a sea level rise of 20 to 50 cm per century with a life expectancy of 100 to 200 years *(Rijkswaterstaat & Deltares, 2008*). According to all 3 of the projections this number will be exceeded, resulting in higher failure probabilities. Table 7 indicates the critical SLR for all Delta Works that provide direct protection against the North Sea. The table indicates that for the Measlant Barrier the sea level rise and increase of extreme events is more critical compared to increase in closing frequency.

Table 7: Return periods of extreme events at coastal barriers in the delta area.

Return periods of extreme events at coastal barriers in the delta area		
Barrier	**Critical SLR**	**Source**
Eastern Scheldt barrier	1,0 m	*(Deltacommisie, 2008)*
Measlant Barrier	0,5 m	*(Deltacommisie, 2008)*
Haringvliet Dam	0,90 m	*Based on (Rijkswaterstaat & Deltares, 2008*).
Veerse Gatdam	0,90 m	*Based on (Rijkswaterstaat & Deltares, 2008*).
Brouwersdam	0,90 m	*Based on (Rijkswaterstaat & Deltares, 2008*).

Dikes and dunes also are essential to ensure that the Delta Works function as a whole. If dikes or dunes do not meet similar safety regulations as other Delta Works, the flooding probability will be negatively impacted due to it. The Delta Works are as strong as it weakest points. While dikes and dunes seem relatively easier to improve and maintain this is not always the case. The Netherlands has an enormous amount of river and sea dikes,

which need to be maintained and constantly improved. However there is a limit for dike improvements, due to different reasons. One of the most important aspects is the lack of available space, due to population density or environmental aspects. There are too many different dikes with variable characteristics which makes it impossible to determine a single date on which dikes are no longer a realistic option.

3.3 CRITICAL POINTS FOR ADDAPTATION

The sea level rise will directly impact the fresh water availability. Saline water will reach further inland, causing problems for the environment and fresh water availability. Along the coast line, low-lying areas will be affected due to groundwater seepage *(Haasnoot et al., 2020).*

The Rhine has a maximum discharge of 16.000 m^3/s, which is expected to increase to 18.000m^3/s in 2100. The winter discharge of the Meuse will also increase from 3.800 m^3/s to 4.600 m^3/s in 2100 *(Deltacommisie, 2008).* The water levels within the rivers will also directly increase due to the sea level rise. Measures have to be taken or there will be an increased chance of river floods.

Table 8 is based on the previous paragraphs. Every structures with exception of the Measlant Barrier indicates an earlier tipping point in RCP 8.5[A] compared to the projection of the Deltacommissie. However this indicates an ultimatum, project like this tend to have an implementation time of 30 years, even in the case of RCP 4.5[A] this implies that implementation of new strategies needs to be started in the middle of the 21st century.

Table 8: Critical points for adaptation.

Structure	Deltacommissie	RCP 4.5[A]	RCP 8.5[A]
Brouwersdam	2085	2090	2080
Eastern Scheldt Barrier	2088	2097	2081
Haringvliet Dam	2085	2090	2080
Measlant Barrier	2060	2075	2065
Veerse Gatdam	2085	2090	2080

The Delta Works won't be able to function as intended from the year 2080 on. Even before this period changes have to be made, for example the Measlant Barrier needs to be replaced at the year 2065. Even though other Delta Works separately will function for a longer period, this is not desirable. This will come at the costs of an increased river water level, environmental problems and salination. The Delta Works function as one collective *(Deltacommissie, 2008)*, adaptations regarding the Measlant barrier will influence other structures within the delta area. And it is essential to have completed construction way before the year 2065, however before construction a lot of arrangement and uncertainties have to be addressed and different designs have to be made, while incorporating stakeholders. This process is very time extensive *(Diana M, et al., 2010)* and thus needs to be initiated already.

The original costs of the Delta Works where estimated at 9 billion euro in 2007. However the total costs of adapting the Delta Works to future situations could cost well over 80 billion euros *(C.J.H. Aerts, et al, 2012)*. This is dependent on many aspects, like the actual severity of sea level rise or the adaptation measures that are used. However the benefits of flood adaptation usually exceed the initial costs *(C.J.H. Aerts, 2018)*.

4. POSSIBLE ADAPTATION MEASURES

This chapter describes four possible adaptation approaches to counter the problems that the current Delta Works will face in the (near) future.

The Delta Works main purpose has always been to protect against flooding. This has been done by shortening the coastline so that dikes and dunes in these areas didn't have to meet the same requirements as in other areas. Due to a significant increase of the sea level rise other strategies should be considered. IPCC describes 6 different response to coastal risk and sea level rise, see figure 15 *(IPCC, 2022).*

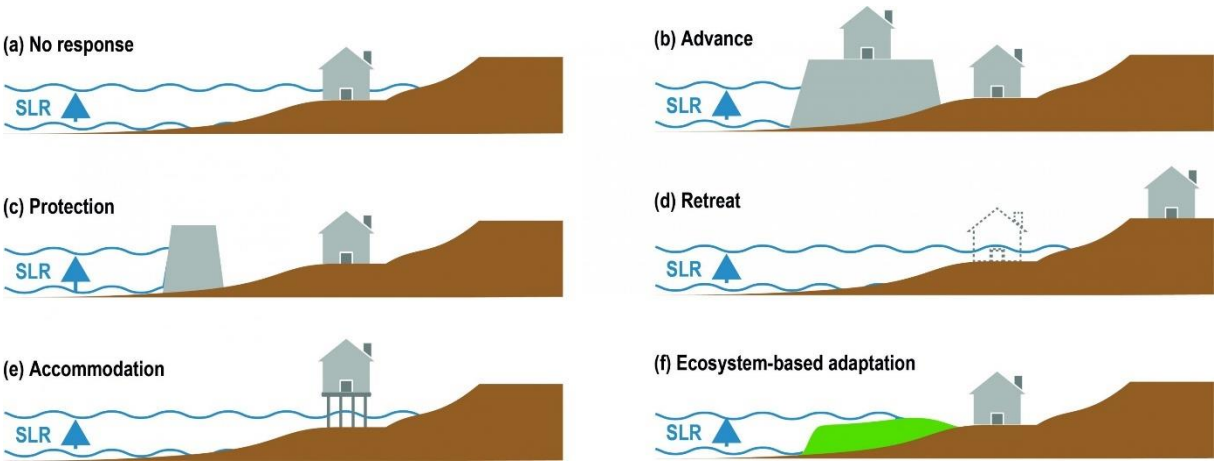


Figure 15: 6 Different responses to Sea Level Rise (IPCC, 2022).

These responses are very broad and not specifically intended for the Netherlands. The first described response is simply to let it happen and do nothing. However this is not realistic option for a country like the Netherlands since a significant part of the Netherlands is located below sea level or in vulnerable areas. This strategy might be realistic on a smaller scale but not on a national scale, this is also the case for similar high-income countries in Europe *(Song, J et al., 2016)*. The other responses are more realistic on a national scale, however need to be redefined.

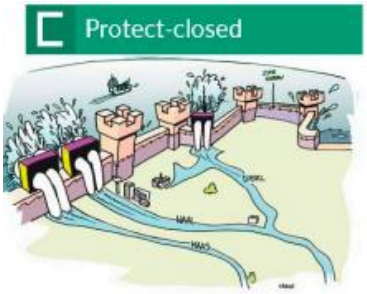
Deltares describes 4 strategies based on these 6 responses, protect-closed, protect-open, advance and accommodate/retreat *(Deltares, 2021*). The initial protection response is divided into protect-closed and protect-open since the distinction between these two approaches has enormous implications for the Netherlands, since it is densely populated and located within a delta. The retreat and accommodation responses are combined since both apply changes in land use while decreasing the need of physical structures to protect against floodings. The ecosystem-based adaptation could combined with multiple strategies like the advance strategy. There are few coastal hazards where the ecosystem-based adaptation response would eliminate all risks, however combined with other solutions there are many cases in which it would make a meaningful contribution *(Reed D, et al., 2018)*. This is why it is important to incorporate this method into the 4 strategies described by Deltares.

Table 9 describes the main points of attention regarding the implementation of these adaptation approaches on a national scale.

Table 9: Main points of attention for adaptation approaches

Protect-Closed approach (4.1)
Current land use can mostly be maintained, which limits the negative effects on the economy. While habitants are not forced to relocate.
Line of exposure against sea level rise is shortened. Resulting in lower cost, maintenance and less possible points of failure.
This approach does require fresh water to be pumped into the North Sea. Mechanical failures or sabotage could lead to river floods.
Salt water and fresh water are separated which is harmful for the fish migration and biodiversity, yet beneficial for agricultural practices.
Current coastline (beach) will be disturbed. Dunes that are frequently exposed to sea water become more prone to erosion.
Ports of Rotterdam and Antwerp have to be accessible, which requires complex sluice systems, which might limit the transport capabilities of both ports.
Protect-Open approach (4.2)
A more natural ecosystem which encourages fish migration and biodiversity.
The ports of Rotterdam and Antwerp remain accessible while increasing river water levels allow bigger ships to pass.
Increased salinization of soil and further decrease of available fresh water sources. Which could harm multiple sectors, especially agriculture.
Improving the sea dikes requires lots of space, which is not always available.
Increase maintenance, costs and in points of failure since more dikes are exposed to SLR.
Advance approach (4.3)
Increase in available space which can be used for multiple purposes, like the energy or tourism sector. This solution could be very promising from an economic perspective.
While this approach could provide opportunities for biodiversity or the environment, it also impacts the current ecosystem of the Dutch coast.
Extra layer of coastal defence, however this implies maintaining the current coastal defence systems simultaneously. This approach is basically a form of the protect-closed/open, however located in the sea. This implies that similar problems like shipping occur in this approach as either of the protect approaches.
The port will be relocated towards the sea, while inland shipping will remain inland.
This approach requires a lot of resources like sand which might prove to be difficult to obtain.
Accommodate/retreat (4.4)
This approach encourages nature to influence the landscape of the Netherlands.
This approach reduces the risks of flooding and need for enormous flood barriers all around the country.
This requires a lot of land use changes and could have significant impacts on many sectors within the Netherlands.

4.1 PROTECT-CLOSED



Protect-closed focusses on protecting vulnerable areas against floodings, especially areas with a high population density, like Rotterdam. This would imply that the Delta Works would completely seal the North Sea of from the delta area. Pumps would be required and dikes should become higher due to increased peak discharge within the rivers. Solutions based on this approach are, the construction or improvement of dams and dikes. The usage of wetland or foreshores and the usage of sediment to protect against water.

Figure 16: Protect-Closed Adaptation Strategy (Carof Deltares, 2021)

Figure 17 indicates how one potential solution regarding the implementation of this adaptation strategy on a national scale, however multiple solutions are possible which also vary on scale. The Delta Works will be closed off from the North Sea and water would be pumped out almost constantly. According to this specific design the pumpstations needs to be located at the Nieuwe Waterweg, Haringvliet and Gevelingen. These designs stretch over the entity of the Dutch coast.

Figure 17: Protect-closed example of national strategy (Haasnoot et al., 2022).

For the Delta Works specifically this would require significant improvements or and in most case the construction of new civil structures. This would result in new water barriers that are capable of providing protection against more extreme water levels. Since all of the current Delta Works function as one collective, these solutions have to be implemented in a national scale. The Scheldt (most southern part of the delta area) is connect to the port of Antwerp, which has to remain accessible. It is essential that before a final decision about the use a protect-closed system is made, this also has to be agreed up on by the Belgium parliament. Currently the protect-open system is used for this area. A combination between the protect-open and protect-closed adaptations seems more desirable and realistic for this reason. There are multiple advantages and disadvantages concerning this approach. It would decrease the length of the shoreline that is directly exposed to the North Sea. This implies that river dikes which are located behind the Delta Works have lower regulations compared to sea dunes. Since the Netherlands is a delta area and has multiple rivers that could threaten a fast majority of the country, this would safe a lot of time and money on improving these dikes. This approach has many similarities with the current system, which is a combination of the protect-open and -closed system. In the past this strategy has always been regarded as an effective coastal defense strategy *(M.M. Hillen, et al., 2010).*

Another benefit from this approach is that it will not force habitants to move to different areas and change their current way of living to ensure their safety. Other approaches do (in)directly have negative effects on the livability or available space in certain parts of the Netherlands. Which could result in either the change of practices for land use or in the relocating of habitants. One of the reason why this approach doesn't have big impacts on the chance of land use, is because it drastically limits the amount of saltwater that mixes with fresh water. While this could be viewed as both a pro or a con, this will decrease the negative effects on for example farming practices. An increase in sea level would mean that salt water would reach significantly further upstream. This decreases the amount of available freshwater and also makes the ground more saline, which can be disastrous for farmers. Salinity limits crop yield and thus profits for farmers *(Xie H, et al., 2021).* Considering that a lot of land in the Netherlands is used for agricultural needs, this would also impact the economy on a national scale.

Like earlier mentioned, there are disadvantages connected to completely separating salt and fresh water. This approach would require pumps to empty river water (fresh) into the sea (salt). Yet sea water would scarcely be allowed to enter the river, since that would defeat the purpose of this approach. This would mean that it becomes almost impossible for fish to migrate from the sea to the river or the other way around. This has a negative effect on the entire ecosystem within the Delta Works and also along the Dutch coast. This approach would not only have negative effects on the ecology, but also the economy. It would decrease the ability for ships to enter or leave the delta system. Which would damage the economy and decrease the importance of the port of Rotterdam. This approach would still allow the port the be used, however some major challenges have to be overcome. The Port of Rotterdam would only be accessible by multiple sluices, which could impact the maximum quantity and size of ships that enter and leave the harbor. It would have a negative effect on the transport speed. Currently the Port of Rotterdam is one of the most important and largest ports in Europe. Yet there are a lot of ports in Europe who could benefit from an increased transport delay in the port of Rotterdam. These ports could attract ships/companies that would otherwise use the port of Rotterdam, resulting in a decrease or limited growth for the port of Rotterdam.

4.2 PROTECT-OPEN

The protected-open strategy is similar with the currently used strategy for the Delta Works. The dikes within the Delta Works would be improved but the connection between the North Sea and the delta would be maintained so that ships can still enter the port of Rotterdam for example. Solutions based on this approach are, the construction or improvement of flood barriers and dikes. The usage of wetland or foreshores and the usage of sediment to protect against water.

Figure 18: Protect-Open Adaptation Strategy (Carof Deltares, 2021)

Figure 19 indicates one of the measures implemented on a national scale. In this example the rivers are connected to North Sea. While this figure illustrates the entire Netherlands, the focus is on the delta area. The Delta Works are removed, yet all of the dikes and dunes that are currently exposed to the Nort sea will be improved. This figure 19 also indicates that the total length of dikes that are exposed to the sea level rise will increase compared to the protect-closed approach. This figure only visualizes a single of the possible solutions, yet there are other solutions possible on a national level that match this approach.

Figure 19: Possible solution according to Protect-Open approach. (Haasnoot et al., 2022).

There are multiple advantages and disadvantages concerning this approach. The protect-open approach would create a more natural ecosystem *(Haasnoot et al., 2022)*, in which fishes could freely migrate from the salt to fresh water and the other way around. The tides would play a big role for the water level within the river system *(Haasnoot et al., 2022)*. This sounds very promising for ecology, however this is not necessarily the case. While this is beneficial for oceanic species and plants, this would have disastrous effects on the plants and species *(Schuler M, et al., 2019)* that are currently living in the Delta Works. Since periods of droughts are also expected to increase in frequency and severity within the Netherlands this could result in even more negative effect on the ecology and the profit from farming within the Zeeland *(van Duinen, et al., 2015).* The combination in de decrease of freshwater availability within in the Netherlands during longer periods and the salinization of freshwater and groundwater would only worsen this problem.

One of the big economic advantage is that ships would still be able to access the port of Rotterdam and travel from river to the sea or the other way around. An increase in water level in the rivers is usually also beneficial for shippers. This allows bigger ships to travel upstream. This approach allows most of the habitants to remain in the area where they are currently living. A downside is that although dikes will be located around the river, salt water would still have an impact on the surrounding areas.

The salt water will infiltrate in the groundwater and cause an increase in the salt concentration in the usually fertile soil around the rivers. This will have negative effects on agriculture practices within those areas *(Negacz et al., 2022).* This is likely to have significant impacts, considering agriculture has been big part of the Dutch economy for a long time through history *(Breedveld, J. et al., 1980)*. This would negatively affect the crop yield, but also growth of plants in general. In more extreme cases this will result in relocating or changing practices in these areas. This could also lead to negative effects in ecosystems that are dependent on the freshwater of the rivers.

This approach increases the shore line compared to the protect-closed system, which results in stricter norms for river dikes. Not only would norms be stricter, the water level in the rivers would increase almost at the same rate as the sea water level. This would mean that a significant amount of river dikes would need to be improved, which according to Deltares leads to many conflicts about the availability of space. Figure 15 indicates the dikes in which these conflicts will occur due to an increase in 1 meter of height. The different colors indicate the increase in width that is required for an increase of 1 meter in height for a particular dike section. Yet some of these dikes have to be increased with more than 1 meter in height. This would simultaneously increase the width of these dikes and also the costs. The solution described in figure 19 requires a significant amount of dikes to be improved compared to the protect-closed strategy mentioned in figure 20. This would mean that people or farmlands that are located closely to the dikes might need to relocated or decrease in size. This in combination with an increase in the salt concentration within the ground level would have negative effects on environmental, economic aspects and also the livability close to the rivers.

Figure 20: Conflicts due to shortage of available space for dike improvements (Deltares, 2022).

Since the entirely of Zeeland is located within the delta area, this could have negative effects on a significant part of the province. The population of Zeeland has been growing slowly for the past few years and has one of the lowest population densities in the Netherlands *(CBS, 2022).* The biggest sector in Zeeland is the commercial sector, making up around 50% of the companies located within Zeeland. However around 20% of the companies within Zeeland are agricultural companies *(CBS, 2022)*, who would be negatively impacted by an increase in the salt concentration within the area. Since the population of Zeeland is slowly growing, these effects might even result in a decrease in the growth of the population in some areas within Zeeland, although further research is required to verify this statement.

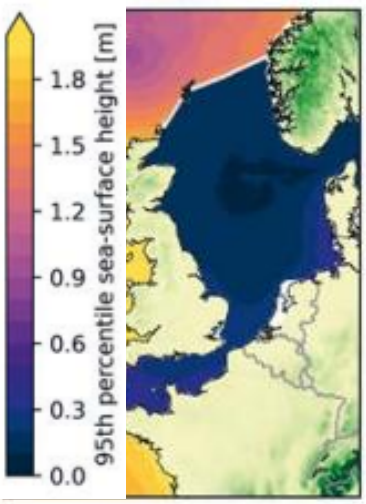
4.3 ADAVANCE

This approach focusses on increasing the safety while also creating more living space. Coastal defenses start within the sea creating more land. Solutions based on this approach are, the construction of flood barriers, islands and dikes outside of Dutch coast. There are a lot of possibilities within this adaptation strategy, since the scope is not limited to the Netherlands land area.

Figure 21: Advance Adaptation Strategy (Carof Deltares, 2021)

Solutions can be applied on a national level, or even on a scale that would affect multiple European countries and indirectly other countries around the globe. The scope could also be focused on the Delta Works, which could mean a civil structure would be located within the North Sea that separates Zeeland form the open Sea. Figure 22 indicates an altered solution based on Deltares, in which the focus is on the delta area. This solution would not only protect Zeeland, but also parts of South-Holland. Within this design multiple sluices have constructed to allow ships to enter and leave the Netherlands. The relocation of (parts) the port of Rotterdam should be considered in this solution.

Figure 22: Possible solution on national level according to the Advance Approach. (Haasnoot et al., 2022).



This solution can also be implemented on an even bigger scale. A system that consists out of a dam with a length of roughly 500km (300 miles) and one of 160 km (100 miles) has even been proposed as a possible solution *(Groeskamp S, et al., 2021)*. A project of this size has an expected cost between 250 and 500 billion euro and will have significant impacts on aquatic life. Groeskamp also mentions that most people are desperately against this plan, due to multiple factors. Yet he also admits that sea level rise might force us to implement a solution similar to this. He also proposes ideas who do not fully close of the North Sea, yet still decrease the water level and wave height in most areas. Figure 23 indicates how enormous these dikes would have to be.

Figure 23: Possible solution on international level according to the Advance Approach (Groeskamp S, et al., 2021)

This approach will increase the land availability while also ensuring the safety of the Netherlanders against coastal floods. It could also stimulate tourism which is beneficial for the Dutch economy. However all of this is heavily dependent on the type of solution, for example the creation of coastal island which have a double function (housing / protection) possibly attracts more tourist compared to a dike located in the sea. There are examples of man created island that increased tourism take for example Palm Jumeirah in Dubai. This project boosted the tourism in Dubai, yet it has also had negative effects on the environment and the aquatic ecosystem in the surrounding area *(Gibling C, 2013).* An example closed to home is the creation of Flevoland, which has increased the land availability within the Netherlands. This has been used for farmlands and housing, yet it has (in combination with the Afsluitdijk) had negative impacts on the ecosystem within this area *(Tiina Nõges, et al., 2008).*

This indicates that a solution like this is not necessary extreme or unrealistic, yet the purpose must be clear and critically analyzed beforehand. This is the case for all of the adaptation strategies. There are multiple strategies that would not only have positive effects on the protection of the Netherlands against coastal floods, but also on other criteria. Another example is the construction of a dike in the sea on which wind turbines are located. These turbines are very effective since the windspeeds are higher at the coast and within the North Sea on average compared to on land *(Wieringa J, 1986).*

Other functions could be tourism or housing, which could also be beneficial for the province of Zeeland. Yet this is not necessarily the case, since many coastal areas in Zeeland already depend on tourism. It is hard to identify how the current coastal areas would be impacted by a solution as this, which would effectively move the coast further seawards. This is obviously dependent on the type of solution and does not necessary have to be a negative. Further analysis have to be made to assess how these areas would be impacted by a different solutions regarding the 'advance' approach.

Ships would still be able to access the port of Rotterdam and travel further land inwards. Yet depending on the specific solution different approaches need to be implemented to ensure that the port of Rotterdam remains a good option for international shipping routes. A (partial) relocation of the port of Rotterdam further seawards could be a possibility or the construction of multiple sluices, which won't significant negative effects on shipping. This is not impossible, yet it is very expensive and just like all other approaches further research should be done.

Current sea dikes and river dikes don't have to be significantly improved anymore, since the sea level rise will not directly have an impact on the water level upstream in the delta area. This approach would also mean that the salinization of the delta area would be significantly less compared to the other solutions since the border between salt and freshwater would be located further seawards. This would also decrease the infiltration of salt water in the groundwater. Salinization of freshwater decreases the amount of available drinking water that is considered safe *(Kaushal S, 2016).* The delta area could be increased in size and the availability of freshwater within the Netherlands would improve. These new freshwater bodies could be used for different practices but also for recreational purposes.

This sounds promising, yet there are multiple downsides to this approach. A solution like this could have significant negative effects on the ecology located at the coast of the Netherlands. Aquatic species and plants that rely on salt water would not be able to survive at the current coast of Zeeland. Different measures have to be taken to allow fish migration from salt to fresh water and vice versa. Fish ladders could be constructed, yet this is unlikely to fully solve this problem since less fish are able to successfully travel from A to B. One of the reason being that fish which use the fish ladders become an easier target for predatory animals *(Agostinho A, et al., 2012).* Not all species are able or likely to make use of fish ladders, which would impact the biodiversity of salt water species in this area.

Another factor that should be taken into account is the dredging that is required to create these protective measures in the North Sea. This also depends on the materials that are used for this project, but all material have to come from somewhere and will thus have impacts on areas outside the scope area. The emissions and other elements that harm the environment during this process should not be taken lightly *(Amelia S, et al., 2017)*. Yet this is the case with all of the adaptation strategies. Not only will this adaptation strategy require a lot of material, but it is likely to more expensive compared to the earlier mentioned adaptation strategies. A cost-benefit analysis has to be make sure if a certain solution is worth it.

4.4 ACCOMODATE

The accommodate/retreat strategy focusses on decreasing the vulnerability caused by sea level rise by water and salt tolerating land use. Solutions could be building houses on poles or on higher ground levels. Even immigrating to less vulnerable areas or restricting building in certain areas are part of this strategy.

Figure 24: Accommodate/retreat Strategy (Carof Deltares, 2021)

Figure 25 indicates a solution based on the 'accommodate' approach, in which higher elevated areas of the Netherlands are further developed. These areas are marked light blue. Other areas with significant importance in terms of population or economic aspects will be surrounded by dikes, these areas are marked dark blue. The higher elevated areas are considered safe against the increasing sea level or relatively easy to protect against coastal floods compared to the other areas. This does not mean that the grey areas won't be used nor populated. Some of these areas are even more secured against coastal flooding.

Figure 25: Possible solution according to the Accommodate approach (Haasnoot et al., 2022).

If correctly executed, this solution would be beneficial for the environment and for migrating fish species. The shape of the Netherlands would be more influenced by nature and global warming. On first thought this sounds beneficial for the environment. Yet a lot of measures have to be taken before this would be the case. For example the flooding of uninhabited areas would be beneficial for sea life, since it expands its territory. Yet these areas have been used for other practices for many years. These practices could be harmful for aquatic life and it's also important to note that the ecosystems that are currently located in those areas would be impacted severely.

If this adaptation method is used without combining it with other measures, this method seems very unlikely and out of the box. This solution if implemented on a national scale would decrease the need for improving dikes and dunes on areas which are located outside the 'safe zones'. These areas outside of the safe zone can still be used if the current flood protection structures are maintained. Yet this risk of flooding would be increased, which does not necessary make these areas unusable. These areas could still be used for example agricultural purposes. Yet there are severe safety risks but also risk in terms of crop yield and vegetation. These areas will be more exposed to salt water, but also to damage from floodings. Which can make some parts of the land unusable for certain practices.
This adaptation measure also includes a change in construction practices. Houses in more vulnerable areas could be located on pillars which would protect the house and habitants when a flood does occur. This would mean that areas with an increase flood risk are still usable. Early warning systems could also ensure that habitants who live in these areas can get to safety ahead of time. Yet the current buildings in many of these areas are not designed for those circumstances, which means a lot of change is necessary before this becomes realistic.

While it would safe costs for the Delta Works, it would require mass relocation of habitants and practices. Which would likely be more costing, especially in a country where there is already a housing crisis *(Boelhoewer P, 2017)*. Combining this method with other methos would however be more realistic, because this plan would take many years to complete. Other methods could allow to give the population of the Netherlands more time to adapt to this plan. Appendix 5 also indicates that Deltares doesn't suggest a solution concerning the accommodate strategy that does not involve the combination of a second adaptation strategy.

5. STAKEHOLDER PREFERENCES

5.1 STAKEHOLDERS

Within this report 6 stakeholders are taken into account. These are the stakeholders that have the biggest influence and/or dependence on the different adaptation measures. The following stakeholders are included:

- **Province South-Holland:** Since a part of the Delta Works are located within this area, they have an influence on and dependence on the different adaptation measures. The province of South-Holland wants a healthy, safe and attractive environment for living, working and leisure purposes. Water plays an important role for multiple sectors, like water supply for nature areas and agricultural purposes. Yet water quantity/quality is also essential to secure drinking water for the province of South-Holland. The port of Rotterdam is also located within the province of South-Holland which is of enormous importance within the province but also on a national level. The province is densely populated, yet significant parts of South-Holland are located below sea level. For this reason it is essential that the province is protected against floods, while securing fresh water supply. Currently the province of South-Holland aims to create the first climate secure region in the world, by improving dikes with durable and reusable materials. Building strategies in which new constructions take the possibility of floods into account are also part of the strategies described by the province. Two representatives of the Province of Zuid-Holland have been interviewed. While both of these representatives have a different expertise compared to each other, they do have adequate knowledge concerning this subject. However personal views might differ from the Province as a hole, see appendix 6.

- **Province Zeeland:** Since a significant part of the Delta Works are located within this area, they have an influence on and dependence on the different adaptation measures. There are many points of attention for the province of Zeeland regarding the delta area. The North Sea and the delta have positive effects on the tourism sector of Zeeland. Yet it is important to maintain the water quality and quantity while also providing security against floods. Zeeland has a significant lower population compared to many other provinces like South-Holland. Yet Zeeland has a lot of areas that are directly located next to either the North Sea or the delta. The costs for improving dikes are mostly financed by the residents of Zeeland in the form of taxes. These taxes would be significant higher compared to other provinces if the current strategy is maintained in future situations. It is also important for the province of Zeeland to decrease negative effects on the fresh water quantity. This water is essential for agricultural practices. The province in combination with the state and waterboard are responsible to make sure that dikes and dams provide enough security, but also blend in within the landscape of Zeeland. The province of Zeeland also states that there are currently to many uncertainties to determine a clear approach for future situations. One representative of the province of Zeeland has been interviewed. This individual has adequate knowledge concerning this subject. However personal views might differ from the province as a hole, see appendix 6.

- **Rijkswaterstaat:** is responsible for maintaining and testing the Delta Works together with the local waterboards. Rijkswaterstaat also encourages companies to integrate new technologies within the delta area. An example are five tide turbines, which produce green energy. Rijkswaterstaat also research the usage of more environmental friendly materials for the Delta Works. While Rijkswaterstaat has many responsibilities on a national scale, it also shares and receives information on a global level. Rijkswaterstaat mentions that the future of the Delta Works is not solid and is dependent on water safety norms and flexible water management. The future of the Delta Works are partly determined according to the Delta program: adaptive delta management. This implies the usage of strategies that are flexible and can be adapted according to climate change. They argue that it is not desirable to determine measures for a period of 50 or even 100 years. Years of experience and accumulated knowledge regarding the Delta Works and other flood defence systems play an significant role in their point of view. They are very influential in determining the future of the Delta Works. One representative of Rijkswaterstaat has been interviewed. This individual has adequate knowledge concerning this subject. However personal views might differ from Rijkswaterstaat as a hole, see appendix 6.

- **Waterboard Hollandse Delta:** A part of the Delta Works are located in their area. Adaptations and the increase in sea level will also influence the water level and quality in the rivers. This means that this waterboard has both an influence as a dependence on the Delta Works. The waterboard is responsible for 800 kilometres of dikes, dunes and quays that have to be maintained. These water barriers have to be robust enough to provide protection against high water levels. This will become more challenging and expensive if the sea level or river water level rises. The waterboard is also responsible for the water quality within the area. This is important for the ecosystem within these rivers. Yet it is also crucial to ensure the fresh water quantity within this area. There should not be too much water within the rivers, because this might result in floods. However preventing a shortage of water is important, since it is crucial for agricultural practices, limiting salinization and increasing the water quality. The waterboard uses a multiple layer safety strategy. This includes preventing floods, spatial ordering and crisis management. The waterboard ambition regarding water safety for 2050 is as follows: *"We provide permanent protection against flooding for habitants within our region. This is done robustly where necessary, naturally if possible and smart where it is rewarding. We realise added value where possible, but don't make concession during this process regarding safety." (Waterbeheerprogramma 2022-2027, 2021)* While in terms of water quantity and quality the following ambition for 2050 is described: *"We provide enough water, not a surplus nor a shortage. We provide healthy water, sparkling of life. Water connects and is of added value to nature, humans, cities and agriculture." (Waterbeheerprogramma 2022-2027, 2021)* Two representative of the Waterboard Hollandse Delta have been interviewed. These individuals have adequate knowledge concerning this subject. However personal views might differ from the waterboard as a hole, see appendix 6.

- **Waterboard Scheldenstromen**: A significant part of the Delta Works are located in their area. Adaptations and the increase in sea level will also influence the water level and quality in the rivers. This means that this waterboard has both an influence as a dependence on the Delta Works. Providing a safe live and work environment is one of the most important responsibilities of the waterboard. The waterboard wants to provide protection according to the juristic norms. They want to reduce the risks of flooding as much as possible, currently and in the future. In 2050 all primary flood defence barriers provide protection according to the juristic norms of that year. During extreme rainfall no damage will be caused regarding river floods. Yet the quantity and quality of fresh water has to be maintained. One representative of the Waterboard Scheldestromen has been interviewed. This individual has adequate knowledge concerning this subject. However personal views might differ from the waterboard as a hole, see appendix 6.
- **Deltacommissie:** In 2008 the commission gave advice regarding the water safety and fresh water security of the Netherlands. The previous regulations came from the sixties, this is why it was important to update these agreements. The deltacommison focuses on the question: *"How does the Netherlands remain protected against flooding, freshwater shortages and extreme weather?"* The goal of this is to ensure that citizens can live, work and recreate safely within the Netherlands for the coming 50 and 100 years. The Deltacommision does not only focus on the state, but all involved parties. A secure Netherlands is of collective social importance, in which the government is responsible. The security level of water safety and freshwater security have to be a factor 10 higher compared to the current level. The Deltacommissie finds it important to be able to adapt to climate change and other ecological processes, while being cost-effective and having an social added value. One representative of the Deltacommissie has been interviewed. This individual has adequate knowledge concerning this subject and is also active in other organisations regarding this subject. However personal views might differ from the commission as a hole, see appendix 6.

Table 10: Stakeholder responsibilities.

Stakeholder	Responsibilities
Province South-Holland	A significant part of the Delta Works are location within this province and a lot of sectors are (in)directly impacted by the delta, like the port of Rotterdam or farmers. Maintaining the flood security, water quality/quantity and stimulating (economic) growth are some of their responsibilities.
Province Zeeland	A significant part of the Delta Works are location within this province and a lot of sectors are (in)directly impacted by the delta, like the port of tourism or farmers. Maintaining the flood security, water quality/quantity and stimulating (economic) growth are some of their responsibilities.
Rijkswaterstaat	Maintaining and testing the Delta Works together with the local waterboards.
Waterboard Hollandse delta	Provide protection against flooding along 800 kilometres of dikes, dunes, Delta Works and quays, while also maintaining the water quality and quantity within the rivers.
Waterboard Schelden-stromen	Providing the entirety of Zeeland against river and coastal flooding due to dikes, dunes, Delta Works and quays, while also maintaining the water quality and quantity within the rivers.
Deltacommissie	Advising regarding protecting the Netherlands against floods on the long term.

These are the most important and influential stakeholders in terms of determining preferable future adaptations strategies. They have been identified due since they are operational or responsible of the delta area. This regards parties that are either operational in the designing, implementation or maintenance phase. These stakeholders either published reports related to these problems or have experts which are up to date with this subject. Yet there are more stakeholders, which have not been interviewed. Take for example locals or municipalities, both of them are (in)directly impacted by changes in adaptation strategies. The construction could for example be an issue for locals, due to sound pollution. However interviewing stakeholders on that level would be very time intensive. Another reason why these stakeholders are excluded, is because there are no specific constructions described which would impact these stakeholders. The stakeholder analysis focusses on implementation on a broader scale. It can also be assumed that the 7 described stakeholders have more background knowledge compared about this subject compared to for example locals or municipalities. However once solutions regarding this subject are becoming concrete, they have to be discussed with all stakeholders.

Another stakeholder, which is not located within the Netherlands is the port of Antwerp. While the Delta Works are located within the Netherlands, they still have to make sure that the port of Antwerp remains accessible. The port of Antwerp has a similar economic value for Belgium as the port of Rotterdam has to the Netherlands. Not all adaptation strategies are possible in the case of the port of Antwerp. International agreements and regulations are in place which have to be obliged. This limits the possibilities of some adaptation strategies, which has to be taken into account.

Lastly Havenbedrijf Rotterdam is an important stakeholders since they are extremely dependent on the ability for ships to enter and exit the port of Rotterdam. They also have a big impact on the Dutch economy as a hole. Attempts have been made to reach out to representatives of this organization in order to get a better understanding on their vision regarding the different adaptation strategies. Yet this proved to be difficult, especially compared to the other stakeholders. There are multiple possible explanations why this process proved to be more challenging compared to other stakeholders. One reason could be that there is no specific person or department regarding this topic. Another explanation is that there are still to many uncertainties to form an adequate vision or they rather not share their vision at this point of time. It is also possible that the multiple requests for an interview did not reach the people with adequate knowledge regarding this subject.

5.2 METHOD

At least one representative with adequate knowledge about this topic per organization has been interviewed. These interviews have either been held face to face or via online video calls. Additional information about this subject and the different adaptations has been sent to stakeholders that requested more information. During the interview an explanation about the thesis and the different adaptation approaches have been given vocally. Once the stakeholder is adequately informed about the subject the following points have been addressed:

Four different categories are be explained. The environmental and economic criteria are important to analyze vulnerabilities and opportunities due to climate risks *(UNFCCC, 2022)* like sea level rise. The economic criteria is required on almost all stages of the assessment of adaptation needs, like identifying desired adaptation actions, compiling them or determining the capacity or finance regarding them. The technical criteria is also essential to determine the capacity and to determine how realistic certain approaches are *(UNFCCC, 2022)*. The main goal of the adaptation strategies is to provide protection against flooding, which requires solutions to be reliable. Since this concerns solutions which have to be efficient and reliable for a long period of time and there it impossible to accurately determine the needs and opportunities within the Netherlands in the year 2150, it is essential to also include the future adaptation criteria.

1. **Environmental:** The positive and negative effects a certain adaptation approach has on the environment, ecology and climate.

For example the negative effects on fish migration caused by the sealing of the Delta area and the North sea. This category can be perceived from multiple angles. Usually the main focus regards the effects on the ecology like for example the biodiversity of the ecosystem. However this category perceived regarding the effects on climate change itself. Less obvious subjects regarding this criteria are the effects on culture or people.

2. **Economic (construction/effects):** The positive and negative effects a certain adaptation approach has on an economic basis.

For example the effects of an increasing closing frequency of the Maeslantbarrier on the transport of goods by ships through the port of Rotterdam. The implementation costs of a certain solution also have to be taken into account. This category is very broad and can be perceived from multiple angles. Construction costs, the effects on multiple different sectors or the creation of new opportunities are some of the possible perspectives.

3. **Reliability:** The reliability of a certain adaptation provides to assure its initial purposes are met.

For example a mechanical complex structure has more possible points of failure compare to a statical structure. This criteria mainly focusses on how likely a certain approach is able to reach its purpose. This includes multiple sectors like water safety but could also imply water security.

4. **Future adaptation (no regret):** To what extent is this adaptation approach effective, applicable and customizable in future situations.

Sea level rise might even increase more further into the future is this adaptation approach still reliable at this point? The population or other aspects in the Netherlands might change over time, are these adaptation measures able to adapt to the future needs and requirements?

After the different categories are explained the different adaptation approaches are analyzed based on these categories. Table 11 has been used for all of the adaptation approaches. An MCA is a useful approach which incorporates a mixture of quantitative and qualitative information while taking the preferences of different stakeholders into account (*Qureshi M.E et al., 1999).* The score ranges from extremely negative (1 point) to extremely positive (5 points). This range is relatively small, since there is still a lot of uncertainty regarding the adaptation approaches and their impacts *(Infrastructure Australia, 2021)*. It would be difficult to use a bigger score range since stakeholders will be unable to link statistical data to most of their choices. Referring to these scores in words, such as negative, neutral or positive decreases the change of different interpretations of these factors *(Infrastructure Australia, 2021)*. It is possible to give multiple criteria or approaches the same rating. Given that these scores are based on the perspectives of representative stakeholders, a further explanation has been given for certain decision. This is necessary to make sure if stakeholders are actually adequately informed about the categories and approaches and if their choices are logical and representative for the organization as a whole.

Table 11: Criteria per adaptation approach.

Criteria	Extremely negative	Negative	Neutral	Positive	Extremely Positive
Enviroment	◯	◯	◯	◯	◯
Economic	◯	◯	◯	◯	◯
Reliability	◯	◯	◯	◯	◯
Future proof	◯	◯	◯	◯	◯

After the adaptation measures are analyzed according to table 11. The different criteria are ranked from most important (4) to least important (1). The factors that are connected with different criteria are now multiplied by the scores according to adaptation tables. The amount of points per adaptation approach indicate the preferences of different stakeholders. This process is essential to determine the weights of different criteria while taking stakeholders perspectives into account *(Infrastructure Australia, 2021)*. Different weights are crucial since it leads to different outcomes *(Odu G, 2019)* and there are clear differences between importance or impacts of certain criteria. The end results have been discussed with the stakeholders to verify if they agree with the outcome.

5.3 STAKEHOLDERS PERSPECTIVES ON CRITERIA

The question: *"What are the views of different stakeholders on the possible measures?"* is answered in this paragraph. For a more detailed explanation regarding certain approaches, it is suggested to read appendix 6.

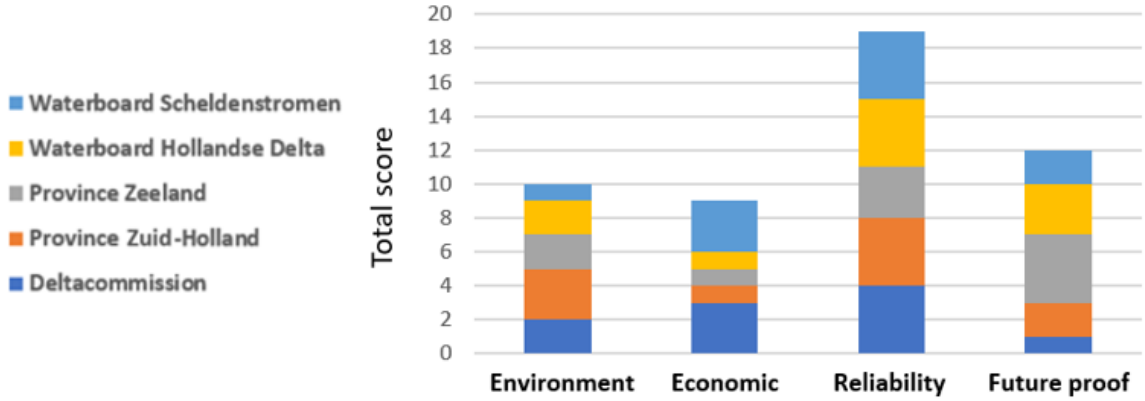


Figure 26: Criteria arranged according to stakeholders.
This figure indicates which categories according to different stakeholders are considered more significant compared to each other. The Y-axis indicates the scores that are associated with the different categories according to the stakeholders. Categories are ranked from 1 to 4, with 4 being the highest score. The figure indicates that there are differences and agreements between the stakeholders. Categories with higher scores are deemed more important compared to the other categories.

There is a clear agreement on the importance of the reliability criteria, since the original purpose of these adaptation strategies is to provide protection against floodings. However there is a significant disparity between stakeholders regarding the economic criteria. All strategies will have impacts on the economy and will force adaptation to the new economic situation. Some of the adaptation strategies are expected to have more significant impacts on different sectors.

It is argued that the economy will adapt to the selected approach, not the other way around. The representatives of the Deltacommision and waterboard Scheldenstromen rate it considerably higher compared to the other stakeholders. This is partly explained due to increasing taxes. The different approaches are mostly funded by Dutch citizens in the form of taxes. For example in Zeeland the need for flood protection is significantly higher compared to other provinces, while the population is lower. Each solution would have different impacts on the taxes in certain areas. Another reason is that Zeeland is dependent on agriculture, fishing and tourism. All of these sectors could be directly impacted by certain adaptation approaches.

The future proof criteria also has a significant disparity between stakeholder perspectives. Representative of the province of Zeeland stresses the importance of this criteria, since it is regarded vital to adapt to a situation in which the water levels become so challenging that the old approaches are no longer realistic. The representative of the Deltacommissie agrees that it is important to use future proof strategies, yet he notes that all of the strategies can be used in future situations to "buy time". However some become less desirable if the water levels increase to significantly.

There is also some disparity between different stakeholders regarding the environmental criteria. Representatives of the province of Zuid-Holland view environmental aspects as the second most important criteria, since the criteria is very broad and these representatives also include the effects on livability and take the loss of culture into account. Other stakeholders acknowledge the importance of environment and also refer to the Delta Works and initial/current problems that came with the construction of it. While the representative of waterboard Scheldenstromen do agree on the importance of this criteria, it is still deemed less critical compared to the other criteria.

Multiple stakeholders mention certain criteria that are not included within the interview. The implementation of these criteria would have impact on the final results and the ranking of the current criteria. Waterboard Hollandse Delta claims the category regarding the environment is too broad and could be spitted in to two parts. One focusing on the freshwater availability, while the other focuses on the impacts on nature.

The representative of the province of Zeeland suggests to split the economic criteria into two parts. One focusing on the affordability (regarding taxpayers or organizations) and one regarding the impacts on the economy. The representative also suggests including an criteria regarding public support. Public support is deemed essential to be able to implement certain strategies successfully. Public support is suspected to be low regarding the Accommodate approach, since it is associated with retreating and giving up on current practices. The representatives of the province of Zuid-Holland suggest a similar criteria regarding the perspectives of local residents who would be (in)directly impacted by certain approaches.

5.4 STAKEHOLDERS PERSPECTIVE ON ADAPTATION MEASURES

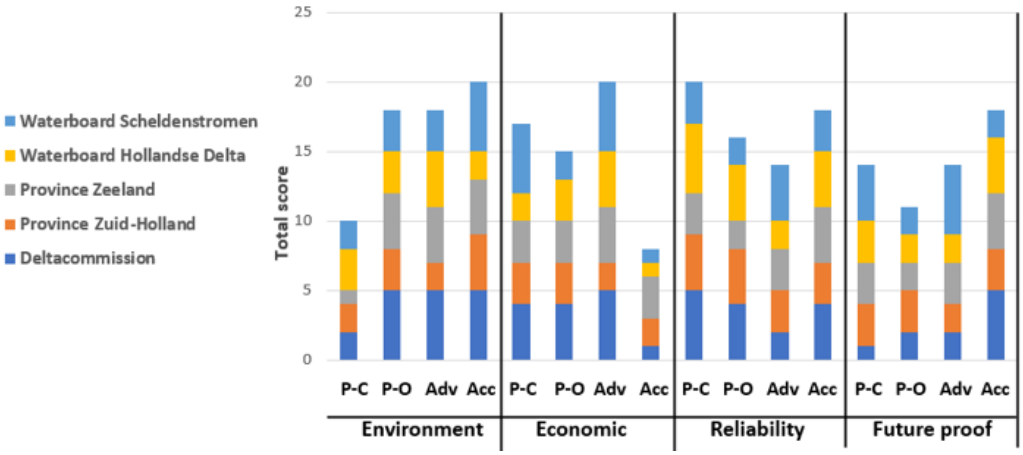


Figure 23: Different stakeholder perspectives on strategies based on different criteria. This figure indicates which stakeholders view certain strategies as positive or negative according to different categories. The X-axis exists out of 4 different categories, which are each divided into 4 strategies. P-C = Protect-Closed, P-O = Protect-Open, Adv = Advance and Acc = Accommodate/retreat. The Y-axis indicates the scores that are associated with the different stakeholders perspectives on Strategies are rated from 1 until 5 points, with 5 being the best score. 5 points indicate that a certain approach is deemed very positive in terms of a specific category. 1 point indicates that a certain approach is deemed very negative in terms of a specific category.

Environmental

Protect-Closed is deemed least favorable in terms of environmental aspects and there is little disparity. Almost all stakeholders agree that sealing of the estuaries will have negative effects on the environment and nature development. In the past the Delta Works have indicated to have negative effects on the natural dynamic in the delta area. This is for example one of the reason why the Oosterscheldt barrier became mostly open, allowing to maintain the an original connection between the sea and the delta. The representatives of waterboard Hollandse Delta agrees that this strategy will have extreme negative effects on nature and the ecosystem. Yet they and other stakeholders argue that the environment is an broad subject and could also be deemed as positive. The representatives of waterboard Hollandse Delta suggest that this approach will be extremely positive in terms of freshwater storage. This water can be used for multiple sectors including the environment. It also limits the effects of salinization which otherwise could have negative effects on plant species and thus local ecosystems. This approach also makes it relatively easier to regulate fresh water levels in certain areas, which can have positive effects on the environment. The waterboard is also responsible for meeting consumers demands for freshwater, which will become increasingly challenging due to climate chance.

The advance approach could generate opportunities in terms of nature development, which is positive regarding the environmental criteria. There is however some disparity between stakeholders, the representative of the Deltacommissie deems this approach extremely positive, since it creates a lot of opportunities in terms of the development of nature.

However the province of Zuid-Holland acknowledges that the creation of more landscapes can have positive effects on the environment. It is questionable how much public support there is to use these areas to create more nature, otherwise it is more likely to have negative impacts. There are also multiple negative impacts, since it would create new lagunes which will mostly be closed off. This limits the nature developments within these areas. If civil structures are used that allow fish to migrate and water to blend, the negative impacts could be somewhat limited.

While all stakeholders are positive regarding the environmental aspects for the accommodate approach, waterboard Hollands Delta views this adaptation approach as negative, since the negative effects on freshwater availability outweigh the positive effects on nature. Depending on the specific solution regarding this adaptation approach, this could also be harmful for the current ecosystem within the Netherlands.

There are some interesting scores that do not seem logical at first sight. For example the representative of the Deltacommissie is the only stakeholder that argues that the advance/retreat approach is extremely positive in terms of the environment. This is due to the fact that the environmental impacts are very dependent on the actual implemented solution regarding this approach. It could be deemed positive if island are created with a double function of creating room for nature while protecting against extreme weather events. These island will function as wave breakers while the current Delta Works are improved. Yet the rating extremely positive seems a bit high, however this has also to do with personal perspectives on rating. This representative has given to most extreme negative and extreme positive ratings within figure 23. It is possible that other stakeholders ratter avoid the extreme positive or extreme negative rating, if there is only limited information available. These ratings are also not bounded to statistics, which means that different interpretations are likely to occur.

Economic

The significant difference between the ratings of the two waterboards regarding the effects of the protect-closed approach on economy is a point of attention. Waterboard Scheldenstromen regards this approach extremely positive in terms economics, since all of the current functions regarding land use can be maintained or further developed. The effects of salt water infiltration into farm lands is also reduced. For the agricultural sector this approach would be beneficial since it would improve the freshwater quantity that can be used for farming. While waterboard Hollandse Delta agree, but also mentions the negative effects in the accessibility of the port of Rotterdam, which is if enormous value to the Dutch economy. However for the regarding the protect-open approach only the representative of waterboard Scheldenstromen deems this to be negative for the economy, since the water barriers across the length of the rivers will require more space and become more expensive.

All stakeholders regard the advance adaptation approach to be positive for the economy, with exception for waterboard the province of Zuid-Holland. They expects this approach to be extremely costly and would still require the improvement of the current Delta Works, dikes and dunes. Since the villages which are located at the coasts, are usually dependent on

the North Sea, multiple sectors could be impacted within those areas. This solution also requires a lot of sand which could prove to be difficult and expensive.
The accommodate/retreat is regarded to be negative for the economy by all but one stakeholder. The representative of the province of Zeeland admits this is an unpopular view, due the changes in land use. Farming for example will prove to be more difficult compared to the current situation. Yet this strategy requires a change in land use, which doesn't necessarily have to be negative. This will require a lot of innovation to ensure the food security of the Netherlands. It will take a lot of time to switch systems and methods, but once it is managed to successfully change land use purposed, it could lead to another product (fish) that could be sold around the world. There are a lot of risk and downsides on the short term, but over a longer period it provides new opportunities. This argument seems unexpected at first sight, however future sea levels do require change which is not always pleasant. If this approach is implemented on an earlier base, there would be more time to make a shift in economic activities. However it does seem somewhat surprising coming from a representative of the province of Zeeland, since it would be one of the areas which would be one of the most impacted provinces of the Netherlands, due to its topographical location and characteristics.

Reliability
All stakeholders agree that protect-closed strategy is either neutral, positive or even extremely positive regarding the reliability. However there is more disparity regarding the protect-open adaptation strategy. Stakeholders disagree on the actual reliability of this approach, due to different reasons. Some argue this is an approach which has been used before and could be very reliable if the construction regulations are enforced. This approach is more adaptable and flexible compared to the protect-closed approach. However the stakeholders that are located within Zeeland deem this approach to be negative, since the length of critical dikes is increased compared to the protect-closed approach.

There is disparity regarding the advance adaptation concerning the reliability. Stakeholders perspective range from negative until positive impacts on the reliability. The representative of waterboard Scheldenstromen regards this approach as positive, the waterbariers move further into the sea, creating a bufferzone. The current waterbarriers are not removed after implementing this approach, which creates a secondary flood defence structure.
Waterboard Zuid Holland argues that the creation of island in front of the current flood defence system could lead to an increase of washing away of sand during storms, while it decrease the supply of sand during normal periods. This approach is also relatively new, which implies that there is limited experience compared to the other approaches. This makes it harder to determine the effects of this solution in a big scale.

Both the Deltacommissie and Waterboard Hollandse Delta rate the reliability of the advance approach to be negative. The arguments regarding for example uncertainties or relocating the problem do make sense. And if the function of these island is to break waves, the effects on coastal floodings are limited. However if this specific solution is implement it would go

paired with one of the other approaches, meaning it would have a similar reliability if not higher. If a second layer of flood defense systems is created it would assumingly have positive impacts on the reliability

Future proof

There is disparity regarding the extent to which the protect closed strategy can be considered future proof. Waterboard Scheldenstromen deems this strategy positive in terms of future adaptation, since it is always possible to expend vertically or even further horizontally into the North Sea, due to a relatively shallow water level near to the coast. By supplementing sand this methods remains a possibility in the future. Other stakeholders argue that it should technically be possible to continue this approach up until a very significant sea level rise. However this solution has a limit until which it is realistic due to for example costs, yet it is expected that the Netherlands is able to extend that limit for quite a while. The Deltacommision argues that this solution is extremely negative in terms of future adaptation, since everything would be solidified. It would be difficult to change adaptation strategies in the future.

Stakeholders have similar views regarding the protect-open adaptation strategy. The total length of water barriers is significantly increased compared to the protect-closed strategy. There is limited space available to continue to improve river dikes. Yet all these dikes have to be constantly improved, which over time will only become more costly in terms of space and money.

Only waterboard Scheldenstromen considers the advance approach to be extremely positive in terms of future adaptability, since it would be designed to defend against a certain sea level. There is also more available space for future improvements. However if the sea level rises to significant it becomes increasingly challenging to supply this area with sand and maintaining it. Calculations about constantly supplying the current coastline indicate that it is very difficult to maintain this process. Other stakeholders also acknowledge the significant future maintenance costs.

There is disparity regarding the accommodate/retreat adaptation strategy. The Deltacommissie suggests that the higher the sea level, the further citizens and economic activity retreats to safer zones. This process is could be used for a very long period of time. This approach will especially have positive impacts on the environment in the future. However others argue that this approach should be split into two areas. In terms of higher located areas (Eastern and Southern Netherlands) this approach is positive for future adaptation. This is because process of retreating could be maintained for a longer period. Yet this approach will be negative for the Randstad, since it would be increasing difficult to provide security for this area in future situation. Another point of attention is the significant threat regarding the future availability of freshwater within the Netherlands.

5.5 STAKEHOLDER PREFERANCES OVERAL

This paragraph analyses the outcome of the combination of different stakeholders perspectives on both the criteria as the adaptation approaches.

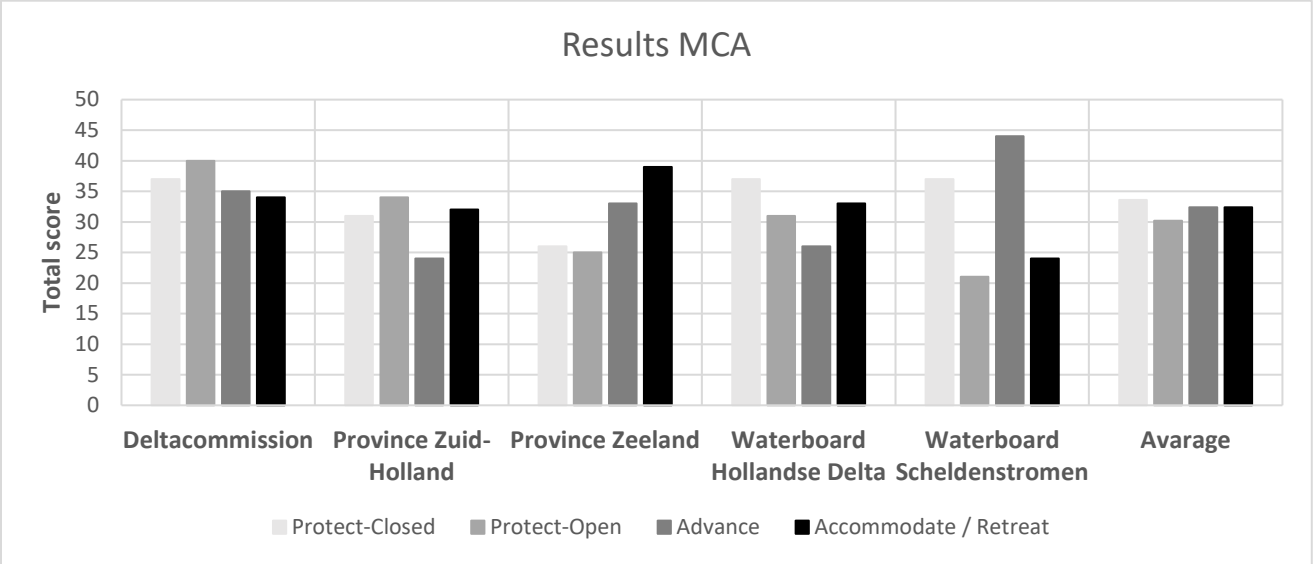


Figure 24: Results MCA.
This figure indicates the results from the MCA. The X-axis indicate the different stakeholders and the average score. The Y-axis visualizes the scores different adaptation approaches have according to the stakeholders. This graph is the result of multiplying the criteria ranking with the stakeholders perspectives. The minimum possible score regarding an approach is 1, while the maximum score is 50.

Figure 24 indicates the significant differences between stakeholder preferences regarding the different adaptation approaches. However if the average of stakeholders is taken into account the differences between the approaches becomes minimal. This indicates that even though all stakeholders have different preferences, there is no clear solution which fits all stakeholders. There is little difference between the scores of different approaches for the Deltacommissie according to the MCA, which could be perceived as an strategy to either not show his cards or leave all options open. However the representative does expects that in the near future the choice will most likely be made between the protect-open and the protect closed strategy. It is also mentioned that it is more likely that the protect-closed approach will be used, because of the reliability and it buys time for other methods. Yet the interviewee himself prefers the protect-open strategy due to environmental facts. The implementation of the advance strategy still requires a choice between the protect-closed and protect-open approaches. He views the accommodate strategy as an last resort approach.

The representatives of the province of Zuid-Holland do seem to prefer the more conservative measures, like the protect-closed and protect-open strategy. However there is some no clear agreement between the two representatives about the total score of the accommodate strategy. One of the representatives does agree with the outcome, while the other with a more civil engineering background prefers ranking this approach lower compared to the protect-closed and protect-open strategies.

The representative of the province of Zeeland has a different perspective in comparison to the other stakeholders. Instead of relying on the “old ways” he seems more open for enormous adaptations changes, even though Zeeland is one of the areas which would be the effected the most by these changes. It is also interesting to note that waterboard Scheldenstromen which is located in the same geographical location also has a vision in which a change in strategies is seriously considered and deemed realistic. Yet the representatives of the two organization do not have similar preferences regarding specific adaptation strategies. Another conclusion which can be extracted from figure 24 regards that these two stakeholders have relatively more significant disparity between the allocated ratings of the adaptation strategies. This indicates stronger preferences regarding the implementation of certain strategies over others. Other stakeholders seem to either leave all options open or are not yet in a phase in which they are willing to make certain preferences clear.

The representatives of waterboard Hollandse Delta do agree with the outcome of the MCA, however they did not expect the accommodate/retreat strategy to score this high beforehand. Yet this does match with their vision on the different criteria and perspectives regarding specific approaches.

The representative of Rijkswaterstaat was not willing to rank the different adaptation approaches, due to the fact that there is still much research been done regarding the many uncertainties that are connected to the approaches. The many uncertainties form a constantly recurrent argument used by multiple stakeholders. While it is true that there is yet little known about some subjects, this argument could also be used as scapegoat to not show one’s cards. The next chapter discusses the need for additional research to determine the exact benefits or downsides of all adaptation strategies. Yet this process is time consuming and would likely take multiple years, while time is limited.

Overall there is a big difference between stakeholders which makes it impossible to determine a single solution which is deemed preferable over the others. There are multiple factors that influence the different perspectives of stakeholders. Firstly all stakeholders have different responsibilities, characteristics and operation areas. Secondly personal perspectives do not always align with an organization as a whole. Thirdly there are many uncertainties and debates regarding the actual effect different approaches have on the criteria. Fourthly some organization or representatives might be more informed about the different approaches and their pros and cons compared to others.

6. DISCUSSION AND CONCLUSION

6.1 CONTENT

The main research question is formulated below:

What are different stakeholder perspectives regarding adaptation measures to ensure the safety against coastal floods caused by sea level rise in 2150 based on environmental, economic and technical aspects?

This research question is divided into 4 sub questions, namely:

1. *How much will the sea level rise till the year 2150 according to different projections?*
2. *Which current coastal flood protection measures are not robust enough to ensure the safety and protection of the Netherlands and its citizens in the year 2150?*
3. *What are possible adaptation measures to ensure the safety and protection of Netherlands and its citizens in 2150?*
4. *What are different stakeholder perspectives on the possible adaptation approaches?*

Q1: Recent climate data models suggest an increased severity of sea level rise compared to the climate data used by the Deltacommissie in 2008. Certain sea levels will be reached in an earlier stage, which further limits the life span of the current Delta Works. RCP8.5^{A} suggest a 2 meter sea level rise in 2103 *(Haasnoot et al., 2020)*, while older data suggest an similar sea level to occur 25 years later *(Deltacommissie, 2008)*. These are significant differences which are crucial in determining the available windows for adaptation. Recent climate data indicate that the need for new adaptation approaches is growing, while the availability of time is shrinking.

Q2: A more severe and rapid sea level rise has negative impacts on the lifespan and capabilities of the current Delta Works. It should also be noted that climate change will have impacts on the severity and frequency of storms while simultaneously impacting the flow rate within the delta area *(Ralf Weisse, 2010)*. The Oosternscheldt barrier is currently able to maintain the direct connection between the North-Sea and the delta area. However a more rapid increase in sea level rise will limit the lifespan of this civil work. Recent climate models suggest that the Oosterscheldt barrier would be functional until roughly 2080 (almost 10 year shorter compared to earlier estimates), however this is not desirable. While Oosterscheldt barrier would be able to protect against coastal floodings, it would be significantly limited in its ability to maintain a connection between the North-Sea and the delta area. Since the closing frequency becomes very frequent multiple problems will occur, like high water levels within the delta area or limiting the migration of fish. The implementation of new adaptation strategies are required before 2080.

A similar problem occurs regarding the Measlantkering, which has to be able to protect against coastal floods without significantly limiting the accessibility of the port of Rotterdam. However this civil work will reach it lifespan significantly earlier, partly because the closing frequency is more critical. Another limitation is the ability to prevent against coastal floods in the near future. Interestingly recent climate data does not have negative impacts on the life span of this civil structure, since the recent models only predict a more rapid sea level rise after 2075. Yet the lifespan of the Measlantkering is estimated between 2060 and 2065. This indicates a serious need for a reassessment of different adaptation strategies regarding

this part of the delta area. However the lifespan of the other Delta Works is decreased by 5 years according to recent climate data. Yet the process of determining preferable is time consuming and requires a lot of additional research. The implementation or construction of these approaches itself are also time consuming, meaning that the time to select an adaptation approach is limited. Furthermore the Delta Works function as one interconnected system, in which one chance or failure would impact all of the other Delta Works in a way.

Q3: There are four adaptation strategies which could be implemented in order to limit the impacts of sea level rise.

1. **Protect-closed** implies that the Delta Works would completely seal the North Sea of from the delta area. Pumps would be required and dikes should become higher due to increased peak discharge within the rivers. Sea dikes would have to be improved, yet it there would be less pressure on river dikes.

2. **Protected-open** strategy is similar with the currently used strategy for the Delta Works. A lot of sea but especially river dikes would be improved but the connection between the North Sea and the delta would be maintained/improved in order to allow ships to enter the port of Rotterdam for example. This can be achieved by the usage of a sluice system.

3. **Advance** strategy focusses on increasing the safety while also creating more space for other sectors. Coastal defenses start within the sea creating more land. There are a lot of possibilities within this adaptation strategy and could be implemented on multiple scales.

4. **Accommodate / retreat** strategy implies the relocation of vulnerable areas or sectors towards more secure locations. This also implies the chance of land use practices or building strategies to decrease flooding risks.

Q4: All of the four strategies are very different in terms of their pros and cons regarding the environment, economy, reliability or future adaptation possibilities. Interestingly there is no adaptation approach which is preferred by all stakeholders. In fact there is a lot of disparity between stakeholders regarding the pros and cons of certain approaches and their impact. There are multiple factors that influence the different perspectives of stakeholders. All stakeholders have different responsibilities, characteristics and operation areas. Since stakeholders have different operation areas and responsibilities it is logical to have different preferences compared to each other *(Hegger, D et al., 2012)*. However stakeholders do agree on the fact that the reliability of adaptation strategies is the most important criteria.

There are still many uncertainties and debates regarding the actual effect different approaches have, which causes further disparity between stakeholders perspectives *(Head. W, 2014).* However it can also be used as excuse to restrain from giving specific answers or provide clear preferences *(Gollier, C., 2014)*. Some organization or representatives might be more informed about the different approaches and their pros and cons compared to others, which can also lead to different preferences *(Citroen, C., 2011)*. Stakeholders might prefer

adaptation approaches that are similar to our current approaches, while others are more open to significant changes in adaptation strategies. Six different stakeholders have been interviewed yet only five where willing to rank the criteria and adaptation strategies based on the MCA. The representative of Rijkswaterstaat argued that it is impossible to compare the different adaptations strategies since they are very different and operate in different time frames. She argues that the different approaches could be implemented after each other. The Netherlands is currently mostly using the protect-open strategy *(Haasnoot et al., 2020)*, however before this fails it is possible to switch to the protect-closed strategy. When this becomes ineffective a choice has to be made between the advance and accommodate strategies. The advance strategy also has a limited time of effectiveness, which would finally result to a switch to the accommodate approach.

Yet this raises multiple questions, for instance if these adaptation strategies truly have to operate in different time frames. Would it not be more cost-efficient to start with the accommodate/advance strategy for example if this is considered the most extreme measure in case of significant sea level rise? There is no single strategy which would solve all problems, without simultaneously creating new issues. Multiple strategies can be combined on different scales as long as future adaptation possibilities are taken into account. Solutions can be divided into low- and high-regret implementations, in which it can be determined to which extend it limits the ability for more significant adaptation changes in case of a higher sea level rise. These short term low-regret options can be implemented at more vulnerable areas to buy more time *(Deltares, 2019)*. The different approaches and their impacts are currently being researched and there are still many uncertainties. This makes it challenging to compare different strategies, yet it simultaneously makes it challenging to exclude certain strategies at this moment in time. While there are clear benefits and a high likeliness towards the implementation of low-regret solutions the suggested time frames can be interoperated as an effort to relocate the problem of sea level rise to a latter moment to avoid the implementation of adaptation strategies that are expected to differ from public opinion. Admittingly these multiple-step-strategy buys time, however it requires multiple adaptation changes to occur on a national scale.

Climate change models indicate a significant sea level rise to occur *(Haasnoot et al., 2020)* in which it increasingly challenging to continue the current strategies. The uncertainties regarding climate change should not be used as argument for inaction *(Maslin & Austion, 2012).* To avoid facing similar problems soon after implementing a new adaptation strategy, it is crucial to look at the long term and limits of certain approaches. Switching multiple times between national adaptation strategies would likely be relatively less cost-effective and prolong the call for adaptation change for a longer period of time. A cost-benefit analysis of the Haringvliet barrier indicates that adapting to climate change is likely to be a good investment. Yet it is important to design new solutions and structures all over the delta area which are flexible enough to allow for adjustment to climate change given the uncertainty of sea level rise in the long term *(Aerts C.J. et al, 2012)*. Furthermore it is possible to implement multiple adaptation strategies simultaneously instead of one after the other. Yet the delta area functions as one big entity in which local strategies might influence national strategies. The multiple steps strategy is a possible solution, however this does not limit comparing the four different adaptation strategies individually on a single time frame.

The remaining stakeholders made use of the MCA to visualise which adaptation strategies suit their preferences, which is shown in figure 25. This figure indicates that some representatives do not single out a specific adaptation strategy, but rather keep all options open. There are multiple explanations possible for these results. A lack of research regarding the effects of these approaches resulted in more estimations and arguments without data to support them, which can lead to stakeholders being more cautious about singling an option out *(Head, B., 2012)*. It concerns a wicked problem in which there are is not a single solution, but rather four solutions with different pros and cons which are not fully identified. Since there are still a lot of uncertainties regarding the approaches, it might seem preferable to not have significant preferences shared with the public.

Almost all stakeholders do agree that the reliability is the most important criteria in determining if an adaptation is desirable. The main function of these strategies is to provide protection against an increasing sea level, which can only be achieved if the adaptation measure actually is reliable. However interestingly the economic criteria is deemed the least important, since the environmental and future proof criteria are deemed more significant overall. This is interesting since the effects of these adaptation strategies will have enormous impacts on the economy on different sectors. For example agriculture or the port of Rotterdam could be significantly impacted by the approaches, which could be harmful to the national economy. Some stakeholders argue that the economy is able to adapt to the approaches, instead of the other way around.

There are multiple disparities between the stakeholders regarding the remaining criteria. Both waterboards gave a different ranking regarding the criteria, while on forehand one could expect many similarities. However the differences are logical since both waterboards have a similar function, but a different operation area and thus problems and visions. The representatives of Hollandse Delta do include the effects on livability and the loss of culture into the criteria of environment, while Scheldenstromen did not. This partly explains the difference between the two stakeholders. It is likely that solutions would be more costly in the area of waterboard Scheldenstromen, because it is more exposed to the sea and rivers, while having fewer taxpayers. It should also be noted that personal views might differ from each other. The representative of waterboard Scheldenstromen gave both his personal point of view, but also attempted to rank the criteria according to the perspective of the waterboard as a hole. If a second representative was also interviewed it would be unlikely to result in the exact same answers. Yet two representatives of waterboard Hollandse Delta have been interviewed who agreed on most subjects, however there were also multiple discussions. If only one representative was interviewed individually, this might have led to different answers as well.

Furthermore it is surprising that the Deltacommissie considers future adaptation possibilities as the least important criteria, while regarding economic aspects as second most important. However it is argued that all strategies are capable of providing safety in future situations, it is a matter of how far people are willing to go. Even the less future proof strategies do allow for more time and implementation of other strategies if deemed necessary. The economic criteria is in some cases related to the future proof criteria, since certain solutions could require a significant increase or decrease in future spendings.

If the protect-closed strategy is used and a very robust structure is implanted which will provide security for the next 200 years, it would have been worth the initial costs. The economic criteria is also important since it is possible to use strategies which will provide financial opportunities to the Netherlands and its citizens.

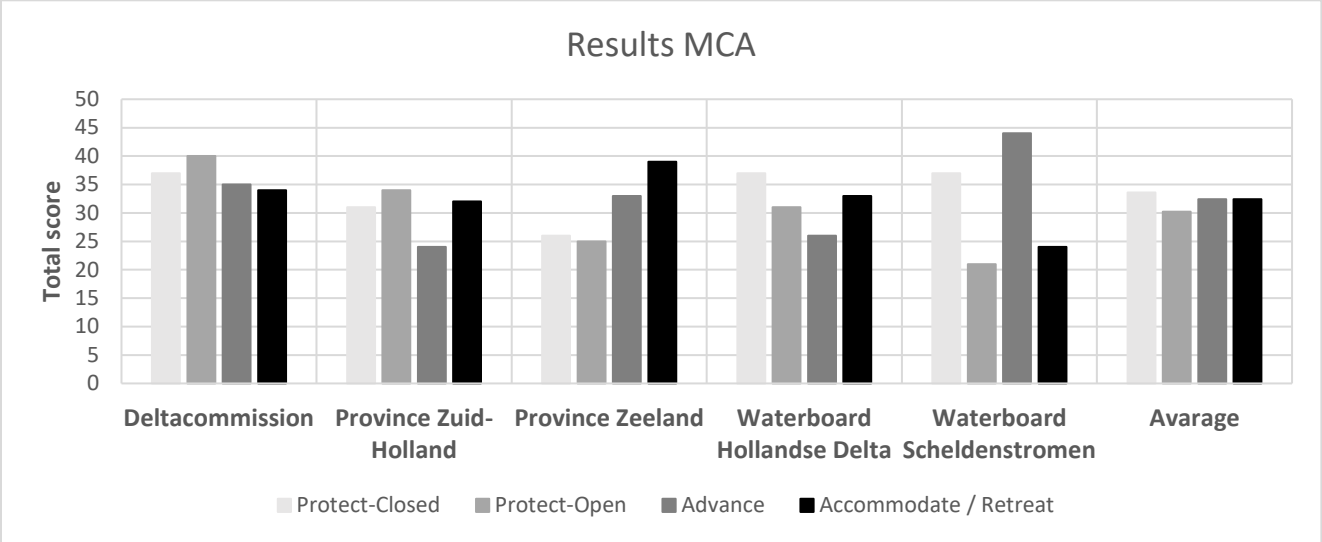


Figure 25: Results MCA.
This figure indicates the results from the MCA. The X-axis indicate the different stakeholders and the average score. The Y-axis visualizes the scores different adaptation approaches have according to the stakeholders. This graph is the result of multiplying the criteria ranking with the stakeholders perspectives. The minimum possible score regarding an approach is 1, while the maximum score is 50.

The figure 25 indicates a small overall preference regarding the protect-closed strategy, however the difference is too insignificant to regard this as the most favourable adaptation strategy. Some stakeholders might be more reluctant to identify clear preferences since it is still "early stage", however there is only limited time available. This indicates that there is still a long way to go to determine which strategy should be implemented within the delta area, while climate data suggest that the time is limited. It is essential that the process of determining a suitable approach should no longer be delayed, since this would seriously endanger the capabilities and possibilities regarding flood protection in the near future.

This figure also indicates a disparity between all of the stakeholders, resulting in no significant overall preference regarding an adaptation approach. The representative of the Deltacommissie expects that in the near future the choice will most likely be made between the protect-open and the protect closed strategy. Especially the protect-closed approach is preferable, because of the reliability and it buys time for other methods. The implementation of the advance strategy still requires a choice between the protect-closed and protect-open approaches. The accommodate strategy is viewed as a last resort approach. The representatives of the province of Zuid-Holland and waterboard Hollandse Delta also seem to prefer more conservative measures, like the protect-closed and protect-open strategy. Yet the accommodate/retreat strategy does score high according to the MCA which is based on their perspectives. On a national scale there are many more stakeholders that are not included into this MCA. With complex problems like these it is common for stakeholders to oppose changes to their living and working conditions, while simultaneously expecting to be kept protected against floods, serviced by water and nature, etc.

This however rases the question regarding the extend and cost towards it is possible or efficient to continue to provide these services. Climate data indicate that a significant sea level rise will occur, which indicate the need for adaptation change. Flood protection is a state issue which means that it is responsible for determining the costs and the capabilities of certain adaptation approaches, in order to provide the required services.

The representatives of waterboard Scheldenstromen and the province of Zeeland have a similar operation area. Interestingly both of them do seriously consider adaptation strategies that differ from the current approaches used within the Netherlands. While the protect-closed/open strategy has been reliable in the past and is a realistic approach for the near future, they still seem to prefer at least one of the “out of the box” strategies. There is however a difference between their reasoning and the actual adaptation strategy. This is logical since they operate within a similar area, yet do not have the exact same responsibilities.

6.2 METHODOLOGY

CLIMATE DATA

The climate data within this report is more recent compared to the initial data used by the Deltacommission in 2008, which is beneficial. Yet the KNMI will publish new data in 2023 regarding climate data and sea level rise. This data will likely be used by stakeholders and policy makers within the Netherlands for further adaptation measures, which could differentiate from the data within this report. This will not necessary make the data used in this report irrelevant, since the strategies and their implementation/impacts will remain mostly the same.

MCA

The MCA consists out of 5 ranking scores, which in itself is a reasonable number. This is due to the fact that there are still a lot of uncertainties regarding adaptation approaches and their impact. However once more data becomes available it would be beneficial to expend the range of these scores since they are very relative *(Infrastructure Australia, 2021)*. This would make it possible to link numbers to each score in order to quantify the impacts. For example an increase in construction costs from 1 to 5 billion euros seems extremely negative. Yet when compared to an increase of 10 to 50 billion it becomes relatively low. Yet they would likely have similar scores in the current MCA.

Only six stakeholders have been interviewed, yet there are a lot of stakeholders which are actually impacted by the different adaptation approaches. These stakeholders are deemed to have the most influence and impacts regarding the adaptation approaches while most of them also take the perspectives of the public into account. For example the waterboards or provinces have a specific area in which they operate and are represented the interests of its habitants or sectors. Ideally more stakeholders should be interviewed including in areas outside of the delta area, since they will also be impacted (in)directly, however due to time limitations and overcomplication this report only six have been interviewed. Another reason why these specific stakeholders have been interviewed, is due to their initial knowledge about the subject and the different adaptation strategies and impacts. This is very helpful

and makes the outcome of the interviews more reliable, since the individuals do possess adequate knowledge regarding this subject.

Only four different adaptation approaches regarding a national scale have been discussed. However it is likely that these adaptation strategies will be combined with each other and the approaches vary in different areas. To keep it simplistic and make sure the different stakeholders have a similar understanding regarding the adaptation approaches, they have been simplified and implemented on a national scale. Yet stakeholders perspectives on these approaches might differ if these approaches where to be implemented on more regional scales.

There is also a limited amount of criteria, which also might be considered too broad. This can be interpreted as both beneficial as negative. Since stimulates stakeholders to use their own perspectives of criteria and indicate their preferences more freely, which is one of the main factors why these criteria have been selected. However when the disparity between perspectives of criteria between stakeholders differentiates to much, it can lead to results that are not comparable to each other. An thus an unfair representation of perspectives on different adaptation approaches in general. These criteria allow stakeholders to include a broad range of perspectives and concerns, since it includes technical, financial, social and environment aspects, which are generally used for MCA's *(Infrastructure Australia, 2021).* Admittingly social aspects could have been integrated better into a separated criteria, in the case of this report its interpretated differently by stakeholders. While social aspects can be combined with criteria concerning for example the environment or economy, it might have led to an even bigger disparity between stakeholders. Some stakeholders actively incorporate these factors into the different criteria, while others do not.

6.3 DISCUSSION

IMPLICATIONS

Currently a lot of research is being executed regarding the sea level rise, climate chance and the need for new adaptation approaches. There have been reports regarding the different adaptations approaches or solutions to protect the Netherlands against sea level rise. However there is very limited information available concerning different stakeholders perspectives on the four adaptation strategies. This report provides more insight into the pros and cons certain approaches have. It also indicates that there is a lot of disparity between stakeholders regarding the consequences of certain approaches and signifies the difficult or even impossible task of determining a single approach which would suit all. This report shows that compromises have to be made and there is no adaptation approach which does not both have significant positive and negative effects simultaneously. Furthermore this report shines a light on the need for decision making regarding these approaches, since recent climate models suggest that there is very limited time available especially compared to the initial climate models used by the Deltacommissie.

LIMITATIONS

There are multiple limitations which have different impacts on this report and its outcome. It is uncertain to what extent the sea level will actually rise, which does have a significant impact on stakeholder perspectives regarding adaptation approaches *(Hegger, D et al., 2012)*. However this should not be used as an excuse for inaction *(Maslin & Austin, 2012).* There are multiple factors that are unpredictable yet are critical in order to determine which strategies are more preferable. It is unclear which climate scenario will actually occur. This does not only impact sea level rise but also has direct impacts on other factors like the environment. This should also be taken into account when deciding which adaptation strategy would be preferable. The bigger the gab in time between the current situation and the predicted future, the higher the uncertainty. It is likely that over time the climate predictions become more accurate *(Räisänen J, 2007)*, however it is not desirable to use this argumentation to postpone the imminent problem regarding sea level rise and the capabilities regarding the Delta Works to ensure protecting against coastal floods *(Maslin & Austin, 2012)*. It is possible that climate models will indicate different values in the near future, however this does not make this report invaluable.

The interviewees gave a representation of the large disparity between stakeholders and uncertainties regarding adaptation approaches. However an important factor that has to be taken into account is that the views of interviewees can differentiate from the views of organisations. A single person or select view cannot be considered to fully represent an organisation as a hole in which there are multiple different visions. In order to determine very reliable perspective of an organisation, either more interviewees per organisation has to be involved, or they have to have a clear vision on this specific subject as an organisation instead of some individuals.

It is challenging to determine the effects certain adaptation approaches have on different sectors like the economy. Some of the suggested adaptation strategies like the advance or retreat strategy have not been executed within the Netherlands on such a scale in the recent past. There are many uncertainties regarding the actual impacts and the reliability. Unfortunately this would require a lot of additional research which was not possible due to the time limits of this report. For example determining the effects adaptation approaches would have on different sectors like the port of Rotterdam would require a lot of time, expertise and would still result in a prediction, since the economy is not a single entity which is predictable. Negative effects on the for example the port of Rotterdam would also have (in)direct impacts on different sectors within the Netherlands or Europe.

RECOMMENDATIONS

Additional research regarding stakeholders perspectives on the different adaptations approaches are required to determine the most suitable solutions. An equal distribution/sharing of knowledge will make it easier for stakeholders to determine preferable solutions, backed up with strong argument *(Berkes F, 2009)*. This is crucial since there is limited time available until the current Delta Works will not be able to withstand the sea level rise and the need for new approaches becomes inevitable. This research should involve more stakeholders that are also located outside of the delta area,

which would be impacted or have influence on the adaptation strategies. It is important to create designs regarding the different adaptation approaches to ensure all stakeholders have the same understanding regarding the approaches. Some of the stakeholders also argue that different criteria are necessary to fully express their views. For example a suggestion of including the criteria 'public support' into future interviews, since this would likely have an significant impact on the choices made by different involved parties. However before implementing this criteria certain issues have to be taken into account. First a long information gathering process needs to take place to determine the support of the public in different impacted regions. When one or more reliable surveys regarding specific areas have taken place, statistics can be linked to it. Since actual numbers would be linked to it, the effects of including it into the MCA would be limited. The current five stakeholders would use the numbers regarding the interview and not their own interpretation.

Dividing the environment criteria into two different criteria is a reasonable suggestion, however water availability is part of all of the current criteria and has been actively used in arguments. Water availability is also part of the reliability criteria, since it different approaches will lead to different results regarding the water availability. The question "How reliable is one of the approaches in terms of future fresh water availability?" is part of the reliability criteria. A similar question could be formulated regarding the future proof criteria. Yet water availability is also part of the economic criteria, since fresh water could also be regarded as an product and does have effect on the Dutch economy in several sectors. Water security could be defined as "the reliable availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economy" *(Grey & Sadoff, 2007).*

More research has to be done regarding the effects of certain adaptation approaches on multiple sectors. For example how significant would the protect-open strategy actually impact the salination of land areas further upstream. At which point will this force farmers to change practices and how would that impact the environment or the economy overall? There are currently to many uncertainties regarding the effects of different adaptation approaches. All of the adaptation approaches have to be assessed and examined to determine and get a better understanding of the positive or negative impacts that are connected to them. This will require some time and its thus essential to start/continue this process as soon as possible, in order to be able to use the outputs to determine a certain adaptation approach. However it is impossible to completely illuminate all uncertainties.

More awareness has to be spread regarding the adaptation strategies and their impacts. Only a select few organizations are aware of the different adaptation approaches, yet all of the Netherlands would be impacted by these strategies. If there is more public awareness about the problem and possible solutions, more organizations will get stimulated into active involvement regarding this subject. This could lead to a better understanding of the possibilities, consequences and support for certain approaches, which is all required in order to determine a suitable approach that is able to have a long lifespan.

6.4 CONCLUSION

Research question: ***What are different stakeholder perspectives regarding adaptation measures to ensure the safety against coastal floods caused by sea level rise in 2150 based on environmental, economic and technical aspects?***

New climate data suggest a sea level rise of 1.9 meters as early as 2100 *(Haasnoot et al., 2020),* this leaves the Netherlands with a shorter timeframe for adaptation compared to earlier models *(Deltacommissie, 2008)*. The lifespan of the current Delta Works will be decreased due to a more rapid sea level rise, increasing the need for new adaptation measures. These four measures are the protect-closed, protect-open, advance and accommodate/retreat strategies.

The protect-closed strategy is currently implemented partly in combination with the protect-open strategy *(Deltares, 2021)*, this is interpretated as a smaller and realistic adaptation step by multiple stakeholders and presumably the public. The advance but especially the accommodate/retreat strategies require significant change in the current Dutch approach regarding coastal and river floods.

All four adaptation strategies have different impacts on environmental, economic and technical sectors/aspects. Stakeholders do agree that the reliability of the approaches is the most important factor of consideration overall, since the main function of these approaches is to provide protection against floods. However there is a significant disparity between the stakeholders regarding the other criteria and the four adaptation methods overall, resulting in no single fit all solution.

There are multiple factors which result in the lack of single fit all solution. Stakeholders have different responsibilities, interests and fields of operations. Since only a very limited amount of representatives have been questioned per organization, personal views and also differences between knowledge regarding this subject did occur. There is limited information available and likely distributed regarding the effects of certain adaptation approaches on different sectors within the Netherlands. The combination between these factors might have led to differences in terms of willingness or capabilities to consider different land and water use strategies.

This report indicates that organizations which are significantly impacted by and influential in adaptation change have different perspectives on the approaches, which limits the ability for decisive decision making in order to provide protection against sea level rise. The lack of for example statistic data regarding the effects of adaptation strategies limits decisive decision making even further. However climate change data suggest that the available timeframe for implementation of adaptation strategies is limited, meaning that difficult choices have to be made rather sooner than later. Even when a certain adaptation approach is selected, political, funding, (conceptual)design, preparation and construction processes will still require a lot of time before an approach becomes fully operational. Considering these adaptation strategies are implemented on a national level, this will take many years. The time to critically consider and compare all adaptation strategies is now.

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I. APPENDIX 1: EXECUTIVE SUMMARY

The Delta Works functions as a crucial flood defence system to protect the Netherlands against coastal floods. These civil works have been adequate enough to provide protection against the current sea level and are even designed to be able to withstand an increase in sea water level *(Rijkswaterstaat, 2022)*. However, sea level rise predictions are more extreme compared to the design period or older reports *(Deltacommissie, 2008)*. This decreases the life expectancy of the current Delta Works and creates multiple challenges in terms of flood protection *(Deltares, 2021)*. An adaptation strategy must be addopted to ensure that the Netherlands remains protected against coastal and river floods in the future. There are multiple possible adaptation strategies which each offer different possibilities but limitations. Since possible adaptation measures would have local also (inter)national impacts, it is essential to consider the perspectives of different stakeholders. This has led to the following main question, which has been divided into four sub questions.

What are different stakeholder perspectives regarding adaptation measures to ensure the safety against coastal floods caused by sea level rise in 2150 based on environmental, economic and technical aspects?

1. *How much will the sea level rise till the year 2150 according to different projections?*

In 2008 the Deltacommissie published a report *(Deltacommissie, 2008)* which indicated the sea level rise and appropriate measures to ensure the protection of the Netherlands against floods. Recent reports indicate significantly higher water levels within the same time frame *(Bezem, 2021)*. These reports even indicate a sea level rise of 2 meters at the start of the 22th century. The RCP8.5[A] projection is the most extreme scenario. And indicates a significant faster sea level rise compared to the Deltacommissie's mission from the year 2075 onwards *(Haasnoot et al., 2020)*.

Table 1: SLR per projection based on (Haasnoot et al., 2020) and (Deltacommsie, 2008).

SLR	0,5m	0,75m	1,0m	1,25m	1,50m	2m	2,5m
Deltacommissie 2008	2060	2075	2088	2105	2113	2128	2146
RCP4.5[A]	2075	2087	2097	2106	2112	2125	2135
RCP8.5[A]	2065	2075	2081	2085	2091	2103	2110

2. *Which current coastal flood protection measures are not robust enough to ensure the safety and protection of the Netherlands and its citizens in the year 2150?*

The Measlant barrier turns out to be the most critical part of the Delta Works partly due to the increase in closing frequency. Another important factor is its limited ability to continue to provide flood protection according to Dutch flood risk regulations. This is also the case for the other parts of the Delta Works. Since the Delta Works operate as one system *(Rijkswaterstaat, 2022)*, adaptation in one place will impact the other Delta Works.

Table 2: Maximum life expectancy (Rijkswaterstaat & Deltares, 2008) and (Deltacommissie, 2008)

Structure	Deltacommissie	RCP 4.5[A]	RCP 8.5[A]
Brouwersdam	2085	2090	2080
Eastern Scheldt Barrier	2088	2097	2081
Haringvliet Dam	2085	2090	2080
Measlant Barrier	2060	2075	2065
Veerse Gatdam	2085	2090	2080

3. *What are possible adaptation measures to ensure the safety and protection of Netherlands and its citizens in 2150?*

There are four different approaches considered within this report *(Deltares, 2021)*, which are based on sea level rise responses by IPCC. *(IPCC, 2022)*

Protect-closed focusses on protecting vulnerable areas against floodings, especially areas with a high population density, like Rotterdam. This would imply that the Delta Works would completely seal the North Sea off from the delta area. Pumps would be required and dikes should become higher due to increased peak discharge within the rivers. Solutions based on this approach are, the construction or improvement of dams and dikes. The usage of wetland or foreshores and the usage of sediment to protect against water.

Figure 1: Protect-closed Adaptation Strategy (Carof Deltares, 2021)

The protected-open strategy is similar with the currently used strategy for the Delta Works. The dikes within the Delta Works would be improved but the connection between the North Sea and the delta would be maintained/restored to enable ships to still enter the port of Rotterdam for example. Solutions based on this approach are, the construction or improvement of flood barriers and dikes. The usage of wetland or foreshores and the usage of sediment to protect against water.

Figure 2: Protect-Open Adaptation Strategy (Carof Deltares, 2021)

This approach focusses on increasing the safety while also creating more landmass which can be used for multiple purposes. Coastal defenses start within the sea creating more land. Solutions based on this approach are, the construction of flood barriers, islands and dikes outside of Dutch coast. There are a lot of possibilities within this adaptation strategy, since the scope is not limited to the Netherlands land area.

Figure 3: Advance Adaptation Strategy (Carof Deltares, 2021)

The accommodate/retreat strategy focusses on decreasing the vulnerability caused by sea level rise by water and salt tolerating land use. Solutions could be building houses on poles or on higher ground levels. Even immigrating to less vulnerable areas or restricting building in certain areas are part of this strategy. Which decreases the need for dikes and complex systems across most parts of the current the current coast and delta.

Figure 4: Accommodate Adaptation Strategy (Carof Deltares, 2021)

4. *What are different stakeholder perspectives on the possible adaptation approaches?*

Within this report 6 stakeholders are taken into account. These are the stakeholders that have the biggest influence and/or dependence on the different adaptation measures, namely the Deltacommissie, Rijkswaterstaat (not included into MCA), waterboard Scheldestromen, waterboard Hollandse Delta, both the provinces of Zeeland and Zuid-Holland. Representatives of these organizations have analyzed the different adaptation approaches based on four criteria, being economic and environmental factors, future adaptation possibilities and the reliability of these approaches. This lead to the results described in figure 5.

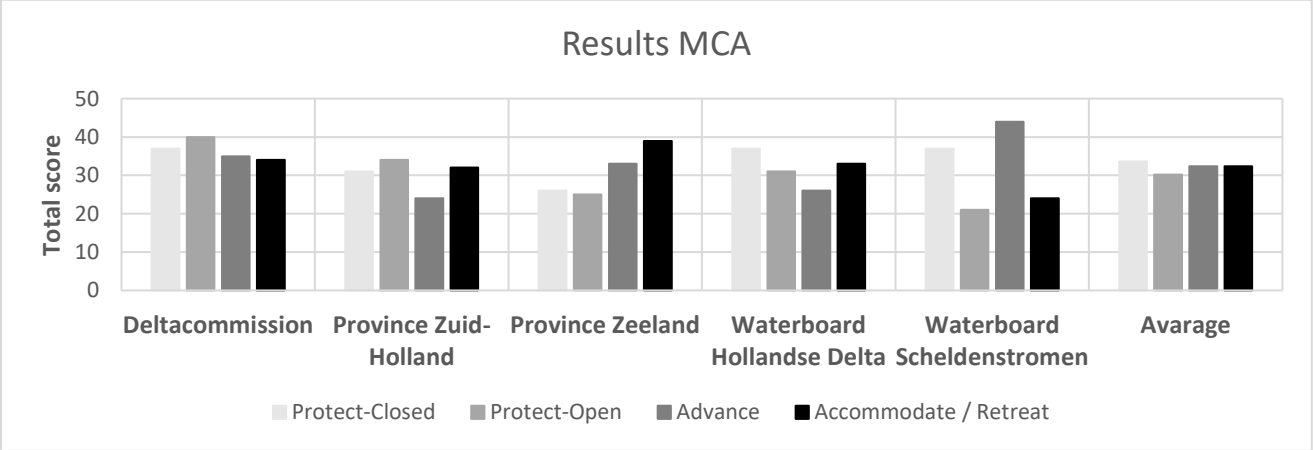

Figure 5: Results MCA.
This figure indicates the results from the MCA. The X-axis indicate the different stakeholders and the average score. The Y-axis visualizes the scores different adaptation approaches have according to the stakeholders. This graph is the result of multiplying the criteria ranking with the stakeholders perspectives. The minimum possible score regarding an approach is 1, while the maximum score is 50.

All four adaptation strategies have different impacts on environmental, economic and technical sectors/aspects. Stakeholders do agree that the reliability of the approaches is the most important factor of consideration overall, since the main function of these approaches is to provide protection against floods. However there is a significant disparity between the stakeholders regarding the other criteria and the four adaptation methods overall, resulting in no single fit all solution. Stakeholders have different perspectives regarding the continuation of the “reliable” current strategies or the usage of more “unknown” adaptation strategies. These strategies have different impacts on the operation areas of the stakeholders.

This report indicates that organizations which are significantly impacted and influential in adaptation change have different perspectives on the approaches, which limits the ability for decisive decision making in order to provide protection against sea level rise. The lack of for example statistic data regarding the effects of adaptation strategies limits decisive decision making even further. However climate change data suggest that the available timeframe for implementation of adaptation strategies is limited, meaning that difficult choices have to be made rather sooner than later. Even when a certain adaptation approach is selected, political, funding, (conceptual)design, preparation and construction processes will still require a lot of time before an approach becomes fully operational. Considering these adaptation strategies are implemented on a national level, this will take many years. The time to critically consider and compare all adaptation strategies is now.

II. APPENDIX 2: ALL OF THE CURRENT DELTA WORKS

1. LOCATION

Figure 1 shows the location of all the Delta Works. The combination of all these civil structures make it possible to provide protection against coastal floods. The structures would not be capable to fulfill their purpose single handedly, this is why it is important to asses all the Delta Works.

Figure 1: Delta Works Zeeland. (Rijkswaterstaat, 2022)

2. MAESLANTKERING

The Maeslantkering consists out of 2 parts that each have a width of 210 meters, a height of 22 meters and a depth of 15 meters. The doors are filled with water in case of an emergency, which allows them to sink to the bottom and close of the river. Each part is connected to a ball joint with a intersection of 10 meters, which allows the structure to open and close. The construction of the Maeslantkering finished in 1997 and fully close in 2007 for the first time to block coastal water during a storm. There have been other incidents in which it had to party close, but in 2018 was the last time the structure had to fully close. Since this structure is located near the Rotterdam harbor closing it will have negative impacts for the trade capability of the entire Netherlands. *(Rijkswaterstaat, 2022)*

Figure 2: Maeslantkering (Watersnoodmuseum, 2022)

3. HARINGVLIETDAM

The construction of the Haringvlietdam was finished in 1970 and consists out of 17 discharge openings of 56,5 meter width each. The Haringvlietdam has a length of 1 kilometer. During high tide the sluices are partly opened to ensure fish migration and create a more natural transition between salt and fresh water. It also functions as bridge between Goeree-Overflakkee and Voorne-Putten. *(Rijkswaterstaat, 2022*)

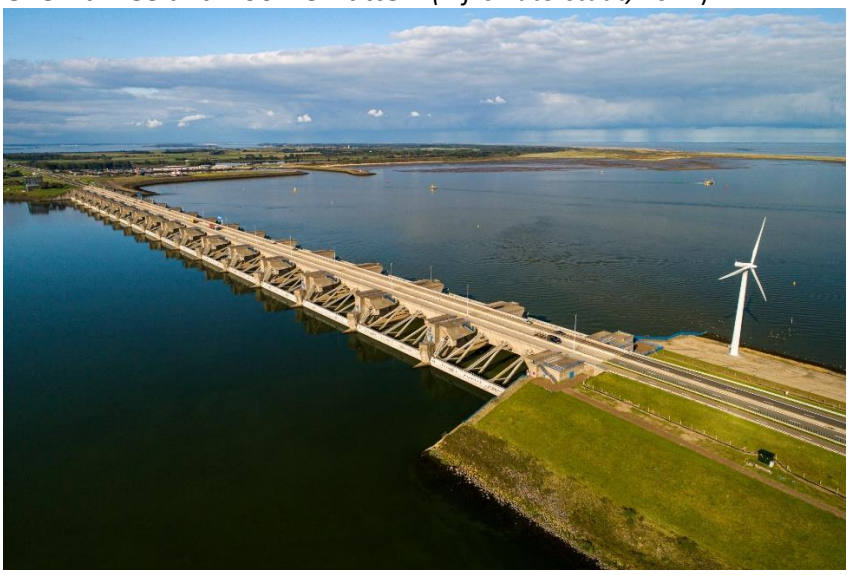

Figure 3: Haringvlietdam. (Op Voorne-Putten, 2022)

4. BROUWERSDAM

The Brouwersdam has a length of 6,5 kilometres and a height of 12 meters. Construction took place from 1962 until 1971. The dam divides West-Europe's biggest saltwater lake (11.000 ha) from the North Sea, and connects Goerree-Overflakkee with Schouwen-Duiveland. The water turned brackish after the construction of the dam because the water stopped flowing. This resulted in a loss of plants and animals. In 1978 the Brouwersluice was opened to restore the nature and give the lake a similar salt concentration as the North Sea. Animals and plants are slowly returning. *(Rijkswaterstaat, 2022)*

Figure 4: Brouwersdam. (Rijkswaterstaat, 2022)

5. OOSTERSCHELDEKERING

The Oosterscheldekering is the biggest Delta Work due to a total length of 9 kilometres. Three of the nine kilometres are able to open and close depending on the sea level. The construction of this massive flood barrier started in 1976 and finished in 1986. The structure consists out of 65 pillars which each have slides with a width of 42 meters and a height between 6 and 12 meter between them. The Oosterscheldekering closes once a year on average. This structure makes it possible to have a minimal effect on the occurrence of high and low tide within the area, while still being able to provide protection against coastal floods. *(Rijkswaterstaat, 2022)*

Figure 5: Oosterscheldekering. (NLNederland, 2022)

6. VEERSE GATDAM

The Veerse Gatdam has a length of 2,8 kilometers. The dam itself has been integrated within the area and has a beach on one side of the structure. The dam finished construction in 1961 and in combination with the Zandkreekdam it is able to close the Veerse Lake. To keep the surrounding polders dry the water level is reduced till 30 centimeters below NAP during the winter. In the summer the water level is increased again, because it is beneficial for the nature and tourists. *(Rijkswaterstaat, 2022)*

Figure 6: Veersedam (Watersnoodmuseum, 2022)

7. GREVELINGENDAM

The Grevelingendam finished contrustion in 1965 and reduces the water flow in Grevelingen, Haringvliet and Volkerak. This effectively reduces the pressure on the Haringvlietdam, Brouwersdam and the Oosterscheldenkering. The dam itself has a length of 6 kilometers and also improves the transport between different parts of Zeeland, because the N59 is located on top of the dam. *(Rijkswaterstaat, 2022)*

Figure 7: Grevelingendam (Watersnoodmuseum, 2022)

8. ZANDKREEKDAM

The Zandkreekdam was completed in 1960 and has a total length of 830 meters. It has 3 functions, which are a connection between roads, sluice and a dam. *(Rijkswaterstaat, 2022)*

Figure 8: Zandkreekdam (Watersnoodmuseum, 2022)

9. PHILIPSDAM

The Philipsdam has a length of 7 kilometers and finished construction in 1987. The dam devides the freshwater in the Volkerak-Zoommeer from the salt water from the Oosterscheldt. Within the Philipsdam the Krammersluices are located, which allow ships to pass through this area. There are 2 sluices that have a 280 by 24 meter width which are meant for commercial shipping. It also contains 2 smaller sluices which are meant for pleasure crafts. The Philipsdam in combination with the Oesterdam have an important role in decreasing the size of the Oosterscheldt. By decreasing this area the effects of the tides have increased again, which is beneficial for nature. *(Rijkswaterstaat, 2022)*

Figure 9: Philipsdam (Watersnoodmuseum, 2022)

10. OESTERDAM

The Oesterdam is the biggest dam of the Delta Works and completed in 1986. The Oesterdam has a length of 10,5 kilometers. The dam protects the area against high water levels, while deviding the nature area the Oosterscheldt from the Scheldt-Rhineconnection from ships. There is also a road on top the dam that connects reduces traveltime between different places. *(Rijkswaterstaat, 2022)*

Figure 10: Oesterdam. (Watersnoodmuseum, 2022)

11. HARTELKERING

The Hartelkering has 2 passages one has a width of 49 meters and the other 98 meters. Which can be closed due to slides which are located 14 meter above sea level. The slides are able to withstand a waterlevel of 3 meter above NAP and has only been closed twice since its existence (2007 and 2008). *(Rijkswaterstaat, 2022)*

Figure 11: Hartelkering. (Rijkswaterstaat, 2022)

12. HOLLANDSCHE-IJSELKERING

The Hollandsche-IJselkering finished construction in 1958 and protects the lowest areas within the Netherlands. It is able to protect against high water by letting one of the vertical slides sink in the water, by extreme weather the 2nd slide is also closed. Both these slides have a width of 80 meters and a hight of 12 meters. On average the Hollandsche-IJselkering closes 3 or 4 times a year, this happens when a water level above 2,25mNAP is expect. *(Rijkswaterstaat, 2022)*

Figure 12: Hollandsche-IJselkering. (Rijkswaterstaat, 2022)

13. VOLKERAKDAM

The Volkerakdam finished construction in 1967 and divides the Haringvliet and the Oosterscheldt. It is Europese most frequently used shipping sluice complex. Which means that it is off enormous economic importance to the Netherlands. 150.000 ships pass this sluice complex on average per year. The Volkerakdam protect the southern part of Zeeland against high water levels. *(Rijkswaterstaat, 2022)*

Figure 13: Volkerakdam. (Watersnoodmuseum, 2022)

14. BATHSE SPUISLUIS

The Bathse Spuisluis finished construction in 1987 and is able to discharge 300.000 litre per second. It is meant to discharge excess water and is the only Delta work which task is not to protect against high water levels. It improves the water quality of the Zoommeer. If the water is not being discharged the water level would increase to much due to groundwater. (Rijkswaterstaat, 2022)

Figure 14: Spuisluis. (Rijkswaterstaat, 2022)

15. ADDITIONAL INFORMATION: EUROPOORTKERING

The Europoortkering is the latest part of the Delta Works and protects Southern-Holland against floodings, while also allowing ships to pass through the Nieuwe Waterweg. It consists out of the Maeslantkering, the Hartelkering and dike Rozenburg. The Maeslantkering currently closes at a water level of 3mNAP in Rotterdam or 2,9mNAP in Dordrecht. The Maeslantkering is able to withstand a tidal wave of 5mNAP (Rijkswaterstaat, 2022) and has originally been designed to function with a sea water level rise of 50 centimeters (Deltacommisie, 2008). This means it functions as intended until 2050, after that it would still be able to defend against coastal flooding. The downside is that the Maeslantkering would have to be closed more frequently which in combination with increased river discharges during that period would result in an increase of extreme water levels. Another problem of closing the Maeslantkering on a more frequent basis is that it limits the ability for ships to enter or leave the port of Rotterdam. Which will have negative effects of the economy within this area, but also the Netherlands and possible other European countries. This doesn't necessary mean that the Maeslantkering should be removed in 2050, it could also be combined with other measures. However after the year 2100 it is expected that Maeslantkering would be closed on a to frequent basis and a solution has to be implemented before this. The Hollandse IJsselkering is not part of the Europoortkering, yet it is connected to the New Meuse. The New Meuse is divided from the North Sea by the Maeslantkering.

III. APPENDIX 3: SEA LEVEL UNTIL 2150

3.1 EXPECTED SEA LEVEL UNTIL 2150.

There a multiple reason for the increase of the global sea level. The three main reasons that are linked to climate change are thermal expansion, melting glaciers and the loss of Greenland and Antarctica's ice sheets.

- **Thermal expansion** is caused by an increase in the temperature of a waterbody. Warm water consumes more space, which naturally causes an increase in sea level rise. Thermal expansion has had a significant impact on global sea level rise. Figure 1 visualizes the influence of thermal expansion on the total sea level rise in the year 1992 till 2008. The blue line indicates the sea level rise caused by thermal expansion. The black line indicates the total sea level rise, while the red line displays the residual sea level. *(Cazenave, A., & Llovel, W. 2010)*

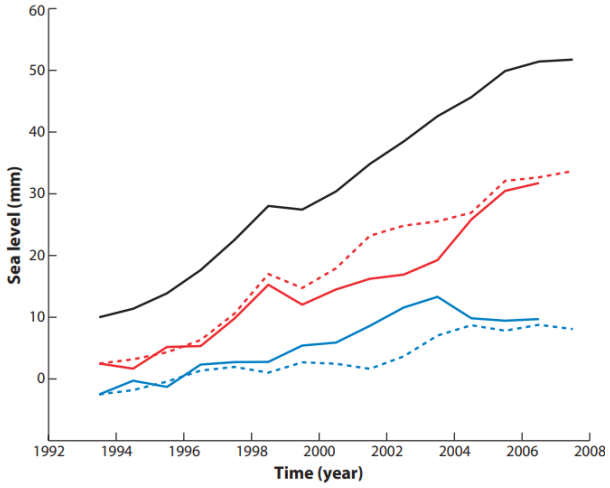

Figure 1: The effect of thermal expansion on sea level rise from 1992 till 2008. (*Cazenave, A., & Llovel, W. 2010)*

Figure 2 indicates the effects of thermal expansion on sea level trends from 1955 until 1995. The figure indicates a mean increase of 0,22 mm/year, yet there is a high difference between the sea level trends within this time period. Since thermal expansion is highly influenced by temperature the sea level can change on a yearly basis. This means that an increase or decrease in thermal expansion is not permanent. Yet an increase of the average temperature will also increase the average thermal expansion. *(Lombard, A et al., 2005)*

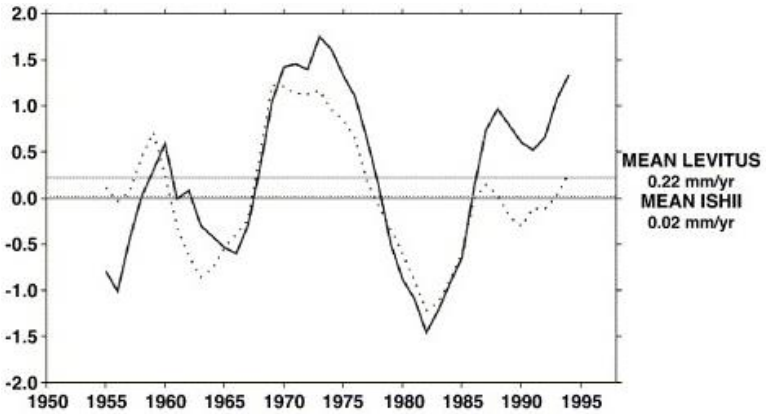

Figure 2: 10-year period global mean steric sea level trends (mm/yr). (Lombard, A et al., 2005)

Between the years 1993 and 2007 thermal expansion caused an average increase in the sea level of 1,0 mm/year ± 0,3 (mean of *Levitus et al. 2009* and *Ishii & Kimoto 2009* values). While the period between 2003 and 2007 indicates an increase of 0,25mm/year ±0,8 (mean of *Willis et al. 2008, Cazenave et al. 2009*, and *Leuliette & Miller 2009* values). This indicates that the impact of thermal expansion decreased, yet there is a significant insecurity (0,8mm/year) about the actual impact. Thermal expansion is highly depend on the yearly temperature, which results in big fluctuations on a yearly basis.

- **Melting glaciers** are naturally restored in the winter due to evaporated seawater which forms snow. Yet the persistently higher average temperatures causes more snow and ice to melt during the summer, which cannot be fully restored during the winter. The average length of winters is decreasing, since temperature change causes it to start later, while spring generally happens earlier. This results in less time for snowfall and thus limited time to restore the melting. The results are a decrease of the quantity and size of glaciers and an increase of the sea water level. Between the years 1993-2007 the sea level rise was increased by 1,1mm/year ± 0,25 due to melting glaciers *(Kaser et al. 2006)*, *(Meier et al. 2007)*. While measurements from 2003-2007 indicate an increase 1,4mm/year± 0,25 due to melting glaciers (*Cogley 2009).* Which indicates an increase the effect of melting glaciers on the sea water level.
- **The loss of Greenland and Antarctica's ice sheets:** Climate change causes these icesheets to melt on a faster rate than before. The melting ice ends up in the oceans which increases the required space for these waterbody's and thus increases the sea level. Between the years 1993-2007 the melting ice sheets caused an average sea level rise of 0,7mm/year ± 0,2 (*Cazenave, A., & Llovel, W. 2010).* Between 2003 and 2007 an average increase of 1,0mm/year ± 0,2 was determined (*Cazenave, A., & Llovel, W. 2010)*. This indicates that the impact of the melting ice sheets on the sea level rise has increased.

Land waters like for example river, lakes and man-made reservoirs also influence the sea level. Factors like pumping up water, deforestation or urbanization all impact the sea level. From the year 2003 till 2007 these factors limited the sea level rise by 0,2 mm/year (W. Llovel, K. et al, unpublished manuscript). In table 1 all factors are compared. The percentages indicate the effect of each factor on the sea level rise within this period. The observed data and the combination of factors do not share the same value for the average sea level rise. There are multiple reason for this. The main cause are the measure uncertainties. Yet this table can still be used as indication for the influence of the different factors on sea level rise.

Table 1: Sea level rise comparison between 1993-2007 to 2003-2007. (based on: Cazenave, A., & Llovel, W. 2010).

Sea level rise	**1993-2007 mm/year**	**1993-2007 percentage %**	**2003-2007 mm/year**	**2003-2007 percentage %**
Observed	3,3 ± 0,4	100	2,5 ± 0,4	100
Thermal expanse	1,0 ± 0,3	30,3	0,25 ± 0,8	10
Glaciers	1,1 ± 0,25	33,3	1,4 ± 0,25	56
Total ice sheets	0,7 ± 0,2	21,2	1,0 ± 0,2	40
Land waters	-	0,0	-0,2 ± 0,1	-8
Total	2,8 ± 0,35	84,8	2,45 ± 0,85	98%

3.2 EXTREME EVENTS

Climate change does not only impact the sea level, but also the frequency of extreme events. For example a heavy storm in combination with a higher water level can create bigger waves then before. This is important to also take into account, since flooding usually happen during extreme weather events.

The windspeed and the frequency of storms will both increase in the future *(Gregor C. et al., 2006).* Studies suggest that within the North sea changes in wind conditions (Pryor et al. 2006) and storm water levels *(Woth 2005; Woth et al. 2006)* will occur due to climate change. Another publication *(Grabemann & Weisse. 2008)* deals with potential future changes in the wave climate within the North sea. The publication uses a combination of two global general circulation models (HadAM3H and ECHAM4/OPYC3) and two different climate scenarios (A2 and B2) for the years 2071-2100. This data has been compared with data from the period of 1961-1990. The publication indicates a wave height increase between 7% and 18% within the North Sea during a 99 percentile wind speed. Extreme wave heights may increase by 0,25 to 0,35 meter in 2100 in the southern and eastern parts of the North Sea *(Grabemann & Weisse. 2008)*.

In a more recent analysis *(Iris Grabemann et al., 2015)* the same time period is further analysed. Ten different projections are compared, most of these suggest an increase in the significant wave height (SWH) at the coast of Zeeland and Rotterdam. An average increase in the SWH of 0,15 meters within this area has been determined based on the data (appendix 3). This is lower compared to earlier named increases in wave heights, because it is more location specific. Yet it should also be noted that within the delta itself the projections all agree on a SWH increase between 0 and 0,25 meter. Which has to be taken into account if the Delta Works located between the North Sea and the delta are redesigned or removed. The wave height is dependent on the civil structures that are located within the delta. A dam could significantly impact the wave height for example.

Table 4: SWH according to (Iris Grabemann et al., 2015).

Year	1961-1990	1990-2071	2071-2100	2100+
SWH coastline	0	0 – 0,15 m	0,15 m	>0,15 m
SWH delta	0	0 – 0,25 m	0,25 m	>0,25 m

3.3 RIVER DISCHARGE

Not only the sea level will increase, but also the discharge of the Meuse and the Rhine. Currently the Rhine has a maximum winter discharge of 16.000 m^3/s, which is expected to increase to 18.000m^3/s in 2100. The winter discharge of the Meuse will also increase from 3.800 m^3/s to 4.600 m^3/s in 2100 *(Deltacommisie, 2008).* The increase in discharge should be taken into account, since it will increase the water level within the delta, which can cause flooding form the rivers.

IV. APPENDIX 4: SWH AT THE COAST OF ZEELAND AND ROTTERDAM.

This appendix explains how the average SWH at the coast of Zeeland and Rotterdam has been determined. Figure 1 indicates 10 different projections of the change in SWH of 2071-2100 compared to the SWH of 1961-1990. All calculations are based on a 99 percentile wind.

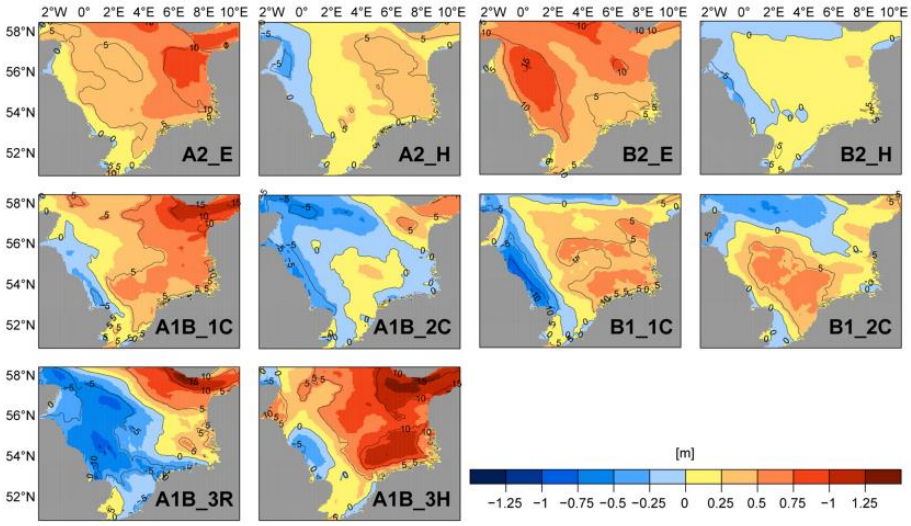

Figure 1: Spatial distribution of the climate change signals of the 30-year mean of annual maximum SWH in meters for the period 2071-2100 compared to the period 1961-1990. (Iris Grabemann et al., 2015)

Yet these projections indicate a significantly bigger area, while only a relatively small part directly influences the Delta Works. Figure 2 zooms in on the areas that are relevant to this report. One projection indicates a SWH decrease between -0,25 and -0,50 meter at the coastlines. Three projections indicate a decrease of SWH between -0,25 and 0 meter at the coastlines. Four projections indicate a SWH increase between 0 and 0,25 meter at the coastlines. Two projections indicate a SWH increase between 0,25 and 0,50 meter. For each of the projection the maximum SWH is used, since this the most extreme and thus will have a bigger impact on designing or analysing solutions.

Figure 2: Zoomed in version of figure 1 (Iris Grabemann et al., 2015)

The average increase in SWH is calculated below, in which:
P_x = Amount of projections between a certain value.
MaxSWH = The maximum change in significant wave height.
x = amount of projections in total.

$$avarage\ SWH\ increase = \frac{p1 * \mathrm{MaxSWH} + p2 * \mathrm{MaxSWH} + \mathrm{p3} * \mathrm{MaxSWH} + \ p4 * \mathrm{MaxSWH}}{x}$$

$$avarage\ SWH\ increase = \frac{2 * -0{,}25 + 3 * 0 + 4 * 0{,}25 + 2 * 0{,}50}{10}$$

$$avarage\ SWH\ increase = 0{,}15\ meter$$

Yet it should also be noted that within the delta itself the projections all agree on a SWH increase between 0 and 0,25 meter. Which has to be taken into account if the Delta Works located between the North Sea and the delta are redesigned or removed. For more information about future SWH changes, read (*Iris Grabemann et al., 2015)* and *(Grabemann & Weisse. 2008).*

V. APPENDIX 5: DIFFERENT SOLUTIONS

Solutions and adaptation approaches could be considered on a (inter)national or more regional scale. Within this appendix the focus is on separate solutions, described by Haasnoot. The following solutions in figure 1 are separated into 5 different types of solutions. These 5 groups will also be used within this chapter.

Waterbarrier – Hard (H)
H1. Improve dikes
H2. Compartmentalization
H3. Dam local/mega
H4. Storm surge barrier
H5. Double dikes
H6. Wave breaker

Waterbarrier – Soft (Z)
Z1. Coastal supplementation
Z2. Vegetation
Z3. Seaward land strip
Z4. Naturally raising ground level
Z5. Artificially raising ground level

Drain & Store river water (R)
R1. More space for rivers
R2. Different drain river distribution
R3. Store in lakes/delta
R4. Closing-pumping

Adjusted building (A)
A1. Elevated
A2. Floating
A3. Damage reduced (wetproof)

Move & Avoid (V)
V1. Buildfree areas
V2. Building with short life expectancy
V3. Relocate
V4. Develop high laying parts of the Netherlands

Figure 1: Specific solutions regarding adaptation strategies. (Haasnoot et al., 2022).

WATERBARRIER – HARD (H)

H1. One frequently used measures to provide protection against coastal flooding is improving the current dikes. This can be interpreted in different ways. The structure of the dikes itself could be improved in material, width or height. A change in materials increase the robustness of a dike and decrease the chance of a breach in the dike. Increasing the height of the dikes will help to protect against an increasing water level, since it would take a higher water level before the dike overflows. Increasing the height of dikes while making use of the same materials requires an increase in width, to provide more support against the increased pressure the dike has to be able to withstand. Increasing the width of dikes is not always possible, in some areas there might be a limited amount of space available. This will require decisions and compromises to be made between stakeholders.

H2. Compartmentalization implies the construction of new dikes that are not permanently located next to water. These are dikes located in a landscape usually surrounding vulnerable cities which will provide protection once rivers have overflown *(Deltares, 2021).*

H3. The construction of a dam can be part of multiple adaptations strategies depended on the location. The dams can also vary a lot in size, take for example the proposition by Groeskamp to build a mega dam in the North Sea to protect multiple countries against the rising sea level *(Groeskamp S, et al., 2021)*. However these dams are also possible in a smaller scale, for example one that protect Zealand against floods. This can be done by building a dam separating Zealand and the North Sea according to the "advance" approach. A dam can also be implemented on a more local scale, in which it located within rivers. This can reduce the chance of floods downstream a river, if appropriate measures are taken to store the upstream water.

H4. Storm surge barriers are civil structures that are able to regulate the passage and blocking of water. An example of a storm surge barrier is the Maeslantbarrier, which allows ships to pass during normal circumstances, but protects against floods during extreme weather. This strategy is currently used for multiple Delta Works, and could be used in the future. However this would require a completely new Delta Works system that is capable of protecting against significantly higher water levels. A point of attention that makes this approach more and more challenging is the fact that the Sea level will rise significantly compared to average water level in the river. Measures have to be taken to combat this difference without significantly damaging the ecosystem or the economy.

H5. Double dikes are mainly used for river floods. The land between the 2 dikes can be used as farmland but has an increased chance of flooding. While the first dike is allowed to flood from time to time, the second dike shouldn't be flooded. One of the reason why this approach is mainly used for river floods, is because the flooding of the land between the dikes can be beneficial for farmers. However flooding land with salt water will almost definitely negatively affect farm practices within this area.

H6. Wave breaker are used in coastal areas to decrease the force and height of waves. A certain water level will not necessarily pose a big threat to flood protection systems, until it is combined with extreme waves *(Lydonn C, et al., 2019)*. Breaking waves will thus decrease the chance of flooding and failure of an civil work. There are many different methods to decrease the hight of wave before they reach the shore. A waves breakpoint or size is heavily influenced by changing the depth of the underlaying waterbody *(Lemy E, 2003)*. Placing object like stones, poles or even floating breakers will also decrease the force and height of waves.

WATERBARRIER – SOFT (S)

Z1. Coastal supplementation is a strategy that is frequently used in order to protect the Dutch coasts against erosion and flooding. The coast is supplemented by dredged sand. This method can also provide assistance in breaking or decreasing the height of waves.

Z2. The usage of vegetation in front of primary flood defences can reduce the exposure to waves *(Haasnoot et al., 2022).* Vegetation can also reduce the effect of erosion or even hold sediment, which can increase the strength and height of this area due to natural processes.

Z3. A seaward land strip or man-made islands both have a similar function, yet different characteristics. The seaward land strip increases the width of the coasts, which decrease the force of waves on the dikes, dunes or other primary flood protection structures. Man made islands also reduce the force and height of coastal waves. If these islands are connected with water barriers an artificial lake can be created in which the water level can be lower compared to the area outside of the protected area.

Z4. Raising the ground level decreases the height and force of coastal waves before they reach primary water barriers *(Lemy E, 2003)*. This can be achieved with different methods. Most methods focus on increasing the sedimentation within a certain area, by for example slowing the flowrate. It is also possible to use a seagrass or other types of vegetation that have a double function. These types of vegetation growth according to the sea level rise, while also slowing flowrates and thus increasing sedimentation *(Haasnoot et al., 2022)*.

Z5. It is also possible to artificially raise the ground level, by creating a mound. This mound provides protection against flooding, due to its height. While this method is mainly used to provide protection against river floods, it can also still function as method to reduce the height and force of coastal waves.

DRAIN & STORE RIVER WATER (R)

R1. Increasing the space for rivers can decrease the water level while increasing the peak discharge and water storage capabilities. There are multiple methods to increase the space of rivers. This can be done by increasing the width or creating/improving side channels. Due to an expected increase in discharge during the winter period solutions like this will become necessary.

R2. Changing the drain river distribution can relieve pressure from some rivers. Waterways that are relatively close to critical or densely populated areas would experience a decrease in flooding risks, if the parts of the river water is relocated to other waterways.

R3. Storing fresh water in the delta area or in lakes like the IJsselmeer decreases the chance of river flooding when pump systems are not able to keep up with the discharge of the rivers.

R4. Pumps can provide a solution in transporting fresh water to the sea or other areas. By closing of the natural connection between rivers and the sea, areas are bound to be flooded if no other measures are taken. A river or waterbody can only store a certain amount of water before it fails or overflows.

ADJUSTED BUILDING (A)

A1. Adjusting building to increased flooding risks can reduce possible risks and damages. Methods of adjusted building are constructing buildings on mounds or poles to provide protection against river or even coastal floods. However the design has to be able to withstand the frequency and severity of these floodings. The maintenance and security is dependent on the these factors. For example in the case of using poles underneath buildings, reliable materials have to be used in which a difference is made between salt or fresh water.

A2. Floating buildings are able to stay above the water level even if this increases significantly. The usage of houseboats are quite common in the Netherlands, yet other methods are also possible. There are examples and studies from all over the world with different (expected) price ranges. A study about floating houses in Bangladesh provides really cheap houses *(Ishaque F, 2014)*, yet these don't meet the living or safety standards within the Netherlands. Yet there are also multiple floating houses already located within the Netherlands or even other countries *(Moon C, 2015)*.

A3. Another method for providing security in vulnerable areas can be achieved by reducing the damages caused by flooding. This can be done by making buildings more resistant to fresh or salt water floods. The buildings will still be exposed to increased flood risks, yet they are able to withstand most of the damage or effects.

MOVE & AVOID (V)

V1. Build free areas indicate areas where new construction projects are not allowed to take place. These areas do not meet the same security standards regarding flood protection. These areas could also be used to store water during times of increased flooding chances at more critical areas.

V2. Non-permanent buildings are able to chance location or easily being demolished and cheap to rebuild elsewhere. The life expectancy of these buildings can also be significantly lower, in return these building are often cheaper. These methods allows people to live in more flood prone areas.

V3. Relocating parts of the population to less flood prone areas makes it easier to protect them. Less money has to be spend on protecting measures, since most people live close to each other.

V4. Developing elevated parts of the Netherlands reduces the risks floodings and costs of flood protection in the lower located areas of the Netherlands.

VI. APPENDIX 6: STAKHOLDERS

This appendix contains additional information regarding the stakeholder interviews.

RIJKSWATERSTAAT

One representative of Rijkswaterstaat has been interviewed. This individual has adequate knowledge concerning this subject. However personal views might differ from Rijkswaterstaat as a hole. The individual has been tasked with providing answers from the Rijkswaterstaat's perspective. The interviewee has experience in using models to calculate the effects of certain strategies on different sectors. She argues that there are too many uncertainties to fill in the tables that are used for the other interviews. A lot of assumptions have to be made and experts on every single criteria would be necessary. However even these expert would likely make assumptions, because there is still a lot of research to be done in to the effects of certain approaches. This means that for this interview the tables are not being used. Instead she gave a description of the different strategies and their pros and cons.

The interviewee mentions that the different solutions are used to describe long term solutions that are comparable, yet this is not the case in the reality. The protect open strategy is basically the same strategy that is currently used. It is important to mention until which level of sea level rise a certain approach would be adequate enough to provide protection against flooding. This creates an overview of when certain approaches are effective and when there is a need for chance. **The different solutions could be implemented after each other. We are currently mostly using the protect-open strategy, however when this fails we can switch to protect-closed. When this becomes ineffective a choice has to be made between the advance and accommodate strategies. While the advance strategy also has a limited time in which it is effective. Which would finally result to a switch to the accommodate approach.** It is also possible to skip certain steps and also combine different strategies.

Protect-closed

- It is hard to actually determine the effects of the environment, since there are solutions possible to for example maintain fish migration even in scenarios as this. It is also important to consider there a different climate scenario's possible, which all have direct impacts on nature. Temperature rise has impact on the sea level, but also directly on nature and ecosystems. Yet this is the case for all of the solutions, it is hard to predict how nature will be like in for example 100 years.

- This solution does allow to continue with most of the current practices that are done within the Netherlands. There is no significant land lose compared to the other solutions.

- This approach would increase the dependency on pumps. While the need quantities that need to be pumped towards the Sea are likely to increase over the years. This makes the system very dependable on pumps and energy, while it is also more vulnerable for cyberattacks or extreme scenario's bombings.

- The future adaptation is very dependent on the actual sea level rise. Like mentioned earlier, this approach has a limit to which the positive effects outweigh the negative effects. However if this solution for example makes it possible to protect against sea level rise for next 200 years it would be very good investment. If this approach however would only be useful for less than 50 years, it would become very expensive.

Protect-open

This is basically the current approach and further implementation is being researched. Continuing this approach would become more expensive and take up more space compared to the current situation. It is currently hard to determine at which point one of these factors would become too significant to continue this approach. This is still being investigated and is expected to be finished in the near future. This approach has been used for a long time within the Netherlands and the same regulations and standards will be used for improving the dikes. This means that the reliability will remain similar to the current situation.

Advance

The effects of creating for example island in front of the coast of Zeeland are currently being investigated. The effects on the environment would be enormous since it will create a big fresh water lake in a place that used to be salt. This has also been done within the IJsselmeer, yet this could be implemented on an even bigger scale. Of course this is very dependent on the exact solution. This approach will be used as either a protect-open or protect-closed system. It is hard to determine the economic effects of this approach. This approach would be very expensive, however it could also provide different economic opportunities. Calculations regarding the availability of dredge able sand in order to create man-made islands have to be made. For example within the 20mile zone of the Netherlands a lot of windmills will be constructed, which means that another area has to be used for dredging. There are also military zones, ship routes, anker areas or fishing zones, all of which make it increasingly difficult to dredge sand. The dept of the North Sea in which these island could be constructed averages around 20 meters. Yet these island also have to be significantly higher compared to the sea level, to be able to protect the residents. This would cost enormous amounts of sand and money, making it less realistic. It should also be mentioned that the current primary water barrier should still be maintained.

Accommodate

This approach will have enormous impacts on all sectors. The impacts will especially be big on economic aspects. This approach has both negative and positive effects on the environment. Permanently flooded areas would damage the current ecosystems. Yet areas that only flood once in while could experience positive effects on the biodiversity within these areas. This solution very reliable and future proof since it is possible to continue the usage of this strategy by constantly moving further away for the sea. It is possible to maintain current cities in some areas, yet this is depend on the actual water level.

WATERBOARD SCHELDESTROMEN

One representative of the Waterboard Scheldestromen has been interviewed. This individual has adequate knowledge concerning this subject. However personal views might differ from the waterboard as a hole. The individual has been tasked with providing answers from the waterboards perspective. Some criteria are more difficult to analyse because it does not directly match the expertise of the interviewee. Decisions are often not based on factual numbers, because there is still a lot of uncertainty about the actual impacts of different approaches.

Protect closed

Criteria	Extremely Netative	Negative	Neutral	Positive	Extremely Positive	P
Environment		2				2
Economic					5	15
Reliability			3			12
Future proof				4		8
Total						37

- This approach is deemed negative in terms of the environment since it requires an estuary to be sealed off, which will become a fresh water lake without tides. This will have negative impacts on nature development.

- This approach is deemed extremely positive in terms of the economy, since all of the functions regarding land use can be maintained or even developed further. The effects of salt water infiltration into farmlands is reduced.

- This approach is deemed neutral in terms of reliability since there is a risk of high river discharge levels which cannot be drained in time. If one of the structures fail this would result in enormous floodings since it is the only protective measure.

- This approach is deemed positive in terms of adaptability, because it remains a possibility to further expend into the North Sea, since it's not that deep close to the coast. By supplementing sand this methods remains a possibility in the future.

Protect Open

Criteria	Extremely Netative	Negative	Neutral	Positive	Extremely Positive	P
Environment			3			3
Economic		2				6
Reliability		2				8
Future proof		2				4
Total						21

- This approach is deemed neutral in terms of the environment, since the current estuaries mostly remain intact.
- This approach is deemed negative in terms of economic factors, since water barriers across the length of the rivers will cost more space and become more expensive. This will also increase salinization problems which can negatively affect farmers.
- This approach is deemed negative in terms of reliability, because there are more structures that have to be monitored and an increased amount of possible points of failure.
- This approach is deemed negative in terms of adaptability, since there is limited space available to continue to improve those dikes. An increase in height by one meter requires an increase in width by six meters.

Advance

Criteria	Extremely Netative	Negative	Neutral	Positive	Extremely Positive	P
Environment			3			3
Economic					5	15
Reliability				4		16
Future proof					5	10
Total						44

- This approach is deemed neutral in terms of environmental factors, since it is possible to create new nature friendly areas.
- This approach is deemed extremely possitive in terms of economic factors, since there are a lot of possibilities with the newly created land. It can also serve as an example for the rest of the world, which can lead Dutch involvement in project in other countries accros the world.
- This approach is deemed reliabile, since you the waterbariers move further into the sea, creating a bufferzone. Considering that the current waterbarriers are not removed after implementing this approach.
- This approach is considered extremely positive in terms of future adaptability, since it is designed to defend against a certain sea level. There is also more available space for future improvements.

Accomedate

Criteria	Extremely Netative	Negative	Neutral	Positive	Extremely Positive	P
Environment					5	5
Economic	1					3
Reliability			3			12
Future proof		2				4
Total						24

- This approach is deemed extremely positive in terms of the environment, since more space is created for nature.

- This approach is deemed extremely negative in terms of the economy, since there is already a shortage of available space.

- This approach is deemed neutral in terms of reliability, since some areas are allowed to flood. There are no significant risks within these areas because of their change in land use. However there are less buffer zones, since all habituated areas will be located directly behind a water barrier.

- This approach is deemed negative in terms of future adaptation. Since these areas are isolated and other areas frequently flood, these areas become less interesting for investors.

Criteria ranking

	Criteria	Environment	Economic	Reliability	Future proof
Personal	*Factor*	*3*	*2*	*1*	*4*
Waterboard	Factor	1	3	4	2

The individual perspective and that of the waterboard differ. While the perspective of the waterboard is used for this report, it is interesting to see the differences.

Result

Number	1	2	3	4
Points	44	37	24	21
Approach	Advance	Protect-Closed	Accommodate	Protect-Open

The results do not entirely match the current approach of the waterboard. The main focus is on constantly improving the existing structures. For example the waterboard would currently prefer the protect open strategy compared to the accommodate strategy. The waterboard is usually focussed on a period of 30 years, which is different compared to the situation described in this report. However considering the sea level rise described in this report the results from this interview are deemed realistic according to the interviewee.

WATERBOARD HOLLANDSE DELTA

Two representative of the Waterboard Hollandse Delta have been interviewed. These individuals have adequate knowledge concerning this subject. However personal views might differ from the waterboard as a hole. They have been tasked with providing answers from the waterboards perspective. Some criteria are more difficult to analyse because it does not directly match the expertise of the interviewees. Decisions are often not based on factual numbers, because there is still a lot of uncertainty about the actual impacts of different approaches.

Protect closed

Criteria	Extremely Netative	Negative	Neutral	Positive	Extremely Positive	P
Environment			3			6
Economic		2				2
Reliability					5	20
Future proof			3			9
Total						37

- This approach is deemed neutral in terms of the environment, because it has both negative and positive aspects. Separating salt and fresh water will have negative effects on the biodiversity and fish migration within this area. Yet this approach does allow to store more fresh water which can be used for agricultural purposes. It also decreases salination which can damage the current environment. In short this approach is negative for nature yet positive for fresh water.

- This approach is deemed negative in terms of economic aspects, since it limits the accessibility of the port of Rotterdam. The port of Rotterdam is of enormous economic value to the Netherlands. Yet this approach does allow most of the economic activity in other sectors to continue.

- This approach is deemed extremely positive in terms reliability, since it is a realistic measure which has been implemented on several occasions.

- This approach is deemed in neutral terms of future adaptability, technically it should be possible to continue this approach up until a very significant sea level rise. This solution has a limit until which it is realistic, yet it is expected that the Netherlands is able to extend that limit for quite a while, but not endlessly.

Protect open

Criteria	Extremely Netative	Negative	Neutral	Positive	Extremely Positive	P
Environment			3			6
Economic			3			3
Reliability				4		16
Future proof		2				6
Total						31

- This approach is deemed neutral in terms of the environment, since salt water will infiltrate far land inwards. This would imply that a lot of the current freshwater systems would become salt. Improving all of the river dikes will require a lot of additional space, which comes at the costs of other land uses. Yet it does allow for a more natural transition between salt and fresh water, which is better in terms of fish migration.

- This approach is deemed neutral in terms of the economic aspects, yet it is very dependent on the specific sectors. This could be beneficial for shipping compared to the protect-closed system. Yet it can also have negative impacts on other sectors, like for example agriculture.

- This approach is deemed positive in terms of the reliability, since this approach itself is reliable. This approach has been used for a long time, a downside is that the dikes have to be increased and maintained frequently if the sea level rises fast.

- This approach is deemed negative in terms of the future adaptation, because the total length of water barriers is significantly increased compared to the protect-closed strategy. Yet all these dikes have to be constantly improved, which will only become more costly in terms of space and money.

Advance

Criteria	Extremely Netative	Negative	Neutral	Positive	Extremely Positive	P
Environment				4		8
Economic				4		4
Reliability		2				8
Future proof		2				6
Total						26

- This approach is deemed positive in terms of the environment, since it could (if implemented correctly) have positive effects on the environment and the freshwater.

- This approach is deemed positive in terms of economic aspects, since the creation of land provides a lot of possibilities. Yet the connectivity of the port of Rotterdam has to be maintained. However this adaptation strategy will be extremely costly.

- This approach is deemed negative in terms of the reliability, since it will have negative impacts on the current flood defence systems. It should be noted that this is very dependent on the actual specific solution that is used. Solutions within this approach differ a lot. There is a lot of discussion about this criteria regarding this approach. The creation of island in front of the current flood defence system could lead to an increase of washing away of sand during storms, while it decrease the supply of sand during normal periods. This approach is also very new, which implies that there is limited experience compared to the other approaches. This makes it harder to determine the effects of this solution in a big scale.

- This approach is deemed negative in terms of the future adaptation, depending on the specific solution, this approach could be used for a long period. However if the sea level rises to significant it becomes increasingly challenging to supply this area with sand and maintaining it. Calculations about constantly supplying the current coastline have been done, which indicate that it is very difficult to maintain this.

Accommodate

Criteria	Extremely Netative	Negative	Neutral	Positive	Extremely Positive	P
Environment		2				4
Economic	1					1
Reliability				4		16
Future proof				4		12
Total						33

- This approach is deemed negative in terms of the environment, since it does have positive effects on nature. However there will also be an decrease in the amount of available fresh water, since a lot of areas will turn into salt water.

- This approach is deemed extremely negative in terms of the economic aspects, since it is very difficult and costly to relocate all the vulnerable areas towards 'safe-zones'.

- This approach is deemed positive in terms of the reliability, because the places at risk become less populated while the 'safe-zones' are less prone to flooding. However the western parts of the Netherlands are still at risk and require robust flood protection.

- This approach is deemed positive in terms of the future adaptation, however this is location specific. On a national scale (and for the safe-zones) this solution can be maintained with a significant sea level rise. However for the Randstad areas, this approach is not future proof since these areas will become more challenging to protect. If this approach would be extremely positive if applied over a longer period of time in which people and economic activity are stimulated to migrate to the safer zones. However this process will take a lot of time.

Criteria ranking

Criteria	Environment	Economic	Reliability	Future proof
Factor	2	1	4	3

The reliability is the most important factor, since the main goal of the approaches is to protect the Netherlands against flooding. Future adaptation is also very important, since it limits the chance of implying short term solutions which have to be adapted later. It is also important to be sure that certain solutions won't lead to regret in a later phase. The environment is rated on the third place, while economic factors are fourth. It should also be noted that political strategy also plays a role in these criteria. If politics for example determine to step away from agriculture, this would have a lot of effects on the approaches and categories. An suggestion is to specify or divide the category of environment. Freshwater availability is a separate problem which can be part of the environment, yet it makes more sense to separate it. The economic category is also considered very broad, since it consists out of a lot of sectors.

Result

Number	1	2	3	4
Points	37	33	31	26
Approach	Protect-closed	Accommodate	Protect-open	Advance

The interviewees agree with the outcome of the interview. However they didn't expect accommodate to score this high beforehand. Yet this does match their criteria and is logical.

PROVINCE ZEELAND

One representative of the province of Zeeland has been interviewed. This individual has adequate knowledge concerning this subject. However personal views might differ from the province as a hole. The individual has been tasked with providing answers from the perspective of the province of Zeeland. Some criteria are more difficult to analyse because it does not directly match the expertise of the interviewee. Decisions are often not based on factual numbers, because there is still a lot of uncertainty about the actual impacts of different approaches.

Protect-Closed

Criteria	Extremely Negative	Negative	Neutral	Positive	Extremely Positive	P
Environment	1					2
Economic			3			3
Reliability			3			9
Future proof			3			12
Total						26

- This approach is deemed extremely negative in terms of the effects on the environment. Because this requires a lot of steps to maintain the biodiversity. The delta area within Zeeland plays an important role in fish migration. Alternative routes could be created for fish, but if the Protect-Closed strategy is implemented on a big scale, this will have extremely negative impacts on fish migration overall.

- This approach is deemed neutral in terms of economic factors, since it has positive and negative results. For the agricultural sector this approach would be beneficial since it would improve the freshwater quantity that can be used for farming. This also decreases the risks of salinization of freshwater and groundwater. For the recreation sector this approach would be negative for the province of Zeeland. Since the coast of Zeeland and the delta areas are currently used for recreational purposes. When this becomes as closed of system, this could have negative effects on the recreational sector, which is an important part of Zeeland. There would for example be an increased chance of blue-green algae within the delta area.

- This approach is deemed neutral in terms of reliability, since the reliability is as strong as its weakest link. It is possible to make very robust structures, but if they fail on one location, there impact will be big.

- This approach is deemed neutral in terms of future adaptation, since this solution does allow to provide protection until quit a high water level. However if the sea level increase becomes to extreme, it will become more challenging and expensive to maintain this approach.

Protect-Open

Criteria	Extremely Negative	Negative	Neutral	Positive	Extremely Positive	P
Environment				4		8
Economic			3			3
Reliability		2				12
Future proof		2				8
Total						25

- This approach is deemed positive in terms of environmental factors, since it is beneficial for the natural system within the delta area.

- This approach is deemed neutral (or even slightly negative) in terms of economic factors, since it requires a lot of money which cannot be allocated to different sectors.

- This approach is deemed negative in terms of reliability, since the lengths of dikes would be considerably longer compared to the Protect-Closed approach. This makes it more expensive and more challenging to maintain the dikes.

- This approach is deemed negative in terms of future adaptation, since this approach would only be realistic if the sea level doesn't rase above 1 meter. Otherwise the costs and availability of space would become a bigger problem.

Advance

Criteria	Extremely Negative	Negative	Neutral	Positive	Extremely Positive	P
Environment				4		8
Economic				4		4
Reliability			3			9
Future proof			3			12
Total						33

- This approach is deemed positive in terms of the environment, if building with nature methods are used. For example creating island in front of the coasts could be beneficial if executed correctly. This could provide a solution for habitats that are currently under pressure, like for example dune areas.

- This approach is deemed positive in terms of economic factors, since it creates extra space that could be used for new functions. This space could be used for the energy sector, ports or for example recreation.

- This approach is deemed neutral in terms of reliability, however it is not clear if this can be implemented everywhere. Certain agreements have been made with Belgium regarding the Western Scheldt, however this is also the case for the other approaches. However it will still be necessary to improve the current coastline.

- This approach is deemed neutral in terms of future adaptation, since this approach will not be endlessly applicable. This can be caused by different factors, like a shortage of sand or a to high sea level rise.

Accommodate

Criteria	Extremely Negative	Negative	Neutral	Positive	Extremely Positive	P
Environment				4		8
Economic			3			3
Reliability				4		12
Future proof				4		16
Total						39

The interviewee is very positive about this approach, because eventually we will need to adapt to a situation in which the water level becomes too high. This approach is described as the necessity to adapt to the increasing sea level.

- This approach is deemed positive in terms of the environment, considering it allows nature to influence the landscape.

- This approach is deemed neutral in terms of economic factors. Admittingly this is expected to be an unpopular view, due the changes in land use. Farming for example will prove to be more difficult compared to the current situation. Yet this strategy requires a chance in land use, which doesn't necessarily have to be bad. This will require a lot of innovation to ensure the food security of the Netherlands. This is not necessarily bad, but it will take a lot of time to switch systems and methods. But once you managed to successfully change land use purposed, it could lead to another product (fish) that could be sold around the world. In short there are a lot of risk and downsides on the short term, but over a longer period it provides new opportunities.

- This approach is deemed positive in terms of the reliability, since this approach has the most potential to be applicable for a longer term. Admittingly you will always have to use dikes for protection, this is the case in all of the adaptation strategies.

- This approach is deemed positive in terms of the future adaptation, for similar reasons as mentioned for the reliability.

Criteria ranking

Criteria	Environment	Economic	Reliability	Future proof
Factor	2	1	3	4

Explanation choices/preferences:
Future proof and reliability is deemed most important. Yet it is more difficult to determine the importance of economic factors. Since every strategy has different impacts on the economy, on which it has to adapt.

The interviewee also mentioned another criteria that is important to include. This criteria would be focussing on **public support**, which is very important for the province of Zeeland. The public support is currently low for the accommodate approach, since it requires a lot of changes. The implementation of changes often create a lot of resistance, because a lot of people don't want to chance from their current views. **The implementation of this criteria would result in a lower score for the accommodate approach, while other strategies will score higher.**

Another suggestion is splitting the economic criteria into two different criteria. The affordability and the effects that it will have on economy. Since the protection against floods is being financed by the public, while the impacts on the economy is being felt across a lot of different sectors. The strategies will force citizens to pay higher taxes compared to the current situation. This is especially critical in the province of Zeeland since it the area with the most dikes, while being less populated compared to other areas. **Thus splitting these criteria will have an impact on the scores given to different solutions.**

Result

Number	1	2	3	4
Points	39	33	26	25
Approach	Accommodate	Advance	Protect-Closed	Protect-Open

The interviewee has a personal preference for the advance approach. He is very positive about this approach, because eventually we will need to adapt to a situation in which the water level becomes too high. This approach is described as the necessity to adapt to the increasing sea level. He views the advance approach more as embracing the North Sea to create a situation in which the sea takes and gives, like it used to be in the past. Yet we have to decrease the risks by adapting (building methods) in areas that are more vulnerable.

However he mentioned that this is does not align with the vision of the province of Zeeland. Because this approach is mostly associated as giving up on certain areas and move to more secure places. This would have negative effects on the province of Zeeland. It is also hard to determine which strategy would be preferred by the province, since it is depending on personal views. **He also mentioned that the 4 approaches are not separately applicable and should be combined.**

PROVINCE ZUID-HOLLAND

Two representatives of the Province of Zuid-Holland have been interviewed. While both of these representatives have a different expertise compared to each other, they do have adequate knowledge concerning this subject. However personal views might differ from the Province as a hole. Some criteria are more difficult to analyse because it does not directly match the expertise of the interviewees. Decisions are often not based on factual numbers, because there is still a lot of uncertainty about the actual impacts of different approaches.

Protect closed

Criteria	Extremely Netative	Negative	Neutral	Positive	Extremely Positive	P
Environment		2				6
Economic			3			3
Reliability				4		16
Future proof			3			6
Total						31

- This approach is deemed negative in terms of the environment. In the past the Delta Works have indicated to have negative effects on the natural dynamic in the delta area. This is for example one of the reason why the Oosterscheldt barrier became mostly open. Another example is the water quality in Grevelingen, which has decreased since the construction of the Delta Works. Continuing this trend (protect-open) will likely be negative for the environment. If new civil structures do not allow water to pass, it will result in a decrease in water quality within the delta area. The separation between salt and fresh water will also have negative effects on the biodiversity within the delta area. It is deemed possible to create civil structures that do not negatively affect spatial quality.

- This approach is deemed neutral in terms of economic factors, since it has both positive and negative aspects. It is also hard to make an estimate about the effects of this adaptation strategy on the economy. For example if this strategy guaranties to protect the entirety of the Netherlands against floods, for the next 100 years it can be deemed positive. But this solution might limit the accessibility of the port of Rotterdam, which will have negative effects. It might be possible to use sluices to access the port of Rotterdam, however it is unclear how this will affect the accessibility. However brackish water or an decrease in salinisation can be beneficial for agricultural aspects, compared to salt water.

- This approach is deemed positive in terms of the reliability, since these structures can be made very robust. However there are some points of attention, before this can strategy can truly be considered positive. For example once one of the structures fail, the negative effects will be big. Another point of attention is the pump capacity, what happens if there is a failure? Will this result in river floods? While this strategy is

focussed on improving coastal defence systems, this doesn't mean that river dikes won't have to be improved. Future climate scenarios predict higher river discharge levels during some periods. This means that river dikes still have to be improved.

- This approach is deemed neutral in terms of adaptation strategies. It is very difficult to make an accurate estimation about the future adaptation possibilities, this requires more insight. It might be possible the keep adjusting this method according to new sea level predictions, yet the costs will increase, while this method might have negative impacts on the liveability of the surrounding land area.

Protect open

Criteria	Extremely Negative	Negative	Neutral	Positive	Extremely Positive	P
Environment			3			9
Economic			3			3
Reliability				4		16
Future proof			3			6
Total						34

- This approach is deemed neutral in terms of the environmental impacts, since it has slight advantages compared to protect-closed, yet it also has downsides. There will be an increase in brackish water. This strategy also requires to improve a lot of dikes land inwards, which could be negative for the environment. This could mean we will be forced to decrease the room for rivers that we recreated in past years. What will result in an increased speed within the river. It is unclear if this approach would be able to supply sediment fast enough to keep up with the sea level rise. There will also be impacts on the mudflats and marshes within the area, which plays a role in the ecosystem. To make this system successful in terms of the environment, it is important to create more space for the rivers.

- This approach is deemed neutral in terms of the economic aspects, since there will be an increase in seepage and salinization. It will also have negative impacts on the agriculture, since their fresh water supply will be limited. Yet this approach is positive for the port of Rotterdam.

- This approach is deemed positive in terms of the reliability, since it is more adaptable and flexible compared to the protect-closed approach. However the length of critical dikes is increased compared to the protect-closed approach.

- This approach is deemed neutral in terms of the future adaptation, it is expected to be somewhat similar compared to the protect-closed approach.

Advance

Criteria	Extremely Negative	Negative	Neutral	Positive	Extremely Positive	P
Environment		2				6
Economic		2				2
Reliability			3			12
Future proof		2				4
Total						24

- This approach is deemed negative in terms of the environment, since it would create new lagunes which will mostly be closed off. This limits the nature developments within these areas. If civil structures are used that allow fish to migrate and water to blend, the negative impacts could be somewhat limited. A positive factor is the creation of more landscapes which can have positive effects on the environment. It is questionable how much public support there is to use these areas to create more nature, otherwise it is more likely to have negative impacts.

- This approach is deemed negative in terms of the economic aspects, since the villages which are located at the coasts, are dependent on the North Sea. Multiple sectors will be impacted within those areas. This solution also requires a lot of sand which could prove to be difficult and expensive.

- This approach is deemed neutral in terms of the reliability, since it provides more flexibility. These structures could be used as first line of defence against coastal floods, while the current dikes and dunes remain. However if these newly created areas will also be habitat, it basically relocates the problem. When these areas are not used, it will become a very expensive solution. A solution would be to make this area itself completely secure against flooding, yet this would also be very expensive.

- This approach is deemed negative in terms of the future adaptation, because the maintenance cost will become extremely high.

Accommodate

Criteria	Extremely Negative	Negative	Neutral	Positive	Extremely Positive	P
Environment				4		12
Economic		2				2
Reliability			3			12
Future proof			3			6
Total						32

- This approach is deemed positive in terms of the environment, since it allows nature have an bigger impact on the Netherlands and control certain area. However if u take the perspective of local residents, it is questionable if they would be satisfied with an approach like this. The most critical areas will be protected against floods, meaning that cities like Rotterdam will be surrounded by dikes and become islands. There is also a loss in culture history if this approach is used. Since the main focus of this category is on the ecology, it is deemed positive overall.

- This approach is deemed negative in terms of the economic aspects, because the entire Randstad is located and surrounded by water. If these are not relocated in time, this would become very inconvenient. Also the most of the fertile ground in the Netherlands will be negatively impacted by this approach. It is also questionable what the effects would be on the port of Rotterdam or Schiphol.

- This approach is deemed neutral in terms of the reliability, since the areas that are densely populated will be protected very well. While you also create enough space for river discharges to not have significant impacts. The higher laying areas would become more secure against flooding. Yet the protection in the Randstad has to very robust, since a lot of people and economic activities are located within these areas. If a dike would fail these 'islands' would flood very fast and have enormous impacts.

- This approach is deemed neutral in terms of the future adaptation, because it could also be split into two areas. In terms of the higher located areas (Eastern and Southern Netherlands) this approach is positive for future adaptation. This is because process of retreating could be maintained for a longer period. Yet this approach will be negative for the Randstad, since it would be hard to provide security for this area in future situation. In this scenario it is too late to move all economic activity and the population out of these areas to more secure areas.

Criteria ranking

Criteria	Environment	Economic	Reliability	Future proof
Factor	3	1	4	2

Explanation choices/preferences:

There was not a clear agreement between the two interviewees, yet the table above indicates the preferences. One of the interviewee also mentioned that she did not have extreme preferences between the criteria. Reliability is most important however it is also mentioned that this is more personal than necessarily a view from the Province as a hole. Economical aspects are considered least important since the economy adapts to the solution not the other way around. Environment and Future proof are both very close and could be switched.

Result

Number	1	2	3	4
Points	34	32	31	24
Approach	Protect-Open	Accommodate	Protect-Closed	Advance

The outcome does mostly match the reasoning of the interviewees, however there is some disagreement between the two interviewees. One of the interviewees does prefer the protect-closed/open strategies more compared to the other strategies. She prefers the protect-closed strategy above the accommodate approach. She argues that the accommodate strategy has more significant negative impacts on the local residents. Yet the different strategies are very close to each other in terms of ranking, with the exception of the Advance strategy.

It is important to note that another category could be added. There should be a category that also takes into account the view of local residents. For example the accommodate strategy might be positive in terms of the environment, yet it will have big impacts on the local residents. First of a lot of residents would be required to relocate or chance practices. But for example the Randstad would be surrounded by dikes. The residents of the Randstad would lose places that would be used to for example walk in nature.

DELTACOMMISIE

One representative of the Deltacommissie has been interviewed. This individual has adequate knowledge concerning this subject and is also active in other organisations regarding this subject. However personal views might differ from the commission as a hole. The individual has been tasked with providing answers from the Deltacommissie's perspective. Some criteria are more difficult to analyse because they can't be based on factual numbers, because there is still a lot of uncertainty about the actual impacts of different approaches.

Protect closed

Criteria	Extremely Negative	Negative	Neutral	Positive	Extremely Positive	P
Environment		2				4
Economic				4		12
Reliability					5	20
Future proof	1					1
Total						37

- This approach is deemed negative in terms of the environment since your remove natural aspects. This isn't considered extremely negative, since there is still room to adapt to the environment.

- This approach is deemed positive in terms of economic aspects, since it creates new opportunities like the Delta Works did in the past. This could have positive effects in future situations. For example the Brouwersdam has proven to be an touristic hotspot, while also functioning as waterbarrier.

- This approach is deemed extremely positive in terms of the reliability, since the structures can be made very robust. This approach also shortens the coastline, which decrease the amount of maintenance.

- This approach is deemed extremely negative in terms of future adaptation, since everything is being solidified. Switching from this strategy on a late stage could be difficult.

Protect-open

Criteria	Extremely Negative	Negative	Neutral	Positive	Extremely Positive	P
Environment					5	10
Economic				4		12
Reliability				4		16
Future proof		2				2
Total						40

- This approach is deemed extremely positive in terms of environmental aspects, since it allows the natural aspects to return into the system. This is positive for the environmental aspects.

- This approach is deemed neutral in terms in terms of economic aspects, but this depends on the specific sectors. Restoring nature could have positive effects on the economic in terms of for example tourism. While at the same time this approach could be negative in other sectors, like construction within these areas. The situation is comparable to the protect-closed approach, since both approaches have multiple downsides but also opportunities.

- This approach is deemed positive in terms of the reliability, since it is less positive compared to the protect-closed approach. Yet this approach can still be accommodated with dikes and other civil works.

- This approach is deemed negative in terms of the future adaptation, since it would be increasingly difficult to maintain this approach if the water level rises significantly. Yet it is hard to provide accurate numbers or values to back up to which extent this approach could be deemed future proof.

Advance

Criteria	Extremely Negative	Negative	Neutral	Positive	Extremely Positive	P
Environment					5	10
Economic					5	15
Reliability		2				8
Future proof		2				2
Total						35

- This approach is deemed extremely positive in terms of environmental aspects, since it creates a lot of opportunities in terms development in nature (but also a lot of other sectors).

- This approach is deemed extremely positive in terms of economic aspects, for similar reasons compared to the environmental factors. This area could be used for tourism but also other purposes like the energy sector.

- This approach is deemed negative in terms of the reliability, the interviewee combines this criteria with the future adaptation criteria. The two criteria have a lot of interface between each other and can't been see separately for this strategy.

- This approach is deemed negative in terms of future adaptability, since a lot can be achieved if sand is used. Yet it would be difficult to continue to use this strategy if the sea level rises faster or higher than expected.

Accommodate

Criteria	Extremely Negative	Negative	Neutral	Positive	Extremely Positive	P
Environment					5	10
Economic	1					3
Reliability				4		16
Future proof					5	5
Total						34

- This approach is deemed extremely positive in terms of the environment, for similar reasons as the protect open strategy.

- This approach is deemed extremely negative in terms of economic factors, since a lot of space within the Netherlands have has to be sacrificed.

- This approach is deemed positive in terms in terms of the reliability, since the areas critical areas are easier to protect against flooding.

- This approach is deemed extremely positive in terms of future adaptation, because the higher the sea level the further we move away from the Sea. This approach will especially have positive impacts on the environment in the future.

Criteria ranking

Criteria	Environment	Economic	Reliability	Future proof
Factor	2	3	4	1

The interviewee claims that these criteria have been ranked according to his realistic view which presuming closely aligns with that of the Deltacommisie as a hole. Although he also mentioned that environment could be the most important criteria.

Result

Number	1	2	3	4
Points	Protect-Open	Protect-Closed	Advance	Accommodate
Approach	40	37	35	34

All of the results are very close to each other and the ranking does match with the views of the interviewee. The protect-open approach can be beneficial for the environment, because it allows to bring back estuaries, nature and sea arms. It is also somewhat adaptable to different climate scenarios. The protect-closed approach is comparable with the current situation. This approach is an realistic method to provide protection against significant sea level rises. It is also buys time to later adapt to the advance or protect-open approach depending on the actual sea level rise. **The interviewee expects that in the near future the choice will most likely be made between the protect-open and protect closed strategy. He also mentioned that it is more likely that the protect-closed approach will be used, because of the reliability and it buys time for other methods. Yet the interviewee himself prefers the protect-open strategy due to environmental facts.** The implementation of the advance strategy still requires a choice between the protect-closed and protect-open approaches. He views the accommodate strategy as an last resort approach.

It is hard to exactly determine the sea level rise in future situations. Only the Oosternscheldt and the WesternScheldt have to be closed to chance our current approach into an protect-closed strategy. Currently the future of Graveling and Haringvliet are also being discussed. Should they be opened or not? This would allow estuaries and the natural dynamic to return within these areas, yet these choices depend on the actual sea level rise. It is also important to keep in mind that these approaches can be combined and used on a local scale. Views differ between different areas or water systems.

The interviewee also mentions that the criteria environment is too big and should be divided. Also the reliability is interpretated as water safety, yet it could also mean fresh water supply. This means that it is important to specify what different criteria indicate and split them into more specific criteria.