Improved long-term coastal management as a result of a large-scale spatial perspective

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Summary

Problem definition & research objective

Present coastal management policy in the Netherlands mainly consists of reacting to observed changes and acting in anticipation of expected short-term changes for the next 50 years. Longer-term developments are only accounted for in outlooks that are applied for considering the no-regret level of proposed projects. Projects forthcoming from this approach often have a confined spatial scope.

Meanwhile, no reliable expectations are available on the requirements of the coastal defences within the next 200 years. It is also unknown whether this long-term perspective may introduce new insights with respect to the existing coastal management policy. A quick scan on the issue of scaling up in both coastal management and water management in general, shows that this long-term perspective increases the relevance of a larger spatial scale perspective. Until now however, no systematic studies have been accomplished into the potential advantages of developing long-term strategies for enhancing the coastal defences at larger spatial scales. Therefore, the goal of this research is:

To establish whether a long-term perspective raises the need for new coastal management strategies at a larger spatial scale than the present coastal management practice and to explore the consequences of implementing such new coastal management strategies.

Outline of this research

To find out whether a long-term perspective introduces new insights to coastal management, this research presents the results of a case study based on the area consisting of the mainland coasts of the provinces of Noord-Holland and Zuid-Holland in the Netherlands. The first step consists of a study into long-term climate change effects and their impacts on coastal safety. Next, eight coastal management strategies are derived for preserving the present safety level of the coastal defences up to 200 years from now. Afterwards, an assessment methodology is set-up and applied in order to find out how these proposed strategies compare to each other. This brings us to some new insights on the implications of a long-term perspective for coastal management policy.

Future developments

Available literature on climate change impacts is applied to derive three scenarios for the increasing hydraulic boundary conditions for the coastal defences up to 2200. Additionally, it is supposed that the bed levels of the coastal zone seaward of the dunetoes will keep up with sea level rise due to ongoing nourishments. Subsequently, the safety of the future coastal defences is assessed according to the increased hydraulic boundary conditions. The existing assessment method for coastal defences is applied, including a longshore component to account for longshore discontinuities in the dune profiles. These assessments show that by the year 2200, more than 70% of the coastal defences will be disapproved if the most extreme climate change scenario will come true. For the intermediate and the lower scenarios, these figures are 60% and 40% respectively.

Spatial scales

This study identifies two reasons why future developments do raise the need to consider coastal management strategies at larger spatial scales. First, assessing the coastal defences for the impeding boundary conditions indicates a significant expansion of the spatial scale of the weak links that will occur on the long term. This inherently raises the need to look for coastal enhancement strategies at increased spatial scales. Secondly, there are some potential measures for enhancing the coastal defences that are unsuitable to be implemented at confined spatial scales. So both the problems and the solutions ask for a larger spatial scale perspective. However, there are also measures that are incompatible with a large spatial scale implementation, so smaller spatial scales are also included.

Coastal management strategies are considered at four different spatial scales within this study:
- Uniform coast; one solution for the entire study area.
- Large spatial scale; separating the southern, densely populated part and the northern, less densely populated part of the study area.
- Intermediate spatial scale; dividing the study area into twelve longshore sections according to major land use characteristics.
- Small spatial scale; dividing the study area in many short longshore sections that are related to very specific characteristics of each area (e.g. land use and attributes of the defences).

Coastal management strategies

Different (existing) measures are connected to these spatial scales. This way, eight different coastal management strategies are created for preserving the present safety level of the coastal defences over the next 200 years. The proposed strategies are:
- Two islands in front of the entire coast of the study area.
- Artificial but dynamic sandbanks in front of the entire coast.
- A new row of foredunes in front of the existing foredunes for the entire coast.
- An island in front of the southern part of the study area and new foredunes at the northern part.
- New foredunes in front of the southern part of the coast and sandbanks at the northern part.
- An intermediate scale seaward strategy combining seaward dune extensions with new sandbanks and artificial reefs, depending on the major land use functions.
- An intermediate scale landward strategy consisting of landward dune extensions and some minor seaward dune extensions, depending on the major land use functions.
- The small scale basic alternative representing the continuation of present small-scale coastal management policies being very well adjusted to the specific, local land use functions and showing a major longshore variation in the measures for improving the coastal defences.

The required dimensions of the measures within these strategies are derived for both the highest and the lowest climate change scenarios.

Assessment framework

Until now, little is known on how new coastal management strategies compare to the continuation of the present coastal management policy. Moreover, scientific publications still mainly concentrate on the technical feasibility of new strategies. This study compares the proposed coastal management strategies to the basic alternative by applying a mainly qualitative assessment method that is partly based on rough estimates of the (socioeconomic) costs and benefits. All strategies are assessed on a wide range of criteria, representing costs, welfare impacts, non-welfare impacts (intrinsic value of nature) and some other criteria (technical complexity, robustness, phasing and governmental complexity).

Different views are set-up that each award different weights to the criteria and leave some criteria out of the assessment. These views are applied to explore the influence of different policy outlooks. Since the assessments on some of the criteria are quite uncertain, this study only considers significant values of the total scores on these views. Minor deviations from the score of the basic alternative are left out of the analysis. A sensitivity analysis shows that this method results into rather stable results.

Conclusions

Concerning the results of the assessments of the proposed coastal management strategies for all policy views and for both the highest and the lowest climate change scenario, some general conclusions are found. First, the small scale strategy representing the continuation of present coastal management practice appeared to be not the best strategy. Other strategies, applying larger spatial scales, create better chances for enhancing the coastal defences and the related spatial impacts. The basic alternative (small scale strategy) is ranked relatively high for both a ‘leading criteria’ view (based on the criteria most important at present) and for a ‘risk averting’ view.

It turns out that there are three alternative strategies that show some major advantages over the basic alternative, both when the highest and the lowest climate scenarios are considered:

- The uniform coast strategy with a new row of foredunes in front of the entire coast. This strategy is assessed best from a sustainability point of view since a new, smooth coastline is established. Moreover, new nature will be created which might be useful for recreational purposes.
- The large scale strategy with an island in front of the southern part of the study area and new foredunes for the northern part is assessed best from a spatial development point of view since new space would be created to relieve the ever-increasing densities in this region. However, it is assessed negative from a risk averting point of view.
- The intermediate scale landward strategy, consisting of landward dune extensions and some minor seaward dune extensions depending on the major land use functions, is assessed best from a risk averting point of view. This is caused by its rather low maintenance costs and the possibility to separate the construction in phases.

The uniform strategy with two islands in front of the entire coast of the study area also shows some major advantages in comparison to the basic alternative, especially on spatial development. However, this goes along with significant disadvantages for some other views like sustainability.

A main characteristic of those strategies that are assessed best is that they aim at maintaining the longshore smooth, concave shape of the coast. This shape represents some sort of natural equilibrium situation of the coastal morphology, in contrary to the disruptions of this smooth coastline caused by the basic alternative. So accounting for and cooperating with the natural dynamics of the coastal system could significantly contribute to improving coastal management. Possibilities to do so increase when a larger spatial scale perspective is applied for developing coastal management strategies.

This research shows that rankings of the proposed coastal management strategies do not change too much for the two climate change scenarios that are studied, despite of the large uncertainties that are inherent to the long-term future. For more detailed designs that are based on the proposed strategies however, these uncertainties are certainly important and therefore flexible solutions should be preferred. This should enable the possibility of the coastal defences to be extended over time in accordance with the latest predictions of the boundary conditions for the next decades. From this point of view, static solutions are less preferable.

The results of this study indicate that a solid analysis can be accomplished of the significant advantages and disadvantages of different strategies for long-term coastal management, although future uncertainties are quite large. So there is no need to wait with establishing a new direction for coastal management until all future uncertainties are reduced as much as possible.

This study underlines the usefulness of increasing the temporal and spatial scales at the basis of our coastal management policy. A long-term strategy based on a larger spatial scale perspective can result in significant advantages compared to the continuation of the present small-scale and project-wise approach of coastal management.

Samenvatting

Probleemdefinitie & doelstelling
Het huidige beleid voor het kustbeheer in Nederland laat zich voornamelijk kenmerken door het reageren op waargenomen veranderingen en het anticiperen op korte termijn veranderingen die voor de komende 50 jaar verwacht worden. Ontwikkelingen op de langere termijn worden slechts meegenomen in een lange-termijn doorkijk om het no-regret gehalte van een voorgesteld project te beoordelen. Projecten die uit deze benadering voortkomen, hebben vaak een beperkte ruimtelijke scope.

Er zijn echter geen betrouwbare verwachtingen beschikbaar met betrekking tot de dimensies van de benodigde kustverdediging voor de komende 200 jaar. Het is ook onduidelijk of een dergelijk lange-termijn perspectief zal leiden tot nieuwe inzichten ten opzichte van het huidige beleid voor het kustbeheer. Een quick scan naar nut en noodzaak van schaalvergroting in zowel het kustbeheer als watermanagement in het algemeen, geeft al een indicatie dat een lange-termijn perspectief de vraag om een grootschaliger ruimtelijke benadering doet toenemen. Tot op heden zijn er echter nog geen systematische studies uitgevoerd naar de potentiële voordelen van het ontwikkelen van lange-termijn kustversterkingsstrategieën met een grootschaliger ruimtelijke benadering. Het doel van deze studie is daarom:

Vaststellen of een lange-termijn benadering leidt tot een behoefte aan nieuwe strategieën voor het kustbeheer die worden gekenmerkt door een grotere ruimtelijke schaal dan het huidige kustbeheer, en nagaan welke consequenties de implementatie van dergelijke nieuwe strategieën voor het kustbeheer met zich mee brengt.

Opzet van het onderzoek
Om na te kunnen gaan of een lange-termijn benadering nieuwe inzichten met betrekking tot het kustbeheer oplevert, worden in dit onderzoek de resultaten gepresenteerd van een case study die is gebaseerd op de kust van het vasteland van de provincies Noord-Holland en Zuid-Holland. De eerste stap van het onderzoek bestaat uit een inventarisatie van de lange-termijn effecten ten gevolge van de voorspelde klimaatveranderingen en de impact van die effecten op de veiligheid geboden door de kustverdediging. Vervolgens zijn acht kustverdedigingsstrategieën opgesteld voor het behoud van het huidige veiligheidsniveau van de kustverdediging tot het jaar 2200. Tot slot is een beoordelingskader opgezet en toegepast op de voorgestelde strategieën om ze onderling te kunnen vergelijken. Dit heeft geleid tot enkele nieuwe inzichten over de betekenis van een lange-termijn benadering voor het beleid rond het kustbeheer.

Toekomstige ontwikkelingen
Uit de beschikbare literatuur over de potentiële gevolgen van de klimaatveranderingen zijn voor het jaar 2200 drie scenario’s afgeleid voor de toename van de hydraulische randvoorwaarden waaraan de kustverdediging blootgesteld kan worden. Daarnaast wordt verondersteld dat ten gevolge van het voortzetten van het suppletiebeleid het bodemniveau van het deel van de kustzone zeewaarts van de duinteen even snel stijgt als de zeespiegel. Vervolgens is de veiligheid van de toekomstige kustverdedigingen getoetst aan de verzwaarde hydraulische randvoorwaarden. Hiertoe is de bestaande methode voor de toetsing van de zeeweringen toegepast, inclusief een kustlangse component om rekening te houden met kustlangse discontinuïteiten in de duinprofielen. De uitkomsten van deze toetsingen laten zien dat rond 2200 meer dan 70% van de zeeweringen niet voldoet wanneer het meest extreme klimaatscenario wordt gevolgd. Voor het middenscenario en het laagste scenario zijn deze percentages respectievelijk 60% en 40%.

Ruimtelijke schalen

Deze studie identificeert twee redenen waarom toekomstige ontwikkelingen de behoefte doen toenemen om kustbeheersstrategieën op grotere ruimtelijke schalen te benaderen. In de eerste plaats heeft de beoordeling van de zeeweringen voor de verslechterende randvoorwaarden uitgewezen dat de ruimtelijke omvang van de zwakke schakels in de toekomst sterk zal toenemen. Dit leidt inherent tot de behoefte om ook op grotere ruimtelijke schalen naar strategieën voor de versterking van de kustverdediging te zoeken. Daarnaast zijn er mogelijke maatregelen voor de versterking van de kustverdediging die niet geschikt zijn om op (zeer) beperkte schaal toegepast te worden. Dus zowel vanuit de probleemzijde als vanuit de oplossingszijde ontstaat de behoefte aan een grootschaliger ruimtelijk perspectief. Anderzijds zijn er overigens ook mogelijke maatregelen die juist niet geschikt zijn om op grote schaal toegepast te worden. Daarom zijn verschillende ruimtelijke schaalniveaus meegenomen.

Er worden vier verschillende ruimtelijke schaalniveaus onderscheiden bij het zoeken naar (nieuwe) kustbeheersstrategieën:

- Uniforme kust; hierbij wordt één oplossing toegepast over de gehele lengte van de kust.
- Grote ruimtelijke schaal; waarbij onderscheid wordt gemaakt tussen het zuidelijke, dichtbevolkte gedeelte van het gebied en het noordelijke gedeelte dat minder dicht bevolkt is.
- Tussenliggende ruimtelijke schaal; die het studiegebied in twaalf kustlangse secties verdeelt naar aanleiding van overheersende landgebruikspatronen.
- Kleine ruimtelijke schaal; waarbij het studiegebied in vele korte kustlangse secties wordt verdeeld naar aanleiding van specifieke lokale eigenschappen als landgebruik en kenmerken van de zeewering.

Strategieën voor het kustbeheer

Verschillende (bestaande) maatregelen ter versterking van de kustverdediging zijn verbonden aan deze ruimtelijke schalen. Hieruit zijn acht verschillende kustbeheersstrategieën afgeleid om de het huidige veiligheidsniveau dat wordt geboden door de zeeweringen ook gedurende de komende 200 jaar nog te kunnen garanderen. De voorgestelde strategieën zijn:

- Twee eilanden die samen de gehele kust van het studiegebied afschermen.
- Kunstmatige maar dynamische zandbanken voor de hele kust.
- Een nieuwe rij voorduinen (zeereep) voor de bestaande voorduinen, langs de hele kust.
- Een eiland voor de kust van het zuidelijke gedeelte van het studiegebied en een nieuwe rij voorduinen voor het noordelijke gedeelte.
- Een nieuwe rij voorduinen voor de bestaande duinen in het zuidelijke deel van het studiegebied en kunstmatige, dynamische zandbanken voor het noordelijke deel.
- Een zeewaartse strategie volgens het middelste ruimtelijke schaalniveau, waarbij zeewaartse duinverbredingen worden afgewisseld met nieuwe zandbanken en kunstriffen, afhankelijk van het overheersende type landgebruik.
- Een landwaartse strategie volgens de tussenliggende schaal, waarbij landwaartse duinuitbreidingen worden afgewisseld met enkele kleinschalige zeewaartse duinverbredingen. De soort uitbreiding hangt af van het overheersende type landgebruik.
- Een kleinschalig basisalternatief dat uitgaat van de voortzetting van het huidige kleinschalige beleid voor kustbeheer dat erg goed afgestemd is op de specifieke, lokale landgebruikfuncties en waardoor in kustlangse richting een sterke variatie ontstaat in de gekozen maatregelen ter versterking van de kustverdediging.

De benodigde dimensies van de maatregelen binnen deze strategieën zijn zowel voor het hoogste als voor het laagste klimaatscenario afgeleid.

Vergelijkingskader
Tot op heden is er weinig bekend over hoe de consequenties van nieuwe kustbeheersstrategieën zich verhouden tot de consequenties van een voortzetting van het huidige beleid voor het kustbeheer. Daarnaast richten wetenschappelijke publicaties zich nog vooral op de technische haalbaarheid van nieuwe strategieën. In deze studie worden de voorgestelde strategieën voor het kustbeheer vergeleken met het basisalternatief door middel van een afwegingsmethode die hoofdzakelijk kwalitatief van aard is. De onderbouwing is echter deels gebaseerd op ruwe schattingen van de (sociaal-economische) kosten en baten. Alle strategieën zijn beoordeeld op een gevarieerde reeks criteria representatief voor de kosten, welvaartseffecten, niet-welvaartseffecten (intrinsieke waarde van natuur) en een aantal andere criteria (technische complexiteit, robuustheid, faseerbaarheid en politieke complexiteit).

Daarnaast worden verschillende perspectieven bepaald die elk een verschillende gewichtenset aan de criteria toekennen, waarbij sommige criteria soms ook buiten beschouwing worden gelaten. Deze perspectieven worden toegepast om na te gaan hoe verschillende beleidsstandpunten de beoordeling van de kustversterkingsstrategieën kunnen beïnvloeden. En omdat de beoordelingen op sommige van de criteria grote onzekerheden bevatten, wordt in deze studie alleen naar significante waarden van de totaaloordelen volgens deze perspectieven gekeken. Kleine afwijkingen van de eindscores ten opzichte van de score van het basisalternatief worden niet meegenomen in de analyse. Een gevoeligheidsanalyse van de eindresultaten toont aan dat deze werkwijze resulteert in redelijk stabiele uitkomsten.

Conclusies
Enkele algemene conclusies worden gevonden wanneer wordt gekeken naar de resultaten van de beoordelingen van de voorgestelde kustbeheersstrategieën volgens alle beleidsperspectieven en zowel voor het hoogste als voor het laagste klimaatscenario. Ten eerste blijkt de kleinschalige strategie die is gebaseerd op het voortzetten van het huidige beleid voor de kustbeheersing niet de beste strategie te zijn. Andere strategieën bieden betere kansen voor het versterken van de kustverdediging en de daarmee gepaard gaande ruimtelijke consequenties. Het basisalternatief (de kleinschalige strategie) scoort voornamelijk goed vanuit een perspectief gericht op de op dit moment belangrijkste criteria en vanuit een risicomijdend perspectief.

Het blijkt dat er drie alternatieve strategieën zijn, die uitgaan van een grootschaliger ruimtelijke benadering en die grote voordelen laten zien ten opzichte van het basisalternatief, zowel wanneer van het hoogste als het laagste klimaatscenario wordt uitgegaan:

- De strategie voor een uniforme kust me een nieuwe rij voorduinen voor de bestaande zeereep. Deze strategie wordt als beste beoordeeld vanuit een duurzaamheidsperspectief doordat een nieuwe, gladde kustlijn wordt gevormd.
- De strategie ontworpen op een groot ruimtelijk schaalniveau waarbij een eiland is voorzien voor het zuidelijke deel van de kust van het studiegebied en nieuwe voorduinen voor het noordelijke deel, wordt als beste beoordeeld vanuit een perspectief gericht op ruimtelijke ontwikkeling. Dit omdat er nieuwe ruimte beschikbaar komt om de immer toenemende ruimtelijke druk in het zuidelijke deel van het studiegebied te verlichten. Deze strategie is echter negatief beoordeeld vanuit een risicomijdend perspectief.
- De landwaartse strategie die is ontworpen op een tussenliggende ruimtelijke schaal en voornamelijk bestaat uit landwaartse duinuitbreidingen, wordt als beste beoordeeld vanuit een risicomijdend perspectief. Dit wordt veroorzaakt door het feit dat de onderhoudskosten laag zijn en door de mogelijkheid om de aanleg te faseren.

Daarnaast toont de uniforme strategie met twee eilanden voor de kust van het studiegebied vanuit enkele perspectieven ook belangrijke voordelen ten opzichte van het basisalternatief, vooral vanuit het perspectief gericht op ruimtelijke ontwikkeling. Dit gaat echter samen met een aantal significante nadelen vanuit enkele andere perspectieven waarvan duurzaamheid de belangrijkste is.

Een belangrijke eigenschap van de strategieën die als beste beoordeeld zijn is dat ze erop gericht zijn de bestaande gladde, holle kustlijn te behouden. Deze vorm hoort bij een soort natuurlijke evenwichtssituatie van de kust, in tegenstelling tot de verstoringen van deze gladde kustlijn die voortkomen uit het basisalternatief. Rekening houden en samenwerken met de natuurlijke dynamiek van het kustsysteem lijkt dus een significante bijdrage te kunnen leveren aan de verbetering van het kustbeheer. De mogelijkheden hiertoe nemen toe wanneer een grootschaliger ruimtelijke benadering wordt toegepast bij het ontwikkelen van nieuwe kustbeheersstrategieën.

Dit onderzoek laat zien dat de voorkeur voor de voorgestelde kustbeheersstrategieën niet veel verandert voor de twee bestudeerde klimaatscenario's, ondanks de grote onzekerheden die de verre toekomst met zich meebrengt. Voor concrete ontwerpen gebaseerd op de voorgestelde strategieën zijn deze onzekerheden echter wel degelijk van belang en moet er toch vooral de voorkeur gegeven worden aan flexibele oplossingen. Dit moet er voor zorgen dat het mogelijk blijft om de kustverdedigingen met de tijd te versterken naar aanleiding van de laatste inzichten in en voorspellingen van de randvoorwaarden voor de komende decennia. Vanuit dit opzicht zijn statische oplossingen, die zich minder makkelijk laten aanpassen, minder gunstig.

De resultaten van deze studie tonen aan dat een betrouwbare analyse gemaakt kan worden van de significante voordelen en nadelen van verschillende strategieën voor het lange-termijn kustbeheer, ook al zijn de onzekerheden die de toekomst met zich meebrengt vrij groot. Er is dus geen noodzaak om te wachten met het vaststellen van een nieuwe richting voor het kustbeheer totdat alle toekomstige onzekerheden zoveel mogelijk zijn teruggedrongen.

Deze studie onderstreept het nut van een vergroting van de temporele en ruimtelijke schalen die ten grondslag liggen aan ons kustbeheer. Een lange-termijn strategie die wordt gebaseerd op een grootschaliger ruimtelijk perspectief kan resulteren in significante voordelen ten opzichte van een voortzetting van de huidige, kleinschalige en projectmatige benadering van het kustbeheer.

Preface

About a year ago I started looking for an interesting topic for my master's thesis. But what is interesting? This is quite a hard question when you are interested in a lot of topics. Unfortunately, I was not allowed to graduate on a study into the preparation of the best salad or baking the most delicious apple pie. But with great help of some people at the University, I chose to dedicate the research for my thesis to coastal management. Quite important actually, since where to bake and enjoy your apple pie if your house is located at the bottom of Lake Holland?

After studying lots of literature, I knew how coastal management in the Netherlands is arranged right now. But I also identified some problems that might occur when this same coastal management policy is continued for the next two centuries. The expected climate change effects cause the requirements for our coastal defences to increase over time. This made me ask whether such a long-term perspective would potentially increase the need for some changes to our coastal management policy.

The people who helped me with finding this topic for my master's thesis fortunately where also willing to supervise me during the past six months in which I performed this study. Moreover, Witteveen+Bos was prepared to facilitate my research. I was given the opportunity to work at their office in Deventer and to bother their people with all my questions. And there were lots of questions since some specific topics of this research were still quite undeveloped. How to assess the safety of the dunes two centuries from now? How to compare coastal management strategies for the next 200 years? Doing this research was a bit like rowing a tiny boat on a mountain river. Sometimes I could just accomplish some plans and the research went on just with the flow, but at some other times it was really hard when I did not exactly now how to solve new problems and my boat got in some wild rapids. Luckily, there were always people to get me out of these troubles. I hope that I have finally reached my destination and that this thesis may contribute somehow to a sustainable preservation of the safety of our coastal defences.

I would like to thank all my supervisors for their support and their enthusiasm. Hans, your critical attitude and your never-ending interest in the progression of my research really helped me to improve this thesis. The two-weekly meetings with Kathelijne really kept me on track, she always reminded me of the goal of my study. Assessing different strategies for coastal management would have failed without the talks with Alfons in Rotterdam. It was nice to be there now and then. Suzanne and Marjolein, thanks for reading my extensive reports and for your critical notes. Some other people that really helped me are Eveline Buter (Witteveen+Bos) and Jan Mulder (University of Twente). Your input was quite important to me and I am grateful you were willing to lend me some of your knowledge. I also thank all other people who have contributed to this study.

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Erik Horstman
Enschede, May 2008

Content

1 Introduction

In this introductory chapter, the problem that is considered in this study will be introduced. First, the present situation of low-lying coastal areas is confronted with expected climate change effects and socioeconomic developments, in order to state the importance of adequate coastal management. Next, some attention is given to the issue of scales in water management since temporal and spatial scales are at the heart of this study. Then, the problem analysis states which problems are faced in managing the coastal defences. A problem definition will be derived. Based on this information, the research objective is stated and the major research questions are defined. Afterwards, the scope of this study is confined. In the final section, the outline of the remainder of this report is presented.

1.1 Present situation & future developments

Recent events and developments created a large interest in flood protection of low-lying coastal areas. One of these events is the disaster in New Orleans caused by hurricane Katrina (almost 2000 casualties), which clearly showed the threats of living in coastal areas and underlined the importance of adequate coastal defences. At the same time, effects of the expected climate change increase concerns about the present and future adequacy of coastal defence systems all over the world. Rising sea levels and large uncertainties regarding possible changes in the occurrence and strength of storms are among those effects of climate change and are increasing the pressure on coastal defences [IPCC, 2007; KNMI, 2006].

Together with the worldwide intensification of the extreme conditions at the seaside of the coastal defences, at the landside the number of people to be protected keeps growing. Therefore, the worldwide attention for the potential effects of climate change and for improving coastal defences is timely.

The Netherlands faces these problems too. About 9 million inhabitants are living in areas below mean sea level (Figure 1) and 70% of the gross domestic product is earned in these areas [Min V&W, 2006].

Figure 1: Areas below sea level in the Netherlands.

The Dutch coastal management policy is aimed at providing safety levels connected to a certain probability of flooding. For the central part of the Holland coast, this probability of flooding should be kept smaller than 1:100,000 per year. In order to do so, the coastal defences of this area should satisfy the design conditions that are based on extreme storm-conditions with a probability of occurrence of 1:10,000 per year. Currently, there are some weak links in the Dutch coastal defences that do not satisfy this criterion. Projects are started to upgrade the defences at these locations. However, the future intensification of the extreme circumstances will create new weak links while the value of the hinterland increases too.

Until now, flood protection measures are designed and evaluated for only a fifty-year time span. However, the above-mentioned developments may ask for a more long-term vision. To be protected against the potential danger of climate change effects, we should anticipate on these effects. It can be questioned whether the present project-wise and rather small-scale approach of improving our coastal defences is a suitable approach. This study will investigate whether a long-term perspective on future changes asks for a larger spatial scale approach. Next, it will be analysed whether applying larger temporal and spatial scale perspectives could improve coastal management.

1.2 Scale issues

Issues of temporal and spatial scales play an important role within this study. We are specifically interested in long time spans and the related spatial scales. This section starts with a brief overview of issues related to scaling-up in water management in general. Next, we will consider some reasons for scaling-up in managing coastal flood defences.

1.2.1 Increasing scales in water management practice

An interesting example to start with is the development of the Dutch water boards (called 'waterschappen') over time. These boards are the oldest democratic institutions in the Netherlands and have been managing the water since the Middle Ages. Between 800 and 1250 those regional water boards emerged, being responsible for some specific water management issues like maintaining the dikes, drainage canals or a sluice or dam within its area [Van de Ven, 2003]. Since then, the number of boards increased up to about 3,500 in 1,850 [Woltjer & Al, 2007]. However, increasing geographic scale has gradually decreased this number to 26 boards at present. At the same time the activities of the water boards have evolved from protecting single resources to addressing multidisciplinary problems concerning economics, environment, society, agriculture and water problems simultaneously [Woltjer & Al, 2007].

Another example of increasing scales in water management is the Water Framework Directive initiated by the European union [EU, 2000]. The directive is mainly aimed at managing water quality of both surface water and groundwater. In order to do so, the directive adheres a river basin approach since water quality is depending on activities along the total length of a river. Previously, water quality management was mainly subjected to local and national policies. Large-scale cooperation (certainly trans-national) was rather difficult and was rarely realised. This is one of the first trans-national water management directives in Europe, clearly stating the importance of a river basin approach. Illustrative for the effectiveness of a trans-national river basin approach is the fight against deteriorating water quality of the river Rhine. Its real crisis was in 1971 when the water in the lower parts of the Rhine was completely dead due to severe pollution by chemicals [Van Ast, 2000]. These problems are combated effectively due to several international treaties of the Rhine states [Min V&W, 2008], and the water quality of the Rhine is much better nowadays.

Next to the spatial scaling-up described by the two previous examples, there is also an integration of disciplines. Integrated coastal management or integrated coastal zone management (ICZM) becomes increasingly important in our current society where social and economic interests in the coastal area are enormous (and still keep growing) and largely interconnected. ICZM stimulates the integration of different disciplines at the land-water interface (e.g. morphology, environment, fishery, recreation) in order to develop sustainable solutions for coastal management issues [Christie e.a., 2005]. Exemplary for the potential effectivity and multifunctionality of ICZM strategies are the ComCoast pilot projects [ComCoast, 2008]. A key aspect of ICZM is to overcome the fragmentation inherent in the existing sectoral management approach and in the splits in jurisdiction between levels of government involved [Cicin-Sain & Belfiore, 2005].

1.2.2 Scales in coastal management

Returning to temporal and spatial scales in coastal management, several researchers have stated the interdependency between those two scales in coastal evolution. Hydrodynamic, morphodynamic and geodynamic processes in the coastal zone operate at wide ranged temporal and spatial scales, as can be seen in Figure 2. Both natural and human-induced processes influence sand transport in the coastal zone. Figure 3 shows us at what spatial and temporal scales these factors are affecting sand transport, and thus morphology, in the coastal zone.

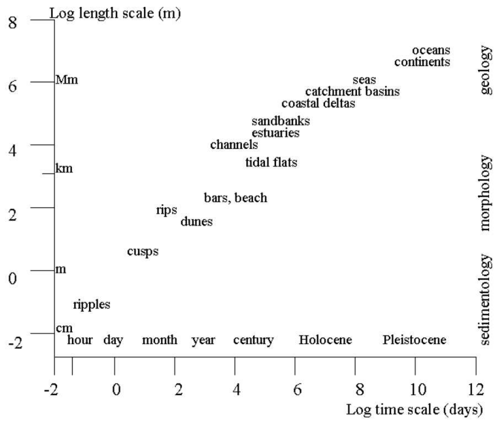


Figure 2: Morphodynamic phenomena in the coastal zone are related to different temporal and spatial scales [Bochev-van der Burgh, 2008].

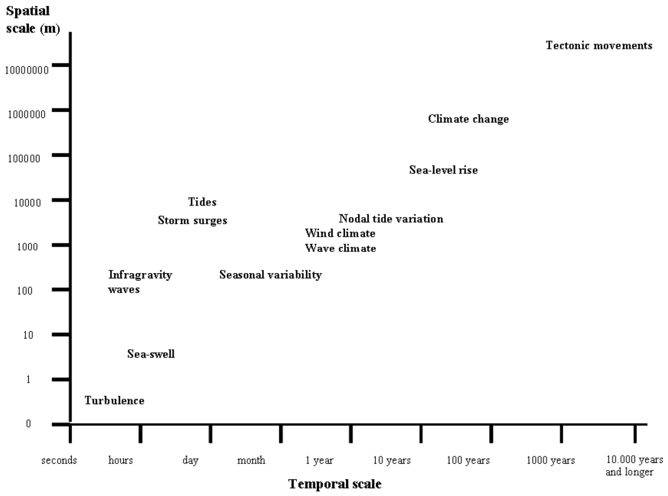


Figure 3: Processes influencing sand transport in the coastal zone are related to temporal and spatial scales [Bochev-van der Burgh, 2008].

The aim of this study is to investigate the effect of considering long-term developments in coastal management, where long-term is defined as the next two centuries. Within this period our climate is expected to change significantly resulting in for example sea level rise. According to Figure 3 these changes do occur at spatial scales of 100's to 1000's of kilometres. Figure 2 indicates that for a temporal scale of centuries, the length scale of morphological features (sandbanks, estuaries, channels, tidal flats, bars and beaches) changing at this time interval is 10's of kilometres. So morphologic changes might extend over large areas at this temporal scale. This implies that when considering coastal management at a temporal scale of centuries, the related spatial scale should be rather large (tens of kilometres) and should go beyond a local approach.

The spatial scales connected to morphological features in the coastal zone are partly reflected in the present approach of coastal management. According to Mulder e.a. [2006], coastal policy in the Netherlands has shown a gradual development from a small-scale to a large-scale approach over the last decades. Currently, the strategic management objective is defined at three different scales with the larger scales setting boundary conditions for the smaller scales (Figure 4):

- Preservation of the 'rest strength' (see glossary) of the dunes provides the safety against flooding at any place (metres) and any time (days).
- Preservation of the Basal Coast Line (see glossary) creates boundary conditions for the rest strength of the dunes over a period of (10) years and over longshore distances of kilometres.
- Preservation of the coastal foundation (reaching to 20 m below Amsterdam Ordnance Datum) in turn provides boundary conditions for the Basal Coastline preservation over decades to centuries and over length scales of 10's up to 100's of kilometres [Mulder e.a., 2006].

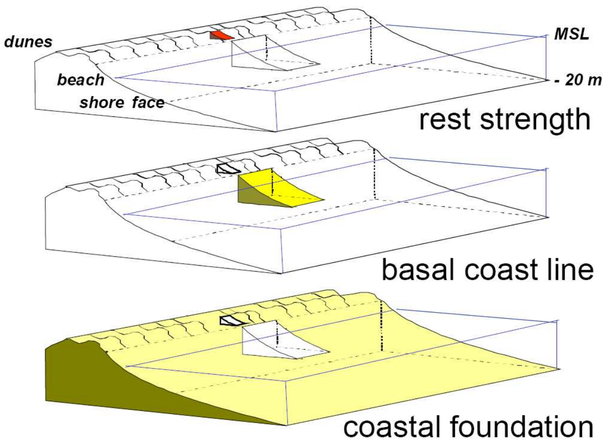


Figure 4: Representation of the three different scales in coastal management: dune rest strength (days, metres), Basal Coastline (years, kilometres) and coastal foundation (decades-centuries, 10's-100's kilometres) [Mulder e.a., 2006].

It is concluded that for solving the problems related to coastal safety emerging within the next two centuries, the morphology of the coastal zone (and thus the coastal defences) should be considered at

extensive spatial scales (e.g. tens of kilometres). Meanwhile, potential measures enhancing the safety of the coastal flood defences on this temporal scale (centuries) will affect the morphology of the coastal zone. This explains the morphological importance of studying future safety and (the effects of) potential measures at larger spatial scales.
It is just another question at what spatial scale these measures should be designed. An evaluation of the present coastal management policy learns that there is no answer to this question yet since spatial scales in different policies and plans are highly variable [Lubbers e.a., 2007]. The study of Lubbers e.a. concludes that coastal management is in need of a vision on the appropriate spatial scale for coastal management activities; it should be established whether a local strategy is right or whether measures at larger spatial scales are more appropriate.

Making bad choices for coastal enhancement, possibly by applying inappropriate (too confined) scales, may have severe and long lasting consequences. An example is given by McNamara & Werner [2007] who discovered that the present coastal management for barrier islands in the USA on the long term could result in the destabilization of these islands. This would cause low-frequency inundation disasters with enormous impacts.

1.3 Problem analysis

The importance of larger temporal and spatial scales in coastal management is stated now and we turn back to the present situation. In this section, the problems motivating this study are analysed and translated into a problem definition. The problems observed in coastal management were already analysed and described in the preparatory literature study [Horstman, 2007]. The main conclusions of this research are presented in the first sub-section.

1.3.1 Observed problems

Concerning the temporal scales, it is found that we already take into account potential climate change effects. This often results in the selection of no-regret measures that can easily be extended over time. However, the effects of climate change are highly uncertain and predictions contain large bandwidths. At the same time, models are unable to predict long-term developments of the coastline caused by morphodynamics in the coastal zone. The present knowledge on both the future strength of the coastal defences and the future boundary conditions causes the future to be rather uncertain.

Spatial scales are found to be of minor importance in present-day coastal management practice. Plans for the present weak links in the coastal defences are developed separately assuming that possible effects will not interfere. The input of local interests stimulates this small-scale approach. Often, other potential impacts are also considered for rather small longshore coastal areas only. For our present coastal management policy, which is still rather conservative, this approach might work. More extensive measures may create the need for considering impacts within a larger spatial frame.

Together with these spatial scales, the scope of coastal management is extended to spatial planning in the wider coastal zone. A growing population and economy will both increase the need for adequate coastal defences. However, future socio-economic developments are quite uncertain. Nevertheless, we should anticipate on this development and therefore regulation of the integration of planning and water management is improving.

This development towards integrated planning at larger spatial scales will increase the amount of relevant actors when nothing is changed to the existing administrative framework. Nowadays, legal responsibilities within the coastal zone are quite fragmented. The national government (the ministry for Transport, Public Works and Water Management in this case) is responsible for maintaining the Basal Coastline (see Figure 4). However, in most cases the water boards are responsible for maintaining the dunes and dikes backing the beaches and protecting the hinterland from flooding. The provinces are, from an administrative point of view, located between those two actors. They control the state of all sea defences and their findings are reported to the national government every five years.

Even more actors come into play when coastal enhancement projects are concerned, e.g. for the weak links. At the national level, the ministries responsible for spatial planning (Min VROM), agriculture and nature (Min LNV) and the ministry of economic affairs (Min EZ) all have interests in the coastal zone. The province is responsible for the regional coordination and spatial planning, the water board is still responsible for the sea defence itself, and municipalities are responsible for development plans for both the areas behind the sea defences as for the beaches. In addition, there is always a wide range of other people and parties representing their own interests.

A final point of attention is the absence of an assessment method suited for long-term measures. Existing methods for cost-benefit analysis appear to be insufficient for handling the dynamics, complexities and distribution (both in space and in time) of such measures.

It is concluded that a long-term perspective on the development of the coastal defences is missing. Partly because scenarios for expected climate changes and socio-economic developments are rather uncertain. This does not take away our opportunities for trying to develop a long-term vision on the coastal defences. The importance of a long-term policy, that comprises larger spatial scales, was recently stated by the national government itself and in several advisory reports (e.g. of the so called ‘Adviescommissie Water’). Until now however, no systematic studies have been undertaken into the potential advantages of developing long-term strategies for enhancing the coastal defences at larger spatial scales.

1.3.2 Problem definition

Based on (I) the observed problems, (II) the call for a long-term vision in coastal management and (III) all other information presented in the previous sections, the following problem definition is deduced for this study:

The present coastal management policy is mainly based on locally reacting to observed changes and anticipating on short-term expectations. It is unknown yet whether a long-term perspective on the development of the coast and on the required measures for maintaining coastal protection (I) will induce a larger spatial scale perspective and (II) may lead to new coastal management strategies departing from the present coastal management policy.

This problem definition focuses this research towards the role of coastal protection in a long-term vision on coastal safety. This study will concentrate on preserving the present safety levels. Flood risks are related to these safety levels, but they do also comprise the economic value and development of the hinterland (risk = probability * damage). The development of the flood risk is even more complex than the development of the flood safety since socioeconomic developments (that determine the potential future damages in case of flooding) are very uncertain (see appendix A).

Moreover, socioeconomic developments are not supposed to be boundary conditions for developing coastal management strategies, according to the layer approach. This approach is introduced in the last policy document on spatial planning of the Dutch government [Min VROM, Min LNV, Min V&W & Min EZ, 2005]. The layer approach represents the landscape by three interacting layers: surface, networks and occupation (Figure 5). Coastal defences are part of the surface layer, together with geological features of the bottom, the surface waters and the biotic system. Some more information on this approach is included in appendix A.3.

From the layer approach, it follows that any (future) spatial development will certainly need a solid ‘infrastructure’ in the surface layer. The surface layer (together with the network layer) provides the basis for developments in the occupied layer.

This approach indicates that socio-economic and inherent spatial developments no longer are boundary conditions for the development of coastal defences (surface layer). On the contrary, spatial developments in low-lying areas can be considered to be a result of (integrated) coastal management, since coastal management impacts in the surface layer. At the same time, there are some interactions between the upper and lower layers, since a need for spatial developments will stimulate improvements of the infrastructure in the surface layer.

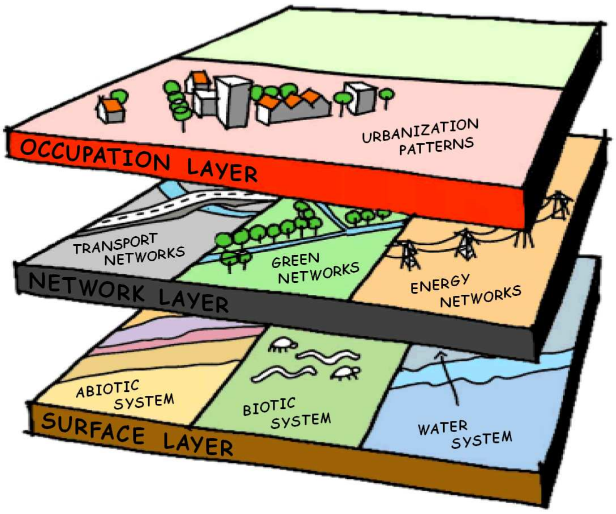


Figure 5: Schematic representation of the spatial layer approach.

Based on the layer approach, spatial developments will not be included in scenarios indicating the future needs for coastal protection. Spatial developments will be considered as a result of the coastal management strategies to be developed and will be part of the analysis of the effects related to different coastal management strategies, instead of being boundary conditions for the development of these strategies.

These deliberations are stating the difficulties in considering long-term flood risk developments. Therefore, this study is confined to preserving the safety level of the hinterland for inundations from the sea. It presents a first attempt to find out whether large-scale perspectives could improve coastal management for maintaining the present safety level. This is a probability approach instead of a risk approach.

1.4 Research objective

The goal of this study is stated as:

To establish whether a long-term perspective raises the need for new coastal management strategies at a larger spatial scale than the present coastal management practice and to explore the consequences of implementing such new coastal management strategies.

Although the impacts of climate change on coastal safety will occur worldwide, this report only considers one case study due to time constraints. This case study is based on the situation of the central part of the Holland coast (see the spatial scope in section 1.6). The research objective is applied to this case study. The wider applicability of the results of this case study is discussed afterwards.

The objective of this study is threefold, and consists of the following components:

- To explore scenarios for the long-term needs for enhancing the coastal defences over a period of 200 years, taking into account the potential impacts of climate change and subsidence.
- To identify proper spatial scales for developing coastal defences to meet the long-term needs.
- To explore the consequences of new coastal management strategies based on the results of the previous two steps and to assess how these strategies compare to the continuation of the present short-term and small-scale coastal management policy.

It should be noted that the objective of this study is to explore and to compare several coastal management strategies. In the end, we will still be unable to say which of the proposed coastal management strategies offers the best opportunities and is most advantageous. These are qualitative judgements that depend on political values and decisions.

1.5 Research questions

Based on the problem definition and the research objective for this study, the following main research questions are formulated:

1. To what extent will long-term changes of the boundary conditions, due to climate change and subsidence, affect the preservation of the existing safety level of the coastal defences within the study area?

2. Does the long-term approach raise the need for a large-scale spatial perspective for developing coastal management strategies suited to maintain present safety levels of the coastal defences over the next 200 years?

3. What are the consequences of the newly derived coastal management strategies with respect to the present coastal management practice and do some of these new strategies have significant advantages in comparison to the continuation of the present coastal management policy?

4. How sensitive are the results of this study to the inherent uncertainties at a timescale of 200 years?

1.6 Scope

The first part of this section is devoted to the spatial and temporal scope of this study. Together, these create a framework that determines both the comprehensiveness and the applicability of the study results. Next, some assumptions will be made resulting in boundary conditions for this research.

1.6.1 Spatial scope

This case study presented in this report is based on the Holland coast and is spatially confined to central Holland. This area consists of the coasts of two dike ring areas (see glossary for an explanation of this phrase): dike ring 13 (Noord-Holland) and dike ring 14 (Zuid-Holland). The coastal defences within this area are mainly dunes and there are also some minor reaches protected by dikes (like the Hondsbossche Zeewering). This area is selected because it is densely populated and it accommodates a major part of the Dutch economy. It is evident that the protection of this area is very important from a socioeconomic point of view. The study area is sufficiently large to be able to evaluate measures for different spatial scales.

1.6.2 Temporal scope

The temporal scope of this study is 'confined' to a period of 200 years (as stated before). This period is selected because this seems to be the present interpretation of 'long-term' and due to increasing uncertainties it is impossible to apply an infinite timeframe. There are some indications available on the effects of climate change over this period. For longer periods, these predictions are lacking. For shorter periods, the timeframe of the evaluation would come close to the presently applied 'short-term' scope of 50 years.

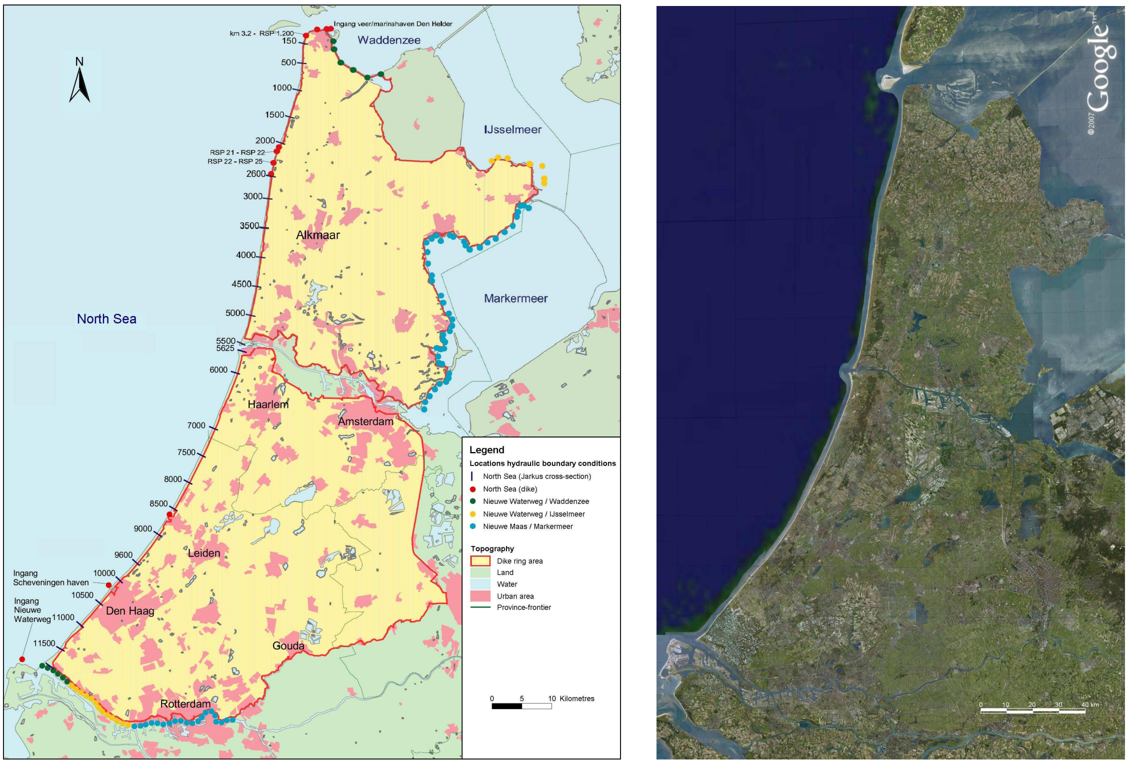


Figure 6: The boundaries of the study area are determined by the boundaries of the dike ring areas 13 (north) and 14 (south) that are depicted at the left [Min V&W, 2007]. At the right an aerial photograph of the study area [Google Maps, 2008].

1.6.3 Boundary conditions

Before and during the research, some assumptions will be made in order to determine the boundaries of this study within the previous stated temporal and spatial frames. These assumptions form the boundary conditions for the research and they are summarized below.

- For the central parts of Holland, the probability of flooding should be smaller than 1:100,000 per year. In order to do so, the coastal defences of this area should satisfy the design storm conditions that are based on extreme circumstances with a probability of occurrence of 1:10,000 per year [ENW, 2007]. The difference between those two frequencies comes from the fact that the coastal defences are still not allowed to fail when the design conditions occur, so their probability of failure should be even smaller than 1:10,000. According to the Directive on Dune Erosion ('Leidraad Duinafslag') the probability of failure of the coastal defences should (by definition) be 10 times smaller than the probability of occurrence of the design conditions [TAW, 1984].
- It is important to note that the probability of inundations from the rivers in the Netherlands is much larger than the probability of inundation from the sea. However, we only study coastal defences and do not account for potential inundations from the rivers.
- The calculation methods prescribed in the manuals for assessing coastal defences are the best methods presently available. Notwithstanding the uncertainties in these models (e.g. DUROS-plus), these results will be used to study the development of future weak links in the coastal defences.
- The coastal enhancement projects presently being planned and executed to improve the defences at the weak link locations are not included in the present situation of the coastal defences, nor in the autonomous development. They will be part of the basic alternative for coastal management representing the continuation of current practice.
- The coastal zone is defined as the area located between the depth contour where the seabed is located at 20 m below Amsterdam Ordnance Datum (=NAP) and the landward toe of the dunes. This toe ('duinteen') is found where the dunes end and the flat hinterland starts.
- The coastal zone is divided in several depth zones according to [Mulder e.a., 2006]:
  - Landward of the 3 m + NAP (=Amsterdam Ordnance Datum) contour, we find dunes.
  - Beaches are found between 3 m +NAP and 2 m –NAP.
  - The zone between 2 m –NAP and 7 m –NAP is called the surfzone.
  - The zone between 7 m –NAP and 13 m –NAP is the upper shoreface.
  - The zone between 13 m –NAP and 20 m –NAP is the lower shoreface.
- Developments of the coast (both under water and at the beaches and the dunes) caused by morphodynamic processes are not included in the autonomous development, since there is a lack of models predicting the long-term impacts of these natural developments at a high spatial resolution [Van der Burgh, 2005]. The only development that will be included is the rise of the bed level of the shoreface, the surfzone and the beaches due to the assumed continuation of present nourishment activities to maintain the Basal Coastline. In this area, bed levels are supposed to keep up with sea level rise.

1.7 Outline of this study

The outline of this report is based on the research questions stated in section 1.5 of this introduction and a schematised overview of this outline is presented in Figure 7.

This study starts with an inventory of the long-term safety of the coastal defences in chapter 2. The final product of this chapter consists of three maps indicating the spatial distribution of the weak links that will emerge in the coastal defences over the next two centuries, according to each of the climate change scenarios. In order to preserve the present safety level of the coastal defences, long-term coastal management strategies are set-up in chapter 3. In this chapter, the study area is also divided according to different spatial scales. Chapter 4 contains the actual assessment of the proposed strategies. At the end of this chapter, it will be clear whether and/or which new strategies might create better opportunities over the next two centuries than the continuation of present coastal management practice. In chapter 5, the results of this research are discussed from different perspectives. Finally, the answers on the research questions are summarized in chapter 6, which contains the conclusions and recommendations of this study.

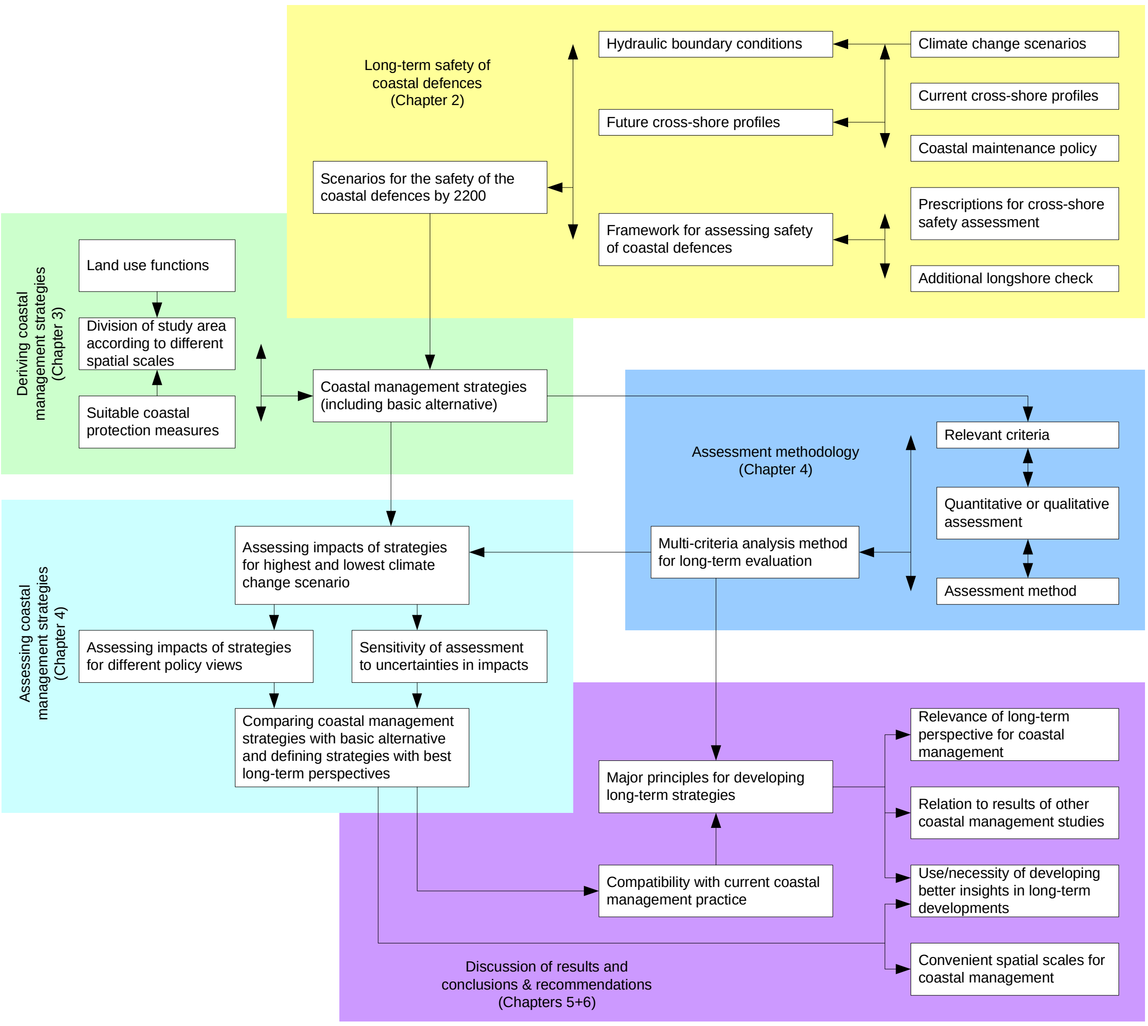


Figure 7: Schematic representation of the outline of this study.

2 Large-scale safety assessments of the coastal defences

This chapter starts with a review of long-term climate change expectations for the year 2200. Three climate change scenarios are derived from these expectations and are subsequently translated into safety scenarios for the Holland coast around the year 2200.

So new climate change scenarios are derived in the first section. The potential impact of sea level rise on the sand volumes contained in the coastal foundation is considered in the next section, together with the potential long-term effect of the continuation of the present coastal nourishment policy. The boundary conditions derived for the climate change scenarios are deviating from the conditions applied in previous studies (for example [Alkyon, 2001]). Therefore, new calculations are executed for assessing the impacts of these climate change scenarios on the safety of the coastal defences. The case that is studied, the Holland coast, brings its own (legally established) assessment framework for determining the safety of the coastal defences. This assessment framework and the methods for calculating the safety of dunes and dikes are shortly described in this chapter. Finally, the results of the newly executed safety assessments are presented in the last section.

It should be noted that this analysis is not meant to exactly state which reaches of the coastal defences will be insufficient at the end of this period. Instead, we are interested in a general analysis showing the percentage and spread of those locations where the coastal defences would fail in case of design storm conditions. This analysis serves to gather insight in the spatial extensiveness of the future weak links that may emerge in the coastal defences according to the different climate change scenarios.

2.1 Climate change effects

2.1.1 Review of knowledge on climate change and subsidence

In this study, we are interested in effects of the globally expected climate changes on sea levels during storm events. Processes of interest are thus: sea level rise and potential changes in wind strengths and directions. Next, parts of the Netherlands are facing subsidence, increasing the relative sea level rise.

Climate change

In the past century, the sea level along the Dutch coast rose with about 20 cm [KNMI, 2006]. However, it is generally accepted that climate change will speed up and the effects will increase. The Intergovernmental Panel on Climate Change studies the worldwide climate change and the effects and developed several scenarios in its 2007 Fourth Assessment Report [IPCC, 2007]. The Dutch meteorological institute (KNMI) studies these predicted world-wide changes and translates them to local effects: sea level rise in the eastern Atlantic and wind speeds in the North Sea area [KNMI, 2006].

The KNMI developed four climate change scenarios for the Netherlands for the period up to 2050 (Figure 8). Within these scenarios, predictions are made for changes in precipitation, wind speeds and for sea level rise. Predicted sea level rise depends on the sensitivity of the sea level to the expected climate change (Table 1). Within the context of this simple analysis the wind speed scenarios combined with the modelled wind direction changes do not give rise to strong changes in the occurrence and strength of North Sea surges [KNMI, 2006].

The figures of the KNMI are generally representative for predicted sea level rise in other scientific studies. However, there are two exceptions. First, the Environmental and Nature Planning Agency predicts a maximum sea level rise of 1.5 m per century based on geological evidence [MNP, 2006]. Meanwhile, Vermeersen states (in [De Pater & Katsman, 2007]) that sea level rise in the Netherlands will be much smaller due to the influence of gravitational effects. However, the influence of this effect is not yet studied thoroughly and experts expect that this new insight will go along with the development of other insights increasing the expectations again. The balance of these counteracting changes may stay more or less the same [Katsman & Van den Hurk, 2007].

A short review of scientific material available on the expected effects of climate change is included in appendix B.

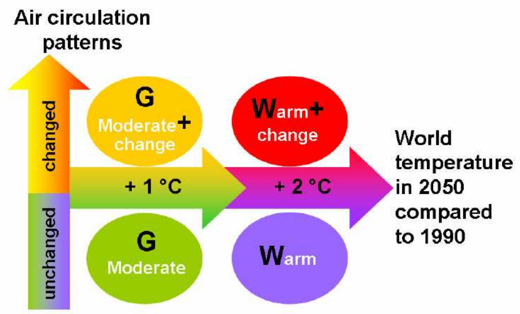


Figure 8: Climate change scenarios for the Netherlands up to 2050 according to the KNMI [KNMI, 2006].

Table 1: Sea level rise predictions for both the lower and higher climate change scenarios and for the potential differences in sea level sensitivity [KNMI, 2006].

Sea level sensitivity	SLR lower scenario [m]		SLR higher scenario [m]	
	2050 (+1°C)	2100 (+2°C)	2050 (+2°C)	2100 (+4°C)
Low	0.15	0.35	0.20	0.40
High	0.25	0.60	0.35	0.85

Subsidence

While the sea level rises, the bottom subsides in the coastal areas of the Netherlands. In order to calculate relative sea level rise, this subsidence should be included.

There are two causes for subsidence in the Netherlands. The most important factor determining the subsidence of the coastal defences is the isostatic rebound of the earth crust. This concerns the vertical movement of Pleistocene sand beds and older bottom layers (see appendix D). This process causes a tilting of the Netherlands in seaward direction and induces a subsidence of about 7 to 8 cm per century of the north-western part of the Netherlands [Werkgroep Klimaatverandering en Bodemdaling, 1997] [TAW, 2002].

Next, there are some anthropogenic factors influencing subsidence. This could be caused by extractions of gas or other materials. These activities are not practiced in the coastal zone of the study area, except for a gas extraction location at Bergen. Lowering water level in polders also causes subsidence, due to the oxidation and compaction of the peat that runs dry. Although these processes form important land subsidence parameters in the hinterland of the coastal defences in the study area, this is not the case at the locations of the majority of the coastal defences [Van der Meulen e.a., 2007]. So subsidence of coastal defences (dunes and dikes) due to anthropogenic influences is negligible, except for the Hondsbossche and Pettemer sea defences (see appendix D for a review of several studies on this topic).

It is concluded that only land subsidence due to tectonic movement is of interest when considering the future safety of the coastal defences within the study area. The subsidence rates connected to this process are about 7 to 8 centimetres per century, so in 200 years one should account for a subsidence of about 15 cm. The only exceptions are the Hondsbossche and Pettemer sea defences (both dikes) where subsidence rates reach up to 20 cm per century [HHNK, 2008].

2.1.2 Aggregated climate change scenarios

Finally, the results of investigations into the effects of climate change and subsidence should be integrated into scenarios applicable in assessing and designing coastal defences. This is done before, for example for the boundary conditions presented in the manual for assessing sandy coasts of the Technical Advisory Committee on Water Defences [TAW, 2002]. These and other policy climate change scenarios are reviewed in appendix C.

Based on the scientific and policy scenarios found in other studies and documents, three climate change scenarios are derived for this study. It is important that these scenarios contain the entire range of possible changes in boundary conditions, in order to comprise all changes that might be expected and the most extreme events that are possible. The final scenarios are presented in Table 2. Note that the sea level rise is relative, so 15 cm subsidence is included in these figures. Both the lower and the intermediate scenarios are derived from the minimum and maximum predicted values of the KNMI and they resemble the intermediate and high scenario of the TAW prescriptions very well. The higher scenario is derived from the observed geological maximum for possible sea level rise.

Table 2: Aggregated climate change scenarios to be applied in this study.

Scenarios for 2200	Sea level rise [m]	Increase in storm surge level [m]	Increase in wave height [%]
Low	0.95 (0.70+0.15)	-	-
Intermediate	1.85 (1.70+0.15)	0.40	5
High	3.15 (3.00+0.15)	0.40	5

In these scenarios, it is supposed that the predicted sea level rise behaves linearly over time. This assumption is applied in many other studies too (see appendix B and C) and it is supposed to be the best possible method. However, it is far from sure whether this assumption resembles the future developments, since sea level rise depends strongly on the uncertain melting and disintegration processes of the Greenland and Antarctic ice sheets [KNMI, 2006] [Katsman & Van den Hurk, 2007].

Next to the sea level rise, expectations on increasing storm surge levels and wave heights are included too. These changes are related to possible changes in wind climate. Even though the KNMI study [KNMI, 2006] shows that wind speeds and directions will not change significantly, the prescriptions of the Technical Advisory Committee on Water Defences on the increase of the storm surge level are included. The boundary conditions prescribed in the manual on assessing sandy coasts (see appendix C.1) present these changes for its maximum climate change scenario. These values are based on a 10% increase in wind speeds [Van de Graaff & Hoogewoning, 2002]. These assumptions are transferred to the upper scenarios since they are widely accepted yet and since one should look for extreme values within scenarios, even when there are large uncertainty ranges (for predictions of changing wind patterns). Moreover, experts showed that a little (4%) increase in wind speeds might cause a significant change in the storm surge levels and wave heights [Smale & Van der Biezen, 2007]. Therefore, it is important to be aware of this uncertainty and to incorporate its effects at least partially.

2.2 Continued nourishment policy

The present nourishment policy for the Dutch coast is quite important for the long-term development of the coastal zone, especially when rising sea levels will be faced. The impacts of this nourishment policy are described here, since it is supposed to be continued.

2.2.1 Coastal maintenance policy

Natural processes like aeolian sand transport and hydrodynamic action cause sedimentation and erosion to occur in the coastal zone. Once eroded from the Holland coast, sand is mainly transported by northward longshore currents towards the Wadden Sea where large amounts are deposited again. The figure shows the sand balances for the Dutch coast. Shallow (up to 8 m below Amsterdam Ordnance Datum) and deep (up to 20 m below Amsterdam Ordnance Datum) waters are distinguished within this figure. The shallow part of the system includes the most seaward row of dunes, the foredunes [Mulder, 2000].

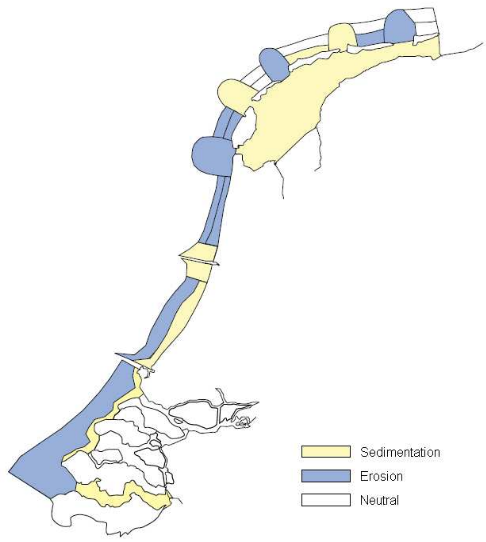


Figure 9: Sand balances of the Dutch coast for the period 1965-1995, showing where net erosion and sedimentation occurred during this period [Min V&W, 2000].

On the long term, ongoing erosion would cause a recession of the beach and dunes. For example: one metre sea level rise would cause a coastline recession of about 40 metres [Van de Graaff & Hoogewoning, 2002]. Next to sea level rise, human influences and natural processes (wind, water) are also moving sand, causing a net loss of sediment in the Dutch coastal system [Nederbragt, 2005]. In order to maintain the coastline, the national government decided in 1990 to apply a dynamic preservation policy based on sand nourishments. These nourishments should maintain the Basal Coastline (Basis Kustlijn, BKL in Dutch). This BKL is defined as the position of the coastline in 1990 and was derived from a linear trend over the past ten years. Wherever the Momentary Coastline (Momentane Kustlijn, MKL in Dutch) exceeds the Basal Coastline, beach or underwater nourishments are applied to refill the local shortage of sediment. The determination of the location of the Momentary Coastline is shown in Figure 10. The dune-toe is defined to be located at 3 m above Amsterdam Ordnance Datum and H is the distance between the dune toe and the mean low water level. When the cross-shore profile is know from a measurement (cross-shore profiles are gauged annually), the area A can be found by integrating the amount of sand available above the lower boundary of the calculation zone. Once H and A are known, the location of the Momentary Coastline can be calculated (B=A/2H).

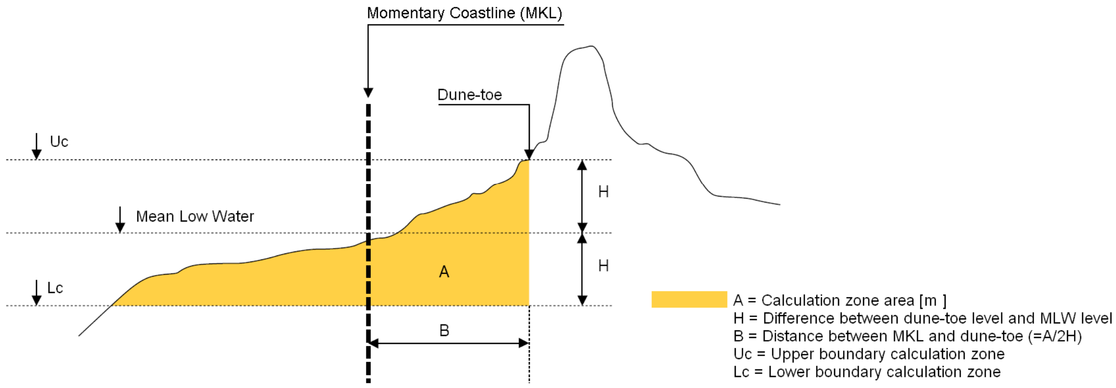


Figure 10: Determination of the location of the Momentary Coastline. Wherever the MKL exceeds the Basal Coastline (the position of the MKL in 1990), sand nourishments are employed [Roelse, 2002].

Contrary to the maintenance of the coastal defences, being the responsibility of provinces and water boards, the national government (the Ministry of Transport, Public Works and Water Management) is responsible for the coastline maintenance policy. The amounts of sand supplied by nourishments between 1991 and 2005 are summarised in Figure 11. Within the period 1991-2000 about 6 million m^3 of sand (about 20 m^3/m) was supplied to the coast per year [Roelse, 2002]. Without these nourishments, a structural loss of sand would have occurred in the shallow parts of the coastal zone. These nourishments were meant to maintain the Basal Coastline (see Figure 4). From 2001 on, nourishment efforts are increased and about 12 million m^3 of sand (40 m^3/m) is supplied every year [Min V&W, 2000]. This increase was necessary to compensate for erosion at deep water and thus to maintain the coastal foundation (see Figure 4). Previously this loss rate was not compensated. Table 3 summarizes the averaged annual nourishments within the areas relevant for this study.

Table 3: Averaged annual nourishment efforts for reaches within the study area, derived from Figure 11.

Reach	Averaged annual nourishment [m^3/m]	
	1991-2000	2001-2005
Noord-Holland	20	61
Rijnland	12	43
Delfland	42	89

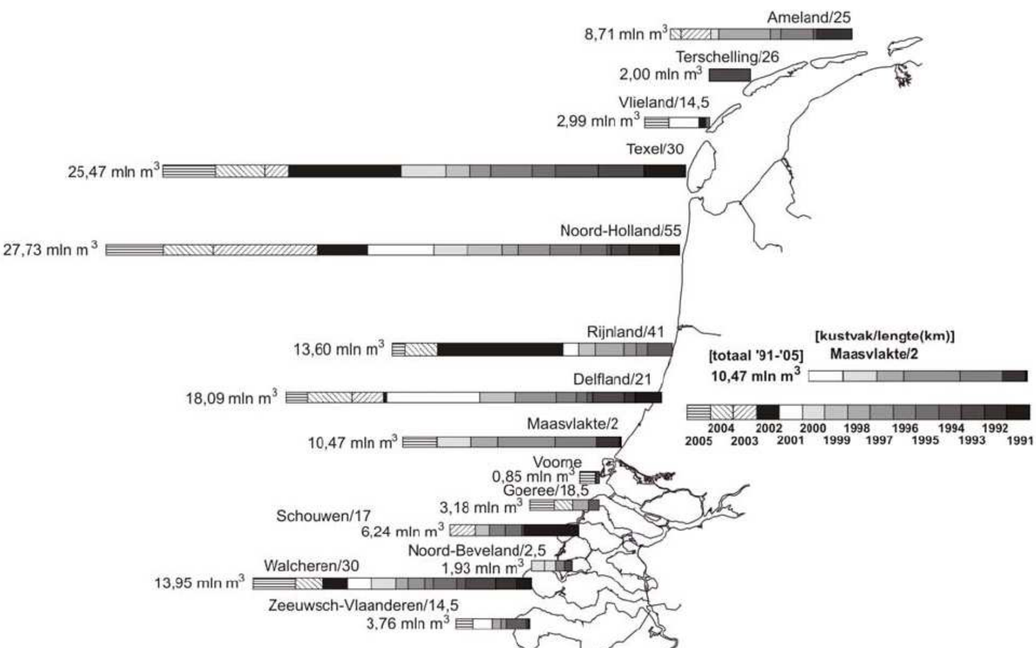


Figure 11: Total sand added by nourishments over the period 1991-2005 for all reaches along the Dutch coast [Nederbragt, 2005].

Next to aeolian and hydrodynamic processes, sea level rise also causes changes in the cross shore sand balance. Since the lower boundary of the coastal system is defined at 20 m below Amsterdam Ordnance Datum, the amount of sand in this system could be found in a strip reaching from the dunes down to a waterdepth of 20 m (Figure 12a). Part of this sand volume becomes located below the 20 m boundary due to sea level rise, and the sand reserves within the coastal foundation are decreasing. At the same time, sea level rise will cause a receding Momentary Coastline since part of the sand will be lost from the calculation zone (Figure 12b) [Mulder, 2000]. Both these losses should be compensated by sand nourishments. It should be noted that these losses are related to the calculation method, there is no physical loss of sand from the system.

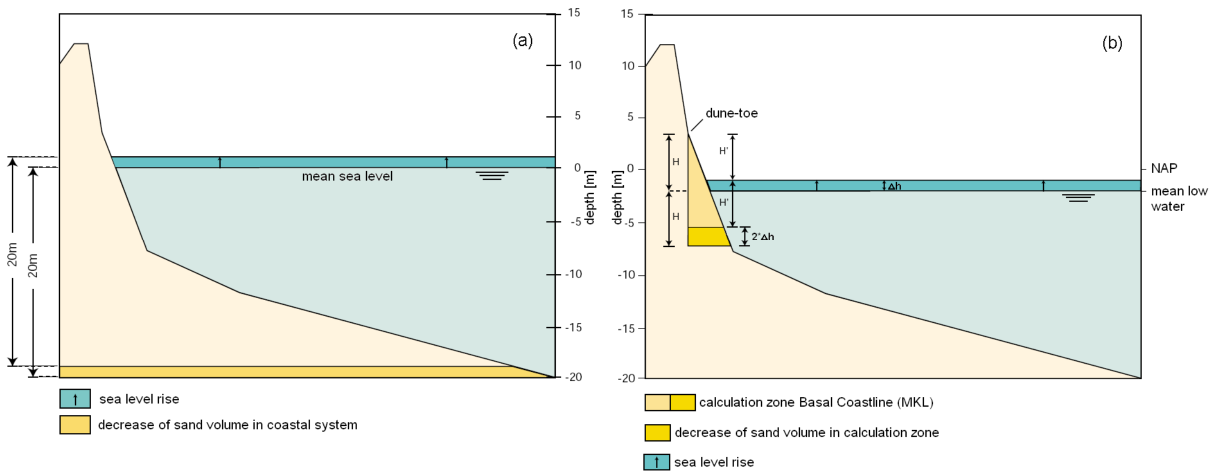


Figure 12: Direct effects of sea level rise on the volume of sand in the coastal system (a) and on the location of the Momentary Coastline due to a changing amount of sand in the calculation zone (b) [Mulder, 2000].

In addition to the aforementioned direct effects, sea level rise will also cause some indirect effects like increasing longshore and cross shore sand transport due to waves and currents. These changes are rather complex and several theories show different effects. However, it is sure that the demand for sand of our estuaries and the Wadden Sea will increase in order to make sure that bottom levels can keep up with sea level rise. This process will increase sand losses by longshore transport, which should also be compensated by sand nourishments [Mulder, 2000]. Figure 13 shows how much sand is needed for maintaining the Dutch coast (the BKL) for different sea level rise scenarios. However, Nederbragt [2005] states that much more sand may be required for future coastline maintenance: up to about 60 million m^3/year in case of 85 cm sea level rise per century.

So the present policy of dynamic preservation of the coastline by sand nourishments is substantial for maintaining the Dutch coast at its current position. These nourishments are repeated every five years according to a long-range scheme for the entire coast [Roelse, 2002].

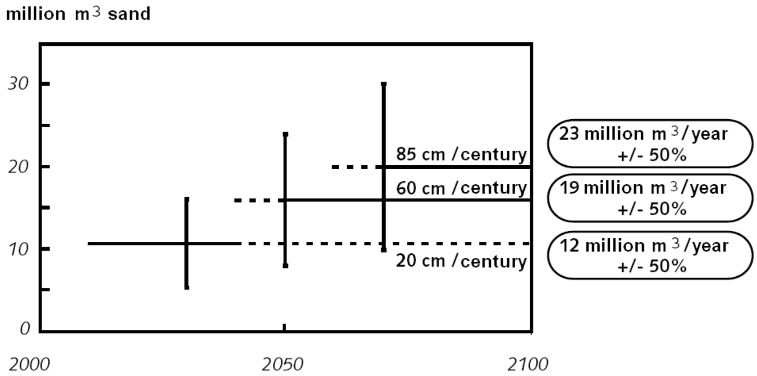


Figure 13: Required sand nourishment volumes to maintain the Dutch coast at different sea level rise scenarios. Uncertainty ranges are very large (+/- 50%!) [Min V&W, 2000].

2.2.2 Implications for autonomous coastal development

Since large amounts of sand will be added to the coastal system for maintaining the BKL, coastal cross-sections will change too. First, sand nourishments should cause the beaches and foreshores (including the surfzone and the shoreface) to keep up with sea level rise. Only then, the location of the Momentary Coastline will not exceed the Basal Coastline. At the same time, this development will prevent the dunes from structural erosion since the rising sea water level will not reach the dunefront.

Moreover, the dunes may grow by the ongoing landward sand transport by aeolian processes since there are large volumes of sand available at the seaside of the dunes. It is uncertain whether this will cause the dunes to increase in height or in width. However, dune configuration influences the amount of erosion during a critical storm event [Van der Burgh e.a., 2007]. And dune configuration also determines to a large extent the acceptable amount of erosion during a critical storm. Due to the uncertain future configuration, safety assessments of the Dutch coast always apply the present dune configuration and no assumptions are made on increasing heights or widths of the dunes. This is a conservative scenario.

At the same time, the rise of beach and foreshore levels (including the surfzone and the upper and lower shoreface) should be included in safety assessments. In this study, it is assumed that the present coastal maintenance policy will be continued, since ending it would result in structural erosion of the coast and an ongoing landward movement of specific locations along the coastline. So sand nourishments in order to maintain the Basal Coastline are considered to be part of the autonomous development of the Dutch coast. In this autonomous development, levels of beaches and foreshores keep up with the sea level rise whatever sea level rise scenario occurs. This assumption can also be found in the policy documents concerning coastal management too [TAW, 2002]. This height increase of the cross-shore profile should be applied seaward from the dune-toe. Note that this autonomous development of the seabed between the 20 m –NAP depth contour and the dunes implies that water depths will not increase in this area.

2.3 Assessment regulations

This section gives a short overview of the existing prescriptions and boundary conditions for assessing the safety of the coastal flood defences, as determined by the Dutch government. These regulations create the framework for the assessment of the coastal defences within the study area.

2.3.1 Prescriptions

Regular checks of the flood safety of the Dutch coasts are required in order to guarantee the defined safety levels of the low-lying areas behind these coastal defences now and in the future. Therefore, the national Law on Flood Defences (established in 1995) states that the manager should execute a technical assessment of the safety of the primary flood defences (see glossary for explanation) every five years [Overheid.nl, 2008]. The manager responsible for these assessments is the province or the water board, which's area contains the flood defence.

The Ministry of Transport, Public Works and Water Management develops the regulations to be applied in these repeating assessments. Recently, the ministry published two new guidelines for the present assessment period (2006-2011). The first one is the Manual for Assessing the Safety of Primary Flood Defences (Voorschrift Toetsen op Veiligheid Primaire Waterkeringen). The second one is the Hydraulic Boundary Conditions for primary flood defences document (Hydraulische Randvoorwaarden). The latter will be the subject of the next section. Both these documents are, among others, based on reports of the Expertise Network on Water Safety (Expertise Netwerk Waterveiligheid) previously known as the Technical Advisory Committee on Water Defences (Technische Adviescommissie Waterkeringen). This committee published several manuals for the design and management of different types of flood defences, e.g. the Directory for the Sandy Coast [TAW, 2002].

The Manual for Assessing the Safety of Primary Flood Defences (see appendix E for a summary of this document) provides the framework for the assessment of the coastal flood defences. The coastal flood defences to be assessed within the study area are all category 'A' primary flood defences. They are preventing the hinterland from being flooded by water from the sea. The next step is to distinguish the different type of defences. The coastal defences within the study area are predominantly dunes. Besides, there are some minor reaches that are protected by dikes (the Hondsbossche and Pettemer defences and the dike at Den Helder).

The manual provides extensive prescriptions for the assessments of both dunes and dikes. For dunes, three mechanisms of failure are distinguished: dune erosion by the seawater, wind erosion at the landside and the influence of non-water-retaining structures. Dune erosion at the seaside is the most important component of this assessment and can be calculated with the DUROS-plus model, which is described in the Technical Report on Dune Erosion of the Expertise Network on Water Safety [ENW, 2007]. More information on this model follows in section 2.4 and is included in appendix E.3.3.

Three tracks should be considered for assessing the safety of the coastal dikes: the height of the dike (with respect to the possibility of overtopping), the stability of the dike and again the influence of non-water-retaining structures. Next to the importance of the crest level within the height assessment, there should also be given attention to the stability of the crest and the inner slope in case of overtopping. Other points of attention for this assessment are the accessibility of the structure and the possibility for discharging and storing overtopping water behind the dike. The stability assessment of dikes considers the susceptibility of the structure to all other failure mechanisms: piping, heave, macro-instability of the structure (at both inner and outer slope), micro-instability (due to rising ground water pressure), instability of the revetment and instability of the foreland of the structure.

2.3.2 Hydraulic boundary conditions

The third and latest (2006) edition of the Hydraulic Boundary Conditions for primary flood defences [Min V&W, 2007] presents the boundary conditions to be used for the assessments within the present assessment period (2006-2011) of the primary flood defences. The document explains the methods and assumptions that the boundary conditions are based on and presents these boundary conditions. Since our knowledge on the relevant processes determining these boundary conditions still increases and some (natural) developments continue to influence those boundary conditions too (appendix F.1), this document is updated every five years.

Concerning the North Sea coast, this latest edition contains some major changes compared to the previous one. First, ongoing research has indicated that wave periods have been underestimated in the previous versions. This new insight has led to the development of a new calculation method for determining the boundary conditions to be applied for assessing the dunes and dikes along the coast. Next, the boundary conditions are conformed to the latest statistics of water levels and waves for the North Sea. Third, state-of-the-art wave modelling is applied to translate the offshore wave conditions to the shallow water in front of the defences. Finally, the rise of the tidal high water levels due to climate change is included in the boundary conditions. The increase in tidal high water levels turns out to be more important than the average (still water) sea level rise.

The relevant threats determining the boundary conditions for assessing the coastal defences are caused by: the water level, tidal differences in the water level, wind generated waves and short-period water level changes (caused by rainstorms). More on these processes and their influence on the boundary conditions can be found in appendix F.2. These threats are caused by storm surge levels and extreme wind speeds. The derivation of these boundary conditions assumes a strong correlation between the occurrences of those two events. A probabilistic approach is applied to account for the probability that certain combinations of storm surge levels and extreme wind speeds occur (see appendix F.3).

The final boundary conditions for the coastal defences along the Holland coast determined by this method and corresponding to the 1:10,000 probability of exceeding are included in appendix F.4.

2.4 Calculating safety of dunes

For the safety assessment of the central part of the Dutch coast, calculations will be made on the safety of both dunes and dikes. This section handles the assessment of dunes, the next section goes into the assessment of the coastal dikes.

2.4.1 Erosion calculations

The Manual for Assessing the Safety of Primary Flood Defences [Min V&W, 2007] prescribes how the safety of dunes should be assessed (see section 2.3 and appendix E). The main track of this assessment considers dune erosion due to hydraulic action during an extreme storm event. Besides, dune erosion due to wind action and possible effects of non-water retaining structures in the cross-sections should be considered. However, the impact of the latter effects is uncertain (asks for advanced assessment) and will be (very) small compared to the first source of dune erosion. Therefore, erosion calculations in this study only comprise dune erosion due to hydraulic action. This is justified by the fact that the aim of this study is to get an indication of potential future weak links in the coastal defences, we do not strive after an exact representation of the future safety of the dunes.

The manual requires the application of the latest DUROS model for calculating dune erosion for critical storm surge conditions. This DUROS-plus model balances the erosion and sedimentation occurring under the extreme conditions that are modelled. This means that the eroded volume of sand during a certain high water event in Figure 14 should equal the accreted volume. This balance should be reached by shifting the erosion profile in landward direction with point P fixed at the predicted storm surge level. The shape of the parabolic part of the erosion profile and the length of this parabolic section (x_{max}, y_{max}) depends on the significant wave height, the wave period and the settling velocity of the sediment eroded. The other two parts of the erosion profile are defined by constant slopes [ENW, 2007]. More information on the calculations within this model is included in appendix E.3.3.

This model allows to predict the locations of the points P (new dune-toe) and R* (erosion point) and the prediction of the erosion volume. However, it should be noted that this model is based on some major assumptions. Longshore transport is not included for example. All assumptions are summarised in appendix E.3.3.

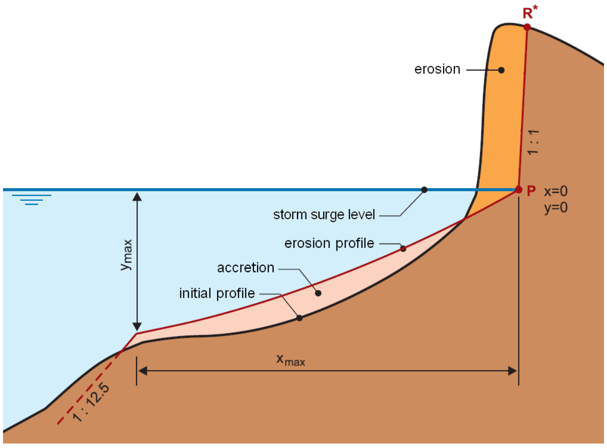


Figure 14: Erosion profile calculated according to the DUROS-plus model. Point P represents the new dune-toe after the storm surge and point R* indicates the erosion point [ENW, 2007].

Next, to compensate for uncertainties in the DUROS-plus model, some additional volumes should be taken into account in addition to the calculated erosion volume (Figure 15). First, the erosion volume should be extended with an addition compensating for uncertainties resulting from the applied model and inherent in the prescribed storm surge duration. This additional volume (T, toeslagvolume) is proportional to the total amount of sand eroded from above the storm surge level (A m^3/m) and is said to be 0.25*A m^3/m. The next step is to shift the erosion point landward until the extra amount of sand between those two points equals a volume of 0.25A m^3/m (Figure 15). The length of ΔR depends on the dune configuration landward of R*. The location of the new erosion point R and the new location of P follow from this procedure.

Finally, the calculated locations of R and P should not be too close to the landward end of the dune profile since the hinterland should still be protected from flooding during the extreme storm event conditions. Therefore, landward of the erosion profile a certain boundary profile should still fit in the cross section of the dunes (Figure 15). This boundary profile should prevent the hinterland from being flooded when the critical storm-event erodes the entire erosion profile from the dunes. In order to prevent the dunes from a total break through, this boundary profile is also specified by some characteristic dimensions (see appendix E.3.3).

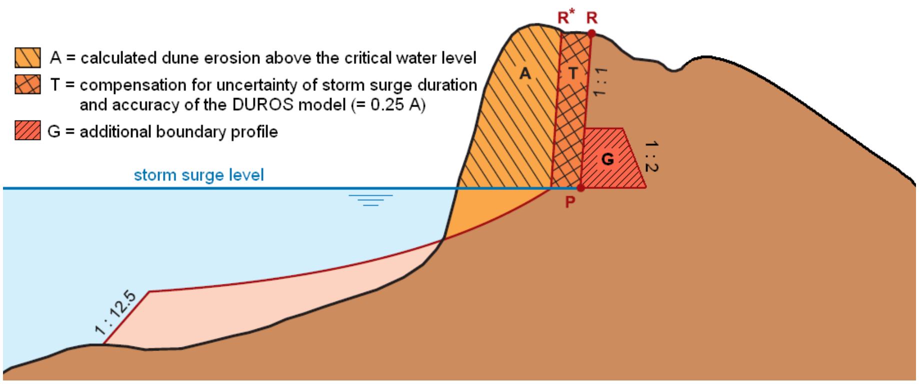


Figure 15: Cross profile of a dune section with a calculated erosion profile, additional erosion volume (T) and boundary profile (G) as applied in the DUROS-plus model [ENW, 2007].

For this study the above calculations are executed by an existing model in MATLAB that is developed by Witteveen+Bos. This model applies these prescriptions to the input data of cross-shore profiles and boundary conditions (as stated by the Hydraulic Boundary Conditions document of 2006). This MATLAB script is summarized in appendix G. In this study, the erosion calculations are executed for the 2007

cross-shore profiles of the dunes in the study area. These cross-shore profiles are frequently updated by the Jarkus measurements applied for tracking changes in the cross-shore profiles.
At last, it should be noted that these calculations neglect the presence of dune-toe revetments. Erosion calculations are primarily concerned with the sand in the cross-shore profile. Possible corrections for the presence of revetments [ENW, 2007] are left out of this study since this would increase the complexity of the calculations and again the aim of this study is not to generate exact safety calculation results. Moreover, official studies on future erosion lines of the Dutch coast [Alkyon, 2001] also do not take into account this type of structures in the coastal defences.

2.4.2 Interpreting calculated results

The executed erosion calculations demonstrate whether the erosion volume, the calculated additional volume and the boundary profile will fit in the cross section of the dunes. Therefore, three different failure modes could occur in cross-shore direction. First, there is the possibility that no balance is reached since the volume of the dunes is too small to deliver the amount of sediment needed for foreshore sedimentation (Figure 16a). These locations will definitely break through during a critical storm surge. Next, when the volume of the dunes is sufficient for reaching a sedimentation-erosion balance, the additional erosion volume for compensating uncertainties might not fit in the cross section of the dunes (Figure 16b). These cross-sections might break through during a storm surge since uncertainties might cause the additional volume to erode. When both the erosion volume and the compensation for uncertainties do fit, the last check is the boundary profile (Figure 16c). When the boundary profile does not fit in the cross-section, the dunes might still break through during a critical storm surge event since the cross-section left over after erosion might be insufficient for protecting the hinterland from flooding. When all components fit in the dunes, the situation compares to Figure 15 and the hinterland will be protected sufficiently.

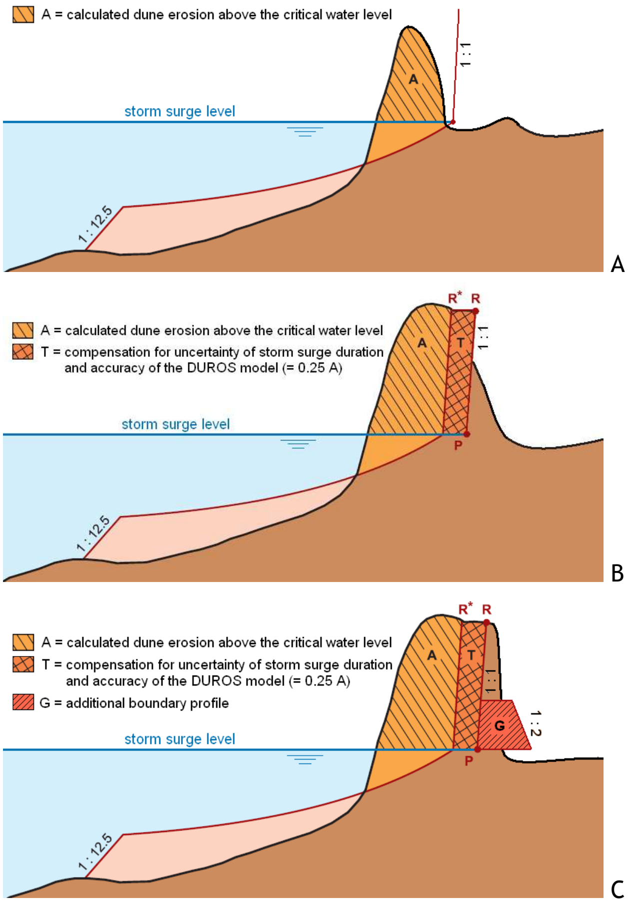


Figure 16: Failure modes for dune cross-sections: cross profile too small for equilibrium between sedimentation and erosion (A); cross profile too small for additional erosion volume (B); boundary profile does not fit in the dune cross section (C).

Next to this cross-shore check, one should also consider the longshore direction despite the fact that the DUROS model does not consider this aspect (see appendix E.3.5). Sometimes, parts of the calculated erosion profile (or additional or boundary profile) are located in dune crests behind the seaward dune front (the foredune). This could occur since some parts of the Holland coast have wide dune zones with several dune crests in the cross-shore direction. From a cross-shore point of view the situation may be assessed to be safe when the volume of sand in the landward dune crests is adequate.

However, some exceptions are made in this study. First, the situation will still be assessed as insufficient when this landward dune crest is located several hundreds of metres landward of the foredunes since the incurred receding of the dune-toe is supposed to be unacceptable. Second, from a longshore perspective, this assessment could be erroneous. Figure 17 shows two different situations where two dune crests are found in the cross-shore direction. The upper part of this figure shows that the landward dune crest closes the valley between the two crests. In this case a breakthrough of the foredune will not inundate the hinterland. On the contrary, the lower part represents a situation with two parallel dune crests and a valley in between. Whenever the storm surge level is higher than the bottom level of this valley, a breakthrough of the foredune will cause an inundation of the hinterland. This approach is also applied to the results of the model calculations (see appendix H for some examples).

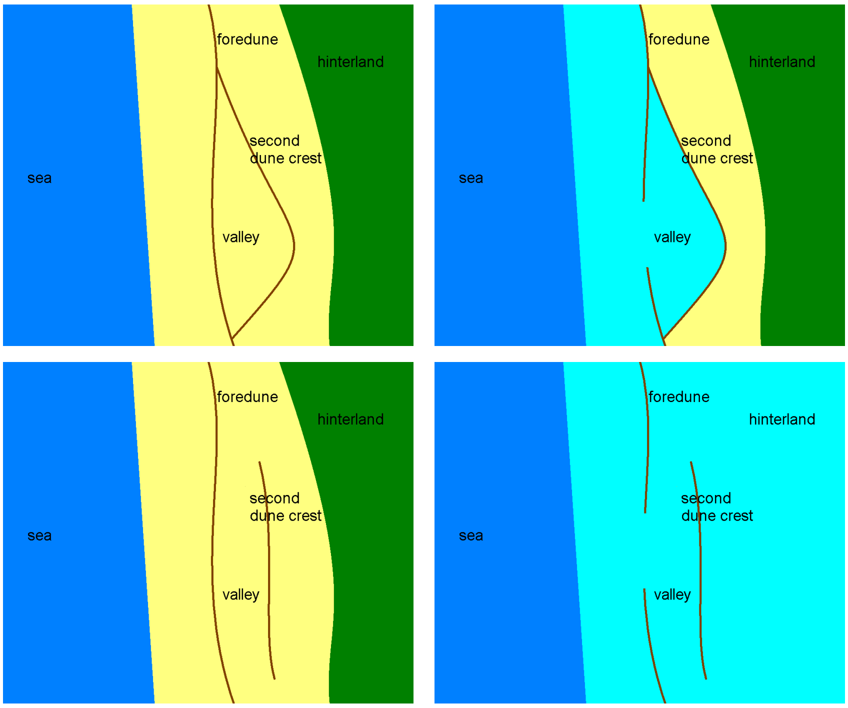


Figure 17: Two situations with multiple dune crests in a coastal cross-section. The upper figures show a situation with a closed valley able to stop a breakthrough of the first dune crest. The lower panel shows a situation with two parallel crests unable to stop a breakthrough of the first dune crest.

This is only a first attempt to include a longshore perspective in the coastal safety assessments. The measured cross-sections are still located at about 250 m apart, so there is no continuous image of the longshore development of the cross-shore profiles. In order to improve the longshore component of the coastal safety assessment, this information is needed for the entire length of the coastal defences. A GIS-tool (GIS = geographic information system) may create opportunities to do so, however this is not studied within this research.

Finally, the results of the assessments for all cross sections are aggregated. All assessments (for about 3 to 5 cross-sections) over each single km of the coastline are summarised into one assessment. Within this study this is done by selecting the worst judgement of every reach that is assigned to more than one-fourth of the sections in that reach. When the reach contains a cross-section where the volume of sand is too small for balancing erosion and sedimentation (Figure 16a), then the entire reach is assumed to be judged insufficient. This is in accordance with the weakest-link principle: when one cross-section fails, the strength of the neighbouring reaches does not matter anymore.

2.5 Determining safety of dikes

All coastal defences within the study area are assessed with the model presented in the previous section, except for the dike at Den Helder and the Hondsbossche and Pettemer defences. Dikes can not be assessed with this method since they will not erode. Dikes are susceptible to failure mechanisms like overtopping, piping and macro-instability (see appendix E.4.1).

According to the prescriptions for assessing dikes (appendix E.4), the assessment of dikes is more complex than the assessment of dunes. There are more failure mechanisms to be considered and for most of these mechanisms (except for overtopping) there are no simple models available to assess the safety of the dikes [Min V&W, 2007]. Moreover, the length of these three dikes is small compared to the total length of the coast of the study area. Taking into account these considerations, it was decided that the safety assessment results of previous studies would be used for these dikes.

The Mapped Safety of the Netherlands report for Noord-Holland [Min V&W, 2005] states that the crest levels of the Hondsbossche and Pettemer sea defences appeared to be too low (1.5 up to even 5 m) in a 2003 assessment with new boundary conditions. Moreover the revetments of the Helderse, Hondsbossche and Pettemer sea defences were assessed insufficient.

Meanwhile, the assumed boundary conditions of this study are outdated and too pessimistic according to the latest insights so they are adjusted down. Applying the new prescriptions (comparable to those applied in this study), the Helderse sea defence is not assessed as a potential weak link anymore on the short term. However, it is uncertain whether this defence will still be adequate within 200 years from now. Based on the negative outcome of the previous assessment it is supposed that this defence will not be able to withstand the sea level rise predicted for the next 200 years (which is at least 4 times as high as the 0.30 m sea level rise over 50 years assumed for this study). At the same time, overtopping of the Hondsbossche and Pettemer defences will still become a problem even on the short run (within 50 years) [Van Koningsveld, 2004] [Onderwater, 2005].

These results imply that, when no improvements are carried out, these three dikes will not meet the safety requirements over the next 200 years. The only difference is that the Hondsbossche and Pettemer defences should be improved immediately, while the dike at Den Helder will still be adequate for the next 50 years at least.

Next to the dikes, the connections between these dikes and the neighbouring dunes are very important. There are some prescriptions on how to assess these points [Min V&W, 2007] but still it is rather complex. For the Hondsbossche and Pettemer sea defences, several studies state that the connections to the dunes are insufficient [Min V&W, 2005] [Van Koningsveld, 2004]. However, after reinforcements by adding sand in 2004, these connections might be save for the next 200 years assuming the autonomous development of the coast [Onderwater, 2005]. Since the developments of these connections are uncertain, ongoing evaluation will be needed. No results are found for the connection of the Helderse sea defence.

2.6 Safety assessments

This section contains the results of the assessment that is executed for the coastal defences within the study area. A short summary of this assessment method, described in the previous sections of this chapter, is presented in Figure 18. Next, a comparison is made between our new results and the results of previous studies.

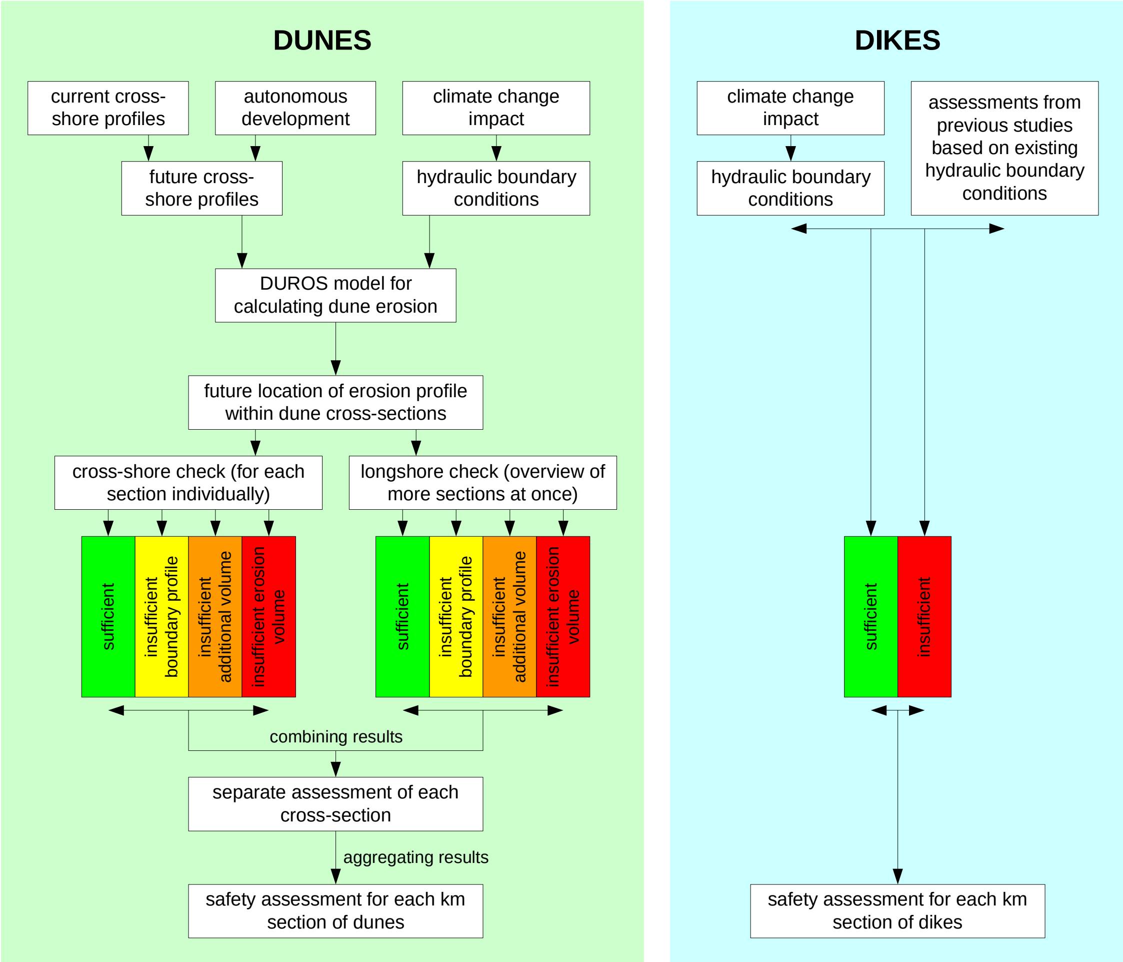


Figure 18: Schematic overview of the applied assessment method for the coastal defences within the study area.

The assessment method depicted in Figure 18 is applied to the coastal defences in the study area. In this assessment the longshore position is indicated by Jarkus cross-section numbers, which are indicated in Figure 19. The results of these assessments are also summarized in this figure and in Table 4. Within this latter table, four different judgements are awarded, based on the failure modes distinguished in the erosion calculations of the dunes. Dunes are assessed positive (green) when no problems are foreseen based on the calculations and the assessments. A slightly negative judgement is awarded (yellow) in case both the erosion and the additional volume do fit within the dune cross section, but the boundary profile could not be guaranteed. In case the additional erosion volume needed for compensating uncertainties also does not fit within the cross-shore dune profile, the judgement of the section is moderately negative (orange). Cross-sections with a volume of sand even too small for coping with the erosion during a critical storm surge are assessed negative (red). For dikes, the only scores applied are positive (green) and negative (red), since no calculations are made for assessing these structures. It should be noted that (according to the Hydraulic Boundary Conditions document) the only dikes present in the coastal defences of the study area are the Hondsbossche and Pettemer seawalls and the seawall at Den Helder.

It is important to realise that these assessments are based on the present situation of the coastal defences. Planned or currently started reinforcement activities of the weak links in the Dutch coast, like the realisation of a dike in the existing dunes at Noordwijk, are not included in this study. This might reduce the possibilities for the implementation of new and large-scale measures based on a long-term perspective. Moreover, natural developments of the dunes due to dynamic sand transport processes in the coastal zone are neglected by this assumption. However, it is impossible to do any predictions on the exact future outline of the dunes and assuming the present cross-shore profiles is the best available option.

The results clearly show an increase in the extent of the problem areas with the increase of the climate change scenarios. More extreme climate change scenarios cause a distinct increase in the length of the coastal stretches with insufficiently assessed defences. This length increases from about 40% of the total length of the coastline for the lower climate change scenario, to about 60% in case of the intermediate climate change scenario and more than 70% for the most extreme scenario. This statement becomes even more evident in Figure 19 where all insufficient stretches of sea defences are marked red.

It is difficult to compare these results to the results of previous studies on the safety of the Dutch coast [Min V&W, 2005] [Onderwater, 2005]. Over the last years, the boundary conditions for assessing the coastal defences (mainly the assumed wave period) have been changed several times. The studies on improving the weak links in the coastal defences of Noord-Holland [Onderwater, 2005] and into the expected erosion lines for the North Sea coast of the Netherlands [Alkyon, 2001] for example, are based on more severe boundary conditions than those applied nowadays. Next, some of these studies (those forecasting future positions of the erosion lines during design storms) do not include the longshore check that the present study applies to the safety assessment of the coastal defences. And in addition, different climate change scenarios are applied in this study. So there are some major differences that hamper a straightforward comparison.

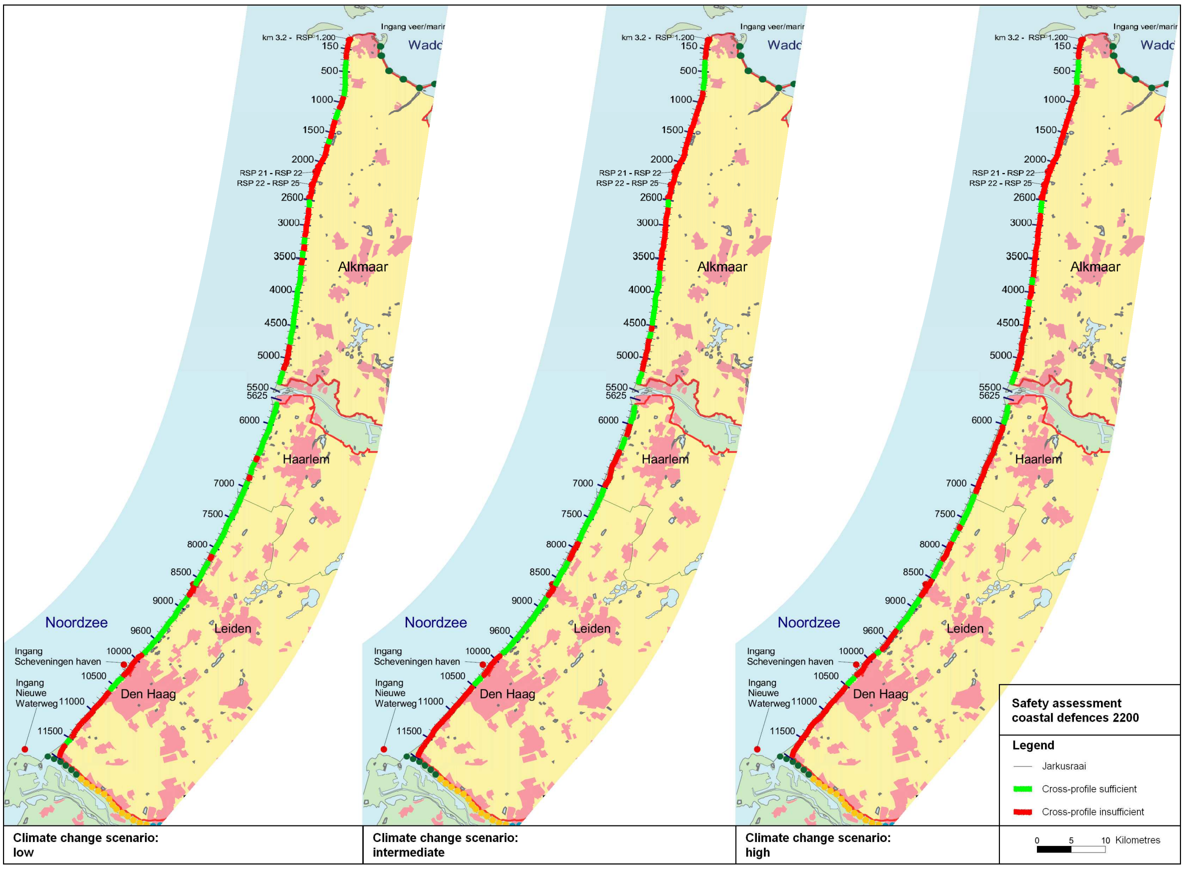


Figure 19: Aggregated results of the safety assessments presented in Table 4, showing the increasing scale of insufficient coastal defences for an increasing climate change scenario. Both red, orange and yellow cells in Table 4 represent rejected coastal defences which are all marked red in these overviews.

Table 4: Safety assessment of the coastal defences along the Holland coast: green = sufficient, yellow = insufficient (boundary profile), orange = insufficient (additional volume), red = insufficient (erosion volume for dunes or failure in general for dikes).

From section	To section	Climate change scenario		
		Low	Intermediate	High
Dike ring 13				
0	120	red	red	red
130	199	orange	orange	orange
200	299	orange	orange	orange
300	399	green	green	green
400	499	green	green	green
500	599	green	green	green
600	699	green	green	green
700	799	green	green	orange
800	899	green	yellow	orange
900	999	yellow	yellow	orange
1000	1099	yellow	yellow	orange
1100	1199	green	yellow	orange
1200	1299	green	orange	orange
1300	1399	orange	orange	orange
1400	1499	yellow	yellow	orange
1500	1599	yellow	orange	orange
1600	1699	green	yellow	orange
1700	1799	yellow	yellow	orange
1800	1899	orange	orange	orange
1900	2023	orange	orange	orange
2041	2099	red	red	red
2100	2199	red	red	red
2200	2299	red	red	red
2300	2399	red	red	red
2400	2499	red	red	red
2500	2582	red	red	red
2600	2699	green	green	green
2700	2799	yellow	orange	orange
2800	2899	orange	orange	orange
2900	2999	orange	orange	orange
3000	3099	orange	orange	orange
3100	3199	orange	orange	orange
3200	3299	green	orange	orange
3300	3399	yellow	yellow	yellow
3400	3499	green	yellow	orange
3500	3599	yellow	orange	orange
3600	3699	green	yellow	orange
3700	3799	green	green	yellow
3800	3899	green	green	green
3900	3999	green	green	yellow
4000	4099	green	green	yellow
4100	4199	green	green	green
4200	4299	green	green	yellow
4300	4399	green	green	yellow
4400	4499	green	green	yellow
4500	4599	green	yellow	orange
4600	4699	green	green	yellow
4700	4799	green	yellow	orange
4800	4899	orange	orange	red
4900	4999	orange	orange	orange
5000	5099	orange	orange	orange
5100	5199	yellow	orange	orange
5200	5299	green	green	green
5300	5399	green	green	green
5400	5499	green	green	yellow
Dike ring 14				
5700	5799	green	green	green
5800	5899	green	green	green
5900	5999	green	green	green
6000	6099	green	yellow	orange
6100	6199	green	yellow	orange
6200	6299	green	green	yellow
6300	6399	green	green	yellow
6400	6499	green	yellow	yellow
6500	6599	yellow	yellow	yellow
6600	6699	green	yellow	yellow
6700	6799	green	yellow	orange
6800	6899	yellow	orange	orange
6900	6999	green	orange	orange
7000	7099	green	green	orange
7100	7199	green	green	green
7200	7299	green	green	green
7300	7399	green	green	green
7400	7499	green	green	green
7500	7599	green	green	green
7600	7699	green	green	yellow
7700	7799	green	green	green
7800	7899	green	green	green
7900	7999	green	orange	orange
8000	8099	green	orange	orange
8100	8199	yellow	orange	red
8200	8299	green	green	green
8300	8399	green	green	green
8400	8499	green	green	green
8500	8599	green	green	yellow
8600	8699	yellow	orange	red
8700	8799	orange	orange	red
8800	8899	green	green	green
8900	8999	green	green	green
9000	9099	green	green	green
9100	9199	green	green	green
9200	9299	green	green	green
9300	9399	green	green	green
9400	9499	green	green	yellow
9500	9599	green	green	yellow
9600	9699	green	green	yellow
9700	9799	green	green	yellow
9800	9899	green	green	green
9900	9999	yellow	yellow	orange
10000	10099	yellow	yellow	orange
10100	10199	orange	orange	red
10200	10299	yellow	orange	red
10300	10399	green	green	green
10400	10499	green	green	green
10500	10599	green	yellow	orange
10600	10699	yellow	yellow	yellow
10700	10799	orange	orange	orange
10800	10899	orange	orange	orange
10900	10999	orange	orange	orange
11000	11099	orange	orange	orange
11100	11199	orange	orange	orange
11200	11299	orange	orange	orange
11300	11399	orange	orange	orange
11400	11499	orange	orange	red
11500	11599	green	yellow	orange
11600	11699	yellow	yellow	orange
11700	11799	yellow	yellow	yellow
11800	11850	yellow	orange	orange

2.7 Concluding

The results of the case study presented in the previous section are not meant to find the specific future locations of weak links within the coastal defences, as is indicated before. The main aim of the steps subsequently presented in this chapter is to find out on what spatial scale safety problems might occur over the next two centuries when the coastal defences face increased hydraulic boundary conditions due to climate change.

These new calculations for the newly derived climate change scenarios and the application of the extended assessment method clearly indicate the large-scale character of future safety problems of the coastal defences within the study area. Extremer climate change scenarios cause a distinct increase in the length of the coastal tracts with insufficiently assessed defences. Even when it is supposed that the present nourishment policy is continued. The total length of the coastal defences that are assessed insufficient within the next two centuries increases from about 40% of the total length of the studied coastline for the lower climate change scenario, to about 60% in case of the intermediate climate change scenario and more than 70% for the highest climate change scenario.

Especially the results for the highest climate change scenario show some quite large longshore areas where the safety level provided by the coastal defences will become insufficient over the next 200 years. At many locations, the interruptions by sections with sufficiently assessed coastal defences are rather short. To a lesser extent, these conclusions are also true for the other two climate change scenarios. When one of these scenarios would come true, still some rather long weak links are found of at least several km’s length in longshore direction. At the same time however, the lowest climate change scenario would make that a large section in the middle of the study area will cause almost no safety problems.

3 Coastal management strategies for 2200

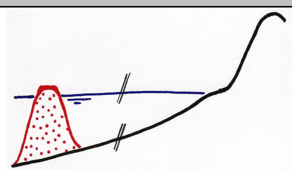
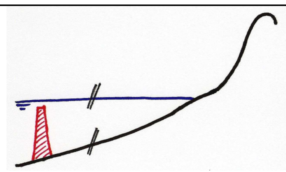
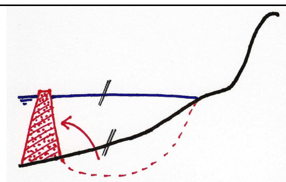
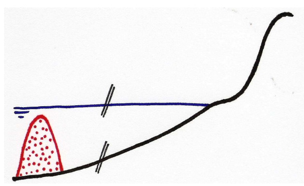
Now we are looking for measures able to improve the coastal defences along the Holland coast so that the situation in 2200 still complies with the present safety demands. The aim of this chapter is to set-up management solutions for satisfying the needs for improving the coastal defences 200 years from now. In order to do so, the first section contains an inventory of all possible measures presently being thought of. Next, it will be explained why coastal management solutions are designed at different spatial scales. The third section finally presents the proposed coastal management strategies.

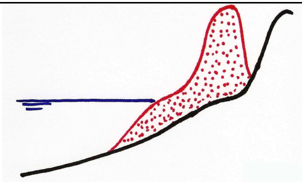
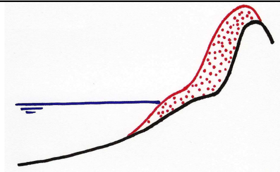
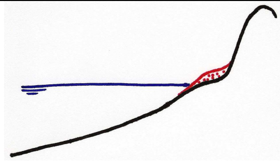
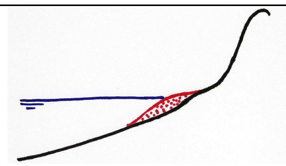
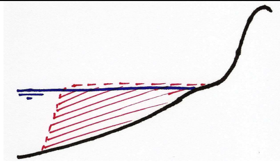
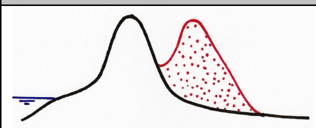
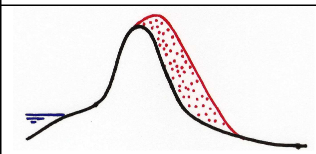
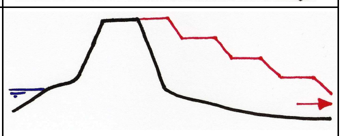
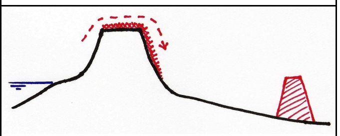
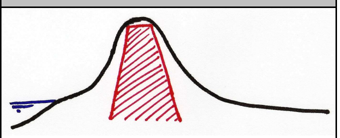
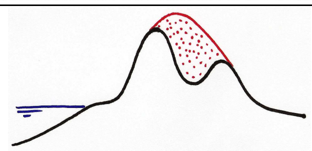
3.1 Available measures

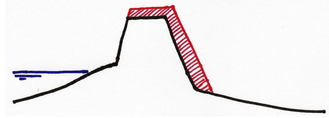
There are lots of measures available for increasing the safety provided by the coastal defences. There are two major characteristics to be distinguished. At first, the area of interest for the available measures distinguishes between seaward, landward and consolidating solutions. Seaward solutions mainly occupy the area seaward of the toe of the existing defence. Landward solutions, on the contrary, are located landward of the existing defences. Consolidating solutions are mainly realized within the seaward and landward boundaries of the existing defences.
Next, there is a difference between 'hard' and 'soft' engineering solutions. Hard measures are static and will not change significantly due to natural (hydro-) dynamics. Examples are fixed structures like dikes and groynes. Soft measures are flexible and will change over time due to sand transporting capacities of water and wind.

All measures available are shortly described in appendix I. Table 5 presents a summary of these measures. For every measure the main principle(s) of its effectivity and the potential effects on (existing) functions in the coastal zone are described in this table.

Table 5: Summary of available measures for improving coastal defences (s=soft; h=hard), their principles, their impacts on functions in the coastal zone and their general outline.

Coastal management solution	Mechanism for improving safety of coastal defences	Effects on functions in coastal zone	Outline
Seaward solutions			
Islands (h)	Decreasing wave load on coastal defences by stopping waves before reaching the mainland coast.	Natural dynamics behind the islands are lost due to this static structure, new functions (recreation & nature) possible on islands. Maybe loss of fishery grounds.	
Artificial reefs (h)	Decreasing wave load on coastal defences by dissipating energy of long waves before reaching the mainland coast.	No effects on existing functions, natural dynamics are lost due to this static structure.	
Offshore seawalls (h)	Decreasing wave load on coastal defences by stopping waves before reaching the mainland coast. These seawalls will create enclosed lakes in front of the coast.	Natural dynamics are lost due to this static structure, new functions (recreation & nature) possible on seawall.	
Sandbanks (s)	Decreasing wave load on coastal defences by dissipating energy of long waves before reaching the mainland coast. Increasing volume of sand in cross-shore profile by sand being transported in landward direction (very uncertain).	Natural dynamics are maintained in stead of being stopped. Beaches and dunes might be extended in seaward direction.	

Dune in front of existing defences (s)	Increasing the volume of sand available in the cross-shore profile.	Extending possibilities for recreation and nature, increasing area for drinking water filtration and decreasing saline intrusion.	
Reinforcing first row of defences in seaward direction (with sand) (s)	Increasing the volume of sand available in the cross-shore profile.	Extending possibilities for recreation and nature.	
Beach heightening (s)	Increasing the volume of sand available in the cross-shore profile.	Affecting recreational value for swimming (beach slope increases).	
Beach widening (s)	Increasing the volume of sand available in the cross-shore profile.	Extending possibilities for recreation.	
Groynes (h)	Retaining sand of the longshore sand river between these groynes and increasing the volume of sand available in the cross-shore profile.	Affecting recreational value and natural dynamics in longshore direction.	
Landward solutions			
Dune behind existing defences (s)	Increasing the volume of sand available in the cross-shore profile.	Extending possibilities for recreation and nature, increasing area for drinking water filtration and decreasing saline intrusion. Existing functions should be removed.	
Reinforcing existing defences in landward direction (s)	Increasing the volume of sand available in the cross-shore profile.	Extending possibilities for recreation and nature. Existing functions should be removed.	
Super levees (h)	Increasing the dimensions (width & height) of the coastal defences.	Super levees could be used for building houses and creating other functions at the landward slopes. Existing functions should be removed before construction.	
Withdrawal (h)	Increasing the strength of the top layer making it resistant to overtopping. A landward dike should retain the water overtopping the sea defence.	Creating valuable area for new nature and extending possibilities for recreation. Existing functions should be removed.	
Consolidating solutions			
Dike in dune (h)	Improving stability of coastal defences by increasing the strength of a dune by constructing a dike within the dune.	No effects.	
Heightening dunes (s)	Increasing the volume of sand available in the cross-shore profile.	Existing nature might be buried within the new dune.	

Heightening dikes (h)	Increasing the height and width of dikes to prevent overtopping and other mechanisms of failure to occur.	Visual relation between land and sea deteriorates.	

3.2 Different spatial scales

The available measures presented in the previous section should be translated to coastal management strategies for the entire coast within the study area. Since this area is rather large and the time frame of this study is really long, it is interesting to review solutions with different spatial variability (see section 1.2). Moreover, the results of the previous chapter indicate that the spatial scale of the weak links in the coastal defences may increase significantly up to 2200. This inherently raises the need for more extensive coastal management strategies and thus creates the possibility to look for coastal enhancement measures at larger spatial scales too. However, these extensive, insufficiently assessed longshore areas can be divided into smaller sections according to land-use types in the areas close behind the coastal defences.

The spatial scales of the variability of the coastal management strategies to be proposed are related to (I) the characteristics of the measures and to both (II) the functions of the coastal zone itself and (III) of the hinterland directly behind the defences. The measures identified in the previous section are quite different regarding their dimensions and their impacts on existing functions in the coastal zone. Some measures are only suitable for large-scale implementation, some other measures can only be applied at smaller spatial scales. Moreover, land use functions of the hinterland could be considered at different levels of detail. Four spatial scales are distinguished this way: uniform coast, large scale, intermediate scale and small scale (see Figure 22).

3.2.1 Uniform coast

At this level, one strategy will be applied to the entire coast. No local differences are considered, since the entire area is supposed to be quite valuable. This is caused by the socio-economic development of the hinterland and is also the reason that both dike ring areas within the study area have the same safety level.

Next, there are measures that could not be applied to the entire length of the Holland coast because of practical impediments (e.g. effects on morphodynamics or existing land use). These measures need some sort of spatial differentiation according to the difference in land use functions of the hinterland. This is facilitated by the three smaller spatial scales. We first start with a large spatial scale consisting of only two sections in order to maintain the uniformity of the coast. The subsequent smaller spatial scales (intermediate and small) facilitate a better tuning of the proposed strategies to specific local needs. These smaller spatial scales also allow to account for sections where the coastal defences do not need to be enhanced.

3.2.2 Large scale

The study area is split-up in two parts: a part north of the North Sea Canal (dike ring 13) and a part below this canal (dike ring 14). The basis for this separation are the different population densities and land use of both areas (Figure 20). The southern half is very densely populated and built-up area is a major type of land use (both houses and companies). On the contrary, the northern half only contains several medium-sized cities, the population-density is much smaller and agriculture is the main type of land use in this part. Moreover, these two parts form morphological entities (Figure 21), meaning that morphodynamic interactions between those two parts and with the remaining parts of the Dutch coast are much smaller than morphodynamic interactions within these sections. The second morphologic separation within the study area, caused by the Hondsbossche seawall is more diffuse according to Mulder [2000] and is therefore not included.

3.2.3 Intermediate scale

At this level, a separation is made based on specific types of land-use behind the coastal defences. Every type of land use behind the defences (greenhouses, coastal towns or agriculture for example) could be related to specific preferences for coastal improvement measures. Therefore, an inventory of these land uses should be made and suitable measures should be selected for every type of land use. However, not every (relatively) small spot of a certain land use will be incorporated at this spatial scale. Land uses occupying only several kilometres (in length) behind the coastal defences are integrated in functions representative for a larger area. In the end, only four general functions are distinguished:

- Agriculture;
- Nature, this function is also awarded to extended dune sections with a width of several kilometres;
- Coastal towns, or just urban areas along the coastal defences;
- Greenhouses or other industries.

Present land use characteristics are applied for this intermediate scale (and also for the small scale) division of the study area. This is done since these characteristics are supposed to be rather static over time. Existing land use patterns will dominate spatial developments over the next (two) centuries. The past has shown a similar development, especially in relation to high-valued areas like coastal towns and urban concentrations (see appendix A).

Figure 22 shows the division of the study area according to this intermediate spatial scale (together with the division according to the three remaining spatial scales).

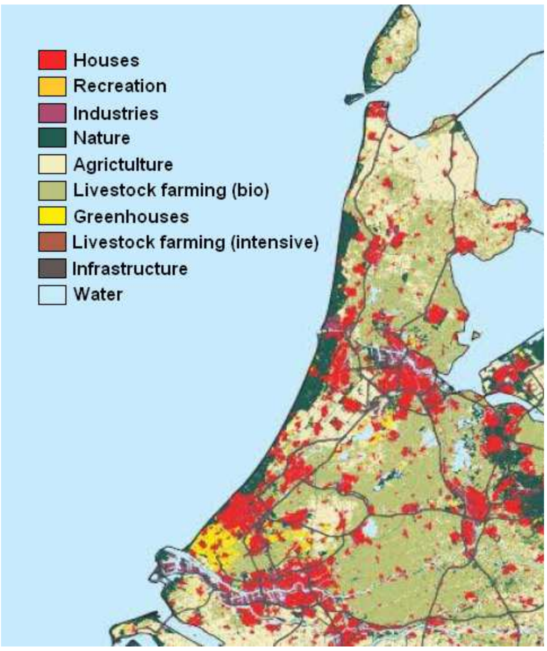


Figure 20: Land use within the study area [MNP, 2007]. Below the North Sea Canal (in dike ring 14) built-up area is much more extended than above this canal (in dike ring 13).

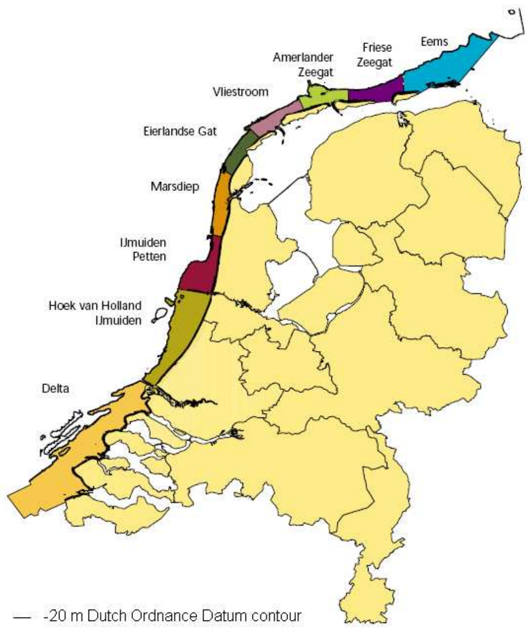


Figure 21: Concerning a time-scale of decades, the Dutch coast could be divided in nine (more or less) independent morphologic sub-systems [Mulder, 2000].

3.2.4 Small scale

This spatial scale is related to the basic alternative representing the continuation of present coastal management policies. Measures for improving coastal defences are looked after at a rather small spatial scale with an order of magnitude of kilometres. Every time improvements are needed (right now for the present weak link locations for example), activities are confined to the specific locations that are found to be too weak. At the same time, measures are developed that comply with the specific characteristics and needs currently existing at every separate location.

For this spatial scale, the coastal zone of the study area is again divided according to the four land use functions defined before. Now however, the length of the individual sections is much smaller. This implies a higher accuracy of the description of the land use functions (unless still only four functions are distinguished). Sufficiently assessed coastal defences and dikes are also distinguished at this small spatial scale. This increases the spatial differentiation even more. The resulting division of the study area is shown in Figure 22.

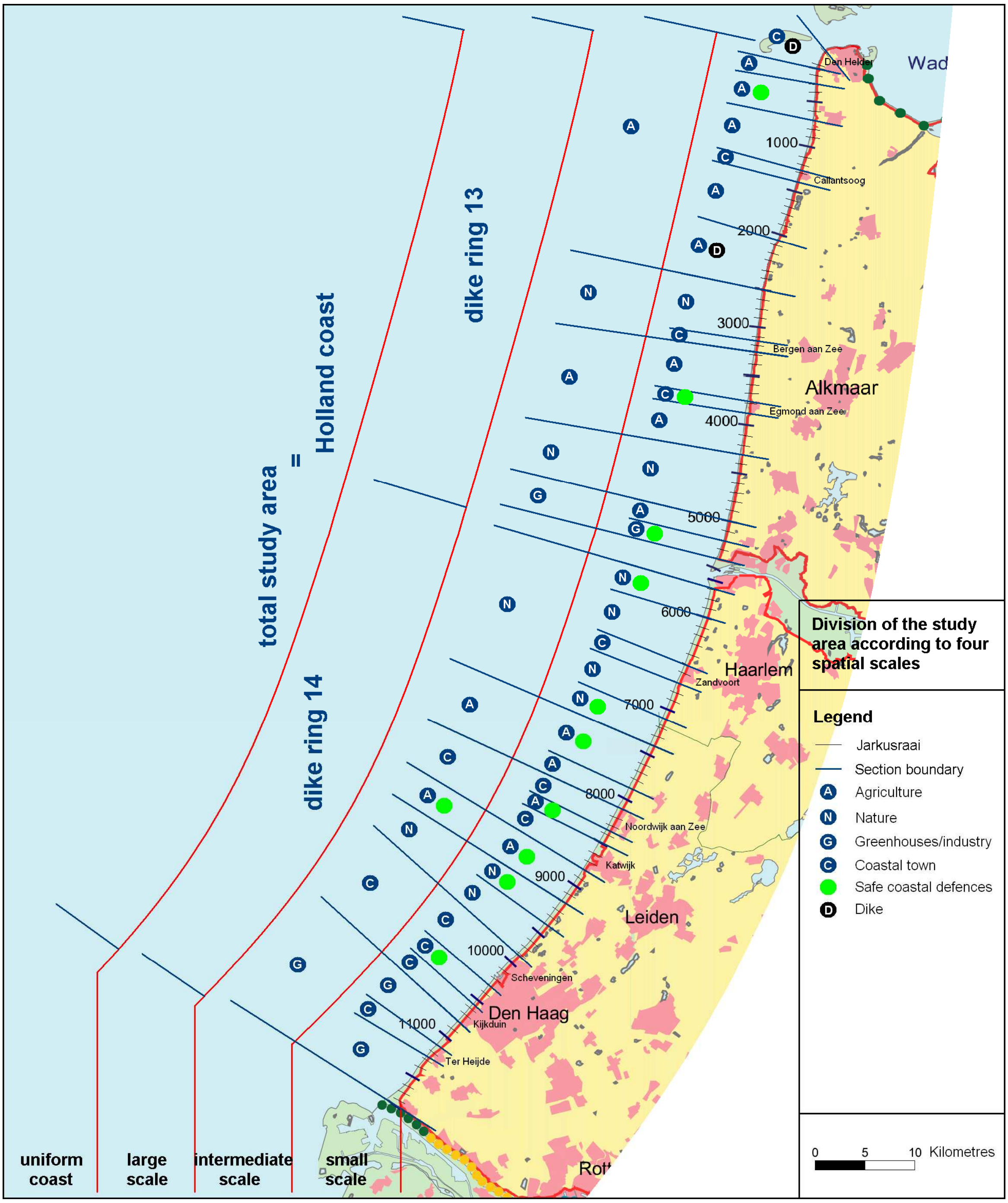


Figure 22: Functional division of the study area according to four spatial scales for applying coastal management solutions.

3.3 Coastal management strategies

Now the available coastal management measures are known and the coast of the study area is divided according to four different spatial scales. The next step is to couple specific measures to those sections of the coastal defences that need to be improved. This will be done by selecting measures that comply with the functions and needs of each section. For the smaller spatial scales applied for dividing the area in longshore sections, this will result in a larger longshore variability in the final state foreseen for the coastal defences in 2200. In the following sub-sections, coastal management strategies will be presented for each of the applied spatial scales. Every strategy covers the total study area in order to enable the comparison of these solutions. Preliminary dimensions of the measures being part of every strategy are derived in appendix J for the high climate change scenario.

3.3.1 Uniform coast strategies

When the entire coast is defined as one unit, the applied management solution is the same for the total length of the study area. Therefore there are some major constraints for the selection of a management solution from all measures available. Certain measures are conflicting with some important functions of the nearshore zone and are therefore impossible to be applied to the total length of the coast. This is valid for all kind of landward coastal strengthening measures. It is impossible to apply these measures to areas where the nearshore zone is quite well developed (e.g. when coastal towns are present).

Next, consolidating measures will also be less appropriate. At many locations along the coast, where constraints in the cross-shore direction are absent, it will be much easier and thus less expensive to realize seaward solutions. For example: both adding sand in between existing dunes and constructing a dike within the dune will face substantially more disadvantages (destroying nature, higher costs, affecting landscape) than adding sand in front of the existing dunes. Moreover, consolidating measures do not create any positive effects for existing or new functions (see section 3.1).

Seaward management strategies are thus most suitable for uniformly enhancing the coastal defences, but still there are some options facing major disadvantages when applied at this spatial scale.

- Constructing an offshore seawall is too extreme, even when using a 200 year perspective. Construction costs will be enormous and inundation risks for the hinterland may increase due to the decreasing strength of the mainland coast and the increasing depth of the artificial lake created behind the seawall. At the same time, the attractiveness of existing coastal towns and beaches will decrease, affecting a major economic core-business of the study area.
- Extending the dunes (in seaward direction) or the beaches (height or width), will be insufficient for improving extended longshore sections assessed negative in section 2.6. Extending the dunes or beaches at other locations with less severe safety problems will strongly affect the coastal views of the foredunes and the beaches. Therefore creating new dunes in front of the existing foredunes is preferred over extending dunes or beaches for application to the total study area.
- Constructing groynes does not solve the main problem of the lack of sand in the coastal defence system, they just cause a redistribution of the amount of sediment within the system. Groynes are also little effective in breaking the waves during critical storm events due to their cross-shore orientation. Moreover, hard structures are inflexible and are difficult to be adjusted to changing circumstances. These are important reasons for omitting this measure. Nowadays, constructing groynes at the weak link locations is widely disapproved as well because of these reasons.
- Finally, creating artificial reefs in front of the coast is not included because it resembles the construction of offshore sandbanks. The outline of these measures is the same, but they are different in the fact that artificial reefs are hard structures lacking the characteristic flexibility of sandbanks. Moreover, sandbanks might stimulate the development of the coastline over time by sand being transported in landward direction. Artificial reefs contrarily impede cross-shore sand transport and hamper natural development of the coast and coastal defences. Because of their resemblance and the substantial advantages of sandbanks over artificial reefs, the latter are not considered as a potential solution at this spatial scale.

Based on these deliberations, three measures are left for improving the coastal defences over the total length of the studied coast:

- Islands
  Two islands reaching from Hoek van Holland to Callantsoog with a narrow outlet for a fairway in front of IJmuiden. This island follows the concave shape of the Holland coast and will resemble the Wadden Islands. It is supposed to be about 3 km wide at the southern end and about 1 km at the northern end and its mean surface level is about 2.5 m above mean sea level. This surface level is located several metres below the extreme sea level occurring during a design storm-event. The island should be located about 10 km in front of the existing coastline. To the north the island will gradually become narrower and located somewhat closer to the coast. Furthermore it should be noted that the safety against flooding on these islands will be much lower than on the mainland. More details are presented in appendix J.1.1. A sketch of this measure is presented in Figure 23.
- Sandbanks
  The dimensions of these sandbanks are based on the outline of the artificial reefs proposed by Royal Haskoning and Rijkswaterstaat. The banks will be located at 1.5 to 3 km offshore, where mean water depths are about 10 m. These structures will be 30 m wide at the top (at several metres below mean sea level) and about 120 m wide at the seabed. These banks will dissipate energy of long waves approaching the coast but at the same time their sand might be transported in both landward (feeding the extension of dunes and beaches) and seaward direction. This will raise the need for structural maintenance of these features.
- Dunes in front of existing dunes
  These dunes are modelled in the DUROS-plus model in order to calculate the dimensions needed in order to resist future boundary conditions. Four representative cross-sections were selected to represent the total length of the Holland coast. From calculations optimising the dimensions of the new foredunes it is derived that the crest levels of these new dunes should be 17 up to 20 m above Amsterdam Ordnance Datum and that their widths should be 150 up to 200 m (at 5 m above Amsterdam Ordnance Datum, where they are connected to the existing dunes).

For the dimensions of these measures it should be noted that mean sea levels are supposed to be 3.15 m higher by the year 2200 according to the high climate change scenario. Meanwhile, according to the autonomous development of the coast, bed levels seaward of the dune toe will rise by the same growth rate. So water depths are supposed to remain more or less the same. The dimensions of the new foredunes are related to Amsterdam Ordnance Datum, which is supposed to remain unchanged over time and equals the present mean sea level.

More information on the preliminary dimensions of these measures is contained in appendix J.1. Figure 23 shows the rough outlines of these three solutions for maintaining a safe coast. Larger overviews of these solutions are included in appendix K.

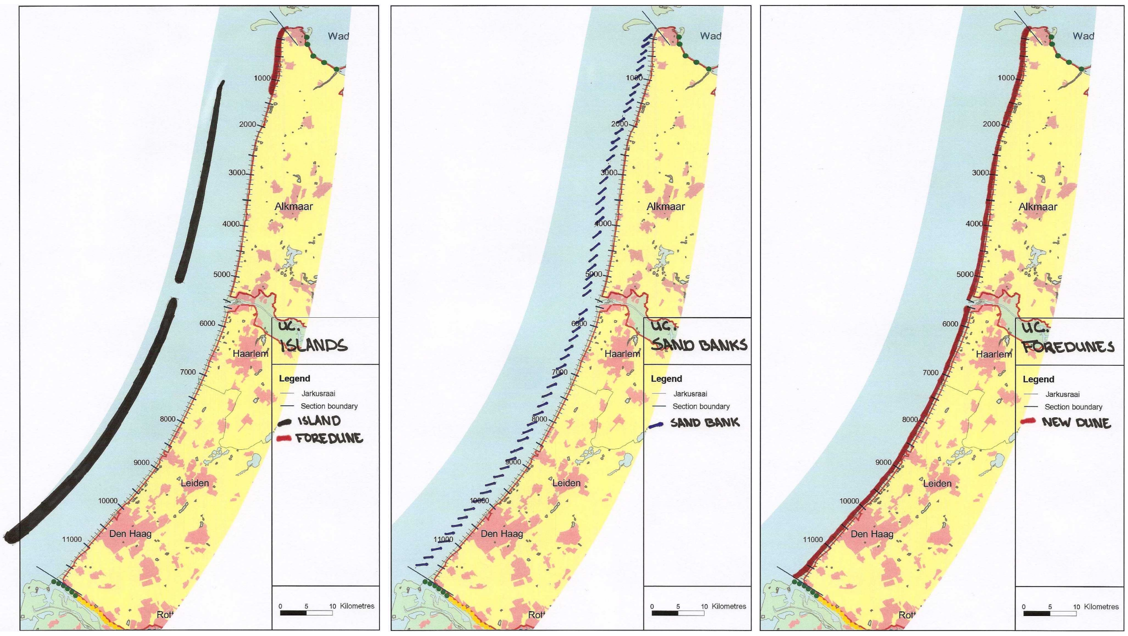


Figure 23: Preliminary designs of the proposed uniform coast strategies for maintaining the present safety levels up to the year 2200 for the highest climate change scenario.

3.3.2 Large scale strategies

At this spatial scale, two regions are distinguished within the study area: dike ring 13 and dike ring 14. The presence of the moles and the fairway at IJmuiden create a morphologic separation between the northern part and the southern part of the study area. This creates the possibility for realising different measures in these two sections without raising the need for extended research into the interaction of these measures at the transition zone.

The southern part is characterized by higher population densities and large (coastal) cities. The northern part is less densely populated and agriculture is the major type of land use. This leads to different needs for the two sections. In dike ring 14 the need for additional space for recreation and nature or other functions is larger than in dike ring 13.

The measures that could be applied at this spatial scale can be transferred from the uniform coast alternatives. This is due to the fact that the sections are still quite large in longshore direction so the possibility for spatial differentiation is very limited. This means that local advantages of landward or consolidating measures or the rejected seaward options still do not outweigh the negative impacts of large-scale application of these options. So combinations should be made of islands, sandbanks and dunes in front of existing dunes.

Based on the fact that the southern section has a larger need for additional space, two alternative solutions are found for the total length of the studied coast:

- Islands for the southern part and dunes in front of existing dunes in the northern part;
- Dunes in front of existing dunes in the southern part and sandbanks for the northern part.

The rough dimensions and configuration of these solutions are copied from the uniform coast solutions that are incorporated in these smaller scale solutions (appendix J.2). Depending on the solution, the uniform coast designs are applied only to the northern part or the southern part of the study area. Maps showing these solutions are shown in Figure 24 and are also included in appendix K.

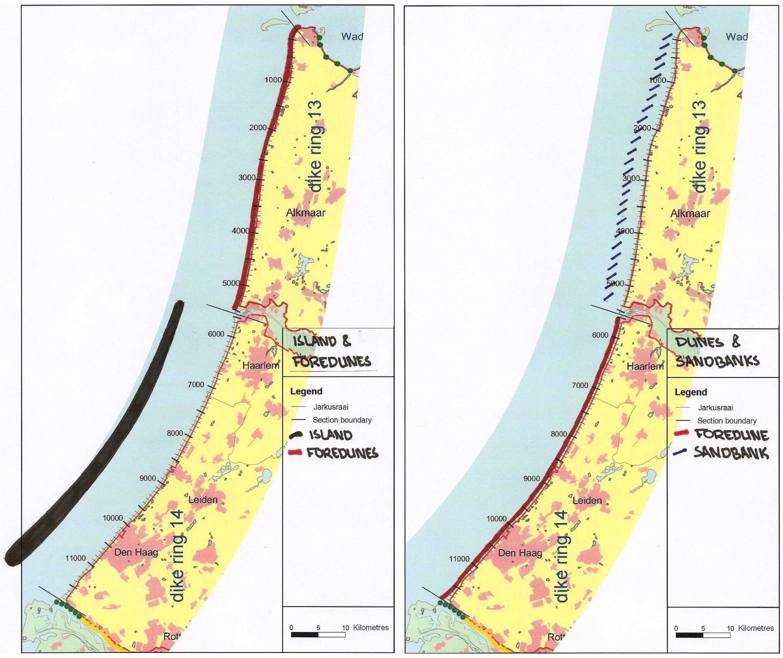


Figure 24: Preliminary designs of the proposed large scale strategies for maintaining the present safety levels up to the year 2200 for the highest climate change scenario.

3.3.3 Intermediate scale strategies

At the intermediate spatial scale, the studied coast is divided according to generic land use functions that are representative for sections with a minimal length of several kilometres. These functions are defined as the type of land use landward of the coastal defences. Only four major functions are distinguished according to section 3.2.3: agriculture, nature, coastal towns and greenhouses or other industries (see the map in Figure 22 for their spatial distribution).

Next to maintaining (or increasing) safety levels of the hinterland, structural improvements to the coastal defences could also affect or stimulate land use functions (section 3.1). Some generic needs can be defined for the four land use types applied for the intermediate spatial differentiation of the study area. For agricultural areas it is important that not too much grounds are lost due to landward extensions of the coastal defences. An advantage for agriculture could be generated when saline intrusion at those farming grounds is decreased.

The natural function is served best if existing nature is preserved and if natural dynamics and values are increased where possible. Coastal towns however want to remain their present character and their direct relation with the sea. At these locations, growth of beaches and dunes should be restricted and landward measures are impossible at all. Large sandy measures with the probability of sand sprays occurring are also undesirable near urban areas. Where greenhouses or other industries occupy the area behind the coastal defences, landward measures are very expensive due to the high value of these assets. Moreover, these areas are often occupied very densely (think of the Delfland region), so the creation of new space for nature and/or recreation could significantly improve the living environment in these industrialized areas.

Subsequently, possible measures can be related to these land use functions by means of selecting measures that comply with the specific needs of every function. Table 5 shows the potential effects of the available measures on the functions in the coastal zone.

At this scale of spatial differentiation, landward and consolidating measures are also realistic since a better adjustment to local needs and restrictions is possible now. At the same time, rather large structures are incompatible with this spatial scale. Constructing one small island in front of a certain section will not be very effective since waves could pass the island by the sides. Moreover, exploitation of these small, remote islands will become increasingly difficult. Offshore seawalls and groynes are still not included based on the same negative impacts as those given at larger spatial scales.

Based on these considerations, two alternative coastal management solutions are designed: a seaward and a landward option (Table 6 and Table 7). The landward option contains some exceptions at sections for coastal towns being unsuitable for landward measures. A visualisation of these two intermediate spatial scale coastal management solutions is shown in Figure 25.

Table 6: Seaward coastal management solution with a semi-small spatial differentiation. Notes: section numbers refer to Jarkus cross-section numbers and the colours in the assessment column refer to the colours in Table 4.

Section	Land use function	Assessment	Solution
0-2600	agriculture	red	Dune in front of existing dune
2600-3300	nature	orange	Sand bank (+ extended beach and dunes)
3300-4300	agriculture	orange	Dune in front of existing dune
4300-5000	nature	orange (red)	Sand bank (+ extended beach and dunes)
5000-5400	greenhouses/industry	orange	Dune in front of existing dune
5700-7400	nature	orange	Sand bank (+ extended beach and dunes)
7400-8100	agriculture	orange	Dune in front of existing dune
8100-8800	coastal towns	red	Artificial reef
8800-9200	agriculture	green	-
9200-9900	nature	yellow	Sand bank (+ extended beach and dunes)
9900-10800	coastal towns	red	Artificial reef
10800-11850	greenhouses/industry	orange (red)	Dune in front of existing dune

This seaward alternative is based on four main choices:

- Insufficient defences in front of agricultural areas are strengthened by creating dunes in front of the existing dunes (or dike), because this might (slightly) decrease saline intrusion landward of the defences. It would also increase the area available for drinking water filtration. These dunes are somewhat larger for the weakest defences assessed red in stead of orange.
- The defences in front of areas occupied by greenhouses or industries will also be improved by creating new dunes in front of the existing dunes. These new dunes extend the area available for nature and recreation in these densely occupied areas.
- Coastal defences in front of nature areas or extended dunes could be improved by creating sandbanks in front of these sections. Due to natural morphodynamic processes, these sandy features in front of the coast might also support the natural development of the coast. This positive side-effect could start directly after the implementation of this measure.
- Coastal towns will be protected by artificial reefs since these structures do not affect the present coastline of these tourist locations. Excessive sand spray by new sand added to the coastal defences could be avoided this way.

Table 7: Landward coastal management solution with a semi-small spatial differentiation. Notes: section numbers refer to Jarkus cross-section numbers and the colours in the assessment column refer to the colours in Table 4.

Section	Land use function	Assessment	Solution
0-2600	agriculture	red	Extending dune in landward direction
2600-3300	nature	orange	Dune behind existing dunes
3300-4300	agriculture	orange	Extending dune in landward direction
4300-5000	nature	orange (red)	Dune behind existing dunes
5000-5400	greenhouses/industry	orange	Extending dune in landward direction
5700-7400	nature	orange	Dune behind existing dunes
7400-8100	agriculture	orange	Extending dune in landward direction
8100-8800	coastal towns	red	Dike in dune + extending dune in seaward direction
8800-9200	agriculture	green	-
9200-9900	nature	yellow	Dune behind existing dunes
9900-10800	coastal towns	red	Dike in dune + extending dune in seaward direction
10800-11850	greenhouses/industry	orange (red)	Extending dune in landward direction

The landward alternative is based on four different arguments:

- Defences in front of agricultural areas that should be strengthened, will be extended in landward direction with sand. This measure is the least landward extending option of the available landward strategies. Moreover, the wider dune area will increase possibilities for developing nature and recreation.
- The same measure is selected for weak coastal defences backed by greenhouses or industries. This choice is based on the high value of these grounds and the minimal landward land use of this measure. Increasing opportunities for nature and recreation is also welcome in these densely occupied areas.
- Where weak defences are located in front of nature, these defences could be strengthened by creating a dune landward of the existing dunes. This would improve the natural values of the dunes since the dune area will be extended and a new valley will emerge. When weak defences are backed by more dunes however, this measure will come down to an improvement of the second row of dunes behind the foredunes. This extension might comprise the connection or heightening of several dunes in order to close the coastal defences and to prevent the water during storms to pass the defences through a system of dune valleys.
- Where coastal towns are located behind the coastal defences, a truly landward measure is impossible. Therefore, a combination of the consolidating dike in dune measure and the seaward dune extension is proposed for these sections. This will not significantly affect the coastal views of these locations.

Note that one of the problems in combining different coastal enhancement measures at this intermediate (and at the small) scale might cause problems at the interfaces between two sections enhanced by different measures. Dimensioning these connection points is rather difficult, but important since weak connections might decrease the strength of the coastal defences. However, designing these connections would be a far too specialist activity within the scope of this study. Therefore, designing interfaces between different measures is left out of this study. A possible solution for designing these interfaces is creating a transitional zone where both measures are overlapping and gradually merge into one another.

The rough outlines of these two strategies are sketched in Figure 25. The preliminary dimensions of the measures being part of these intermediate scale strategies are described in appendix J.3. A larger visualisation of these two intermediate scale coastal management solutions is included in appendix K.

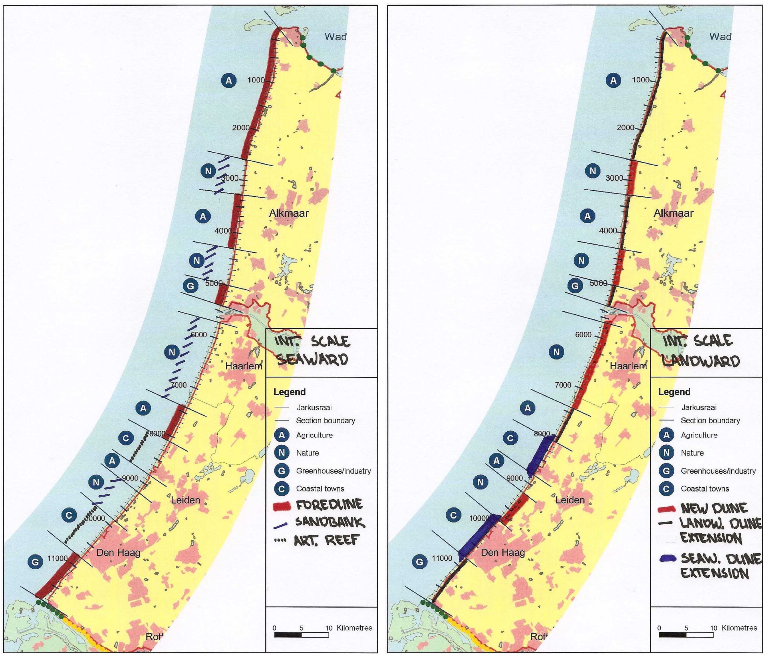


Figure 25: Preliminary designs of the proposed intermediate scale strategies for maintaining the present safety levels up to the year 2200 for the highest climate change scenario.

3.3.4 Small scale strategy – the basic alternative

The smallest spatial scale is comparable to the continuation of present coastal policies. Problems are detected and solved at a rather small spatial scale of kilometres. Again the coastline of the area is divided into sections based on the land use functions of the area directly landward of the coastal defences. This time, the aggregation of land uses applied at the intermediate spatial scale is omitted and the differentiation of land use in longshore direction is increased (see Figure 22). More attention is given to the safety assessments of the coastal defences. Sections that are assessed safe are separated, since no actions will be undertaken at these locations. The other (insufficient) assessment results, indicating the degree of insufficiency are also separated more often in order to be able to simulate a coastal management policy that is dedicated to minimize the efforts for maintenance of the coastal safety. Therefore, no extensive measures will be realized. In stead, incremental improvements will be done to comply with short-term safety requirements. This policy will mainly lead to the gradual extension of beaches and dunes in width and in height.

Table 8 presents the sections concerned within this small scale solution accompanied by their functions and the safety assessments. The last column contains the final state solutions for these sections. These solutions are partly based on the existing plans for the present weak links: the northern part of Noord-Holland (Den Helder up to Callantsoog); the Hondsbossche and Pettemer seawall; Noordwijk; Scheveningen; and the southern part of Zuid-Holland (Kijkduin up to Hoek van Holland) [Min VROM, Min LNV, Min V&W & Min EZ, 2005]. For other sections, the solutions are tuned to the needs of the specific land use functions as was done at the intermediate scale level, but this time solutions are selected that could be implemented by incremental actions. The results of the safety assessments of the sections are included in defining the extent of the selected solutions.

An overview of the spatial variation of the measures in this small scale solution is presented in Figure 26 (larger map in appendix K). The dimensions of the measures being part of this solution are estimated in appendix J.4.

Table 8: Coastal management solution with a small scale spatial differentiation. Notes: section numbers refer to Jarkus cross-section numbers; the colours in the assessment column refer to the colours in Table 4; and the references refer to literature presenting potential or final measures for improving the present weak links in the coastal defences.

Section	Land use function	Assessment	Solution
0-120	coastal town (Den Helder)	red	Dike heightening [RIKZ, 2004]
120-300	agriculture	orange	Extending dune in seaward direction [Provincie Noord-Holland, 2008]
300-700	agriculture	green	-
700-1300	agriculture	orange	Extending dune in seaward direction + increasing beach width [Provincie Noord-Holland, 2008]
1300 1400	coastal town (Callantsoog)	orange	Increasing beach width [Provincie Noord-Holland, 2008]
1400-2040	agriculture (dune)	orange	Extending dune in seaward direction + increasing beach width [Provincie Noord-Holland, 2008]
2040-2600	agriculture (dike)	red	Dike heightening
2600-3150	nature	orange	Extending dune in seaward direction + increasing beach width
3150-3250	coastal town (Bergen aZ)	orange	Extending dune in seaward direction + increasing beach width[1]
3250-3800	agriculture	orange	Extending dune in seaward direction + increasing beach width
3800-3900	coastal town (Egmond aZ)	green	-
3900-4300	agriculture	yellow	Increasing beach width
4300-5000	nature	orange (red)	Extending dune in seaward direction + increasing beach width
5000-5200	greenhouses/industry	orange	Extending dune in seaward direction + increasing beach width
5200-5400	greenhouses/industry	green	-
5700-6000	nature	green	-
6000-6500	nature	orange	Extending dune in seaward direction + increasing beach width
6500-6700	coastal town (Zandvoort)	yellow	Dike in dune[1]
6700-7100	nature	orange	Extending dune in seaward direction + increasing beach width
7100-7400	nature	green	-
7400-7900	agriculture	green	-
7900-8100	agriculture	orange	Extending dune in seaward direction + increasing beach width
8100-8350	coastal town (Noordwijk aZ)	red	Dike in dune + extending dune in seaward direction [Kustvisie Zuid-Holland, 2006]
8350-8500	agriculture	green	-
8500-8800	coastal town (Katwijk)	red	Dike in dune + extending dune in seaward direction (weak link measure not yet known)
8800-9200	agriculture	green	-
9200-9500	nature	green	-
9500-9900	nature	yellow	Increasing beach width
9900-10300	coastal town (Scheveningen)	red	Water retaining structure in boulevard + increasing beach height [Kustvisie Zuid-Holland, 2006]
10300-10550	coastal town (Den Haag)	green	-
10550-10800	coastal town (Kijkduin)	orange	Extending dune in seaward direction + increasing beach width [Kustvisie Zuid-Holland, 2006]
10800-11100	greenhouses/industry	orange	Extending dune in seaward direction + increasing beach width [Kustvisie Zuid-Holland, 2006]
11100-11250	coastal town (Ter Heijde)	orange	Extending dune in seaward direction + increasing beach width [Kustvisie Zuid-Holland, 2006]
11250-11850	greenhouses/industry	orange (red)	Dune in front of existing dunes + increasing beach width [Kustvisie Zuid-Holland, 2006]

[1] Initially a single beach extension was planned for this sections, but just extending the beach proved to be insufficient.

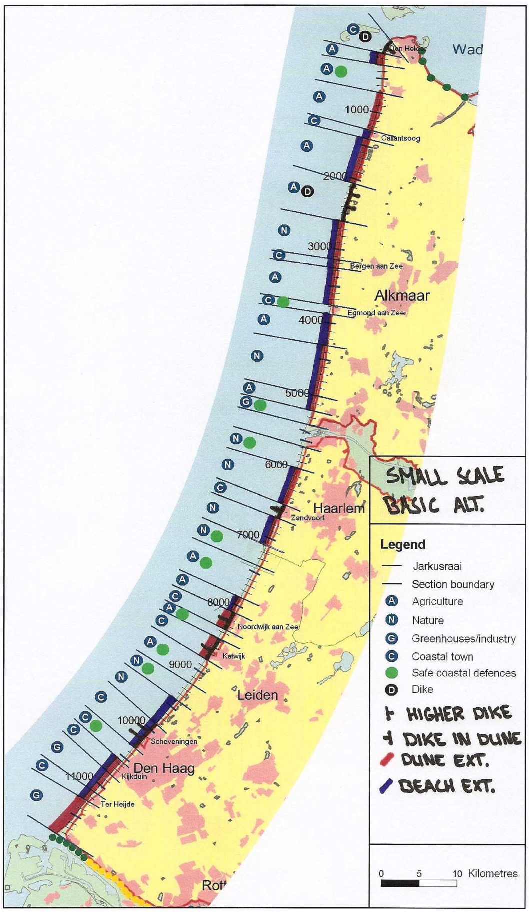


Figure 26: Preliminary design of the proposed small scale strategies for maintaining the present safety levels up to the year 2200 for the highest climate change scenario. This strategy represents the basic alternative.

4 Comparing coastal management strategies

This chapter contains the heart of this study. The coastal management strategies proposed in the previous chapter are assessed now, after the assessment methodology is explained in the first section. It is also studied how these assessments will be changed if the strategies were tuned to the lower scenario for climate change instead of the higher scenario. Next, the results of these assessments are summarized according to some optional policy views. These analyses show which strategies score well according to which views and result in several rankings. Subsequently, it is tested by a sensitivity analysis whether the implicit uncertainties in the assessments affect these rankings. Finally, some preliminary conclusions from this chapter will be presented.

4.1 Assessment methodology

The assessment method for comparing the proposed coastal management strategies is presented in this section. It starts with presenting the assessment framework, which is a combination of both cost-benefit analysis techniques and multi-criteria analysis techniques. Next, the criteria to be included in the assessments are presented and their indicators are described shortly. The final part of this section explains how the results of the assessments will be aggregated.

4.1.1 Framework for assessing coastal management strategies

According to the assessment directive for water related projects (‘de waterwaarderingswijzer’) of the Dutch governmental organization for water management (Rijkswaterstaat), both multi-criteria analysis (MCA) and pre-feasibility cost-benefit analysis (pre-feasibility CBA) are most suited for the assessment to be executed in this study [Rijkswaterstaat, 2003]. These two methods are preferred over some other types of cost-benefit analysis (e.g. a fully financial CBA) and methods for presenting potential impacts (e.g. scorecards).

MCA and CBA methodologies are described in appendix L. A major disadvantage of applying CBA (also of pre-feasibility and socioeconomic CBA’s) is that welfare impacts are quantified and monetarized as much as possible. Otherwise, they can not be included in the final assessment. Unfortunately, not all impacts of the proposed coastal management strategies can be monetarized. Some effects can even not be quantified. Monetary and non-monetary impacts are therefore distinguished within this study. Monetary impacts are initially assessed with CBA techniques. Non-monetary impacts are assessed qualitatively from the start.

The integration of MCA and CBA into one assessment method results in a combination of the UK and the Dutch state of the art on including economic, environmental and social impacts in project assessments [Ruijgrok & Kirchholltes, 2006]. Integrating the results of a CBA into an MCA is also recommended by an evaluative study on the possibilities of the application of the Innovative Management Cycle Model (IMCM) at the Dutch Rijkswaterstaat [Bel & Ruijgrok, 2005]. This IMCM consists of different analysis methods in order to support the planning process of technical and/or administrative innovations. An overview of the final assessment method that is applied in this study is presented in Figure 27. The derivation of this assessment method is explained in appendix L.

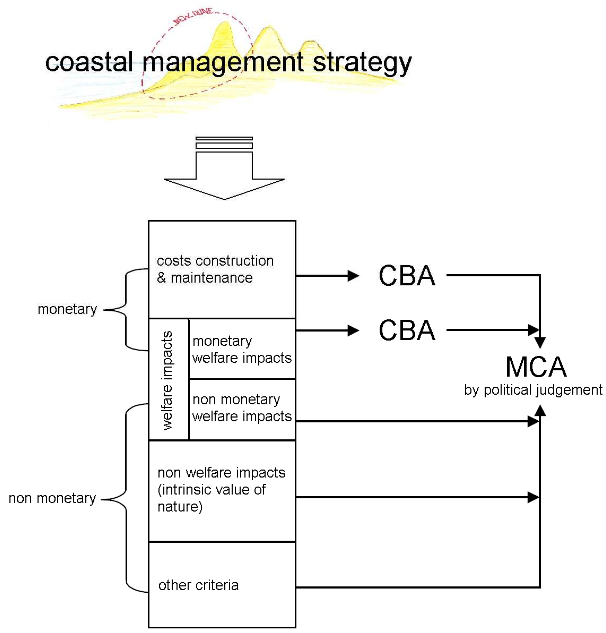


Figure 27: General set-up of the assessment method that is applied in this study.

Figure 27 clearly shows the separation of monetary impacts and impacts that can not be monetarized. For the first group, costs and benefits will be estimated according to the CBA methodology that is presented in appendix M. These quantitative scores will subsequently be translated to qualitative assessments (--/-/0/+/++). The non-monetary impacts are assessed at the same qualitative scale from the start. Except for those aspects that can be expressed easily in a quantitative natural unit (like nature area). These aspects are first assessed quantitatively and afterwards they are translated into the qualitative assessment scale.

Note that all costs and benefits calculated for the monetary impacts are not added into one final balance before being included in the MCA. Several monetary criteria are distinguished and are evaluated separately. These are not added up to find a final balance, since this would reduce the transparency of the method. In that case, one value would represent different impacts. Moreover, calculating a final balance suggests that all costs and benefits are taken into account. This study, however, neglects the safety benefits of maintaining the protection of the hinterland against floods since this benefit will be the same for all coastal management strategies (all proposed strategies should satisfy the preservation of the present safety levels). These safety benefits are the major benefits of coastal defences. In this sense, the assessment method of this study departs from the recommendation of the study of Bel & Ruijgrok [2005] that the final balance of the CBA (or another value or ratio concerning all costs and benefits) should be included in the MCA. However, the same study also states that water management problems sometimes raise the question whether the final balance of a CBA is a correct criterion. Here it is supposed that it is not an adequate criterion. This is also supposed because all uncertainties in the individual costs and benefits would add up to a highly uncertain (almost meaningless) final balance.

In the end, four categories of criteria are considered for this study:

- **Costs** comprise the investments needed to create and maintain safe coastal defences. Costs have a monetary natural unit.
- **Welfare impacts** comprise all effects related to the welfare of the society. These impacts can have both a monetary and a non-monetary unit.
- **Non-welfare impacts** describe the impacts on the intrinsic value of nature (which is the welfare of plants and animals). This is a non-monetary impact.
- **Other criteria** are related to specific characteristics of the proposed coastal management strategies, which are connected to their construction and their development over time. These characteristics can not be assessed in monetary terms.

4.1.2 Overview of criteria & indicators

Table 9 gives a clear overview of all criteria that will be considered in the MCA. The criteria are categorised according to the division presented in Figure 27. In some cases, different partial aspects will be included under the same criterion. These partial aspects are only distinguished when their impacts are quite different. The latter column of this table shows the indicators for all criteria and partial aspects. These indicators state how the coastal management strategies will be assessed on these criteria. All criteria are individually described below this table. Specific impacts are not included in two or more of these criteria to prevent for accounting twice for the same impact in the final assessment (‘doubling’). Doubling is one of the dangers of separating monetary and non-monetary welfare impacts [Kirchholtes & Ruijgrok, 2007] and of multi criteria assessment methods in general [Hellendoorn, 2001]. This could occur for example when both the economic and the social benefits of an increase of the dune area available for recreation are included as two separate criteria.

Table 9: Overview of the criteria to be applied in the MCA. For some criteria several aspects should be considered in order to state a comprehensive assessment.

Criterion	Partial aspect	Indicator
Costs		
Construction costs	Net costs for investment	Costs calculated with unit prizes
Maintenance costs	Net costs for maintenance	Costs calculated with unit prizes
Welfare impacts		
Nature values	Environment & recreation benefits (or costs)	Benefits calculated with authorised values
	Water supply benefits (or costs)	Benefits calculated with authorised values
Safety benefits	Decreased inundation risk of built-up areas in front of dunes (= seaward of legal defences)	Decreased risk calculated with general economic values
Man-made functions	Housing benefits (or costs)	Benefits calculated with authorised values
	Agriculture benefits (or costs)	Benefits calculated with authorised values
Equity	Distribution of costs and benefits over study area	Qualitative assessment based on distribution of (dis)advantages
Safety perception	Safety level as perceived by inhabitants	Qualitative assessment derived from extensiveness and knowledge of measures
Non-welfare impacts		
Intrinsic value of nature	Nature area gained (or lost)	Change of nature area
	Potential for linking nature areas	Qualitative assessment based on longshore distribution of measures
	Impact on protected nature areas	Qualitative assessment based on interference with protected areas
Other criteria		
Technical complexity	Application of approved techniques	Qualitative assessment based on knowledge and constructing facilities available
Robustness	Uncertainties surrounding (future) effectiveness	Qualitative assessment based on knowledge on both initial effectiveness and evolution over time
	Flexibility	Qualitative assessment based on the sustainability and resilience of a measure
Phasing	Construction in phases for risk reduction	Qualitative assessment based on potential to construct a measure in several phases
Governmental complexity	Involvement of several governments	Qualitative assessment based on the number of governments that should cooperate at the same or different administrative levels

Construction costs
This criterion is meant to give an indication of the investments needed in order to realize a planned coastal management strategy. These costs can occur at once, but they can also be spread over time. These differences are made comparable through discounting all costs to the year 2008 (see appendix M.5).

Maintenance costs
The studied coast exhibits an ongoing maintenance requirement (section 2.2.1). The proposed coastal management strategies may change the required maintenance efforts. Total maintenance costs over the next two centuries are estimated for this criterion. Note that maintenance costs incurred before the planned realisation of one of the coastal management strategies are also included. These costs are also discounted to the year 2008.

Nature values
Benefits and costs can also be incurred by changing nature values. First there are the environmental and recreational advantages of increasing dune areas (both foredunes and inner dunes) and beaches. Environmental advantages are caused by the presence of dune vegetation that is able to clean the air. Recreational advantages are caused by the possibilities to exploit new nature areas and new beaches for tourism. Another source of recreational benefits is the increased appreciation by the visitors of extended dunes and beaches.

Nature values also comprise drinking water supply. Dune areas are often applied for drinking water filtration. So extending dune areas may increase the availability of areas suited to filtering drinking water.

Note that both the environmental and recreational advantages and the water supply benefits can also turn into disadvantages/costs in case the dunes and beaches are affected and their area decreases. All costs and benefits are discounted to the year 2008.

Safety benefits

Some coastal residences in the study area do have areas that are not fully protected by the dunes or dikes. These areas are called ‘buitendijks’ (outside the dike) and are located outside the legally defined dike ring areas for which general safety levels are prescribed. On the contrary, for these areas outside the ‘dikes’ no legal safety prescriptions are determined and the inhabitants are mainly responsible for their own safety [Commissie Poelmann, 2005]. The probability of inundation in these areas is much larger than inside the dike ring areas. Zijlstra e.a. [2007] estimate this probability to be about 1:250 per year.

A new coastal management strategy might increase the safety level of these areas in front of the coastal defences. Annual flood risk of these areas will be reduced in that case. This criterion indicates the total flood risk reduction by the year 2200 for all major coastal towns with areas in front of the coastal defences.

Man-made functions

The last monetary criterion describes the impact of the proposed coastal management strategies on the existing land uses. Only two functions are distinguished within this criterion: houses and agriculture. The value of houses may be affected when the environment changes (for example when their view on the sea is lost). Next, some houses may need to be removed in order to realize one of the proposed coastal management strategies. These houses will be rebuild at another location, but meanwhile the additional value of living at the sea is lost.

Concerning agriculture, some agricultural areas may be lost when space is needed landward of the existing coastal defences in order to realize a new coastal management strategy. The same is true for inland agricultural areas when houses removed from the coastal zone are rebuilt at inland locations. It should be noted that especially the greenhouses in the southern part of the study area are very valuable. For convenience, the value of greenhouses is applied to all kinds of industries that may be affected by a new coastal management strategy.

The costs and benefits of all impacts on man-made functions are summarized over the entire period and are translated into a discounted value for the year 2008.

Equity

The equity criterion is meant to assess the spatial distribution of the impacts of a coastal management strategy over the study area. The main question is whether both negative and positive impacts are equally or at least fairly distributed over the study area. When positive and negative impacts are not equally distributed over the area, both costs and benefits should at least emerge at the same locations so that those areas and people that are affected by the negative impacts will also benefit from the positive effects.

Sometimes, equity is also interpreted as intergenerational equity indicating the equal distribution of costs over subsequent generations. This however coincides with the ability to develop a strategy in several phases being spread over time and will be indicated by the criterion of phasing.

Safety perception
All measures are designed to serve the goal of preserving a 1:100,000 safety level of the study area protected by the sea defences. However, this technical approach of the protection of the hinterland is only weakly related to the perceived safety by the inhabitants of the hinterland.

Many studies are available on risk perception, also related to floods. Most determinants found of interest for risk perception however are not related to the sea (or river) defences themselves (the safety component). Examples of determinants for risk perception are: perceived personal risk, fear evoked by the risk, familiarity to those exposed, likelihood of fatal consequences, frequency and also (although to a lesser extent) demographic variables like age and education level [Plapp & Werner, 2006]. At first sight, risk perception thus seems to be more or less independent from the water retaining structures itself. However, these structures are supposed to be important for the perceived personal risk. People have to trust the coastal defences in order to feel safe living behind that defences.

It is difficult to derive valid indicators for this criterion. A separate psychological study could be done in order to find out what really matters in perceived safety levels of coastal defences. For this study, it is supposed that the extensiveness of the measure is a rather good indicator. The larger the dimensions of a protecting structure, the safer people would generally feel. It is also supposed that people’s perception of the safety of a measure is determined by the (scientific) knowledge available on the effectiveness and endurance of a certain measure. Of course, this knowledge should then be communicated effectively to the inhabitants of the hinterland. Although this comes very close to the robustness criterion, these two indicators are applied for determining the perceived safety of the proposed strategies.

Intrinsic value of nature
The only non-welfare impact that will be considered in this study is the intrinsic value of nature. As explained before, intrinsic values represent the welfare of flora and fauna instead of the welfare of humanity. Three indicators are applied to derive the impacts of the proposed strategies on the welfare of the flora and fauna in the coastal region: the amount of nature area gained (or lost); the possibility to create ecological links between different nature areas; and the impact on those areas presently being protected by national or European legislation (e.g. the Birds and Habitat Directive and the Ecological Main Framework). Some more information on these indicators is included in appendix O.3. Finally, one qualitative assessment is derived from these three indicators for the effect on the intrinsic value of nature.

Technical complexity
This criterion is meant to indicate feasibility of realizing a certain coastal management strategy, or the components of that strategy. Technical complexity is related to the knowledge available for designing a strategy and the facilities available for constructing it. When knowledge and/or facilities are lacking, it would be rather complex to realize a management strategy. Technical complexity of a strategy will also increase when more difficult connections have to be designed and constructed for transitions between different coastal enhancement solutions being part of a certain strategy (e.g. the connection between a dike and a dune).

Robustness
Two indicators represent the robustness of the strategies: the uncertainty about their effectiveness and the development over time; and the flexibility of a measure indicating its long-term sustainability.

The uncertainty of a strategy, or the components of a strategy, is derived from the degree to which it has proved to be effective in the past. This could be deduced from positive experiences in the past or from a clear (scientific) understanding of the mechanisms determining the effectiveness of the strategy. First, this is related to the knowledge on how and to what extent a certain measure impacts the failure modes and frequencies of the coastal defences. Second, this criterion is related to the knowledge on the evolution of an implemented measure through time caused by natural dynamics (water and wind). When knowledge on one or both of these aspects is insufficient, it will be uncertain whether the effectiveness of a proposed strategy is realistic and whether it will persist over time.

The flexibility of a strategy, or the components of a strategy, is derived from both its sustainability and its resilience. First, the sustainability component of this criterion tells us how well a measure could be extended when even worse conditions would be faced in the future. Second, the resilience of a measure indicates its self-restoring capabilities once it is damaged due to some natural impacts. In general, 'soft' engineering measures built with sand will be more capable to restore themselves and are better suited to be extended any further in the future than their 'hard' counterparts.

Phasing
This criterion is meant to give an indication on the suitability of a phased implementation of the proposed measures. When the implementation is realized at one longshore location after another (several stages in the longshore construction process), this would imply beneficial effects for the investment risk and the development of social acceptance. First, when the construction of a measure is divided into several phases, knowledge developed during one stage could be applied in the next phase. By doing so, the risk of making mistakes in both the design and the construction is reduced over time. This could cause an optimisation of the costs and benefits of a project. Moreover, a gradual implementation is generally better accepted by society than one enormous project emerging all at once. This is caused by the fact that a phase-wise implementation creates the opportunity to get used to the planned changes.

The possibility to implement coastal management strategies in several phases is limited by the morphological effects of the longshore differences coming into play when measures are only partly realised in the initial stages of project realization.

Governmental complexity
It can be found that governmental difficulties in realising one of the proposed measures should not influence the selection of the optimal strategy. The political framework is then supposed to change in order to facilitate the realization of the selected strategy, when necessary. This assumption might be true for a timeframe of 200 years.

However, large parts of the proposed strategies might need to be implemented rather soon or at least preparations for the implementation might need to be started rather soon. In this case, existing administrative structures will not have been changed significantly yet and complexities might occur. These complexities might come into play when several administrative levels (e.g. ministries and waterboards) should be incorporated and/or when several administrative bodies at an equal level (e.g. two provinces) should cooperate. How the interests of different administrative bodies are distributed in cross-shore direction is explained in section 1.3.1. How much governments should cooperate at the same level largely depends on the longshore extension of the measures of a strategy: the more elongated the longshore areas are where the same measure should be implemented, the more governmental bodies should be incorporated that are representing the same administrative level.

4.1.3 Aggregation
In order to reduce the amount of impact scores to be included in the MCA, all effects on the partial aspects (different indicators within one criterion) should be aggregated into overall criteria scores. For the sake of transparency, no weights are applied in this aggregation step. The application of weights appears to be not very useful in this step since there are no clear and objective reasons for making any differences in the significance of the contribution of the partial aspect scores in their related criteria scores.

The final step of the MCA consists of aggregating all impacts and characteristics of the proposed coastal management strategies for the criteria stated in Table 9. These strategies will all be assessed on these criteria. For those criteria where monetary impacts are inventoried quantitatively, these quantitative impacts should be translated first into a qualitative assessment. The scale of this qualitative assessment varies from -- (very negative) through -, 0 and + up to ++ (very positive). These qualitative scores are awarded by comparing the impact of a certain strategy to the impact of the stated basic alternative. The conditions for awarding a certain qualitative score should be rather coarse, since the impact assessment will contain quite a lot uncertainties. A very positive score (++) for example, might be awarded when the costs of a certain strategy are about an order of magnitude lower than those of the basic alternative. The final conditions depend somewhat on the magnitudes of the impacts found.

At the same time, all qualitative criteria will also be assessed in comparison to the impacts of the basic alternative and on the same scale varying from -- to ++. So in the end, the proposed coastal management strategies will be assessed on all criteria according to the same assessment scale and in comparison to the basic alternative.

The final step in the assessment process of the MCA is aggregating these criteria scores into a final assessment. This aggregation asks for a set of weights to be applied to the criteria. These weights should represent the relative importance of the different criteria and are therefore dependent of the policy view that is pursued. These policy views and the connected weights for the criteria are presented in section 4.4. The final score of each coastal management strategy is calculated through weighted summation of the criteria scores.

4.2 Assessment of coastal management strategies

The potential impacts of the proposed coastal management strategies have been studied. This research is included in appendix O. The results of this research are summarized in this section. It starts with the initial impact assessment containing both quantitative and qualitative assessments. Then all impacts are translated into qualitative impacts in comparison to the basic alternative, being the small scale strategy. A short discussion ends this section.

4.2.1 Impact assessments

Initially, the coastal management strategies defined for the upper climate change scenario will be assessed. A number of criteria has been derived for this assessment in section 4.1 of this study. A separation is made between those criteria that could be assessed on a quantitative scale and those criteria that could only be assessed qualitatively.

For those criteria for which the impacts could be calculated, net present values of benefits and losses are calculated by applying some general indicators (e.g. gain of dune area and loss of housing area) and multiplying them by the authorized values presented in appendix N.

The impacts on the remaining criteria could only be inventoried in a qualitative sense. Therefore the potential impacts are described and translated into a score on an assessment scale with five levels ranging from -- to ++. These scores should be interpreted as:

++	=	positive effect	better
+	=	slightly positive effect	good
0	=	neutral effect	sufficient
-	=	slightly negative effect	bad
--	=	negative effect	worse

Extensive descriptions of all calculations and descriptions for assessing the proposed coastal management strategies are included in appendix O. Table 10 summarizes the results of these impact assessments.

Table 10: Summary of the results of the impact assessments of the proposed coastal management strategies and the basic alternative.

Criterion	Uniform coast; islands	Uniform coast; sandbanks	Uniform coast; dunes in front of existing dunes	Large scale; islands and dunes	Large scale; dunes and sandbanks	Intermediate scale; seaward	Intermediate scale; landward	Small scale; basic alternative
Costs								
Construction costs; NPV[1] 2008 [*10^6 €]	9800	140	470	7300	320	860	720	410
Maintenance costs; NPV 2008 [*10^9 €]	19.8	3.0/1.3[2]	0.8	14.5	1.8/1.0[2]	1.4	1.0	1.3
Welfare impacts								
Nature values								
- Environment & recreation; NPV 2008 [*10^6 €]	389	7.7	223	408	131	58	8.6	22
- Water supply; NPV 2008 [*10^6 €]	3.7	0	13	12	7.1	3.4	0.2	0.7
Safety benefits; annual benefit by 2200 [*10^6 €]	84	56	109	90	97	62	49	73
Man-made functions								
- Housing; NPV 2008 [*10^6 €]	282	0	-184	138	-143	-39	-3.5	-14
- Agriculture; NPV 2008 [*10^6 €]	892	0	0	648	0	0	-11	0
Equity	++	-/0	--	+	--	++	-	+
Safety perception	+	--	++	+	0	0	+	0
Non-welfare impacts								
Intrinsic value of nature								
- Area [ha]	2300	1000	2300	2300	1700	1100	500	500
- Links	0	0	++	+	+	+	+	0
- Protected areas	-	-	0	0	-	0	--	0
Other criteria								
Technical complexity	++	++	++	++	++	+	+	0
Robustness								
- Uncertainty	-	--	++	+	0	0	+	0
- Flexibility	--	-	++	0	+	0	0	-
Phasing	++	-	-	0	-	-	++	0
Governmental complexity	+	+	-	0	-	0	-	0

[1] NPV = Net Present Value

[2] The maintenance requirements of sandbanks are rather uncertain since it is uncertain whether coastal morphology will develop into a new stable state. If this would be true, the lower values are valid. If the sandbanks appear to be rather unstable, maintenance requirements might increase enormously resulting in the higher estimates.

4.2.2 Qualitative overview

Finally, all qualitative and quantitative assessments are compared to the impacts of the basic alternative. This is done for two reasons. First, this comparative assessing is common practice and is stated in the directive for assessing different alternatives in infrastructure projects [Spit e.a., 2008]. In this directive, the basic or reference alternative is interpreted as a combination of the autonomous development and present policy practice. This is exactly what our small scale strategy is supposed to be. Second, weighting methods like interval standardization or vector normalization [Pouwels, 1995] in order to translate those quantitative assessments to a scale ranging from –2 to 2 are improper in this case. This is due to the fact that one or more of the strategies have rather large impacts at each of the criteria, making the difference between the impacts of the other strategies irrelevant. This loss of nuance in the final qualitative assessments could be avoided by this comparative method.

When all qualitative and quantitative assessments are compared to the basic alternative, they are accordingly translated to a scale of -- to ++. Negative assessments state that the concerning strategy has a slightly more negative (-) or much more negative (--) impact than the basic alternative. Positive assessments imply that the strategy concerned has a slightly more positive (+) or much more positive (++) impact than the basic alternative. Neutral (0) assessments indicate that the effects of the strategy are comparable to those of the basic alternative.

In case of the criteria assessed in a quantitative way, this translation to qualitative scores is based on some assumptions on the relevance of the ratio to the basic alternative. For the construction and maintenance costs for example, this transition was done according to the following principles:

- NPV strategy X > 10x NPV basic alternative: -- (costs are an order of magnitude higher)
- NPV strategy X > 2x NPV basic alternative: - (costs are doubled)
- NPV strategy X < 2x NPV basic alternative & NPV strategy X > 0.5x NPV basic alternative: 0
- NPV strategy X < 0.5x NPV basic alternative: + (costs are halved)
- NPV strategy X < 0.1x NPV basic alternative: ++ (costs are an order of magnitude lower)

These criteria are rather subjective, however they give a clear insight into the relation of the construction costs of the different strategies to those of the basic alternative. For all other criteria assessed quantitatively at first, similar rules are derived for translating the quantitative impacts into qualitative assessments.

For all criteria, these qualitative assessments that compare the different strategies to the basic alternative are derived in appendix O. Table 11 summarizes the results and since all impacts are assessed on the same scale now, a total assessment can also be derived. These final assessments, based on equal weights for all criteria, are presented in the lower row of Table 11. These scores are found by just adding all scores for every single strategy.

Table 11: Summary of the results of the impact assessments of the proposed coastal management strategies and the basic alternative. All strategies are assessed in comparison to the basic alternative. The final row of this table presents the total assessment of the different strategies based on equal weights for all criteria.

Criterion	Uniform coast; islands	Uniform coast; sandbanks	Uniform coast; dunes in front of existing dunes	Large scale; islands and dunes	Large scale; dunes and sandbanks	Intermediate scale; seaward	Intermediate scale; landward	Small scale; basic alternative
Costs								
Construction costs	--	+	0	--	0	-	0	0
Maintenance costs	--	0	0	--	0	0	0	0
Welfare impacts								
Nature values	++	-	++	++	+	+	-	0
Safety benefits	0[1]	0	0	0	0	0	0	0
Man-made functions	++	0	--	++	--	-	0	0
Equity	++	-	--	0	--	+	--	0
Safety perception	+	--	++	+	0	0	+	0
Non-welfare impacts								
Intrinsic value of nature	0	0	+	+	0	+	0	0
Other criteria								
Technical complexity	++	++	++	++	++	+	+	0
Robustness	--	--	++	+	+	+	+	0
Phasing	++	-	-	0	-	-	++	0
Governmental complexity	+	+	-	0	-	0	-	0
Total assessment	+6	-3	+3	+5	-2	+2	+1	0

[1] The values calculated for the safety benefits of the strategies show rather small differences concerning the uncertainty of the underlying calculations. Therefore no differences are found in these qualitative scores. Since this will change for other situations, this criterion is not left out of the analysis.

4.2.3 Discussion

From these preliminary results following from Table 11, it follows that two to three strategies are assessed significantly better than the basic alternative: the uniform coast strategies with islands and with foredunes and the large scale combination of islands and foredunes. These three strategies all perform better than the basic alternative considering the nature values criterion and their technical complexity.

Furthermore, the uniform coast strategy comprising of sandbanks is assessed somewhat negative compared to the basic alternative. The remaining strategies are overall comparable to the basic alternative. However, for specific criteria the assessment might show some large deviations from the basic alternative. More attention is given to these differences in section 4.4 of this chapter, where different policy outlooks are applied to the assessment. These views based on these policy outlooks are specifically related to several criteria, giving them higher weights and neglecting the other criteria. This will introduce more differences within the total scores of the strategies and other rankings might emerge.

4.3 Impact of less extreme climate change

The coastal management strategies designed in the previous chapter and assessed in the previous sections are based on the specific requirements in case the upper climate change scenario would come true. However, this is the worst case scenario and there are two less severe scenarios defined in section 2.1.2 that might also come true. In section 2.6 it was shown that the reduction of the expected climate changes causes less and shorter longshore coastal sections to be assessed insufficient by the year 2200. Moreover, the reduction of the climate changes implies a reduction of the boundary conditions (e.g. water level) and therefore those sections that are still assessed insufficient would require less extensive measures than in case the upper climate change scenario would come true.

The question is whether reducing the boundary conditions for the coastal management strategies would change the assessment results and the final ranking of the strategies.

In order to answer this question, the coastal management strategies are adjusted to the less extreme requirements of the lower climate change scenario (see section 2.1.2). For the small scale and intermediate scale strategies, this means that at some of the longshore sections no measures have to be taken anymore since the existing coastal defences will be sufficiently safe for the next 200 years. On the other hand, the large scale and uniform coast strategies are not supposed to be changed in longshore direction due to the fact that some longer sections of the mainland coast would not need their presence. A local application of the measures of these strategies at those locations still being assessed insufficient is not considered since this would create some new intermediate scale alternatives that are not considered in this study. Moreover, this would introduce the negative side-effects of the strategies designed at smaller spatial scales to these strategies designed for larger spatial scales (e.g. increasing maintenance, less new nature).

Next to the longshore characteristics of the different strategies, the dimensions of the measures themselves are also changed. Since no time was available to thoroughly study the required dimensions of the different measures under the lowest climate change scenario, some assumptions are made on the impacts on the required heights and volumes (see appendix P).

Based on these findings, the assessment of the strategies is repeated. How this is done is included in appendix P. In Table 12 below, the comparative results of these new assessments are summarized. This table also indicates which scores have been changed due to the adjustments for the lower climate change scenario and whether these changes are positive or negative.

Table 12: Summary of the results of the impact assessments of the proposed coastal management strategies and the basic alternative for the lower climate change scenario. All strategies are assessed in comparison to the basic alternative. The effects marked in green have been changed positively compared to the effects of the strategies designed for the higher climate change scenario, those that are marked red have been changed negatively.

Criterion	Uniform coast; islands	Uniform coast; sandbanks	Uniform coast; dunes in front of existing dunes	Large scale; islands and dunes	Large scale; dunes and sandbanks	Intermediate scale; seaward	Intermediate scale; landward	Small scale; basic alternative
Costs								
Construction costs	--[1]	0	0	--[1]	0	-	0	0
Maintenance costs	--	0	0	--	0	0	0	0
Welfare impacts								
Nature values	++	0	++	++	++	+	0	0
Safety benefits	0	0	+	0	0	0	0	0
Man-made functions	++	0	--	++	--	-	0	0
Equity	++	-	--	0	--	0	-	0
Safety perception	+	--	++	+	0	0	+	0
Non-welfare impacts								
Intrinsic value of nature	0	0	+	+	+	0	0	0
Other criteria								
Technical complexity	++	++	++	++	++	+	+	0
Robustness	--	--	++	+	+	+	+	0
Phasing	++	-	-	0	-	-	++	0
Governmental complexity	+	+	-	0	-	0	-	0
Total assessment	+6	-3	+4	+5	0	0	+3	0

[1] It should be noted that although the comparative scores of these strategies on the construction costs criterion do not change, the ratios of their construction costs to the costs of the basic alternative are about three times higher than the same ratios found for the highest climate change scenario.

When the coastal management strategies are ranked according to the (non-weighted) results of both the previous and this new assessment, preferences are changing somewhat as follows from Table 13. However, both rankings show some common characteristics:

- Sandbanks are assessed worst for both scenarios. This is due to the uncertainties on the development of these features and the insignificant addition to spatial quality.
- The other uniform and large scale strategies not comprising sandbanks, are in both cases assessed very positive.
- The ranking of the basic alternative, being the representative of present coastal management policies, is rather low in both cases.
- The intermediate scale strategies, both landward and seaward, are ranked higher than (or equal to) the basic alternative in both cases.

However, we are not ready yet to draw some final conclusions from these results, since different sets of weights according to different (political) interests, might change the preferences found by just adding all assessment results with equal weights for all impacts. This is what is done in the next section.

Table 13: Rankings of the proposed coastal management strategies for both the upper and the lower climate change scenarios, based on equal weights for all criteria included in the impact assessment. The total scores from the assessments are indicated by [#].

Ranking for highest climate change scenario	Ranking for lowest climate change scenario
Uniform coast; islands [6]	Uniform coast; islands [6]
Large scale; islands and dunes [5]	Large scale; islands and dunes [5]
Uniform coast; dunes in front of existing dunes [3]	Uniform coast; dunes in front of existing dunes [4]
Intermediate scale; seaward [2]	Intermediate scale; landward [3]
Intermediate scale; landward [1]	Large scale; dunes and sandbanks [0]
Small scale; basic alternative [0]	Intermediate scale; seaward [0]
Large scale; dunes and sandbanks [-2]	Small scale; basic alternative [0]
Uniform coast; sandbanks [-3]	Uniform coast; sandbanks [-3]

4.4 Resulting assessments for different policy views

The assessments of the coastal management strategies on all criteria should be added now. However, defining weights for a set of criteria is often very subjective so this study will not present the ultimate weights to be applied. On the contrary, several sets of weights will be applied, each representing a different policy strategy. Each of these strategies represents a different view on what criteria should be important and which should be less important in assessing new plans. By applying these different views, it is tried to overcome the inherent subjectivity in awarding these weights. When the results of the assessments according to these different views still show more or less resemblance, it might be supposed that the impact of this subjectivity is limited.

This section starts with describing some potential policy views and the sets of weights related to these strategies. Next, the results of applying these views to the assessments are presented and discussed.

4.4.1 Policy views & weights for criteria

For this study, six views are applied in order to find out what differences occur in the ranking of the proposed strategies if a certain policy strategy would be adhered. Short descriptions on these views and their weights awarded to the selection criteria are given below. Total weights of all views add up to twelve for an easy comparison of the assessment results.

Non-weighted

From this point of view, all criteria for which the impacts of the coastal management strategies are defined are equally important. This view is applied to gain some first, neutral insights in the ranking of the strategies based on all assessment results. Although this way of ranking might be neutral, it is far from reality where different interests cause the weights of the criteria to be changed. This view resembles the calculation of the total scores in the previous two sections where equal weights are assumed.

Leading criteria

This view concentrates at established criteria while less established societal impacts are neglected. Technical and governmental complexities are also left out of this assessment since they are supposed to be solved for this very important issue of maintaining coastal safety. This assumption is even more realistic due to the rather long period of this project's scope. Finally, safety benefits are not included in this strategy since there are no large differences in the assessments on this criterion.

It is assumed that this strategy mainly concentrates on the existing criteria for assessing infrastructure projects (see Table 14). The weights of these criteria are supposed to be two times higher than the weights of criteria concerning long-term developments; the robustness of the strategy and the potential for a phased implementation. The remaining criteria are supposed to be of minor interest from this point of view and zero weights are awarded to them.

Spatial development view

From a spatial development point of view, it is interesting to select strategies that enable the extension of both nature areas (for positive effects of nature and for recreation) and areas available for man-made functions. The expected impacts on these criteria are most significant for this strategy (see Table 14). The intrinsic value of nature is also important within spatial development and is given a weight slightly lower than the two criteria mentioned before. Next to these main points, costs and other benefits are also supposed to be of interest within this strategy together with the possibility to realize a strategy in several phases. The remaining criteria (equity, safety perception, technical complexity, robustness and governmental complexity) are supposed to be of minor interest for this spatial development view and are therefore neglected.

Risk averting view

This strategy aims at reducing the financial risk incurred when a certain strategy will be selected for enhancing the coastal defences. Construction costs and maintenance costs are at the heart of this strategy with some more weight for the construction costs since for the total timeframe of this study they add up to a value that is an order of magnitude higher than the construction costs.

Phasing and robustness are as important as the costs. When a strategy can be realized in several phases, financial risks surrounding the implementation might be spread and reduced. This reduction could be caused by a learning process that goes along with the development and construction of the first phases, and when this knowledge is subsequently applied in the next phases. Moreover, robust measures are better tuned to long-term developments and prevent for the emergence of large future investments.

Moreover, positive characteristics on technical and governmental complexities of the proposed projects are favoured within this view. Complexities on these issues might increase the duration of the projects resulting in higher costs. Welfare and non-welfare impacts are assumed to be less important from this point of view and are therefore not included in this view. The distribution of the weights according to this view is presented in Table 14.

Socially acceptable view

This strategy creates more attention to social issues related to the enhancement of the coastal defences. Three criteria are of main interest from this point of view: equity, safety perception and costs. Good results on the equity criterion imply that both positive and negative effects are equally distributed among those people living in areas affected by these measures. At the same time, from a societal view it is important that people feel safe, resulting in a higher weight for the safety perception criterion. Many times, the costs of proposed projects are also of significant influence on the societal perception of a project and since maintenance induces the most costs this criterion is also valued with a higher weight. Construction costs are valued with a lower weight.

Next to these criteria, impacts on nature (both on its use for mankind as on its intrinsic value) and man-made functions and the safety in coastal towns will also be important for the social acceptability of the proposed strategies. However, these criteria are supposed to be somewhat less important within this strategy.

Finally, phasing might also improve the social acceptance of a coastal management strategy since a phased realization of a project facilitates the possibility for the people to get used to a new feature in the coastal landscape.

Technical and governmental matters are supposed to be irrelevant for the social acceptability of coastal management plans. The exact weights of this strategy are presented in Table 14.

Sustainable view

A sustainable viewpoint would concentrate on intrinsic nature values and the long-term efficiency of a coastal management strategy. The first point of attention results in a rather large weight for the same criterion. The long-term efficiency is derived from both the robustness and the maintenance costs of the strategies proposed. Robustness indicates whether a stable morphologic situation might occur in the future and whether the measure could easily be tuned to developing insights into the real impacts of climate change. Maintenance costs on the other side concern the financial impacts on the long-term caused by the maintenance requirements of the proposed strategies.

Of less importance, but still interesting from a sustainable point of view is the chance to benefit from nature values that could be developed by these coastal enhancement strategies. It is also interesting whether the realization of a measure can be phased, since this would also increase the possibility to tune (part of) the plans to new insights (e.g. on climate changes and mode of construction) developed over time. The remaining criteria are supposed to be of minor interest from this sustainable viewpoint since they are mainly related to short-term impacts and characteristics of the proposed measures (e.g. construction costs and technical complexity).

Table 14: Sets of weights for the criteria of the impact assessment according to different (policy) strategies.

Criterion	Non-weighted	Leading criteria	Spatial development view	Risk averting view (financial)	Socially acceptable view	Sustainable view
Construction costs	1	2	1	2	1	
Maintenance costs	1	2	1	3	2	3
Nature values	1	2	3		1	1
Safety benefits	1		1		1	
Man-made functions	1	2	3		1	
Equity	1				2	
Safety perception	1				2	
Intrinsic value of nature	1	2	2		1	3
Technical complexity	1			1		
Robustness	1	1		2		4
Phasing	1	1	1	3	1	1
Governmental complexity	1			1		

4.4.2 Assessment results for different policy views

The weights that are determined above are now applied to the impact assessments of the coastal management strategies for both the highest and the lowest climate change scenario. For each of the views, a total score of every strategy can be calculated. These values are presented in Figure 28 for the highest climate change scenario and Figure 29 for the lowest counterpart. Keep in mind that these scores are all derived in comparison to the basic alternative, so a positive score indicates a benefit over the basic alternative (and the other way round). A separate table showing the ranking of the different strategies from every point of view is included in appendix Q.

Some essential points following from these results are discussed here. General discussion and conclusions follow after the results of a sensitivity analysis of these assessments are presented in the next section.

First, it follows from this figure that the proposed strategies are significantly differing from each other since the results of the assessments are highly variable for the different policy views. Next, it is assumed that assessments resulting in only one or two points (positive or negative) in Figure 28 are too marginal to indicate any significant benefits or disadvantages in comparison to the basic alternative (always assessed neutral).

In case the strategies are designed for the highest climate change scenario (and this scenario would come true), it follows from the assessment results that the uniform coast strategy existing of new foredunes is preferred over the other strategies. This alternative is assessed better than, or equal to, the basic alternative on all views while other strategies are sometimes assessed worse than the basic alternative. Especially from a sustainable viewpoint, this measure scores very well. This is mainly caused by the robustness of these new dunes that will cause a new morphologic equilibrium situation to be established.

The uniform coast strategy with new sandbanks in front of the existing dunes scores negative from all viewpoints. Major negative impacts are found on social acceptance and on sustainability. It is very uncertain whether sandbanks will create a new morphologic equilibrium (if not, then maintenance requirements will be immense) and whether their effectiveness in reducing wave attack at the mainland coast is sufficient. This translates into very negative assessments on the perceived safety and robustness criteria.

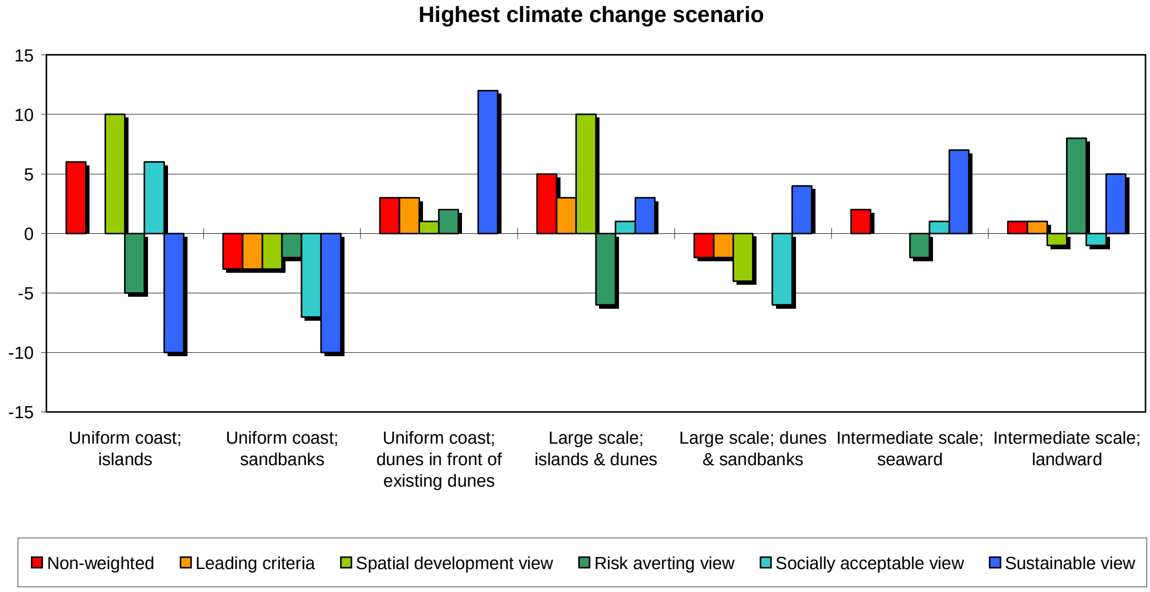


Figure 28: Overview of the total assessment scores of each of the proposed coastal management strategies for the highest climate change scenario. Total scores are calculated for several views, representing different interests. The basic alternative is not included since its total score is always 0.

The assessment of the uniform coast strategy with islands depends largely on the view applied in the assessment. Islands create great opportunities for spatial developments and are socially acceptable since people presently living in the coastal region are not affected; they might even benefit from the new island. On the other hand, the sustainability and financial risk aversion of this strategy are negative assessed due to lacking robustness and relatively high maintenance costs. The robustness of the islands is low since it is both uncertain whether their presence will improve the safety of the mainland coast sufficiently and since it will be difficult to change this island once it is constructed and used (it is inflexible). Maintenance costs in case of new islands are also rather large since both the coast of the islands and the mainland coast should be maintained by then.

The assessments of both large scale strategies clearly show that some positive and negative impacts of the components of these measures (being copied from the uniform coast strategies) are combined. The large scale variant containing an island in front of the Zuid-Holland coast is very well assessed from a spatial planning view and negative from a risk averting view, just like the uniform coast counterpart.

Concerning its sustainability, the positive characteristics of the foredunes and the negative impacts of the island almost neutralize each other.

The large scale strategy containing sandbanks in front of the Noord-Holland coast shows a major influence of the negative assessments of the sandbanks when compared to the assessment results of the uniform coast strategies with sandbanks and with foredunes.

The intermediate scale strategies show only minor differences from the basic alternative for the majority of the assessment views. Remarkable is the increased sustainability of both the seaward and landward strategies and the positive score of the landward strategy on risk aversion.

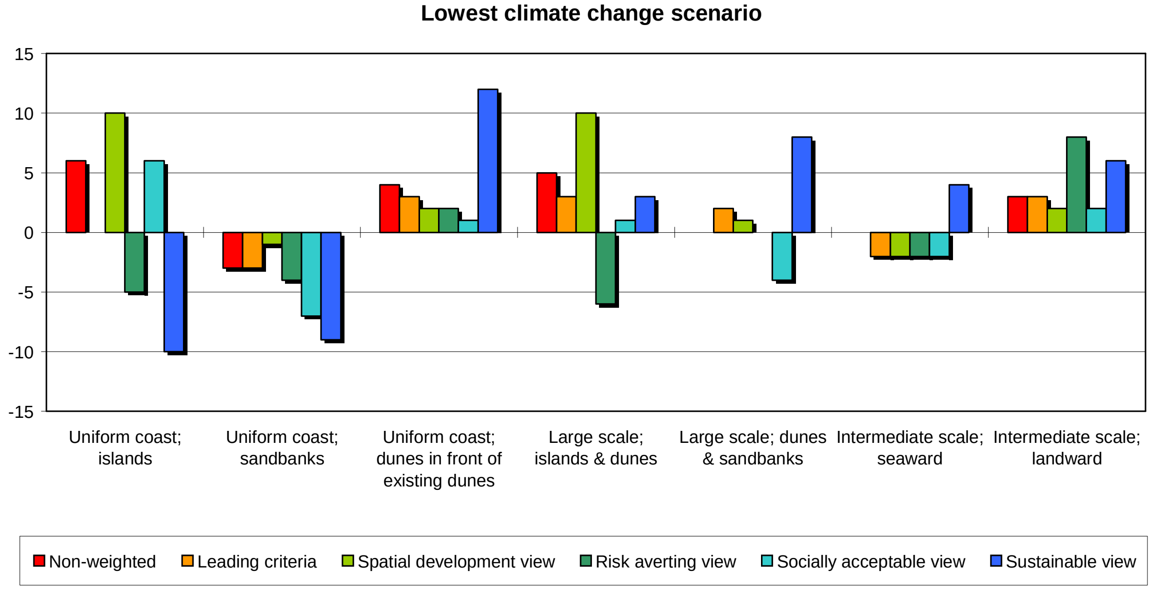


Figure 29: Overview of the total assessment scores of each of the proposed coastal management strategies for the lowest climate change scenario. Total scores are calculated for several views, representing different interests. Note that the basic alternative always scores 0.

When the same assessment is repeated for the impacts of the strategies as they are proposed for the lower climate change scenario, some minor changes occur as follows from Figure 29. Especially the assessments of the intermediate scale strategies show some sign changes of the relative small assessment scores. However, the more extreme assessments (peaks in the plots) remain the same.

The uniform coast strategy with new foredunes in front of the existing foredunes is slightly better assessed from most perspectives in this case. The intermediate scale landward strategy is now assessed positive on all views too.

In case of the lower climate change scenario, the large scale strategy containing dunes and sandbanks is assessed somewhat less negative. Negative assessments concerning the leading criteria and spatial development views in case of the higher scenario are now turned into positive assessments. The only strategy that is assessed worse for this lower scenario is the intermediate scale seaward strategy.

Altogether, it can be stated that in both cases several of the proposed strategies show positive characteristics compared to the basic alternative for all or at least for some of the applied assessment perspectives. Concerning the basic alternative itself, it is remarkable that it is ranked highest for the leading criteria and risk averting views (see appendix Q for the rankings resulting from these assessments). Apparently, these two perspectives are the best descriptors for our present coastal management practice. This indicates that present policy for coastal management mainly emphasizes on construction and maintenance costs and the possibility for planning the realization of the measures in different phases.

4.5 Sensitivity analysis

To analyse the sensitivity of the rankings of the coastal management strategies that are found in the previous section, a sensitivity analysis is applied to the assessment of the strategies designed for the higher and lower climate change scenarios. This analysis starts with an inventory of the uncertainties contained within the impact assessments of the coastal management strategies. The Excel application @RISK is applied to investigate the impacts these uncertainties have on the final assessments of the strategies. The method that is applied in this section for coping with uncertainties quite well resembles the approach of Van der Kleij e.a. [2003]. They compare alternatives for a possible airport island location in the North Sea based on uncertain information on the theme marine ecology and morphology.

4.5.1 Defining uncertainties

For some of the criteria applied in this study, the qualitative assessments are derived from calculated values of costs or benefits. These criteria are: construction costs, maintenance costs, nature values, safety benefits and man-made functions (and to a lesser extent the intrinsic value of nature). The calculations being the basis for the assessments on these criteria are rather crude and contain many uncertainties. Examples of uncertainties are the unit prizes applied, the estimated dimensions of the constructions and the year of realization (having a large impact on the net present values).

For all these calculated net present values of costs and benefits (and plain values in case of safety benefits), it is supposed that the real values could deviate from the calculated values by a factor 2. No higher factor is applied since the calculations at the basis of these assessments are assumed to be not that uncertain. Subsequently, the costs and benefits of all strategies for the higher and the lower climate change scenarios are increased and decreased one by one for every criterion. Every time the resulting qualitative assessments are derived by applying the same translation criteria as those that were applied in the initial assessment. Table 15 contains a summary of the potential assessments that were found in these uncertainty analyses of all strategies for the highest climate change scenario and for the concerned criteria. Table 16 contains the same results for the lowest climate change scenario.

Table 15: Results of an uncertainty analysis of the potential qualitative assessments of the strategies for the higher climate change scenario on these criteria for which the assessments are supposed to be uncertain.

Strategy	Construction costs	Maintenance costs	Nature values	Safety benefits	Man-made functions
Uniform coast; islands	-- / -	-- / -	+ / ++	- / 0 / +	++
Uniform coast; sandbanks	0 / + / ++	- / 0	-- / - / 0	-- / - / 0 / +	0
Uniform coast; dunes in front of existing dunes	- / 0 / +	- / 0 / +	+ / ++	- / 0 / + / ++	-- / -
Large scale; islands and dunes	-- / -	-- / -	+ / ++	- / 0 / +	++
Large scale; dunes and sandbanks	- / 0 / +	- / 0 / +	0 / + / ++	- / 0 / + / ++	-- / -
Intermediate scale; seaward	- / 0	- / 0 / +	0 / + / ++	- / 0 / +	-- / - / 0
Intermediate scale; landward	- / 0 / +	- / 0 / +	-- / - / 0	-- / - / 0 / +	- / 0
Small scale; basic alternative	0	0	0	0	0

Table 16: Results of an uncertainty analysis of the potential qualitative assessments of the strategies for the lower climate change scenario on these criteria for which the assessments are supposed to be uncertain.

Strategy	Construction costs	Maintenance costs	Nature values	Safety benefits	Man-made functions
Uniform coast; islands	--	-- / -	++	- / 0 / + / ++	++
Uniform coast; sandbanks	- / 0 / +	- / 0	- / 0 / +	- / 0 / +	0
Uniform coast; dunes in front of existing dunes	- / 0 / +	- / 0 / +	+ / ++	0 / + / ++	--
Large scale; islands and dunes	--	-- / -	++	- / 0 / + / ++	++
Large scale; dunes and sandbanks	- / 0 / +	- / 0 / +	+ / ++	- / 0 / + / ++	-- / -
Intermediate scale; seaward	- / 0	- / 0 / +	0 / + / ++	-- / - / 0 / +	-- / - / 0
Intermediate scale; landward	- / 0 / +	- / 0 / +	- / 0 / +	- / 0 / +	- / 0
Small scale; basic alternative	0	0	0	0	0

The assessments on the other criteria are related to main principles and characteristics of the concerned strategies (e.g. safety perception and robustness). Since these characteristics are rather well known, it is supposed that these assessments do not contain significant uncertainties.

Probabilities should be awarded to the uncertain outcomes of the qualitative assessments as they are presented in Table 15 and Table 16. The quantitative calculations backing these qualitative statements are rather uncertain and the stated deviations with a factor 2 are quite well possible. Therefore, equal chances are awarded to the potential outcomes of the qualitative assessments. So when two outcomes are possible for example, chances are 0.5:0.5 and when four outcomes are possible, every outcome has a probability of occurrence of 0.25. These discrete probability distributions depart from the continuous distributions that are applied by Van der Kleij e.a. [2003].

Finally, it is supposed that changes in these assessments are completely independent of each other. This assumption is correct since changes that will affect all quantitative assessments on one criterion (like a changing price of sand nourishments) do not have any impacts on the qualitative assessments. This insensitivity of the qualitative assessments is caused by the facts that all assessments are derived in comparison to the basic alternative. So when a certain input factor of the impact calculations changes, quantitative impacts would change accordingly and the ratios between these impacts will remain the same.

4.5.2 Sensitivity of the assessment outcomes

A random simulation should be applied in order to find out how the potentially differing assessments, all stated in Table 15 for the highest climate change scenario and in Table 16 for the lowest scenario, will influence the assessment results. During this simulation, all uncertain impact assessments should be changed randomly according to their ranges identified in the previous sub-section. This will cause variations in the outcomes of the assessments of all strategies and for every single view for awarding weights to the criteria.

This random calculation process is executed by applying a special Excel tool for sensitivity and uncertainty analyses: @RISK. This model is also applied by Van der Kleij e.a. [2005]. Within this model discrete distributions are defined for the different impact assessment according to the uncertainties stated in the previous sub-section. Subsequently, the model calculates 5000 iterations and for every iteration it randomly defines the assessments of the strategies within the stated uncertainty ranges through Latin Hypercube sampling. The results of this simulation are summarized in box plots showing the uncertainty ranges of the final scores of the proposed coastal management strategies for the highest and the lowest climate change scenarios. Figure 30 shows one of these plots. All box plots and some more information on this sensitivity analysis method are included in appendix R.

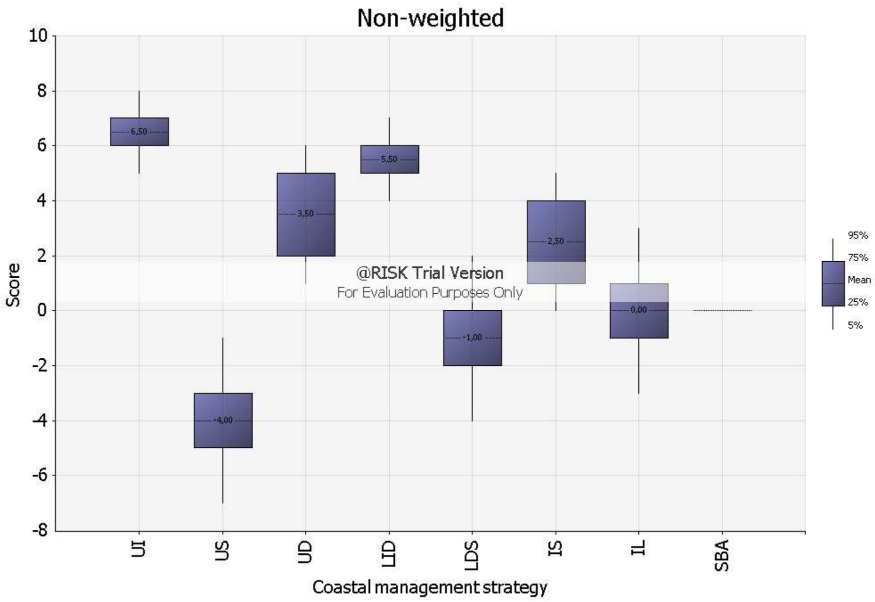


Figure 30: Resulting box plot of the sensitivity analysis of the total scores of the proposed coastal management strategies for the highest climate change scenario according to the non-weighted assessment perspective. Note: UI = Uniform coast; islands - US = Uniform coast; sandbanks - UD = Uniform coast; dunes in front of existing dunes - LID = Large scale; islands and dunes - LDS = Large scale; dunes and sandbanks - IS = Intermediate scale; seaward - IL = Intermediate scale; landward - SBA = Small scale; basic alternative.

The results of this sensitivity analysis indicate which strategies show significant advantages or disadvantages in comparison to the basic alternative. The average assessment scores that depart significantly from the basic alternative are summarized in Figure 31 for the highest climate change scenario and in Figure 32 for the lowest climate change scenario. An advantage is supposed to be significant if the probability of the assessment score of a certain strategy being lower than zero (the assessment of the basic alternative) is smaller than 5%. A significant disadvantage is assumed to occur if the probability of the total score of a certain strategy being higher than zero is smaller than 5%. The values of these probabilities are derived from the box plots presented in appendix R, as are the average values of the total scores of the coastal management strategies. Note that these average assessment scores found by the sensitivity analysis differ somewhat from the total assessment scores presented in Figure 28 and Figure 29 due to the applied variations in the impact assessments.

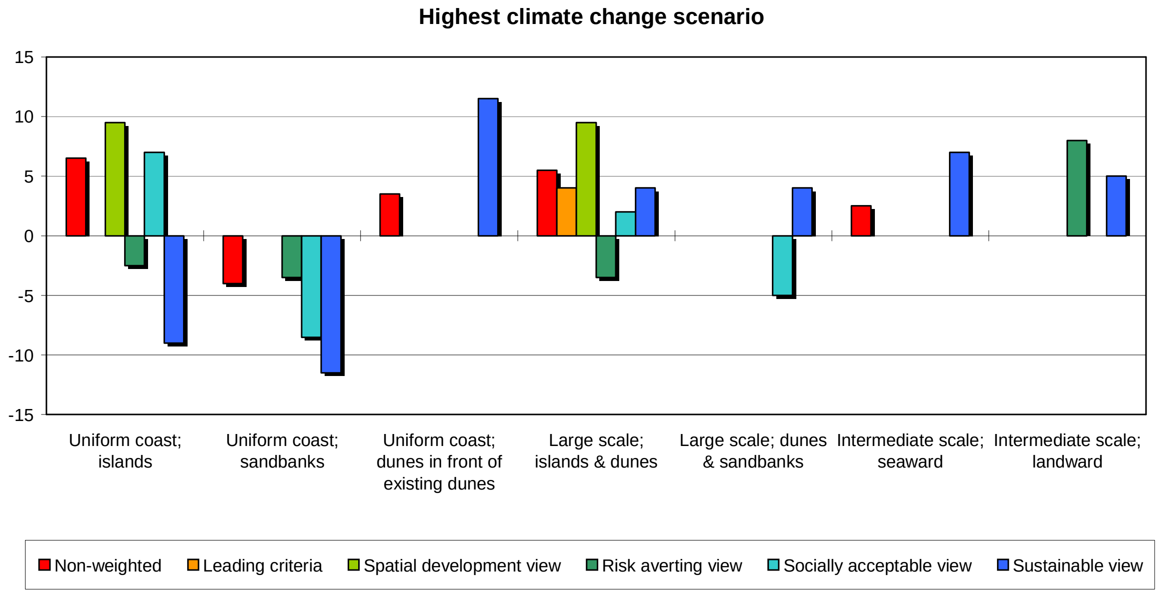


Figure 31: Overview of the average assessment scores for the highest climate change scenario. Only scores showing a significant difference in comparison to the score of the basic alternative (which is always zero) are included.

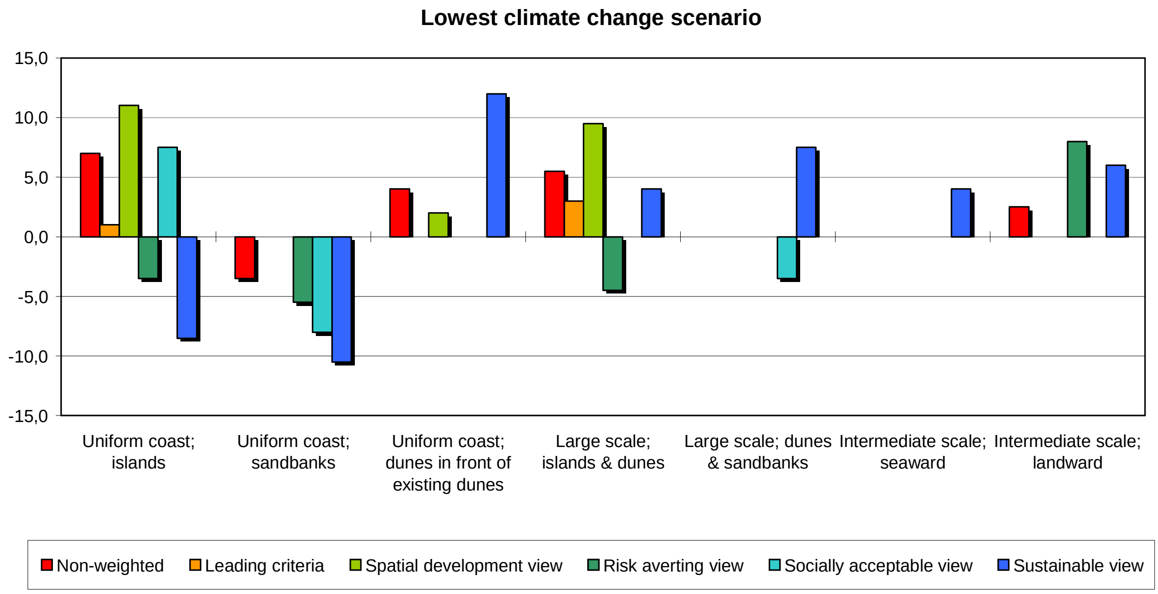


Figure 32: Overview of the average assessment scores for the lowest climate change scenario. Only scores showing a significant difference in comparison to the score of the basic alternative (which is always zero) are included.

The main conclusions derived from these figures and the box plots in appendix R, and thus the main conclusions of this sensitivity analysis, are summarized below:

- In general, the consequences of the coastal management strategies developed at larger spatial scales (both uniform and large scale strategies) seem to be more significant than the consequences of the intermediate scale strategies.
- For both the assessments without weights and the sustainable view, the final scores (and thus the ranking) of the coastal management strategies are least sensitive to the stated uncertainties in the impact assessments.
- On the contrary, final scores from a leading criteria perspective are most sensitive to these uncertainties and it is difficult and (almost) impossible to derive a stable ranking of the coastal management strategies for this view.

- Mean scores following from this sensitivity analysis, are not always the same as the total scores calculated without these uncertainties. This is due to the fact that the uncertainties do not always result in symmetric distributions of the uncertain impact assessments around their initial values.
- The uniform coast strategy with sandbanks still scores clearly worse than the basic alternative according to most views.
- In case no weights are applied, the uniform islands, uniform foredunes and large scale islands and foredunes score significantly better than the basic alternative for both climate change scenarios. The intermediate scale seaward strategy also scores significantly better than the basic alternative in case of the highest climate change scenario, but this advantage is becoming insignificant in case of the lower climate change scenario. For the intermediate landward strategy this is the other way round; this strategy shows only significant advantages in case of the lowest climate change scenario. For the large scale strategy with dunes and sandbanks, the probability is about 75% that it is assessed worse than the basic alternative for the highest scenario and still about 40% for the lowest scenario.
- From a leading criteria viewpoint, the large scale strategy with an island and new foredunes is assessed significantly better than the basic alternative for both scenarios. The uniform strategy with islands shows a probability of 95% to be assessed slightly better than (or equal to) the basic alternative in case of the lower climate change scenario, for the highest scenario it is assessed worse than the basic alternative for 25% of the iterations. The uniform foredunes strategy is still assessed better than the basic alternative for about 85% of the iterations for both climate scenarios. For the LDS, IS and IL strategies the final assessments are too uncertain and too close to the assessment of the basic alternative to conclude whether they should be preferred over the basic alternative or not.
- With a spatial development perspective, both strategies containing islands are assessed significantly better than all other strategies in these sensitivity analyses. In case of the lowest climate change scenario, this is also true for the uniform foredunes. In case of the highest climate change scenario, the probability is still 75% that the uniform foredunes strategy is assessed better than the basic alternative. For the LDS, IS and IL strategies, it is uncertain whether they score better or worse than the basic alternative from a spatial development point of view.
- The only strategy assessed significantly better than the basic alternative for the risk averting view is the intermediate scale landward strategy. For the uniform strategy with foredunes, still about 75% of the iterations is assessed better than the basic alternative for both climate change scenarios. Both the US and the LID strategies are assessed significantly worse than the basic alternative. The other strategies appear to have rather low chances (50% or less) to be assessed better than the basic alternative.
- With a socially acceptable view, the uniform islands strategy is significantly preferred over the basic alternative. To a lesser extent this is also true for the LID strategy. In case of the highest climate change scenario the new islands and foredunes are assessed significantly better than the basic alternative, but in case of the lowest scenario only about 85% of the iterations shows a better assessment than the basic alternative. The uniform strategy with new foredunes has more than 50% but less than 75% probability to be assessed better than the basic alternative for both climate change scenarios. About 75% of the assessments of the intermediate scale seaward strategy is positive for the highest scenario, but negative for the lowest scenario. For the intermediate scale landward strategy this is the other way round. So the IS and IL strategies are not assessed significantly better than the basic alternative. The US and LDS strategies are both assessed significantly worse than the basic alternative.
- From a sustainable perspective, the majority of the alternative strategies is still assessed significantly better than the basic alternative. This is valid for the UD, LID, LDS, IS and IL strategies. A positive highlight of this series is the uniform foredunes strategy, which is in general assessed better than all other strategies in the sensitivity analysis for this sustainability view. The uniform islands and uniform sandbanks strategies score very low from a sustainable point of view.

From this sensitivity analysis it is concluded that final assessment scores higher than 2 or smaller than –2 in the previous section (where no uncertainties were included) are in general sufficient for stating a significant advantage or disadvantage in comparison to the basic alternative. This sensitivity analysis shows that, in general, the inherent uncertainties within the assessments will not change the ranking of a strategy compared to the basic alternative (for a certain view) when the calculated total score of this strategy differs more than two points from 0. Almost the same is valid for the mean scores found when the uncertainty ranges of the impact assessments are included; when these are larger than 3 or smaller than -3 their ranking compared to the basic alternative is in general rather certain. So our preliminary assumption that assessments resulting in only one or two points (positive or negative) in Figure 28 are too marginal to indicate any significant benefits or disadvantages in comparison to the basic alternative (always assessed neutral) is proved to be right and sufficiently counts for uncertainties in the assessments.

A reason why this deviation only has to be rather small to result in a significant impact compared to the basic alternative, is that the final assessment of the basic alternative (0) does not contain any uncertainties. Uncertainties in the impacts of the basic alternative are translated to uncertainties in the qualitative impact assessments of the other strategies since these are derived by comparing the impacts of these strategies to the basic alternative.

When different strategies are compared to each other, larger differences in the (mean values of the) total scores are needed since the scores of both strategies show uncertainty ranges now. The final impact assessments of each of the strategies contain both the uncertainties of the impact of the strategy itself and of the impact of the basic alternative. When the calculated mean values of the scores of two arbitrary strategies deviate more than about 4 points from each other, then their ranking is rather certain. When the difference of the mean scores is smaller, the ranking might change due to the sensitivity of the final assessment to the uncertainties inherent in the impact assessments of the strategies. However, the assessments in this study are mainly meant to derive the ranking compared to the basic alternative.

4.6 Concluding

Some preliminary conclusions resulting from the findings of this chapter will be stated here, before discussing this research and its results in the next chapter.

From this study it can be concluded that the small scale basic alternative that resembles the continuation of the present coastal management policy is not the best strategy for managing coastal defences up to the year 2200. Other strategies might create better chances for enhancing the coastal defences and for managing its spatial impacts. The basic alternative is ranked relatively high on the risk averting and leading criteria views applied to the assessment. These views for coastal management mainly emphasize on construction and maintenance costs and the possibility for planning the realization of the measures in different phases, and this is quite well in line with present coastal management policy.

From other viewpoints, strategies with increased spatial scales are assessed better than this small scale basic alternative. For example the uniform coast strategy with two islands in front of the entire Holland coast and the large scale strategy with only one island in front of the Zuid-Holland coast are assessed much better from a spatial development point of view. Think of all space that would be created to relieve the ever-increasing infrastructural densities in the Randstad region. When sustainability is adhered, the uniform coast strategy inducing the creation of new foredunes in front of the existing ones should be preferred over the basic alternative. A new smooth coastline without seaward humps can create a new morphologic equilibrium and new nature will be created, increasing recreational facilities. On the other hand, a risk averting view mainly asks for a landward solution for its rather low maintenance costs and the possibility to split up the construction in many phases.

However, the intermediate scale coastal management strategies are developed at smaller spatial scales, inducing a larger longshore differentiation. The consequences of these strategies show less significant differences with the basic alternative than the consequences of the larger spatial scale strategies.

From the sensitivity analysis it was found that this assessment model for ranking coastal management strategies is rather stable as long as one looks at significant differences between the calculated scores. Significant differences are stated as a probability of 95% that a strategy is assessed better (or worse) than the basic alternative, when the uncertainties in the impacts of the strategies are included in the assessment. Especially for the leading criteria view, the simulated uncertainties caused the ranking of the strategies to be quite uncertain. However, the scores of the strategies for this view calculated without uncertainties are so close already that adding uncertainties does not really impede the discrimination between the different strategies any further. For all views it is concluded that uncertainties do not affect the discrimination of those strategies showing significant benefits or disadvantages compared to the basic alternative.

The stability of the assessment method is mainly caused by the principles for translating the quantitative impacts into qualitative assessments. The definition of these principles makes this method insensitive to minor changes in expected impacts. For the qualitatively assessed impacts, it should be noted that the assessment scale is quite rough (only five scores are distinguished) and that small changes of these impacts will not directly result in changing assessments too. Moreover, the comparative mode of the final assessment makes that some uncertainties impacting on all strategies (like changing prices of sand) do not influence these relative assessments.

5 Discussion

This research indicates that new coastal management strategies may be preferred over the continuation of present coastal management practice (being the basic alternative) when a long-term perspective is applied. An important characteristic of these new strategies is their increased spatial scale in comparison to the basic alternative, resulting in less longshore differences.
The selection and ranking of the coastal management strategies differs somewhat when a different vision is at the basis of the assessment. In all cases studied in this research however, the basic alternative appeared to be not the best solution. Especially the alternative with a new row of foredunes along the entire coast of the study area and the alternative consisting of an island in front of the southern part of the coast and new foredunes in front of the northern part of the coast are assessed better than the basic alternative. The alternative strategy that foresees islands in front of the entire coast of the study area is also assessed significantly better for some assessment visions, but at some others its impacts are significantly worse than those of the basic alternative. Even a landward strategy (landward extension of dunes, seaward in front of some major coastal towns) with an intermediate spatial differentiation (longshore sections of 4 to 26 km) shows some significant advantages in comparison to the basic alternative.

The results of this research alone are not enough to decide which of the proposed coastal management strategies creates the best opportunities and is most advantageous in comparison to the basic alternative for preserving coastal safety levels up to the year 2200. Neither were they intended to do so. We can just state the significant advantages of some of the strategies over the basic alternative. Extensive political debates and deliberations will be needed in order to develop a solid policy view (for which several options are applied in this study) on the future of our coastal defences and some major decisions should be made on the future core values of these defences. This view and these core values can then be applied to determine which strategy should be preferred.

This discussion starts with considering the implications of these results and the comparison of these implications to the present coastal management policy. Next, the uncertainties within this study and surrounding long-term coastal management in general are discussed. The results of this study are subsequently compared to the outcomes of other studies and to other initiatives for managing the coastal defences. Finally, it will be discussed whether the results of this study may also be useful for other coastal areas.

5.1 Long-term perspective vs. present policy

The first point of discussion is how the (short-term) implications of the selected coastal management strategies compare to present coastal management practice. This comparison facilitates the derivation of some principles that a long-term perspective might introduce to coastal management practice.

Present coastal management practice contains a variety of seaward (e.g. dune and beach extensions), consolidating (e.g. dike-in-dune constructions) and landward strategies (e.g. dike heightening). Moreover, problems and solutions are considered at a rather small spatial scale (most of the times the sections are not longer than several kilometres, for examples see [Provincie Noord-Holland, 2008] & [Kustvisie Zuid-Holland, 2006]). This longshore differentiation disturbs the dynamic morphological equilibrium of the coast and causes the emergence of gradients in longshore sediment transport. When, for example, at a certain location a seaward measure like beach extension is realized while at the upstream and downstream sections (the latter is located at the north) nothing will be done in the seaward direction, the erosion rates of the extended section will increase. So instead of stabilizing the coast at these sections where the defences already need to be enhanced, introducing longshore differentiations by the present coastal management practice will increase the morphological destabilization of the coast.

Coastal management solutions planning measures at larger spatial scales might prevent the occurrence of this problem by better preserving the uniformity of the coastline. The smooth, concave shape of the coastline should be considered as a dynamic equilibrium system that changes over time; the central part of the Holland coast accretes, while the northern and the southern part of the Holland coast are eroding [TAW, 2002]. The concave shape itself is the large-scale equilibrium outline of the coast between the two static 'heads' ('hoofden' in Dutch) at Calais and Den Helder [Van Veen, 1937]. Morphodynamic processes, like longshore sediment transport and gradients therein, have been very important in the development of this shape and are still determining the dynamics and the smoothening of the coastline. Measures that are developed at larger spatial scales might be better able to account for these natural processes. Large-scale strategies might even benefit of these processes instead of fighting them as in case of the basic alternative.

Presently, the sand engine is one of the new plans for enhancing coastal defences. These engines are temporary, dynamic sandbanks or islands in front of the coast and will be eroded over time [Provincie Zuid-Holland, 2008] [Poelmann, 2007]. The sand being eroded from these features will be transported to the coast in order to extend existing beaches and dunes. Sand engines might be an interesting alternative for beach nourishments since their impact is much more gradual and is less disrupting for beaches' ecology and recreation (except for the location where they are 'constructed'). These sand engines might also be interesting for creating a row of new foredunes by the use of natural forces. However, it is not yet known whether these natural nourishments would finally lead to the emergence of a new dune. And even when the sand engine appears to be effective, the rate of seaward extension of the dunes due to the natural sand transport is limited (at about 1 m per year [Zijlstra e.a., 2007]), just like in case of the sandbanks discussed in this study. So on the short term, the sand engine principle might be used to start the uniform extension of the coast. When their efficiency appears to be insufficient over time, additional nourishments may be needed to create the new foredunes.

Meanwhile, the creation of new foredunes still requires a very different approach than the present coastal management policy. Existing functions located in or connected to the coastal zone can not be preserved in case this strategy would be adhered. This strategy implies the development of a new, natural coast with a new distribution of functions. The realization of this strategy can be spread out over time, but one should account for the coastal equilibrium. In cross-shore direction the extension of the coast can be realized in several phases. This is also possible in longshore direction but this would give rise to longshore differentiations increasing erosion of the local seaward extensions. Although this measure could be executed over several decades, on the short it would already require a new long-term strategy of the government taking into account the changing functions of the coastal zone.

The strategies containing new islands are even more different from present coastal management. Planning of these islands should start rather soon, just like further research into their impacts on the development and safety of the existing mainland coast. The construction and development of these islands can be divided in several phases and can be started at those locations most in need of measures to enhance the coastal defences. Until then, existing defences should be maintained and improved to keep up with increasing requirements. In order to create a policy and societal framework for developing these islands, thinking of coastal management should be changed significantly towards much larger spatial and temporal scales. This is quite different from our present approach. Moreover, different administrative fields have to cooperate since these islands are interesting from both a water management and a spatial planning point of view. This combination is already a main issue of our present coastal management policy but is still only marginally elaborated since difficulties rise in funding such co-productions (see section 5.5).

Next, the future uncertainties ask for a certain amount of flexibility of these measures in order to be tuned to new insights developed over time. From this point of view, islands are assessed significantly worse than the basic alternative (once constructed and in use, islands can not be changed easily), but the intermediate scale landward strategy on its turn is assessed significantly better. A landward strategy would also maintain the present uniformity of the coastline. However, this strategy seriously departs from present coastal management in the fact that coastal defences are enhanced at the landward side and at the cost of existing land uses.

From these comparisons concerning long-term developments, it is concluded that those strategies that show significant advantages over the basic alternative, in general, strive for maintaining the uniformity of the coast and for a better sustainability of the measures to be undertaken.

5.2 Knowledge gaps and major assumptions

Another point of discussion is the knowledge that is missing currently and for which assumptions are stated within this research. Knowledge that is missing creates uncertainties. According to Brugnach e.a. [2007] there are two types of uncertainties: situational uncertainties and fundamental uncertainties. Situational uncertainties are those uncertainties that are, at least in principle, reducible by further research. Fundamental uncertainties, on the contrary, refer to uncertainties that are persistent with respect to the problem that is investigated. In this section we will discuss the first type of uncertainties and the potential impacts on the outcomes of this study by the assumptions related to these uncertainties. How to cope with the fundamental uncertainties is discussed in section 5.3.

A major shortcoming of this study is the present lack of knowledge on the measure of creating artificial sandbanks in front of the coast for enhancing the coastal defences. These sandbanks are meant to dissipate wave energy. The design of the sandbanks resembles the design of the artificial reefs presently under investigation. The potential energy dissipating effect of these sandbanks is derived from preliminary study results on these artificial reefs [Royal Haskoning, 2008]. No studies are found however on the long-term stability of these artificial sandbanks. The stability of these sandbanks depends strongly on local morphologic and hydrodynamic characteristics and asks for further research. A possible outcome might be that these sandbanks would appear to be rather stable over time. Natural processes might even amplify them. When this would turn out to be true, many of the negative impacts described in this report will be eliminated and the ranking of the strategies containing sandbanks would change significantly. So it is definitely of interest to investigate the characteristics of these artificial sandbanks into more detail.

On the other hand, some choices and assumptions in the applied assessment methodology seem to be rather arbitrary, especially the weights awarded to the criteria for the different views. Although true to some extent, this poses no serious problems. First, all criteria together cover the total range of potential impacts and the available criteria (as summarized in [Horstman, 2007]) very well. Secondly, different policy views are included in this study. These views show different preferences for awarding weights to the criteria. The establishment of such a policy view is an external factor to this study, but might seriously impact on the ranking of the proposed coastal management strategies. Of course, the weights awarded to the different criteria according to these views remain subjective. This study at least attempts to give some good reasons for the choices that are made.

The impact assessments themselves also contain considerable uncertainties, especially the quantitative (monetary) assessments of for example costs and nature benefits. Concerning these uncertainties, it has been a good choice not to add all calculated costs and benefits into a final balance, but to include separate (monetary) impacts individual in the final assessment. Since adding all costs and benefits (according to CBA methodology) would have included all uncertainties into one figure that would become very uncertain and thus meaningless. According to Roca e.a. [2008] MCA may be more appropriate to cope with this type of uncertain information than CBA. This finding supports the assessment method applied within this study.
Next, a sensitivity analysis is executed for these uncertain quantitative impacts, according to the method for comparing uncertain alternatives presented by Van der Kleij e.a. [2003]. This analysis shows that the ranking of the proposed coastal management strategies is rather insensitive to these uncertainties. This is caused by the fact that the impacts are assessed on some main characteristics only and in comparison to the basic alternative. Moreover, this study looks for consequences significantly departing from those of the basic alternative. This principle of significance is first applied in the

translation of the calculated quantitative impact assessments into qualitative impact scores, where deviations need to be rather large before another qualitative assessment score is awarded. Secondly, we look for significant differences in comparing the final scores of the strategies according to the different assessment views. Together this makes that the final conclusions of these assessments are quite stable.

The uncertainty of the potential impacts of the proposed strategies is related to the fact that the designs of the strategies are quite rough and only describe the main characteristics. The rather undeveloped state of these designs is sufficient for this kind of pre-feasibility study into the ranking of the proposed strategies [Eijgenraam e.a., 2004]. However, intensive research and planning will still be needed in order to translate (one of) these strategies into a preliminary design.

5.3 Coping with fundamental uncertainties

Otter & Copabianco [2000] state that coastal managers are increasingly forced to take decisions based on information that is surrounded by uncertainties due to the increasing need to act in a pro-active way. Anticipating on the future is important in coastal management since defences can not be changed overnight. However, this also induces the need to cope with fundamental uncertainties since we just do not know exactly what will happen in the future, even if time and money were available to do exhaustive research into predicting these developments.

One of the major fundamental uncertainties is the development of the dunes over time. It is supposed that the nourishments for maintaining the coast will be continued. However, it is not known yet what impact these ongoing nourishments will exactly have on the dunes; whether they will extend in width or in height or both or whether they will not extend at all. At the same time, the long-term development of the dunes due to natural dynamics caused by the ongoing impact of water and wind is rather uncertain [Van der Burgh, 2005]. Both processes can significantly influence the future safety level of these sandy coastal defences [Van der Burgh e.a., 2008]. When, for example, future insights show that the dunes significantly grow due to the ongoing nourishments, present estimates of future safety levels may be far too pessimistic. However, these uncertainties are not solved yet and all plans and researches into coastal management face major assumptions on this area. This creates the need to adhere flexible coastal management strategies that can be tuned to new insights when these come available over time. The major resource of these new insights will be the actual developments that are faced over time. After all, improved predictions of the future developments of the coastal defences by ongoing research will always contain the inherent uncertainties in predicting future developments.

The development of the hydraulic boundary conditions is fundamentally uncertain too. A method particularly suited to cope with this fundamental uncertainty is scenario analysis [Brugnach e.a., 2007]. Different scenarios are derived for the impacts of climate change from an extensive literature review. Literature shows a large range for the development of the boundary conditions, especially sea level rise. This entire range is included in the climate change scenarios, in order to be prepared for the worst case scenario but also to be aware of the probability that the changes may be much less extreme. Again, these uncertainties are inherent to all studies on this issue. However, the scenarios derived in this study contain a wider range of potential future developments than the scenarios that are generally applied nowadays. And thus their predictive value might be better since the total range of potential climate change developments is represented by these new scenarios. Moreover, an increasing number of scientists states that sea level rise might speed up to a rate of about 1.5 m/century [WaterForum, 2008]. This rate of sea level rise is included in the highest climate change scenario of this study. The present official climate change scenarios only account for a maximum rate of 0.85 m/century and may thus result in a significant underestimation.

Concerning these fundamental uncertainties, Cowell e.a. [2006] state that methods should be adopted for dealing with uncertainties in predicting coastal changes. Presently, coastal managers tend to seek and accept advice based on precisely stated predictions due to the need to manage intense political and community debates surrounding planning decisions on the coast. However, Cowell e.a. also state that this approach is not justifiable. Politicians should account for these fundamental uncertainties in order to prevent them from taking decisions leading to an unsustainable coastal management policy on the long run (like the present approach that is represented by the basic alternative in this study). A good adaptation policy requires a choice for robust measures that are useful in different climatic circumstances and that can be adapted in a later stage if deemed necessary [Van Ierland e.a., 2007]. The results of this study show that it is quite well possible to design a coastal management strategy that is suited to a wide range of possible climate change impacts (and that can be adapted in a later stage). The ranking of the proposed strategies for the highest climate change scenario does not show serious deviations from the ranking for the lowest climate change scenario.

5.4 Previous studies and policies on coastal management

The main point of this section is how the results of this research compare to the results of previous studies and to previous policies on the maintenance of the coastline and the coastal defences of the Holland coast (the study area of this research).

In the late eighties of the 20th century, a range of studies has been executed on the development of the entire Dutch coast. At this time, the protection offered by the coastal defences along the Dutch coast was in accordance with the requirements stated by the (first) Delta Commission. However, structural erosion caused almost half of the coast to recede. It was foreseen that by the end of the 20th century tens of kilometres of dunes would be insufficient to guarantee the safety of the low-lying polders by the norms of the Delta Commission [Min V&W, 1989]. Four options for coastal management were considered in these studies: retreat, selective preservation, complete preservation and seaward extension. On the basis of these studies, it was decided that a complete, sustainable preservation of the entire coast at the present position was the best option for the preservation of safety and of functions and values in the dune area. This choice was embodied in the First Coastal Policy White Paper and lead to the establishment of a regular nourishment programme for the 'dynamic preservation' of the coastline [Min V&W, 1990].

In the Third Coastal Policy White Paper [Min V&W, 2000], a long-term consideration was added to the requirements for the dynamic preservation policy. It was found that the long-term continuation of this policy would ask for a compensation of sand losses in deeper water too and the nourishment programme was intensified.

Last year, an economic analysis was executed on the coastal management policy for the next 50 years [Zijlstra e.a., 2007]. This study considered the same options that were studied before 1990. From a socioeconomic pre-feasibility cost-benefit analysis it is concluded that dynamic preservation of the coast together with a partial compensation for sand losses in deeper water would still be the best strategy for the period 2011-2060. However, this study only accounted for a sea level rise of only 30 cm over this period.

Opposed to the studies in the late 20th century, the latter study of Zijlstra e.a. [2007] does not explicitly account for the possible emergence of weak links in the coastal defences. This is understandable, since a sea level rise of 30 cm would only lead to some rather small-scale problems concerning the safety offered by the coastal defences. And according to present policy, these small-scale problems are solved by projects that are rather confined in space.
The research presented in this report, however, identifies much higher rates for sea level rise resulting in the emergence of large-scale weak links along the Holland coast. As is found in this study, the emergence of large-scale weak links increases the need for developing measures to enhance the coastal defences at larger spatial scales too. This situation might be compared to the situation in the eighties, when large-scale problems were foreseen for the end of the 20th century [Min V&W, 1989]. At that time, a structural nourishment policy was established, marking a significant change in coastal management history. Now we may be in need of such a significant change again.

5.5 Recent studies and initiatives

We would also like to consider some outcomes of recent studies and some important recent initiatives in order to compare the outcomes of this research to the state-of-the-art knowledge and ideas. We still focus on the situation of the Holland coast.

Scientific articles on coping with the impacts of climate change are rather scarce. Quite recently, the results of a case study on living with sea level rise and climate change in the Netherlands have been published [Van Koningsveld e.a., 2008]. The development of coastal management is analysed with a retrospective view (also accounting for the accelerating rate of sea level rise) and a paradigm shift is identified towards an approach according to the principles of working with nature in a trans-disciplinary way. Establishing this approach is said to be the major challenge for the 21st century. The large-scale coastal management strategies that are assessed well in the present study comply very well with this ‘working with nature’ principle since they prevent for the increase of longshore differentiations that may lead to an instable coastline (see section 5.1).

Meanwhile, relevant studies that are available deal with all kinds of adaptation measures for coping with climate change impacts, ranging from flood proofing of infrastructure to awareness raising for the potential impacts. Often, only a small part of these studies is dedicated to potential coastal management strategies and a thorough in depth description of these measures is missing [Terpstra e.a., 2007] [Van Ierland e.a., 2007] [Van Koningsveld e.a., 2008]. For example: the sand engine principle (which also complies to working with nature) is assessed to be very promising in order to prevent the coast from eroding, based on only some first thoughts on major characteristics like financial and legal impacts [Terpstra e.a., 2007].

Scientists are still principally involved in research into the vulnerability to climate change and uncertainties in these future developments [Nicholls & De la Vega-Leinert, 2008]. According to Tol e.a. [2008], adaptation to reduce the vulnerability of coastal zones to sea level rise is a new issue on which systematic studies are only beginning. They also state that from scientific literature it is still unclear how these adaptations relate to present coastal management practices. At the same time, some studies have evaluated technical feasibility of adaptive measures but they have little or no assessment of socioeconomic and other considerations [Tol e.a., 2008]. This is why the present study may add significantly to the existing knowledge basis. It should at least create attention for the possibilities to consider long-term coastal management strategies (which were shown to depart significantly from the present coastal management policy) even though future circumstances are still largely uncertain.

Preserving the present safety level of our flood defences (which is at the basis of this research) will facilitate the ongoing development of the areas protected by these defences. It will also control the costs of developing buildings or infrastructure within these areas since not every feature needs to be built flood proof. At the same time, it might still be good to combine this approach with risk reduction through flood proofing of part of the infrastructure since risks are ever increasing due to the ongoing growth of socio-economic values present in flood-prone areas (risk = probability * potential damage). Moreover, this might also help with awareness raising of the dangers of living in those areas of which major parts are located below mean sea level right now already.

As stated before, the link between enhancing coastal defences and improving spatial quality is gaining attention. The goal of the current projects for improving the weak links in the coastal defences insists on the relevance of improving both components in a combined project. This study showed that this combination is still rather important when coastal management strategies are designed at larger spatial scales. However, some problems occur in this approach currently, since the governments responsible for the safety of the coastal defences will not pay for improving spatial quality. At the same time, combinations of enhancing coastal defences and redeveloping spatial infrastructure might be postponed because these infrastructural objects may not need to be renewed at this moment already. In both cases, this may result in executing simply those parts of the projects meant for enhancing the coastal defences. From this point of view and reflecting on the characteristics of the preferred coastal management strategies, it is important to prevent that planning is too much restricted by existing infrastructure and functions. One should think of chances and possibilities that may be the starting point for creating a new and innovative coastal management strategy for the next two centuries. Administrative (and financial) matters concerning the harmonization and coordination between different policy making and executing institutions should be managed so to support the best available strategy [Van Ierland e.a., 2007].

Finally, there is much attention for visionary, large spatial scale plans related to coastal management (and water management in general) like the plans of Adriaan Geuze for creating a chain of islands in front of the Belgian and Dutch coasts [Havermans, 2007] and the ‘tulip-projects’ launched by the Innovation Platform. Among those latter projects are the creation of multifunctional islands for energy generation in the North Sea and the major seaward extension of the coast of Zuid-Holland by applying the sand engine principle [Innovatieplatform, 2008]. At the same time, our society seems to be more conscious than ever of the potential impact of climate change and the need to do something to maintain our protection against floods. This awareness is raised for example by the film ‘An Inconvenient Truth’ of Al Gore and by the reports published by the Intergovernmental Panel on Climate Change (e.g. [IPCC, 2007]). The political consciousness of the need to do something is clearly stated by the institution of the new Delta Commission, next to national programs like ‘Room for the River’ and the enhancement studies concerning the weak links in the coastal defences. So at least the societal (and political) momentum is there to make a major step towards a changed, large-scale coastal management policy that is able to cope with the expected (and uncertain) long-term developments.

5.6 General applicability

This last section of the discussion will shortly consider the wider (international) applicability of the results of this study.

Problems with protecting low-lying coastal areas from flooding by the sea are worldwide just like the impacts of climate change. The sensitivity of the coastal areas to these impacts however differs dramatically [Tol e.a., 2008]. The need for adaptation strongly depends on these sensitivities. The fewer inhabitants are living in a flood-prone low-lying area, the less will be the need to enhance the coastal defences (or to implement some other flood risk reducing measures). However, about 80 % of the world’s largest cities are located in low-lying coastal areas and deltas [Boeters, 2008]. Worldwide about 80 % of the population will live in these coastal areas and deltas by 2050 [NWP, 2004]. So there are many other countries that will face similar problems in climate proofing their coastal defences.

Unfortunately, the outcomes of this study cannot literally be copied to other locations, since they are largely dependent of the specific situation of the coastal defences and the hinterland within the studied area. However, the principles and methods at the basis of this study may be quite well applicable to other locations. New scenarios for the impacts of climate change and the resulting future weak links in the coastal defences should be derived for a specific location. Subsequently, measures for enhancing the coastal defences according to the requirements derived in the first step may be determined from both local practice and global knowledge. A new assessment and selection could then be made in order to find out what measures are preferable from a long-term perspective for this specific location.

Repeating these analyses will not necessarily lead to the selection of large-scale coastal management strategies as in case of the Holland coast studied in this report. Moreover, other coasts may show other requirements resulting in the selection of different strategies. However, a long-term perspective will still significantly contribute to coastal management practice. Attention for the potential (long-term) impacts of climate change and for the need to develop a coastal management policy is lacking in many countries, especially developing countries. A long-term perspective may serve as eye-opener in these countries, raising awareness on the potential future impacts. It may also help them with developing a sustainable long-term coastal management policy that is (better) able to preserve the safety of the inhabitants of the low-lying coastal areas and that is suited to cope with the future uncertainties.

6 Conclusions & recommendations

6.1 Conclusions

This research aims at revealing new insights on the question whether a long-term perspective could improve coastal management practice. In this research, the situation of the Holland coast serves as a case study. The research questions at the basis of this study are answered in this concluding section.

6.1.1 Impacts of future changes on coastal defences

Research question 1:
To what extent will long-term changes of the boundary conditions, due to climate change and subsidence, affect the preservation of the existing safety level of the coastal defences within the study area?

Future changes of the boundary conditions for the coastal defences due to the impacts of climate change are largely uncertain. Scenarios for the potential impacts of climate change contain predictions on relative sea level rise, increasing storm surge levels and increasing wave heights. The scenarios applied in this study show a rather large differentiation. The most extreme scenario that we applied is even worse than the existing maximum scenario derived for policy issues. However, increasing evidence is found that the existing scenarios may underestimate the potential impacts.

Due to the existing insight that sea levels are rising, the Netherlands did already start with a coastal maintenance policy. This policy aims to preserve the existing coastline by structural nourishments. As a result of this policy, beaches, the surfzone and the shoreface are rising at the same rate as the sea level rise. However, the impacts of climate change are leading to increasing hydraulic boundary conditions and will increase the extent of the future weak links within the coastal defences. Taking into account these developments, for the lowest climate change scenario about 40% of the coastal defences will be insufficient for defending the hinterland up to the present safety level by the year 2200. For the intermediate and the highest climate change scenarios these amounts are about 60% and even more than 70% respectively.

It can thus be concluded that due to the negative impacts of climate change (and subsidence), the total length of insufficient coastal defences may show a distinct increase on the long term.

6.1.2 Increasing need for a large-scale spatial perspective

Research question 2:
Does the long-term approach raise the need for a large-scale spatial perspective for developing coastal management strategies suited to maintain present safety levels of the coastal defences over the next 200 years?

Future developments do increase the need to consider coastal management strategies at larger spatial scales for two reasons. First, assessing the coastal defences for the increased boundary conditions by the year 2200 indicates a significant expansion of the spatial scale of the weak links that will occur. These future weak links are (much) more extended than the spatially confined weak links that are being investigated right now. This raises the need to look for coastal enhancement strategies at increased spatial scales too. These extensive weak links could still be subdivided according to characteristics of the coastal zone or based on the land-use types represented in the hinterland. Due to the increased requirements for enhancing the coastal defences however, decreasing spatial scales at which enhancement measures are designed go together with increasing longshore variations. This study indicates that these longshore variations are negative for the long-term sustainability of the coastal management strategy (except for landward strategies, preserving the existing coastline).

Secondly, the increasing requirements for enhancing the coastal defences create possibilities for new, large-scale measures like islands. The concepts of such large-scale interventions make that they are incompatible with improving the coastal safety at rather confined longshore locations. So next to the needs, the potential solutions do also raise the need to consider larger spatial scales in designing a coastal management strategy. At the same time however, there are other measures that cannot be applied to extended longshore sections. Some kind of landward dune extensions would for example interfere seriously with existing land-use at some densely populated areas.

These considerations still do not give a consistent answer on the question whether a large-scale spatial perspective should be preferred. This study therefore describes and compares coastal management strategies that are based on different spatial scale perspectives. Eight alternative coastal management strategies are set up for preserving the present safety level of the Holland coast over the next two centuries. These strategies are designed at four different spatial scales to explore what would be the result of considering larger spatial scales in coastal management:

- Uniform coast; one solution for the entire study area.
- Large scale; separating the southern and the northern part of the study area.
- Intermediate scale; dividing the area into twelve longshore sections of 4 up to 26 km length, according to major land use characteristics.
- Small scale; dividing the area in many short sections of several kilometres length that are related to very specific characteristics of each area.

6.1.3 Advantages of new coastal management strategies

Research question 3:
What are the consequences of the newly derived coastal management strategies with respect to the present coastal management practice and do some of these new strategies have significant advantages in comparison to the continuation of the present coastal management policy?

The small spatial scale is representative for the basic alternative for coastal management that implies the continuation of present practice. This means that solutions for emerging weak links are looked for on a small spatial scale and consider increased requirements over relative short periods of time of about 50 years. A major disadvantage of continuing this policy on the long term is that it will cause an increasing disturbance of the morphodynamics of the more or less stable, smooth concave coastline over time. This will occur when seaward, consolidating and landward measures are planned for longshore sections located close to each other, giving rise to longshore gradients in sand transport and causing erosion at locations where it is unwanted. This long-term outlook on the (negative) implications of continuing present coastal management practice has not been identified before.

Until now, little is known on how new coastal management strategies compare to the present strategy. Moreover, available scientific publications mainly concentrate on technical feasibility and attention for socioeconomic and other impacts is lacking. In this study, the proposed coastal management strategies are compared to the basic alternative by a rather qualitative assessment method that is partly based on rough estimates of the (socioeconomic) costs and benefits. A wide range of criteria is considered, representing costs, welfare impacts, non-welfare impacts and some other criteria.

Since the assessments on some of the criteria contain large uncertainties, we only consider significant impacts compared to the basic alternative. By doing so, a sensitivity analysis showed the results to be rather stable. Moreover, the ranking of the measures generally does not change significantly when the lower climate change is supposed to come true instead of the higher climate change scenario.

Different views are applied for awarding weights to the criteria. These views represent possible preferences according to potential policy strategies. It turns out that there are three alternative strategies that show some major advantages over the basic alternative, both when the highest and the lowest climate scenarios are considered:

- A new row of foredunes in front of the existing foredunes for the entire coast, assessed best from a sustainability point of view.
- An island in front of the southern part of the study area and new foredunes at the northern part, assessed best from a spatial development point of view but negative for risk aversion.
- An intermediate scale landward strategy consisting of landward dune extensions and some minor seaward dune extensions depending on the major land use functions, assessed best from a risk averting point of view.

The uniform strategy with two islands in front of the entire coast of the study area also shows some major advantages in comparison to the basic alternative, but this goes along with significant disadvantages for some other views.

A main characteristic of those strategies that are assessed best in comparison to the basic alternative is that they are generally aiming at the preservation of the natural situation of the coastal morphology, resulting in sustainable solutions for coastal management. New foredunes could realize this by creating a new, smooth and concave coastline seaward of the existing coastline. A landward oriented coastal management strategy could also realize this, but then the smooth coastline is mainly retained at its present location. In general, new islands would contribute less to retaining existing morphodynamics. In fact it is quite uncertain what their impact on the mainland coast will be. However, islands could satisfy part of the increasing need for space that the study area will face during the next two centuries.

So in general it is found that some important opportunities exist in cooperating with the natural dynamics of the coastal system, since this could significantly increase the sustainability of coastal management strategies. Overall, these results underline the need of increasing the temporal and spatial scales that are at the basis of our coastal management policy. A long-term strategy based on a larger spatial scale perspective can result in significant advantages compared to the continuation of the present small-scale and project-wise approach of coastal management.

6.1.4 Impact of long-term uncertainties

Research question 4:
How sensitive are the results of this study to the inherent uncertainties at a timescale of 200 years?

The influence of the situational uncertainties inherent in the impact assessments of the proposed coastal management strategies is studied by the already mentioned sensitivity analysis. The impact of these uncertainties proved to be rather small when only significant consequences compared to the basic alternative are considered.

At the same time, there are the fundamental uncertainties surrounding the future impacts of climate change that cannot be removed by further research. A scenario analysis is applied in this study to account for this fundamental uncertainty. The outcomes show that rankings of the proposed coastal management strategies do not change too much for the higher and the lower climate change scenarios for which the coastal management strategies are studied. However, the required dimensions are still largely dependent of the uncertain future boundary conditions and thus flexible solutions may be preferred. This flexibility is included in the robustness criterion of the assessment framework and considers the potential of a certain measure to be adjusted to the latest insights on the development of the boundary conditions. This may prevent us from constructing coastal defences for the worst case scenario right now, but enables us to extend the coastal defences over time in accordance with the latest predictions of the boundary conditions for the next decades. From this point of view, dynamic solutions like the foredunes are preferable since they can be adapted rather easily in comparison to static measures like new islands.

This study indicates that, although future uncertainties are quite large, a solid analysis can be made of the advantages and disadvantages of different options for long-term coastal management. So there is no need to wait with establishing a new direction for coastal management until all future uncertainties are reduced as much as possible.

6.2 Recommendations

The conclusions of this research result in some recommendations on coastal management. These are summarized in the first part of this section. Next, some recommendations on further research are presented in the second part of this section.

6.2.1 On coastal management

From this research several recommendations on the planning and design of future coastal management strategies are derived. These recommendations are summarized below:

- From a morphological point of view, it is found to be useful to consider safety problems of the coastal defences at larger temporal and spatial scales. Continuation of the present policy implies the ongoing implementation of rather small-scale ad-hoc projects for enhancing the coastal defences right where safety problems emerge over time. On the long term this increases longshore differentiations of the coastline. This affects the smooth concave coastline, which is more or less stable over time. Measures to compensate for the decreasing safety of the coastal defences should therefore preserve or enhance the current uniformity of the coast.

- When we want to adhere a large-scale coastal management strategy that is suited to long-term developments, a visionary policy is needed in order to create a widely accepted perspective (or view) that can be applied for the assessment of the potential coastal management strategies.

- Making, implementing and financing such far-reaching decisions as those related to large-scale coastal management strategies is very hard within the present administrative system. In fact, only gradual improvements are possible, but such an incremental approach may not be enough to cope with future changes [Tol e.a., 2008]. Therefore the administrative structure may need to be adapted in order to increase coordination and cooperation between all parties involved.

- It is important to consider all impacts of a potential coastal management strategy. Currently, costs are still a main determinant in the selection of measures for enhancing the coastal defences. And funds are often limited and just facilitate the realization of the minimal alternative that is needed from a short-term perspective to preserve the legally prescribed safety levels.

- Those uncertainties inherent in the future developments of both the boundary conditions for the coastal defences and the development of the dunes themselves should be managed appropriately. This can be done by aiming for a flexible coastal management strategy that is able to handle these uncertainties and that facilitates the adaptation to new insights becoming available over time.

- Reconsider the established climate change scenarios for policy uses on the basis of recent insights on the potential impacts of climate change. The present scenarios are stated in many policy documents and are applied for infrastructure projects that need to be climate proof, but it is found that they may underestimate the potential impacts.

6.2.2 On further research

The most important recommendations for further research are summarized here:

- The measure with newly created sandbanks in front of the coast, as described in this study, asks for further research on its morphodynamics. It is now assessed quite negative due to the uncertainties related to the stability of these features. However, when further research indicates that they may persist over time (this is not unthinkable, maybe their location or initial dimensions should be changed somewhat), they are a serious option for long-term coastal management.

- It is still rather uncertain to what extent new islands or sandbanks in front of the coast will increase the safety of the coastal defences by reducing wave attack at the mainland coast. It is also unknown yet how they will change morphodynamics and whether this would affect the mainland coastal defences. These morphodynamic and hydrodynamic consequences need to be studied into more detail, for example by small-scale testing of the concepts.

- It is also important to study the possibilities for implementing new coastal management strategies (for example the new foredunes) in several phases. This is quite important since the possibility for a phase-wise implementation may create the ability for adapting a coastal management strategy to the latest insights on the required coastal defences. Moreover, a temporal spreading of the construction reduces financial risks and may facilitate the learning process during the implementation.

- On the other hand, it may also be interesting to study the governmental difficulties of implementing long-term and large-scale coastal management strategies. How should and/or could existing administrative structures be changed to improve the possibilities for facilitating large-scale coastal management? This may be an interesting question concerning the present difficulties in implementing trans-disciplinary solutions for the weak links in the coastal defences.

- It is still important to study the long-term development of the coastal system, especially of the dunes, when the existing nourishment policy is continued. This might generate better knowledge on the future configuration of the dunes and the requirements in order to maintain the safety level of these coastal defences. Until now, a conservative now-growth assumption is applied for deriving the future configuration of the dunes.

- Moreover, it would be quite interesting to do the same study on long-term coastal management for another study area with a coast that differs from the smooth, sandy coast that is the subject of this study. This may result in different outcomes.

- It is necessary to continue research into the impacts of climate change on sea level rise and the other hydraulic boundary conditions so to create an ever-improving knowledge database that develops over time. This would improve the insights in the requirements of the coastal defences.

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Glossary

Basal Coastline (Basis KustLijn)
The Basal Coastline is more or less defined as the location of the coastline in 1990, which was derived from a linear trend of the cross-shore location of the coastline over the past ten years. The Basal Coastline is applied for the annual assessment of the location of the Momentary Coastline. This is part of the present nourishment policy. If the Momentary Coastline is structurally located landward of the Basal Coastline, nourishments will solve this problem.

CBA (Kosten Baten Analyse)
Cost-benefit analysis (CBA) is a monetary assessment method. In a financial CBA, all advantages and drawbacks of a proposed project should be translated into monetary units. A socio-economic CBA, on the other hand, includes all changes of societal welfare by quantifying and monetarizing them as much as possible. More information can be found in appendix L.2.

Coastal foundation (kustfundament)
The coastal foundation (or coastal zone) encompasses the entire area, wet and dry, that is relevant for the functions present in the coastal zone. The most important function is the one of the coastal defences. At the seaward side this coastal foundation is confined to the 20 m -NAP depth contour and at the landward side it contains all dunes and the hard defences (sometimes located on these dunes).

Dike ring area (dijkringgebied)
A dike ring area is an area that should be protected from flooding by a system of embankments surrounding it.

Dune crest (duintop)
The dune crest it the top of a dune or the contour indicating the location of the top of a row of dunes.

Dunetoe (duinteen)
The dunetoe is the downward edge of the dunes at the seaside. The dunetoe is located at the transition of the steeper slope of the dunes into the (much) less sloping beaches.

Erosion point (afslagpunt)
The erosion point is the most seaward point of the coastal zone that remains unaffected during a severe storm event. This point indicates the landward extension of the erosion profile caused under extreme circumstances.

Erosion profile (afslagprofiel)
An erosion profile is the cross-shore profile that is supposed to emerge when the dunes are eroding due to a sever storm event. The shape of this profile is established in the DUROS-plus model (see section 2.4). The location of the erosion profile in the cross-shore direction depends on the severity of the circumstances and the cross-shore profile of the dunes. In the end, erosion (sand removed from above the erosion profile) and deposition (sand added below the erosion profile) should be in equilibrium.

Foredune (zeereep)
First row of dunes when approaching the land from the sea-side. The Dutch foredunes are often covered by marram grass at the sea-side. Vegetation at the landward side may consist of small trees, shrubs and grasses.

Foreshore
The foreshore is the lower part of the coastal zone that consists of the surfzone, the upper shoreface and the lower shoreface. So the shoreface is located in general between 2 m -NAP and 20 m -NAP.

Hard defences (harde kustverdediging)
Hard coastal defences are static structures that will not significantly change over time due to natural (hydro-)dynamics. Examples are fixed structures like dikes and groynes.

Lower shoreface (diepe kustzone)
The lower shoreface refers to the part of the seabed that is located too deep to be agitated by daily wave action. Only larger waves generated during storms are able to agitate this part of the seabed [Wikipedia, 2008]. The lower shoreface is supposed to be located between 13 m -NAP and 20 m -NAP.

MCA (Multi Criteria Analyse)
Multi-criteria analysis (MCA) is an assessment method that applies explicit criteria, enables impacts to be expressed in their natural units and facilitates weighing of the criteria [Pouwels, 1995]. More information is included in appendix L.1.

Momentary Coastline (Momentane KustLijn)
The location of the Momentary Coastline is calculated every year by applying measurements of the cross-shore profiles of the coast (see section 2.2). If the Momentary Coastline is structurally located landward of the Basal Coastline, nourishments will be employed according to the present nourishment policy for maintaining the coast.

NAP (Nieuw Amsterdams Peil)
Amsterdam Ordnance Datum (or Dutch Ordnance Datum).

Non-welfare impacts (niet-welvaartseffect)
Non-welfare impacts concern the intrinsic value of nature, which is supposed to describe the well being of flora and fauna.

Primary flood defence (primaire waterkering)
A primary flood defence protects a low-lying area from flooding. This defence should be part of the defence system surrounding a dike ring area, or it is located before a dike ring area, or it connects two separate dike ring areas.

Rest strength (reststerkte)
The rest strength of the dunes is defined as the minimal dune volume that is required for the dunes to be able to withstand the extreme design storm-conditions.

Sand engine (zandmotor)
The basic principle of the sand engine emerges when a certain amount of sand is dumped anywhere in front of the coast, not too far offshore. Due to natural processes, this sand will be transported in both longshore and cross-shore directions and it will be distributed along the coast. This sand transport is called the sand engine and it is supposed to result in a gradual nourishment of the coast. The first pilot projects with the sand engine are being planned at this moment.

Soft defences (zachte kustverdediging)
Soft coastal defences are flexible and will change over time due to the sand transporting capacities of water and wind. Examples are dune extensions and beach nourishments.

Surfzone (brekerzone)
The surf zone (or breaker zone) is the nearshore zone between the outermost breaker bars and the area of wave uprush at the beaches. This zone is supposed to be located in general between 2 m -NAP and 7 m -NAP.

Upper shoreface (ondiepe kustzone)
The upper shoreface refers to the part of the seabed that is shallow enough to be agitated by daily wave action [Wikipedia, 2008]. The upper shoreface is supposed to be located 7 m -NAP and 13 m -NAP.

Welfare impacts (welvaartseffect)
Welfare impacts comprise both monetary and non-monetary impacts that are due to economic, social and environmental changes caused by the project to be considered. These impacts concern the welfare of the society.

Appendices

A Spatial & socioeconomic developments

In order to predict the spatial developments of the next two centuries, two methods can be applied. The first one is an exploration of historic developments and an extrapolation of these developments into the future. On the other hand, spatial developments can also be deduced from expected socio-economic developments. However, both methods appear to result in unrealistic and uncertain predictions. Finally, the layer approach will be introduced to determine how spatial developments and socioeconomic developments should be included in this study.

A.1 History of spatial development

One can use a historical viewpoint and try to make some extrapolations on future spatial developments based on the developments of the past centuries. This method might give some insights in the changes that are possible on a time-scale of centuries. However, it is very questionable whether the growth rate of the past centuries will be applicable for future developments too. The limited amount of room available in the Netherlands is forcing policy planners (national, regional and local authorities) to develop more efficient plans for the scarce space left. Moreover, in the past centuries the Netherlands were subjected to the forces of the sea and some parts were lost and (partly) reclaimed again. This process is not very likely to happen in the future and does not fit within the scope of this project, since it is supposed that the present safety levels will be preserved and no land will be lost to the sea. So this method does not account for discontinuities in developments through time.

However, to give an impression of the possible changes during several centuries, some (historical) maps are presented below.

Figure 33: The Province of Holland in the 'Republic of the seven united Netherlands', 1559-1608 [Wikipedia, 2008].

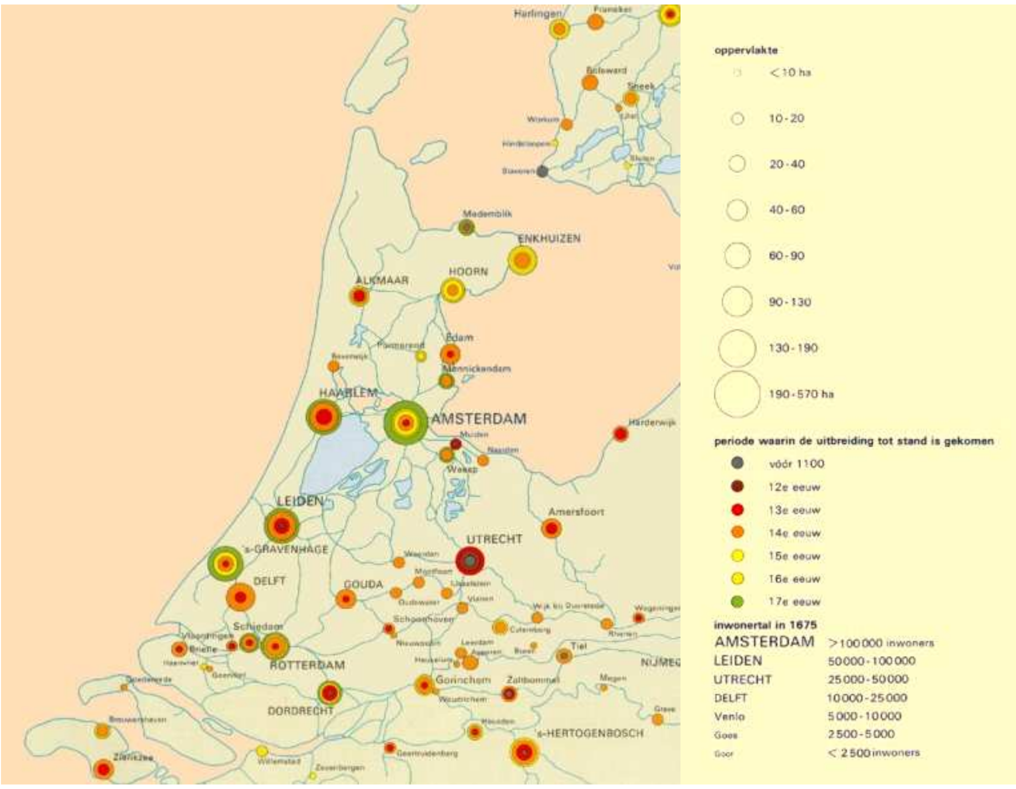


Figure 34: Development of the cities in Holland up to 1795, the Batavian Republic era [Atlas van Nederland, 2008].

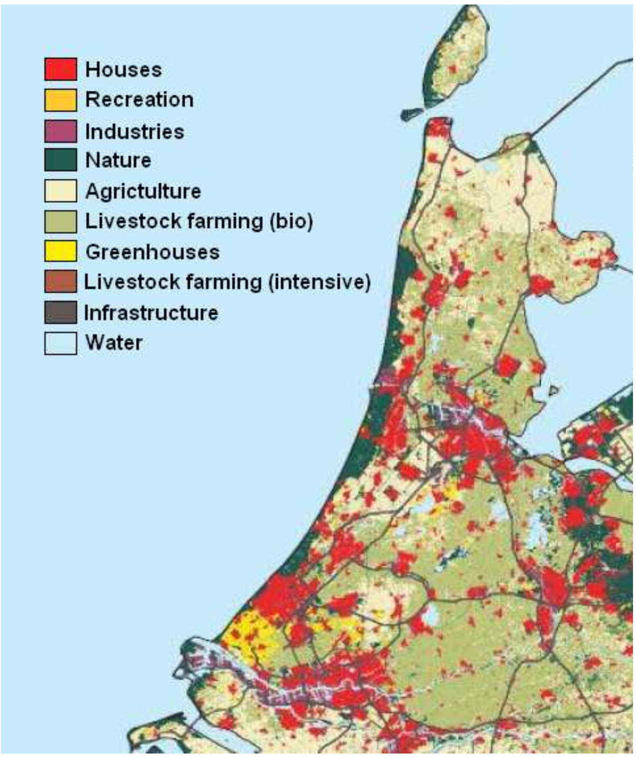


Figure 35: Present (2007) spatial structure in the provinces of Noord-Holland and Zuid-Holland in the Netherlands [MNP, 2007].

A.2 Extrapolating spatial development predictions

Another possibility to predict the spatial developments within the study area is to use predictions set up by the national planning agencies. In 2006 the three main planning agencies in the Netherlands (Centraal Planbureau, Milieu en Natuur Planbureau, Ruimtelijk Planbureau) presented a scenario analysis for the socio-economic situation in 2040 (called 'Welvaart en Leefomgeving' in Dutch). A disadvantage of this study is that they only predict values for up to 40 years ahead. But since these predictions appear to be the best available input for long-term spatial developments, they will be presented and extrapolated in this appendix.

This study [Janssen e.a., 2006] distinguishes four different socio-economic scenarios, which correspond to the SRES scenarios developed by the IPCC [IPCC, 2000]. The IPCC developed these scenarios in their special report on emission scenarios. The scenarios in the Dutch study comprise two directions on change: whether developments will be mainly international or national and whether they induce developments in mainly the public of private area (Figure 36). These scenarios are subsequently translated in some predictions for the general developments of the Dutch society (Table 17).

Figure 36: Socio-economic scenarios for the development of the Netherlands [Janssen e.a., 2006].

Table 17: Predicted developments of population and welfare as presented in [Janssen e.a., 2006].

		Global Economy		Strong Europe		Transatlantic Market		Regional Communities	
	2002 (2001)	2020	2040	2020	2040	2020	2040	2020	2040
Population [mln]	16.2	18.0	19.7	17.6	18.9	17.0	17.1	16.5	15.8
Households [mln]	7.0	8.7	10.1	8.1	8.6	8.0	8.5	7.4	7.0
GDP per capita (2001 = 100)	100	na	221	na	156	na	195	na	133

Note: na = not available

Based on these socio-economic scenarios, predictions are developed on the spatial claims needed for living, working, recreation and nature. Both the socio-economic scenarios and these spatial predictions are given for three separate regions: the Randstad (Holland and Utrecht), the transition zone (Noord-Brabant, Gelderland and Flevoland) and the remaining part of the Netherlands. Here, we will focus on the developments in the Randstad. For this region, spatial claims are predicted for the period 2000-2020 and for the period 2020-2040 (Table 18). Based on the assumption that the trends of decreasing growth showed by these predictions will continue, extrapolations are made for the spatial claims for built-up area (living, working and recreation) for the period up to 2200 (Figure 37). Since these extrapolations are very uncertain, an uncertainty range is indicated in Figure 37. The upper and lower boundaries of this range are indicated by the continuation of respectively the highest and lowest growth rate predictions for the 2020-2040 period.

Subsequently, these extrapolations are integrated in Figure 38. All the extrapolations start at a present built-up area of 139,000 ha in the year 2000 [Knol e.a., 2004]. Figure 38 also contains information on the historic development of the built-up area in the Randstad over the past century. This past development is interpolated from the built-up area figures of 1900 and 2000 for the Randstad [Knol e.a., 2004] by applying the growth rates derived from the built-up area in the Netherlands in 1900, 1950, 1960, 1970, 1980, 1990 and 2000 [Knol e.a., 2004] [Kramer & Knol, 2003].

Table 18: Predicted spatial claims (x1000 ha) for the different socio-economic scenarios [Janssen e.a., 2006].

Function	Global Economy		Strong Europe		Transatlantic Market		Regional Communities	
	2000-2020	2020-2040	2000-2020	2020-2040	2000-2020	2020-2040	2000-2020	2020-2040
Living	24	20	16	11	15	9	8	-2
Working	11	6	5	3	7	0	2	-3
Recreation	17	9	13	7	12	2	9	0
Nature	26	0	31	0	22	0	22	0

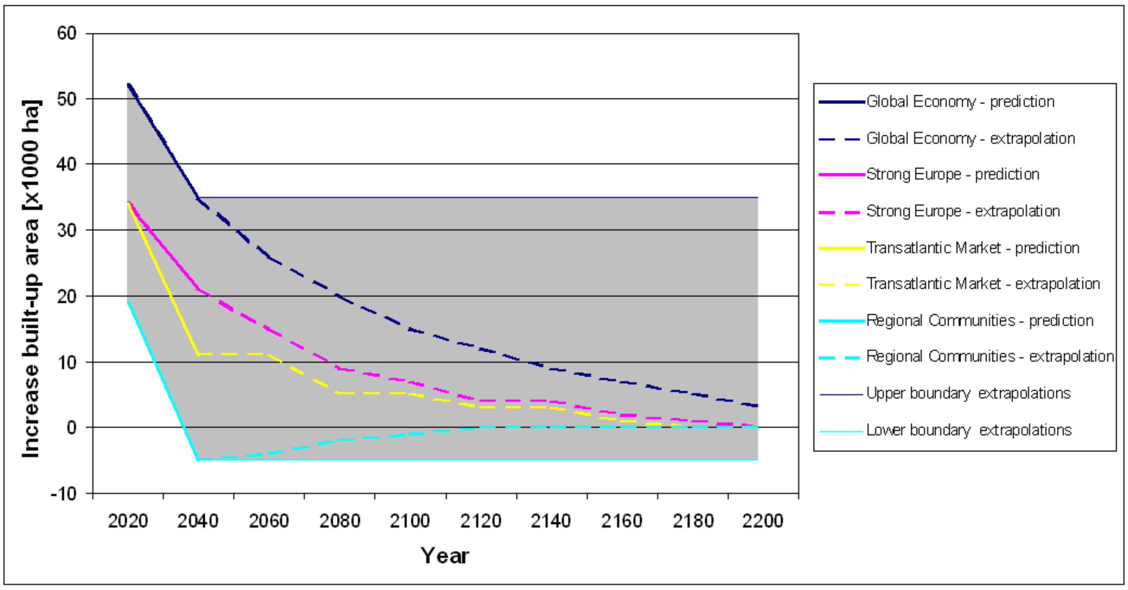


Figure 37: Extrapolations for the development of the spatial claims for built-up area in the Randstad region over the next two centuries, based on the predictions in Table 18. The grey area represents the uncertainty range surrounding the extrapolated values.

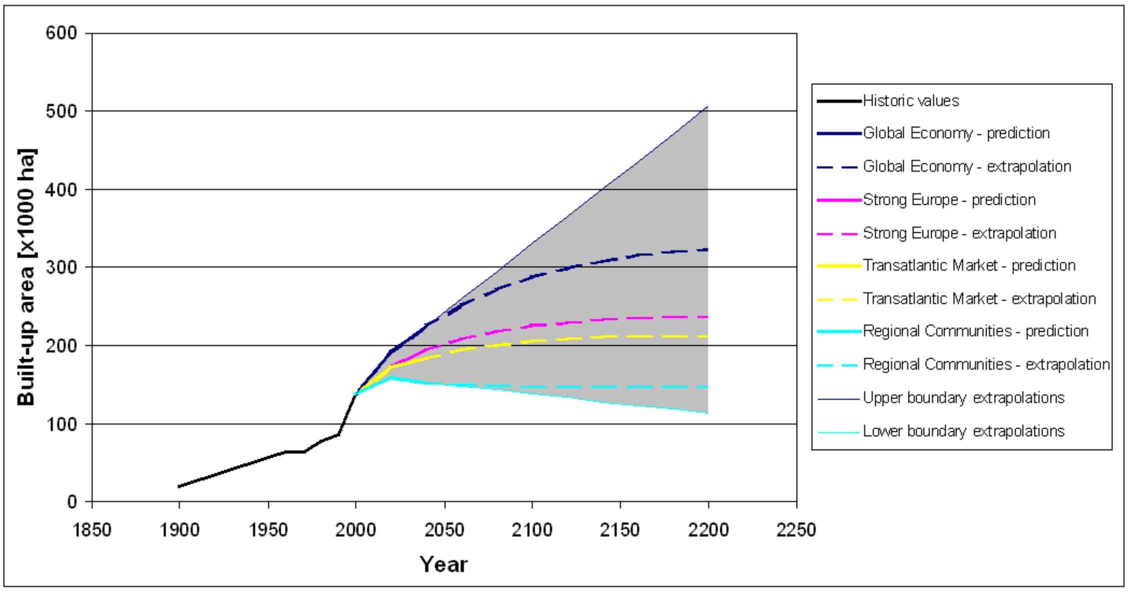


Figure 38: Extrapolations for the development of the built-up area in the Randstad region, based on the extrapolated spatial claims in Figure 37. Again, the uncertainty range is included by drawing a grey envelope. Moreover, the black line represents the past development of the built-up area in the Randstad region.

The predictions show a smoothing trend in the development of the built-up area. The highest growth rates occur in the first two decades. Growth in the second period of twenty years is lower (for the regional communities scenario even negative) and this trend is extrapolated to the remaining period. However, the extrapolated developments seem to be rather unrealistic. Since the space available for these developments is scarce in this region, policy planners want to increase the density of existing infrastructure and urban areas [Cramer, 2007]. This trend is only shown by the regional communities scenario and partly by the transatlantic market scenario.

Moreover, the extrapolations show a large uncertainty in the predicted built-up areas (see the grey area in Figure 38). This uncertainty is already large for the predicted time span up to 2040: the growth of the built-up area for the global economy is predicted to be more than 6 times larger than the predicted value for the regional communities scenario. And these uncertainties just increase for the extrapolated period. Based on these results, it is concluded that the extrapolations for the spatial development to be expected over the next two centuries are unreliable and do not have any significance.

A.3 The layer approach

From the reflections in the previous two sections, it is concluded that it is impossible to give any predictions on the socio-economic developments and the resulting spatial developments over the next two centuries. Therefore, socio-economic developments will not be included in this study as being boundary conditions (in contrary to the climate change impacts that will be included as being boundary conditions) and another approach is needed to include these developments.

Spatial planning in the Netherlands is structured with the layer approach concept. This approach is introduced in the last policy document on spatial planning of the Dutch government [Min VROM, Min LNV, Min V&W & Min EZ, 2005]. The layer approach represents the landscape by three interacting layers: surface, networks and occupation (Figure 39). Coastal defences are part of the surface layer, together with geological features of the bottom, the surface waters and the biotic system.

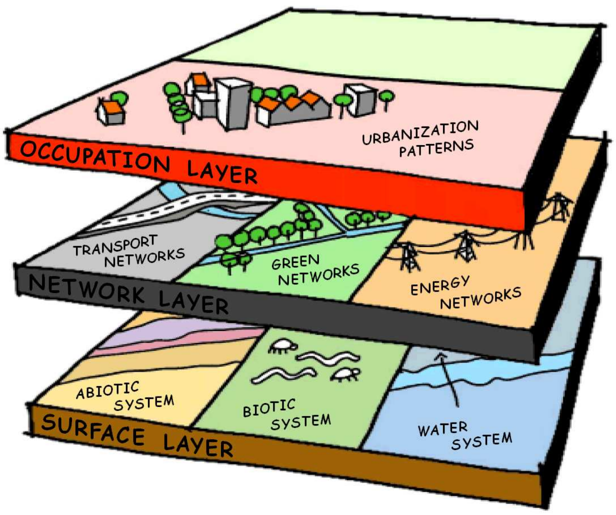


Figure 39: Schematic representation of the spatial layer approach.

In the layer approach, the qualities of the surface layer and (subsequently) the network layer create boundary conditions for the developments in the occupied layer. At the same time, the three layers do interact significantly and no single layer could be appointed as most important for spatial planning policy. When applying the layer concept, it is important to account for this interdependency and the dynamics between the three layers.

A second characteristic of this approach is the temporal scale related to each layer. Features in the surface layer could be characterised by lifetime of 100 up to 500 years, networks in the middle layer do have lifetimes of 50 up to 100 years and structures occupying the upper layer of 25 up to 50 years [Hagens, 2006].

From the layer approach, it follows that any (future) spatial development will certainly need a solid 'infrastructure' in the surface layer. The surface layer (together with the network layer) provides the basis for developments in the occupied layer.

This approach indicates that socio-economic and inherent spatial developments no longer are boundary conditions for the development of coastal defences (surface layer). On the contrary, spatial developments in low-lying areas can be considered to be a result of (integrated) coastal management, since coastal management impacts in the surface layer. At the same time, there are some interactions between the upper and lower layers, since a need for spatial developments will stimulate improvements of the infrastructure in the surface layer.

Based on the layer approach, spatial developments will not be included in scenarios indicating the future needs for coastal protection. Spatial developments will be considered as a result of the coastal management strategies to be developed and will be part of the analysis of the effects related to different coastal management strategies instead of being boundary conditions for the development of these strategies.

B Scientific climate change scenarios

This appendix reviews the scenarios for the effects of climate change provided by scientific institutes.

B.1 Intergovernmental Panel on Climate Change

According to the IPCC's last report, the 4th Assessment Report [IPCC, 2007], human influences have very likely contributed to sea level rise during the latter half of the 20th century and have likely contributed to changes in wind patterns. Moreover, continued greenhouse gas emissions at or above present emission rates would cause further warming and would lead to further changes in global climate systems in the 21st century which would very likely be stronger than the changes observed during the 20th century.

The IPCC applies different emission scenarios (Figure 40), as presented in the Special Report on Emission Scenarios [IPCC, 2000]), each leading to different estimates for climate changes and sea level rise (Table 19) at the end of the 21st century. These predictions include the global effects of thermal expansion due to warming of the oceans, melting of glaciers and ice caps and the disintegration of the Antarctic and Greenland ice sheets.

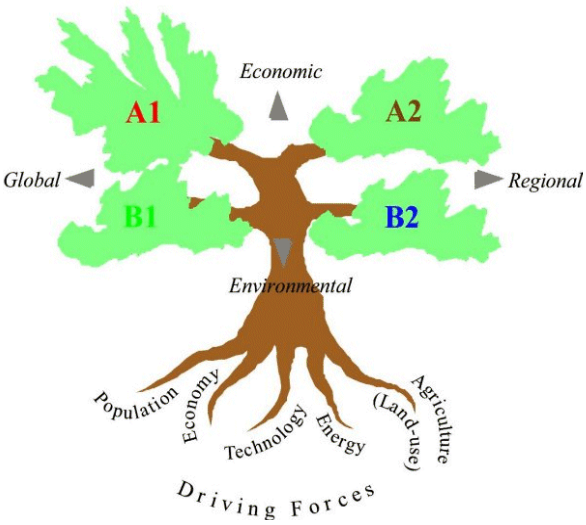


Figure 40: Emission scenarios and driving forces indicated by the IPCC's special report on emission scenarios [IPCC, 2000]. Within scenario A1, three story lines are distinguished based on the applied energy sources: fossil intensive (FI), non-fossil energy sources (T) and a balanced use across all energy sources (B).

Table 19: IPCC global sea level rise predictions for several emission scenarios [IPCC, 2007]

Scenarios for 2099	Sea level rise [m]
B1	0.18 - 0.38
A1T	0.20 - 0.45
B2	0.20 - 0.43
A1B	0.21 - 0.48
A2	0.23 - 0.51
A1FI	0.26 - 0.59

Still, the ultimate sea level rise would be much larger than those values calculated for the 21st century. Thermal expansion and melting of ice sheets would continue for many centuries, even if concentrations of greenhouse gasses would stabilise.
No specific values or best estimates are predicted for the effects of climate change within the next two centuries, since knowledge on some important factors driving sea level rise is lacking (like future rapid and dynamic changes in ice flow and the melting of ice sheets). However, bandwidths in this new IPCC report are smaller than in the previous edition, since the quality of estimates on thermal expansion of sea water and melting of ice sheets is improving [KNMI, 2007]. These uncertainties are also the reason for the fact that it is not yet possible to predict the exact development of sea level rise over time, which might deviate from the currently assumed linear growth for sea level rise.

B.2 Royal Dutch Meteorological Institute (KNMI)

The Royal Dutch Meteorological Institute is one of the leading institutes studying the local effects of global climate changes for the Netherlands. In 2006 they presented their predictions for sea level rise in the eastern part of the Atlantic Ocean and for wind speeds in the North Sea area [KNMI, 2006]. Their study led to the definition of four scenarios for sea level rise along the Dutch coast (Table 20). Although, storms from the north-west are also very important for storm surge levels and wave heights along the Dutch coast, no specific expectations are formulated on this issue.

Table 20: KNMI sea level rise predictions for the Dutch coast [KNMI, 2006].

Scenarios for 2100	Sea level rise [m]
Lower scenario, limited sensitivity sea level rise	0.35
Lower scenario, sea level highly sensitive	0.60
Higher scenario, limited sensitivity sea level rise	0.40
Higher scenario, sea level highly sensitive	0.85

In the 'Nederland Later' study [MNP, 2007] these values for sea level rise are linearly extrapolated, which induces that expected values of sea level rise for the year 2200 are varying between 0.7 and 1.7 m.

These figures show some differences compared to the predictions made by the IPCC. The maximum sea level rise estimates are somewhat higher. These differences can be explained by the contribution of increased melting of ice sheets and regional differences in sea level rise due to thermal expansion which are both included in the KNMI predictions. These contributions were not included in the IPCC predictions.
In the north-eastern part of the Atlantic Ocean, sea level rise caused by thermal expansion of the water may be up to 15 cm higher than the global averaged value. The contribution of the melting of the Greenland and Antarctic ice sheets is extrapolated based on a relatively short observatory database and is predicted to be about 10 to 20 cm. However, these values are highly uncertain because of the short time span of the observations and the unpredictable behaviour of the melting and disintegration of these ice sheets [KNMI, 2006] [Katsman & Van den Hurk, 2007].

Moreover, no increases in storm surge levels and wave heights are predicted. This is due to the fact that the KNMI only predicts changes in wind patterns. The translation into water related parameters, is no part of their expertise. At the same time, the extrapolation of wind patterns for the Dutch situation does not show any change that could be induced by climate changes. Extreme wind strengths and prevailing wind directions are not expected to change significantly, in contrary to the expected changes in (for example) the southern regions of Europe. So for the situation in the Netherlands, the extreme storms that are used at present are also applicable for future projections. Next, wind patterns are very unpredictable so an extrapolation to long term extremes (for sake of the coastal protection, one needs extremes that occur only once in several thousands of years) will contain a very large uncertainty range. It is expected that these uncertainties will largely exceed any probable effect of climate change on wind patterns [Katsman & Van den Hurk, 2007].

More information on the uncertainties in predicting winds and storm surges and on the statistical presence of superstorms could be found in the dissertation of Van den Brink [Van den Brink, 2005].

B.3 Environmental and Nature Planning Agency

The study on the future of the Netherlands by this national planning agency [MNP, 2007] presents a sea level rise prediction based on past evidences. It states that there is geological evidence that a temperature rise exceeding values of about 2 to 2.5 ^oC incurred a total sea level rise on the northern hemisphere of about 4 to 6 metres in the past. The averaged sea level rise per century used to be about 1.5 metre at that time. This rate occurred under a situation that resembles the present situation concerning the amount of ice masses on the planet. It should be noted that the historic value of sea level rise due to melting and disintegration of the Greenland and Antarctic ice sheets (a major uncertainty in the KNMI predictions) is included in this rate. There were also periods in the past when rates of sea level rise were still higher. However, this occurred at times when ice sheets were much larger than nowadays [Katsman & Van den Hurk, 2007].

According to this material, a worst case scenario could be defined with a sea level rise of about 1.5 m per century. However, the probability that this scenario will become reality is very small since it is based on a strong increase of the melting of the Greenland and Antarctic ice sheets, which is supposed to be unlikely.

B.4 Vermeersen

Absolute values of sea level rise show large differences all over the world. According to Vermeersen, gravitational effects and post-glacial elevation of landmasses (among others) cause these differences [De Pater & Katsman, 2007].

Gravitational effects are caused by the fact that large land and water bodies attract other masses. The melting of the Greenland ice sheet, for example, will cause an averaged worldwide sea level rise (the so-called eustatic value). However, the induced sea level rise will be stronger at the southern hemisphere than in the regions closer to this ice mass due to the loss of attractive forces of this melting ice-body. In case of Greenland, this means that the worldwide averaged sea level rise of 7 metres is reduced to a sea level rise of about 2 metres for the Dutch coast due to the gravitational effect.

Next to that, the raising water levels along the Dutch coast will increase the pressure on our continental shelf. Due to this effect, the sea bottom and the coastal regions of the Netherlands are descending. This downward movement goes along with an upward movement of the southern and eastern part of the Netherlands.

Both these effects are very important for local expectations on the sea level rise due to climate changes. At one side, the gravitational effect will lower the absolute sea level rise faced at the Dutch coast compared to the global averaged value. At the same time however, the subsidence of the coastal area will increase relative sea level rise at the Dutch coast.

The climate change scenarios as presented by the KNMI do not incorporate these post-glacial elevations since they are strongly depending on other, locally determined variables like changes in ground water levels and local gas extractions. The more general gravitational effects are not yet included in the scenario-values for sea level rise, nonetheless these effects will be studied soon [Katsman & Van den Hurk, 2007]. The IPCC scenarios for sea level rise also ignore these effects since they present global changes in stead of local variations.

B.5 Attention for Safety

The research program Attention for Safety (Aandacht voor Veiligheid in Dutch) facilitates several studies on the long-term effects of climate change, spatial planning, governmental changes and socio-economic trends on the safety of the Netherlands concerning flood events. Goal of this study is to develop a discussion (not decision!) supporting system consisting of maps and pictures showing the possibilities to make our spatial infrastructure climate proof on the long term [AVV, 2007].

Part of this project is the study ‘Extreme sea level rise and major coastal cities’ [Naples & Aerts, 2007]. This study contains a summary of predicted climatic effects that are considered in local policy statements of major coastal cities around the world. The sea level rise predictions according to these scenarios show a large divergence both for geographical distant locations as for some locations on their own. This is the same for expected increases in storm surge levels, which are found for some locations.

C Policy climate change scenarios

This appendix reviews the scenarios for the effects of climate change as they are provided by policy planners. These scenarios are derived from the scientific predictions for climate change effect and are translated to a format useful for developing plans for improving coastal defences for example.

C.1 Technical Advisory Committee on Water Defences

In the manual for assessing sandy coasts, this Technical Advisory Committee on Water Defences presents three climate change scenarios for the year 2200: minimum, intermediate and maximum [TAW, 2002]. The values of these scenarios (Table 21) are determined by a special working group on coasts and are based on several studies of the IPCC, RIKZ and the Commission on Water Management in the 21st century (WB21) for example. It is also stated that the tidal high water levels will increase faster than the average sea level rise with an additional speed of about 5 cm/century. These changes in tidal water levels are largely induced by direct human interferences in the system (like building barriers and creating polders) and are therefore not included in the climate change scenarios.

Table 21: Predicted effects of climate changes for three scenarios according to the TAW [TAW, 2002].

Scenarios	Relative sea level rise [m]	Increase in storm surge level [m]	Increase in wave height [%]
Minimum			
- 2050	0.10	-	-
- 2100	0.20	-	-
- 2200	0.40	-	-
Intermediate			
- 2050	0.30	-	-
- 2100	0.60	-	-
- 2200	1.20	-	-
Maximum			
- 2050	0.45	0.40	5
- 2100	0.85	0.40	5
- 2200	1.70	0.40	5

Included in these predictions for sea level rise is the subsidence of the coastal areas in the Netherlands. So these values represent relative sea level rise, where other predictions (IPCC, KNMI) describe absolute sea level rise related to a fixed level. The topic of subsidence is elaborated in appendix D.

C.2 Strategic vision Holland coast 2050

In 2002 the provinces of Noord-Holland and Zuid-Holland presented a strategic vision on the development of their coasts up to 2050 [Smolders e.a., 2002]. This policy document presents some expected values and bandwidths of the relevant climate change effects (Table 22).

Table 22: Expected values and bandwidths for climate change effects up to 2100 according to the strategic vision for the Holland coast [Smolders e.a., 2002].

Scenarios for 2100	Relative sea level rise [m]	Increase in storm surge level [%]	Increase in wave height [%]
Expected value	0.50	0	0
Bandwidth	0.20 - 1.00	+/- 10	+/- 5

Moreover, in this document wave directions are supposed to change within a bandwidth of +/- 1 degree per century and tidal amplitudes are expected to increase by 10% with a bandwidth of 5% up to 20%. Altogether, extreme high water levels are supposed to increase by 0.40 m, with a bandwidth of 0.20 to 1.00 m for the next century.

D Subsidence

The scientific climate change scenarios all predict absolute values of sea level rise. However, bottom subsidence of the coastal areas in the Netherlands should be added to these absolute values in order to calculate the relative sea level rise compared to the level of the coastal defences.

However, bottom subsidence in the Netherlands is very location-specific since there are various processes determining the rate of subsidence. In the first place there is the post-glacial (or isostatic) rebound of landmasses due to the vertical movement of Pleistocene sand beds and older bottom layers. This process is caused by the rise of land masses that where depressed by the weight of ice sheets during the last glacial period. Next, the rise of the sea level faced by the melting of these ice sheets increased the water depths in the seas and depresses coastal areas. This process causes a tilting of the Netherlands along the line Emmen-Bergen op Zoom and induces a subsidence of about 7 to 8 cm per century of the north-western part of the Netherlands (Figure 41) [Werkgroep Klimaatverandering en Bodemdaling, 1997] [TAW, 2002].

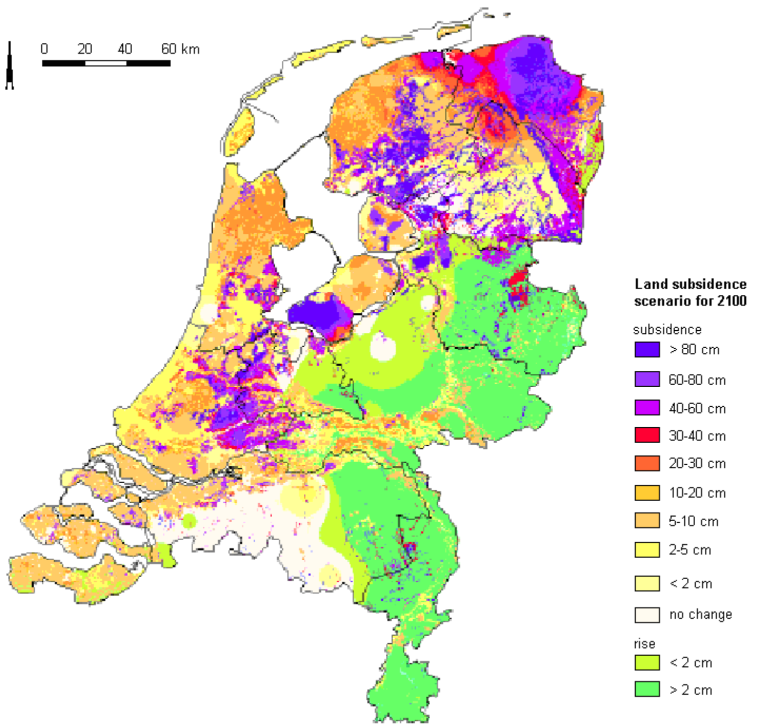


Figure 41: Predicted subsidence rates (including both post-glacial elevation and anthropogenic influences) for the 21st century [Min V&W, 2003].

Next to the post-glacial elevation, there are anthropogenic processes increasing bottom level descent. Subsidence due to gas extraction and extraction of other materials may induce local subsidence of several decimetres per century. However, along the Holland coast only one minor extraction area is found at Bergen. This gas extraction causes a small local increase of the subsidence rate near the Hondsbossche and Pettemer sea defences [Hoogheemraadschap Hollands Noorderkwartier, 2008].

On the contrary, lowering of ground water levels is widely practised within the study area. Embanking and draining polders has initiated a land subsidence process, which is expected to persist in the future. Oxidation and compaction of peat above the (lowered) ground water levels causes head-loss. Meanwhile, the input of new sediment, a natural process for heightening areas in river deltas, is impossible due to the embankments. These processes form important land subsidence parameters in the hinterland of the coastal defences in the study area. Exact values of this subsidence are restrained to specific locations and could be up to 1 metre per century. Moreover, Figure 42 shows that expected subsidence rates due to land drainage are negligible in the coastal zone itself [Van der Meulen e.a., 2007]. So subsidence of coastal defences (dunes and dikes) due to anthropogenic influences is negligible, except for the Hondsbossche and Pettemer sea defences.

So in the end, it is concluded that only land subsidence due to post-glacial elevation is of interest when considering the future safety of the majority of the coastal defences within the study area. This is in line with the conclusions of Van Koningsveld [Van Koningsveld, 2004]. The subsidence rates connected to this process are about 7 to 8 centimetres per century, so in 200 years one should account for a subsidence of about 15 cm. Note that the predicted subsidence in position of the Hondsbossche and Pettemer sea defences (dikes) is somewhat higher (Figure 41). This is caused by the increasing weight of the dike when it is improved and by local gas extraction. Local subsidence rates are estimated at about 20 cm per century [Onderwater, 2005] [Hoogheemraadschap Hollands Noorderkwartier, 2008]. It should be noted that these values are not general applicable for the entire Dutch coast.

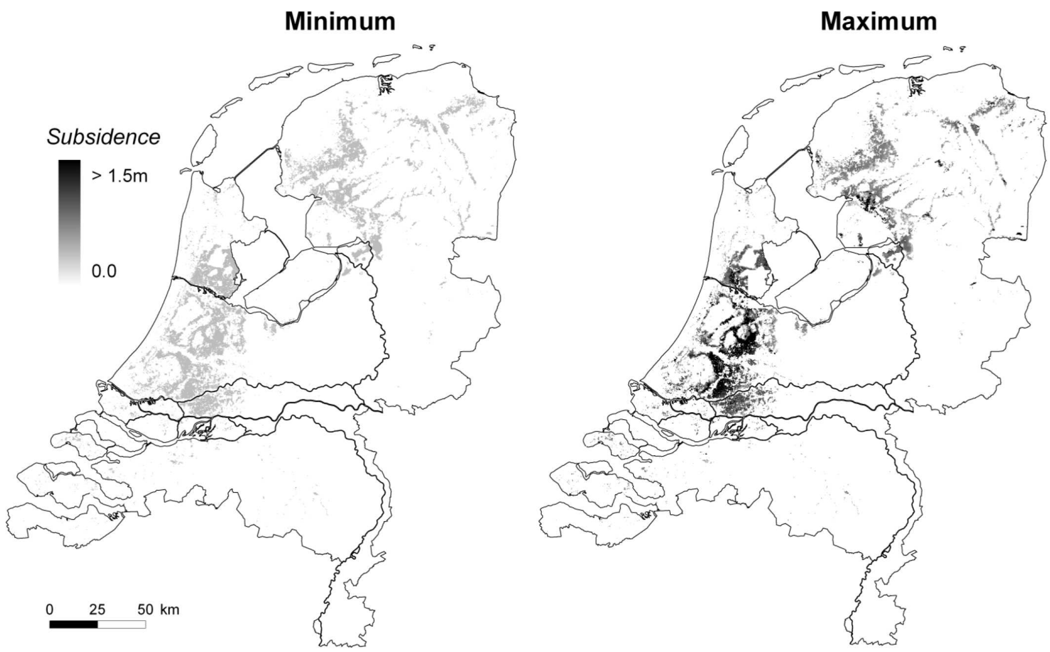


Figure 42: Subsidence associated with land drainage, caused by a century of modelled peat oxidation and compaction in two scenarios. The minimum scenario is the response to a uniform initial, unadjusted unsaturated zone of 50 cm. The maximum scenario has the same starting point, but includes a two-yearly adjustment of the level of the unsaturated zone to subsidence [Van der Meulen e.a., 2007].

E Safety assessment directives

This appendix contains a short explanation on the framework for flood defence safety assessment as defined by the Manual for Assessing the Safety of Primary Flood Defences 2006 [Min V&W, 2007].

E.1 Applicability of the manual

The Law on Water Defences (Wet op de Waterkering) states that updates of the safety in the Netherlands concerning possible flooding caused by high water sea- and river water levels should be made every five years. For this assessment, the hydraulic engineering of all primary flood defences should be considered. In order to facilitate a uniform national assessment framework, this manual states how to carry out this assessment and how to present the results.

This manual is meant exclusively for assessing the safety against flooding of dike ring areas as provided by primary water defences. No other functions than the safety function of the primary flood defences are assessed by the activities described in this manual.

Together, this manual and the Hydraulic Boundary Conditions for Primary Flood Defences Document for the third assessment period 2006-2011 (Hydraulische Randvoorwaarden 2006), present the device for these assessments. Both documents prescribe separate, legally binding instruments for evaluating primary flood defences, based on researches, reports and manuals of the Expertise Network on Water Safety (Expertise Netwerk Waterveiligheid, previously called Technische Adviescommissie voor de Waterkeringen). Some recent insights presented in the Technical Report on Dune Erosion published by the Expertise Network on Water Safety [ENW, 2007], are also included in this manual.

E.2 Categories in primary flood defences

The primary flood defences in the Netherlands are divided in four categories. This separation is based on the importance of the flood defences for limiting flood risks.

Category ‘a’ primary flood defences are part of the flood defence systems surrounding dike ring areas and prevent these areas from being flooded by outer water. These flood defences could also comprise high grounds. Outer water is generally defined here as seas, large lakes and large rivers. These systems could also comprise high grounds. The location of the flood defences within this category are showed in Figure 43. As can be seen, all flood defences relevant for this study are part of this category (except for the locks at IJmuiden).

Category ‘b’ primary flood defences are located in front of dike ring areas or are connecting two dike ring areas. These defences should also control the probability of flooding by outer water. The locks at IJmuiden are part of this category.

Primary flood defences in category ‘c’ are part of the flood defence systems surrounding dike ring areas (just like category a flood defences) but prevent these areas from being flooded by water not being outer water. Examples are flood defences along smaller lakes and rivers.

Category ‘d’ comprises all flood defences described by one of the three previous categories, however they are located abroad.

Figure 43: Primary flood defences of category 'a' in the Netherlands [Min V&W, 2007].

The next step within the manual is to select some cross sections of the (coastal) defences. In order to limit the amount of cross sections to be studied, some critical cross sections should be selected. This could be done since the weakest cross sections will be decisive for the safety of the area protected. Once the weakest link will collapse, the entire dike ring area will be flooded and the safety level of the remaining coastal defences are of minor importance. This selection often takes place by selecting some cross profiles representative for larger stretches of the flood defence to be assessed. However, this study aims to inventory the future weak links in the coastal defences, so the entire length should be studied instead of a selection of the weakest links or several profiles representative for larger stretches.

The assessment of both category a and category b flood defences is not very different. Moreover, the locks at IJmuiden will not be assessed in this study. The coastal defences that will be assessed consist of dunes and dikes, so the next two sections are dedicated to the parts of the manuals describing assessment procedures for category-a dunes and dikes (and dams).

E.3 Assessing dunes

Dunes are defined as naturally formed sandy structures forming more or less continuous flood defences along the coastline. Their strength is deduced from the amount of sand in their body and their geometry. Both these characteristics are variable in time, due to erosion and accretion caused by hydraulic forces (high water levels, waves and flowing water) and eolian forces (wind). Vegetation might stabilize dunes and support accretion. However, these changes of dune morpholgy over time are difficult to include in calculating erosion lines for extreme storms. For assessing the safety of dunes, the present ouline, as measured during the annual JARKUS profile measurements, is applied. In order to compensate for some of the (future) uncertainties, additional erosion volumes are added to the erosion caculcations.

This section will focus on the mechanisms of failure concerning flood protection by dunes, the assessment method and the influence of connecting structures between dunes and dikes. It should be mentioned that this text does not represent all information from the manual, however the information relevant for this study is included.

E.3.1 Mechanisms of failure

During heavy storms, dunes are being exposed to high water levels, high waves, increased currents and the wind itself. The combination of these loads may cause the dunes to erode. In this case, the sand eroded from the dunes will settle down in front of the coast at deeper water. The result is that both the toe of the dune and the dunefront will migrate landward. The part of the dunes that is eroded, is called the erosion volume and the erosion line is located at the calculated erosion points.
Moreover, during storms the landward side of the dunes might also be exposed to serious wind erosion. This will decrease the amount of sand available for retaining the seawater. Next to that, there might be some structures (e.g. buildings, cables, pipelines) present within the dunes, dedicated to other functions than retaining water. These structures could influence the strength of the dune. For both effects it should be investigated whether the strength of the dune is influenced negatively. The assessment scheme below shows the interaction between these three assessment criteria.

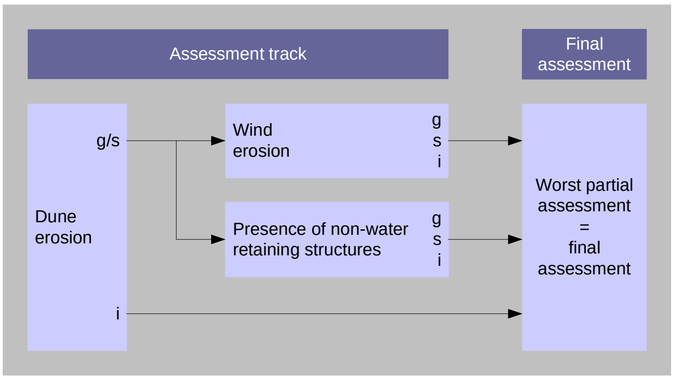


Figure 44: Process scheme for the assessment of the safety of dunes (g = good, s = sufficient, i = insufficient) [Min V&W, 2007].

However, assessing wind erosion and the effets of other, non-retaining structures in the dunes is a specialist activity and the effects will be small compared to the calculated dune erosion caused by extreme hydrodynamic circumstances (water levels, waves and currents). Therefore, this studie only applies the dune erosion assessment in order to develop some insight in the possible locations of future weak links in the coastal defences.

E.3.2 Assessment

How to assess the dune erosion is schematised in Figure 45. Five steps are distinguished within this process.

Step 1:
In the first step of the assessment the presence of other structures within the cross profile should be studied. When structures are present protecting the toe of the dune, one should go on with step 2. When other structures like boulevards or other paved constructions are present, one should go on with step 5. If no structures are present in the cross section, step 3 is the next step to accomplish.

Step 2:
For (parially) protected dunes (dunes with a revetment at the seaside), it should be investigated whether the protective structure is strong enough to withstand the critical circumstances. In case of a positive result of this investigation, the protecting effect of this structure should be included in the erosion calculations of the dunes. This should be done in step 4. In case the protective structures are found to fail under the critical circumstances, step 5 is the next step in the safety assessment of the concerned cross profile.

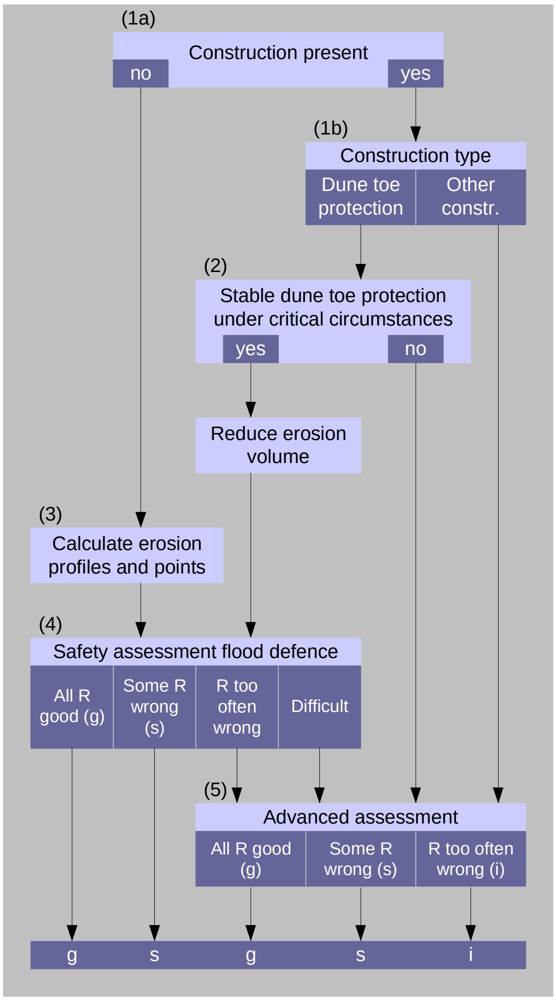


Figure 45: Assessment process for dune erosion (g = good, s = sufficient, i = insufficient) [Min V&W, 2007].

Step 3:
For the selected, unprotected cross sections erosion calculations should be done within this step. Based on the procedures elaborated in the Technical Report for Dune Erosion [ENW, 2007], calculations of the erosion profile under critical circumstances will result in future erosionpoints (for the present assessment period the future is limited to 2011). These points represent the new dunefront after a critical storm event when serious dune erosion has occurred. More on this calculation method can be found in the next sub-section.

Step 4:
Based on the calculated locations of the future erosion points (R), the safety of the dunes could be assessed. Three situations could be distinguished:

- When all calculated erosion points over a period of 15 years (1991-2006 for example) or more are located seaward of the landward boundary of the dunes, the section is judged 'good'.
- When no more than two of these erosion points calculated over a period of at least 15 years are located landward of the dunes and when these exceedences did not occur during the last 5 years and no exceedences are expected for the period up to 2011, the sections is judged 'sufficient'.
- In all other cases (when erosionpoints are located landward of the dunes too often and when te calculation of erosion points is difficult) an advanced assessment should be set up (step 5).

Step 5:
In cases where advanced assessments are necessary, the assistence of specialists should be used. The manual does not say how these specialists should handle. Some of these problems are elaborated in the Technical Report for Dune Erosion [ENW, 2007].

E.3.3 Calculating dune erosion

The expected erosion of the dunes when storm surges occur, should be calculated with a deterministic model called DUROS. The latest version of this model, improved by contributors of the Technical Report for Dune Erosion [ENW, 2007], is called DUROS-plus. This latest version should be applied in the safety assessments described by the 2006 Manual for Assessing the Safety of Primary Flood Defences [Min V&W, 2007]. This model calculates the coastal erosion during a critical storm surge from the cross profile (foreshore, beach and dune) just before the storm. Other input parameters are the grain size (D_{50}) of the dune material, the storm surge level (h_{max}) and the wave conditions at a water depth of about 20 m below Amsterdam Ordnance Datum (NAP). The DUROS calculation model could be applied for both normal and extreme storm surge events. The outline of the coast (e.g. the presence of deep channels near to the coastline) might inhibit the applicability of the model.

This model is based on a number of basic assumptions, which form the basis of the calculation method. These assumptions are:

- During a storm surge, only the upper parts of the coastal profile will erode to form a characteristic erosion profile. Further offshore, where water depths are larger, storm surge effects on the outline of the cross section are neglected.
- The outline of the erosion profile is supposed to be a function of the significant wave height (H_{0s}) and the maximum wave period (T_p). These parameters are both measured at a seaward location with a bottom level at about 20 m below Dutch Ordnance Level.
- The outline of the erosion profile depends on the settling velocity of the sediment eroded from the dunes, measured in still sea water with a temperature of 5^o Celsius.
- The storm surge (water) level is the maximum water level that occurs during the extreme event. The outline of the erosion profile is independent of this storm surge level. However, the vertical location of the erosion profile in the dune cross section does depend on the maximum water level during the storm surge (h_{max}). H_{0s} en T_p are supposed to coincide with this maximum water level.
- The outline of the erosion profile is independent of the initial outline of the coastal defences before the storm surge, except for some complex situations that will not be mentioned here.
- The outline of the erosion profile is also independent of the angle of incidence of the waves.
- The outline of the erosion profile is independent of the remains possibly present due to the demolition of buildings or other structures (e.g. boulevards, seawalls and dune toe defences) within the erosion zone. These remains could end up in the sea.
- The dune-erosion process is schematised as a two-dimensional process. Transport in longshore direction is not included.
- The eroded sediment from dunes, beaches and other elevated areas of the cross profile is transported exclusively in seaward direction.
- The erosion profile is horizontally shifted in comparison with the initial dune profile until the amount of sand eroded equals the amount of sand deposited, both per unit width (1 m). This means that the erosion profile is shifted landward (with its x-axis at storm surge level) until the sand balance in cross-shore direction is closed. This assumption is reproduced in Figure 46.
- The duration of the maximum storm surge level is not taken into account. However, the amount of erosion will certainly depend on the pattern of the water level changes during an extreme storm surge event. The longer the peak water levels occur, the more material will erode from the coastal defences.
- Locations P and R* (Figure 46) are important for safety assessments. P is located within the original dune, where the storm surge level intersects with the equilibrium erosion profile (always at the transition point within this equilibrium profile). R* is located at the surface of the dunes where the 1:1 landward sloping line intersects the surface of the cross profile. Point R* is called the erosion point, connecting those erosion points for several cross profiles results in erosion lines.

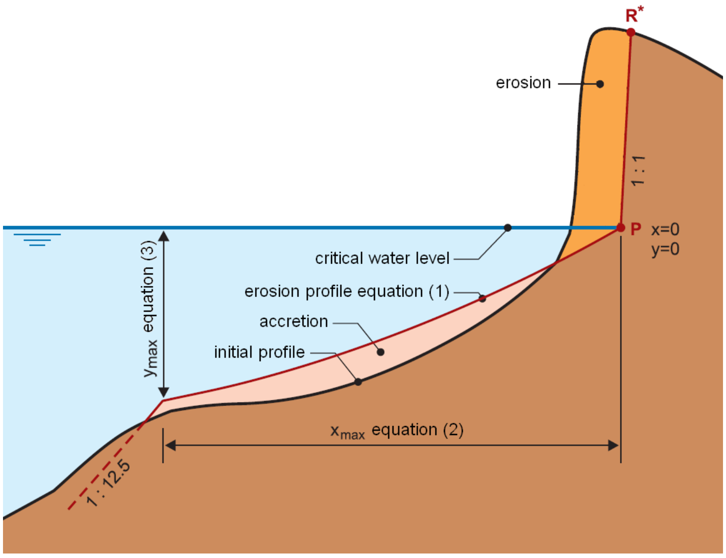


Figure 46: Erosion profile according to the DUROS-plus model [ENW, 2007].

From Figure 46 it follows that the toe of the dune after the eroding event is located at the intersect between the steep front of the eroded dune (with a slope of 1:1) and the much less sloping beach. Seaward from the new toe of the dune, the erosion profile shows a parabolic outline, which is described by the equation:

$$\left(\frac{7{,}6}{H_{0s}}\right)y = 0.4714\left[\left(\frac{7{,}6}{H_{0s}}\right)^{1.28}\left(\frac{12}{T_p}\right)^{0.45}\left(\frac{w}{0.0268}\right)^{0.56}x + 18\right]^{0.5} - 2.0 \qquad (1)$$

This parabolic shape extends to the point x_{max}:

$$x_{\max} = 250\left(\frac{H_{0s}}{7.6}\right)^{1.28}\left(\frac{0.0268}{w}\right)^{0.56} \qquad (2)$$

This results in a value of y_{max}:

$$y_{\max} = \left[0.4714\left\{250\left(\frac{12}{T_p}\right)^{0.45} + 18\right\}^{0.5} - 2.0\right]\left(\frac{H_{0s}}{7.6}\right) \qquad (3)$$

Seaward of this point, the parabolic shape becomes linear with a slope of 1:12.5 until the initial cross profile is reached.

The settling velocity of the sediment (w) as indicated in these equations is calculated with the equation:

$$^{10}\log\left(\frac{1}{w}\right) = 0.476\left(^{10}\log D_{50}\right)^2 + 2.180\,^{10}\log D_{50} + 3.226 \qquad (4)$$

The meaning of the parameters in these equations is:

H_{0s}	=	significant wave height in deep water [m]
T_p	=	wave period at the peak of the energy density spectrum [s]
W	=	settling velocity of dune sand in seawater (at 5° Celsius) [m/s]
X	=	distance from the new toe of the dune [m]
Y	=	depth under storm surge level [m]
D_{50}	=	dune sand diameter exceeded by 50% of the total sand mass [μm]

Equations (1) and (3) are only valid for storm surges with maximum wave periods within the range $12<T_p<20$ s. For periods smaller than 12 seconds, T_p = 12 s should be applied. For periods larger than 20 seconds, one should assume T_p = 20 s.

To compensate for uncertainties in the DUROS-plus model, some additional volumes should be taken into account next to the calculated erosion volumes. First, the erosion volume should be extended with an addition compensating for uncertainties both resulting from the applied model (DUROS-plus) and inherent in the prescribed storm surge duration. In order to define this additional volume, one should start with calculating the total amount of sand eroded above storm surge level (from the erosion profile calculated by DUROS-plus). This volume is said to be A m^3/m and the uncertainty compensation (volume T) accounts for 0.25*A m^3/m. The next step is to shift point R* landward over distance ΔR until the extra amount of sand between those two points equals a volume of 0.25A m^3/m (Figure 47). The length of ΔR depends on the dune configuration landward of R*. The location of the new erosion point R and the new location of P (where the storm surge level intersects with the landward end of the erosion profile) follow from this procedure.

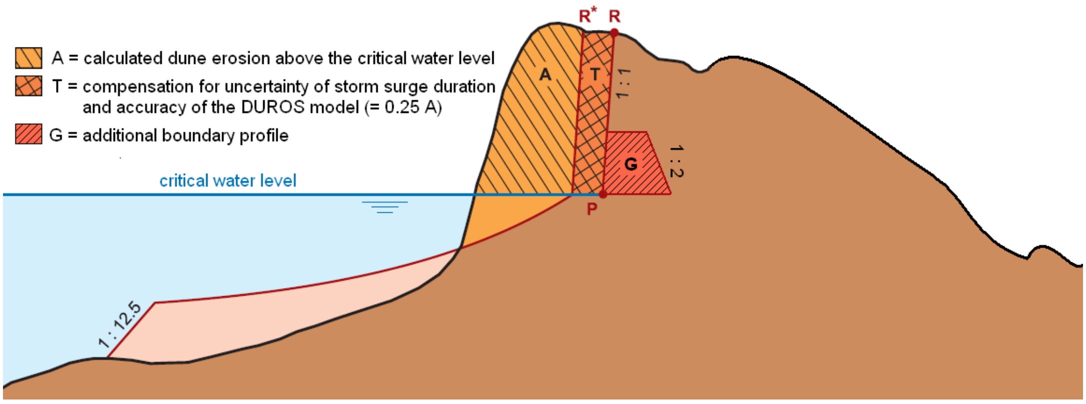


Figure 47: Cross profile of a dune section with erosion profile, additional erosion volume and boundary profile as applied in the DUROS-plus model [ENW, 2007].

Next, it is important that the calculated locations of R and P are not too close to the landward end of the dune profile. Therefore, a certain boundary profile should still fit in the cross section of the dunes landward of the erosion profiles (Figure 47). This boundary profile should prevent the hinterland from being flooded when the occurrence of the critical event erodes the entire erosion profile from the dunes. In order to prevent the dunes from a total break through, the boundary profile is characterized by some design parameters. The width of the top of this profile should be 3 m and the height of the profile (above storm surge level) should be calculated by the formula:

$$H_g = SSL + 0.12 T_p \sqrt{H_{0s}} \quad (5)$$

With:

H_g	=	height of the boundary profile [m above Amsterdam Ordnance Datum]
SSL	=	storm surge level [m above Amsterdam Ordnance Datum]
T_p	=	wave period at the peak of the energy density spectrum [s]
H_{0s}	=	significant wave height in deep water [m]

Independent of the value calculated by the equation above, the height of the boundary profile should at least be SSL + 2.5 m. Next to that, the landward slope of the boundary profile should not exceed 1:2 and the seaside slope is 1:1, as is the landward slope of the erosion profiles. Figure 48 gives an impression of the boundary profile dimensions in an eroded dune. It should be noted that some alternative shapes of the boundary profile are allowed too, when additional conditions on volume and height are met by the cross profile. (These alternative profiles will not be applied in this study, so their specifications are not included.)

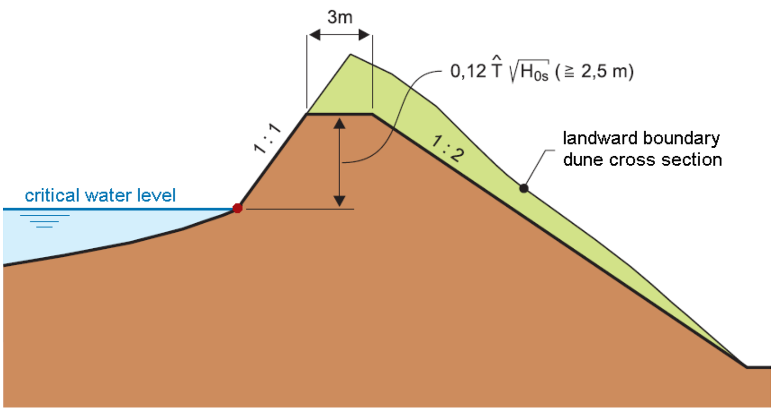


Figure 48: The boundary profile should fit in the dune cross section after a critical erosion event [ENW, 2007].

E.3.4 Connecting structures

In case of dunes, connecting structures could be found at transitions between dunes and other defending structures like dikes. Within the study area, these structures could be found at the ends of the Hondsbossche and Pettemer sea defence works. Officially, a connecting structure consists of the part of a non-natural sea defence with an adjusted cross and/or length profile, smoothening the transition into the neighbouring sea defence. Three types of connections could be distinguished:

- A dune without revetment, connected to a dike;
- A dune without revetment, connected to a dune with revetment;
- A dune with revetment, connected to a dike.

The procedure for assessing these connections resembles the procedure for assessing dunes. Since some corrections should be made for the presence of revetments and the changing cross profiles, the calculations are rather complex (comparable to the calculations for step 5 in the assessment process) and will not be explained here. However, it should be remembered that structures connecting dunes to dikes ask for a special procedure in safety assessments.

E.3.5 Point of attention

Since dunes are natural features, their position in the cross shore direction might change along the coast. As Figure 49 shows, this might cause the seawater to flow through a valley between two dunes. Since large stretches of the Dutch dunes consist of several rows of dunes located behind each other, this situation does not always imply a water retaining problem. However, when assessing the safety of coastal defences it is important to evaluate these ‘two-dimensional’ situations. It should be ascertained that water possibly flowing into a valley after a breakthrough of the first, seaward row of dunes is retained by a more landward located row of dunes. The configuration of this more landward located row should be such that the water in the valley is prevented from reaching the hinterland.

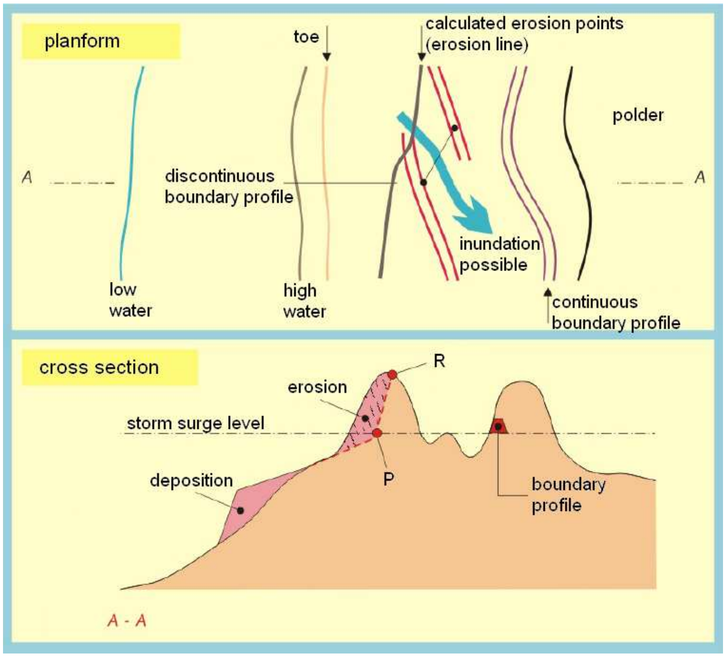


Figure 49: Discontinuities in longshore direction might lead to problems in coastal defences [Min V&W, 2007].

E.4 Assessing dikes and dams

Both dikes and dams could be defined as man-made water retaining earth bodies. In case of a dike, the structure is located at the interface between land and water. Dams face water at both sides. This section gives a short overview of the mechanisms of failure and the assessment procedure of both dams and dikes. Again, it should be mentioned that this text does not represent all information from the assessment manual, however the information relevant for this study is included.

E.4.1 Mechanisms of failure

Figure 50 shows the most important mechanisms of failure for dikes and dams. Two main mechanisms for failure could be distinguished: overtopping and instability. Overtopping occurs in situations where the crest of the structure is too low to prevent the water from flowing into the hinterland during a high water event. Overtopping could at the same time affect the stability of the body by erosion and infiltration. Next, when the crest level of the structure is sufficient, instability could be caused by several other mechanisms:

- Internal erosion of the body due to intensive seepage through an aquifer below or within the body (piping).
- The presence of quicksand at the landward boundary of the body due to the vertically discharged water (heave).
- Degradation of the landward slope of the structure due to sliding (inner-slope macro-instability).
- Degradation of the seaward slope of the structure due to sliding (outer-slope macro-instability).
- Degradation of fine materials from the structure or up-lifting of the upper clay revetment of the structure due to rising ground water levels and the inherent increasing ground water pressure (micro-instability).
- Devastation of the outer-slope revetment due to hydraulic forces (instable revetment).
- Deformation of the foreland of the structure due to sliding and settling processes caused by saturation of the structure.
- Finally, one of the above mechanisms could also be caused by the presence of other objects that do not have a water retaining function.

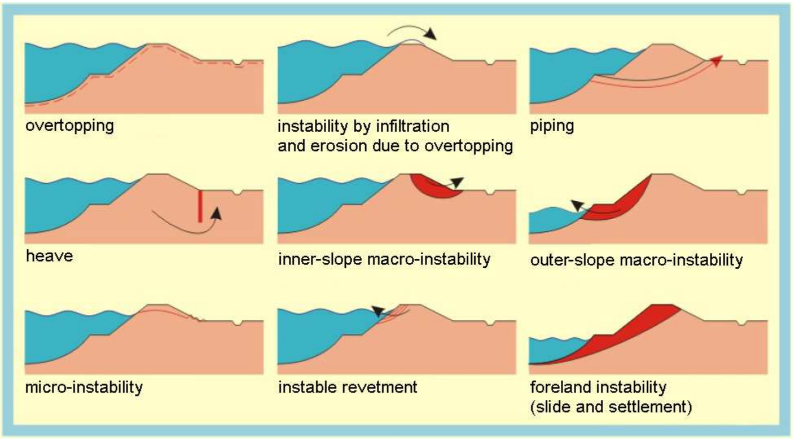


Figure 50: Mechanisms of failure for dikes and dams [Min V&W, 2007].

E.4.2 Assessment

How to assess the safety level of dams and dikes is schematised in Figure 51. Three tracks are distinguished in this process. In general terms, these tracks consist of the following assessments.

Track 1:
The first track assesses the height of the dike or dam. For overtopping, dikes and dams are exposed to the critical combination of extreme water levels and wave runup. Considering the water level, one should apply the legally binding critical water level (Toetspeil) increased with some local additions for local rise of the water due to rain action (in case of coastal defences). Wave runup is calculated from the wave heigt and period and the shape and surface of the outer slope of the structure. Important criteria in this assessment are the overtopping discharges and the surplus height of the structure compared to the critical water level.

Track 2:
The second track assesses the stability of the structure. All mechanisms of failure summarised in the second part of the previous section should be considered for this assessment. How these partial tracks should be assessed is thoroughly elaborated in the manual and some supporting documents.

Track 3:
The last track considers the influence of objects without a water retaining function. For assessing the safety level of dikes and dames, the influence of these objects on the susceptibility of the defences for one of the mechanisms of failure is more important than the strength of the objects themselves. However, both aspects should be included in the assessment.

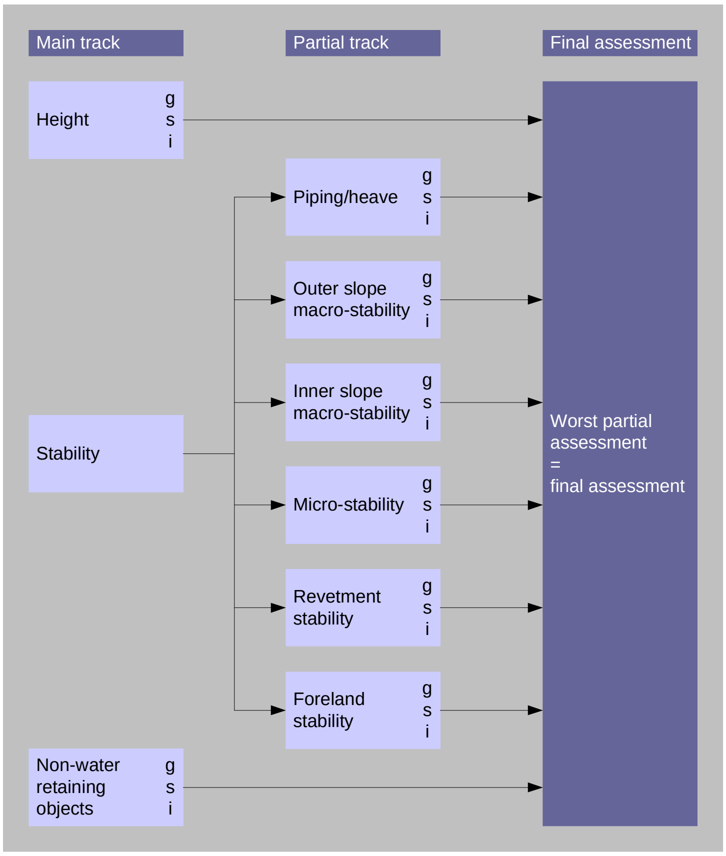


Figure 51: Assessment tracks for assessing dikes and dams (g = good, s = sufficient, i = insufficient) [Min V&W, 2007].

E.4.3 Assessing dike and dam height

This section presents some more information on the height assessment of dikes and dams as prescribed in the manual, since this aspect will return in a later part of this study. The other two tracks prescribe some more complex assessment calculations and will not be applied in this study.

There are four aspects to be assessed in the height check of dikes and dams. Together, these four characteristics determine whether the height of a dike is sufficient. These aspects are:

- The crest level of the structure;
- The stability of the crest and the inner slope in case of overtopping water;
- The possibility to reach a certain location of the structure for emergency measures;
- The possibility to discharge and store the water overtopping the dike.

These are the aspects to be considered when the height of a dam or dike should be assessed. In the manual, a comprehensive prescription is given on how exactly to execute this assessment.

F Hydraulic boundary conditions

The hydraulic boundary conditions to be applied in the current assessments of the primary flood defences are described in the Hydraulic Boundary Conditions 2006 document [Min V&W, 2007]. This appendix contains some relevant information on these boundary conditions.

F.1 Regular updates

Every five years, a new document with hydraulic boundary conditions for the primary flood defences is published by the Ministry of Transport, Public Works and Water Management. Updates of these boundary conditions contain the latest insights and new knowledge and developments. Possible changes come from:

- The autonomous development of the physical environment (due to erosion and accretion for example);
- Human activities and influences (due to the construction of structures for example);
- Extreme circumstances over the past five years, changing the statistics;
- New knowledge on and insights in the statistics of the relevant threats, the movement of the water, wind waves and the behaviour of the entire water system. These developments should be accurately verified and widely accepted before being included in these boundary conditions.

The largest improvement in the third and latest update of the hydraulic boundary conditions has to do with the wave period. Research has shown that wave periods on the North Sea have been underestimated in the past. Therefore, the wave periods are improved (increased) and a new calculation method is developed for determining the hydraulic boundary conditions at any location along the coast. Besides, the latest statistics on water levels and waves are applied in deriving the new boundary conditions and the state-of-the-art SWAN wave model is applied for translating wave conditions at deep water to a shallow water environment near the coastal defences. Finally, a correction is made for the (expected) sea level rise. In this case, the rise of tidal high water levels appeared to be larger and thus more important (for critical events) than the averaged sea level rise.

F.2 External forces

Three external forces should be considered when assessing the North Sea coastal defences in the study area: water levels, wind waves and rain storm influences.

F.2.1 Water levels

For assessing primary flood defences, two different water levels should be considered: the standard level and the assessment level. The standard level represents the water level occurring with the frequency defined by the (policy) standard. The assessment level is applied in the assessment of the primary defences and equals the standard level increased by 2/3 of the decimation height. This decimation height represents the difference between the standard level and the water level with a probability of exceedence that is 10 times smaller than the frequency of the standard level.

F.2.2 Wind waves

Wind waves are represented by a characteristic wave height, wave period and angle of incidence (wave boundary conditions). The wave height is expressed in a significant wave height (H_s) or as the averaged wave height of the waves in a wave field (H_{m0}). Characteristic wave periods (T_p) are applied for assessing the dunes and spectral wave periods are applied for assessing the crest level of dikes ($T_{m-1,0}$). Besides, for assessing revetments of flood defences, the averaged wave period (T_{pm}) should be used. The angle of incidence (B) of the waves is expressed in degrees and measures the angle with the normal to the flood defence. The wave direction itself is defined as the clockwise measured angle between the waves and the northern directions.

F.2.3 Rain/storm influences

Due to heavy rain storms, water levels at sea could change quickly. Wind gusts (buistoten) and oscillations (buioscillaties) are variations in the water levels with a short duration and changing periods caused by heavy rains or storms.

F.3 Statistic determination of boundary conditions

Based on measurements of storm events and high water levels from the past, the critical combination of these factors should be determined by a statistic analysis. This section contains some information on this analysis.

F.3.1 Wind

Wind causes wind waves and is able to raise local water levels, so it could be an important threat to the coastal defences. Both the force and the direction of the wind are important. Chances for the occurrence of extreme storms are determined by applying a Rijkoort Weibull model to the data available from measurements in the past. These measurements resulted in hourly averages of the wind force and direction and are translated into Weibull distributions. By combining these Weibull distributions, extreme wind forces could be extrapolated up to the critical probability of exceedence.

F.3.2 Sea water level

Storm surges are another threat the Dutch coast is exposed to. Storm surges occur when tidal high water levels caused by the astronomic tidal movement are increased due to wind forces. The basic water level is the storm surge level with an probability of exceedence of 1/10.000 per year. This basic level is extrapolated from a series of high water level measurements. From these measurements, the astronomic tide is subtracted in order to determine the so called wind set-up (‘scheve windopzet’). This water level rise due to wind forces is statistically analysed in order to determine the standard water level. This analysis has two tracks.

First, an extreme value distribution is fitted to the measured values at nine measurement stations along the coast. Second, relations are deduced between extreme high water level at Hoek van Holland and the other eight measurement stations by use of hydrodynamic computer models. Based on the critical level at Hoek van Holland, the critical water levels at the other locations along the coast could then be predicted by this model. Finally, the basic water levels are calculated as the weighed averages of the predictions by these two extrapolation methods. Basic water levels for locations between those measurement stations are interpolated from water level contours.

Based on these basic water levels and the measured water levels, exceedence lines are calculated by applying a Generalized Pareto Distribution (GPV-verdeling). From these exceedence lines, high water levels with even smaller probabilities of exceedence could be estimated corresponding to the legally determined safety levels of the dike ring areas to be protected against flooding. Due to the age of the water level measurements, the results of this calculation are valid for the year 1985.

To translate these values to the present situation, one should account for the sea level rise during the past decades. The increase of the averaged high water levels (including the subsidence of the Amsterdam Ordnance Datum) is called high water level rise. This increase of the tidal high water levels appears to be more important than the averaged sea level rise over this short period of time (only 20 years). It is supposed that tidal high water levels will increase with 0.06 up to 0.14 m until 2011 (compared to 1985).

Based on these efforts, the standard and assessment water levels are determined. The standard levels (toetspeilen) are composed of the design water levels for 1985 increased by the tidal high water level rise. The assessment levels (rekenpeilen) are composed of the standard levels, increased by 2/3 of the decimation height. This decimation height represents the difference between the standard level and the water level with a probability of exceedence that is 10 times smaller than the frequency of the standard level. The final values of these levels are rounded off to decimetres.

F.4 Boundary conditions

This sections contains the hydraulic boundary conditions, as they are presented in the Hydraulic Boundary Conditions 2006 document [Min V&W, 2007]. For this study, the only boundary conditions of interest are the conditions for the coastal defences in dike ring areas 13 (Noord-Holland) and 14 (Zuid-Holland). For both dike ring areas a probability of exceeding the critical conditions (boundary condition) is set at 1:10,000 in the Law on Flood Defences [Overheid.nl, 2008]. Boundary conditions are given separately for dunes and dikes along these coastal stretches and are related to the so-called Jarkus section lines (Jarkus raaien) which are related to the annual cross-shore measurements of the coastal profiles. These section lines are presented in Figure 52. The boundary conditions are summarized in Table 23 for dunes and Table 24 for dikes.

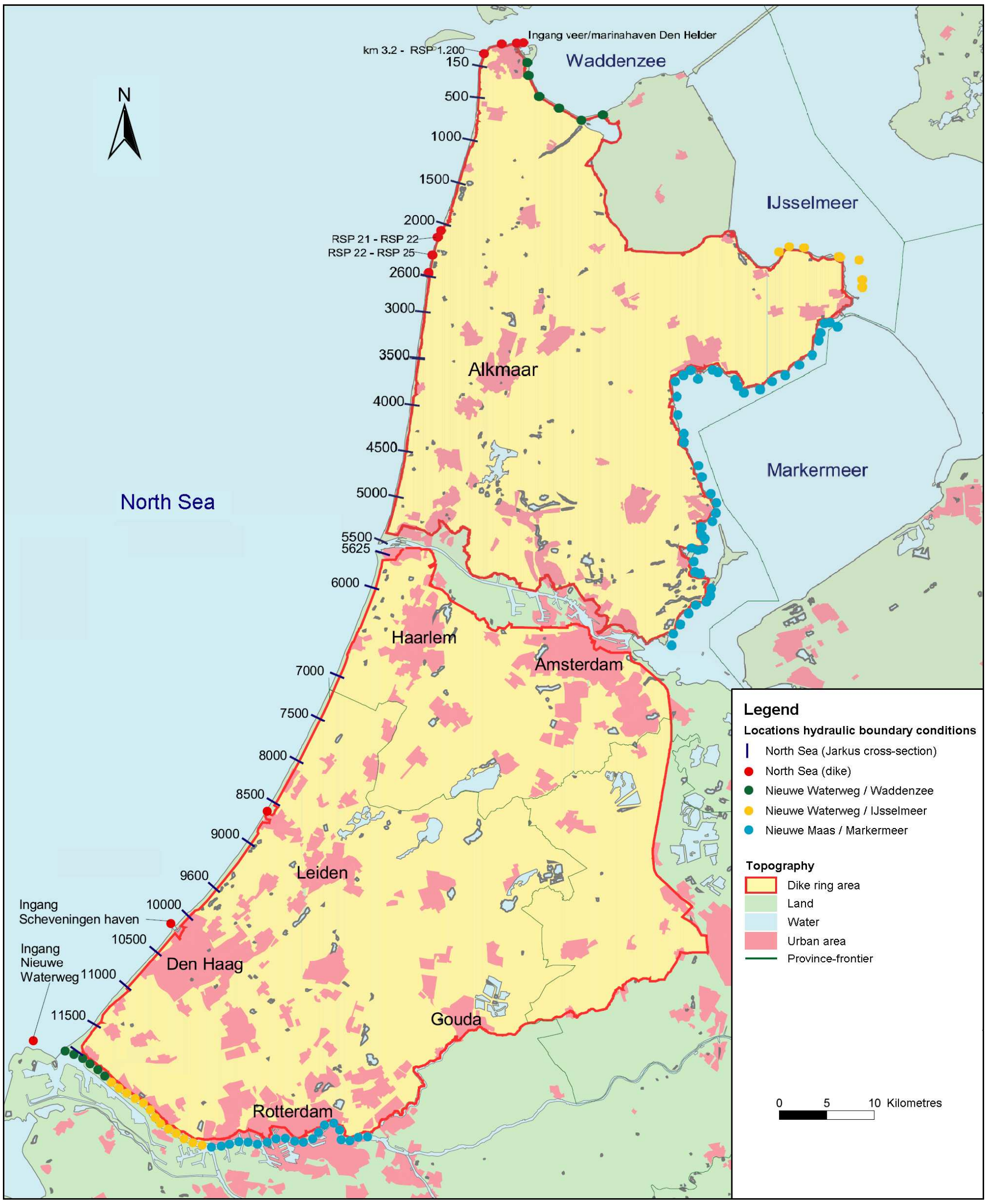


Figure 52: Locations of the Jarkus section lines along the Holland coast. The upper part of the study area is dike ring 13, the lower part is dike ring 14. The red dots along the coast represent the locations of (small) dikes [Min V&W, 2007].

Table 23: Hydraulic boundary conditions for the dunes along the Holland coast: H_{m0} = averaged wave height of the waves in a wave field; T_p = wave period [Min V&W, 2007].

Jarkus section	Location	Assessment level [m +NAP]	H_{m0} [m]	T_p [s]
150-348	Den Helder	4.8	10.50	16.3
356-499		4.9	10.45	16.3
501-598	Noordduinen	4.8	10.45	16.3
600-827		4.9	10.40	16.3
835-999	Callantsoog	4.9	10.40	16.3
1000-1098		5.0	10.35	16.2
1100-1393	Zuidduinen	5.0	10.30	16.2
1401-1565	Pettemer duinen	5.0	10.25	16.2
1573-1798		5.0	10.20	16.2
1800-2041		5.1	10.15	16.2
2600-2782	Camperduin	5.3	9.90	16.2
2800-2882		5.3	9.85	16.2
2900-2997	Schoorlse duinen	5.3	9.85	16.1
3000-3100		5.3	9.85	16.1
3100-3250		5.3	9.80	16.1
3250-3300		5.3	9.75	16.1
3300-3500	Bergen aan Zee	5.4	9.75	16.1
3500-3600		5.4	9.70	16.1
3600-3700	Egmond aan Zee	5.4	9.65	16.1
3700-3800		5.4	9.65	16.1
3800-4000		5.5	9.60	16.1
4000-4200		5.5	9.55	16.1
4200-4300		5.5	9.55	16.1
4300-4450	Castricum aan Zee	5.6	9.50	16.1
4450-4500		5.6	9.50	16.1
4500-4650		5.6	9.50	16.1
4650-4700		5.6	9.45	16.1
4700-4900	Wijk aan Zee	5.7	9.45	16.1
4900-5150		5.7	9.40	16.1
5150-5300		5.7	9.35	16.0
5300-5400		5.7	9.40	16.1
5400-5500		5.7	9.35	16.1
5625-5800		5.7	9.25	16.0
5800-6400		5.7	9.15	15.8
6400-7150		5.8	9.00	15.5
7150-8000		5.8	8.85	15.0
8000-9750		5.8	8.55	14.3
9750-9900		5.8	8.35	13.9
9900-10140		5.7	8.30	13.8
10140-10996		5.7	8.05	13.2
11012-11700		5.7	7.90	12.8
11700-11850		5.6	7.70	12.3

Table 24: Hydraulic boundary conditions for the dikes and other structures along the Holland coast: H_s = significant wave height; $T_{m-1,0}$ = spectral wave period; B = angle of incidence of the waves [Min V&W, 2007].

Location	Standard level [m +NAP]	H_s [m]	$T_{m-1,0}$ [s]	B [°]
km 0.0 - km 1.0	4.5	2.30	4.1	50
km 1.0 - km 3.2	4.5	2.35	4.2	50
km 3.2 - RSP 1.2	4.5	3.05	6.8	30
RSP 20.5 - RSP 21	4.7	3.90	12.1	0
RSP 21 - RSP 22	4.8	4.45	12.1	10
RSP 22 - RSP 25	4.8	4.60	12.2	10
RSP 25 - RSP 26	4.8	4.30	12.2	10
Drainage sluice Katwijk	5.2	3.05	11.8	10
Harbour entrance Scheveningen	5.2	5.85	11.5	10
Entrance Nieuwe Waterweg	5.0	6.95	10.9	318 (wave direction)

G Matlab script of DUROS-plus

This appendix contains a short summary of the Matlab script that is applied to calculate dune erosion and to define the additional volumes and boundary profiles for the dune protected coastal reaches of the study area.

Table 25: Summary of the activities of the Matlab script representing the DUROS-plus model.

Row	Activity
1-4	Start
5-7	Reading Jarkus data of the coastline.
8	Definition of dune feet at 3 m NAP.
9-20	Definition of the effects of climate change for several scenarios: forecast period [years], sea level rise [m], extra storm surge [m], wave height increase [%], cross section rise below dune toe level [m].
21-24	Defining the scenario and Jarkus cross sections to be assessed.
25-43	Determining cross profile of Jarkus cross sections.
44-50	Loading boundary conditions defined by HR2006 and adding climate change impacts: including sea level rise and extra storm surge in still water level (SWL) and wave height increase in significant wave height.
51-54	-
55-74	Including rise of beaches and foreshore due to sand nourishments in cross profiles and defining the dune crest, the starting point of the erosion profile and the location of the toe of the dune.
75-79	Definition of possible solutions: (1) original situation, (2) seaward extension of dune and beach, (3) new dune (top at +10 m NAP) seaward of existing dune and (4) seaward beach extension at -3 m NAP.
80-82	Define management strategy to be calculated → (1) for this study.
83-154	Processing the possible solution if (2), (3) or (4) is chosen in the previous step.
155-159	Processing erosion profiles, calculated by the file ‘afslag.m’.
160-171	Plotting cross profiles and designing figure.
172-183	Determining whether cross profile is not sufficient (‘voldoet niet’).
184-192	Determining whether calculated erosion is too large for the cross section present (‘afslag onvoldoende’).
193-197	Calculating the location of the erosion ridge (afslagrand), point R.
198-218	Calculating the additional erosion as a function of the part of the previously calculated degradation profile located above still water level.
219-224	Determining whether the calculated additional erosion volume is too large for the dune cross sections (‘toeslag onvoldoende’).
225-232	Another test for determining whether the remaining cross profile after erosion is not sufficient (‘voldoet niet’).
233-253	Calculation of the critical profile and addition of this profile to the erosion profile, resulting in the location of point P.
254-264	Determining whether the critical profile does not fit in the dune cross profile at all (‘grensprofiel onvoldoende’) or is to steep to fit in the dune cross profile (‘grensprofiel te steil’).
265-277	-
278-292	Calculation of the amount of sand needed for realising the simulated measure.
293-315	Plotting the location of point P, R and R* in the cross profile.
316-319	Determining the title of the plotted figure and the result of the assessment.
320-329	Saving the plots.
330-341	-

H Longshore safety assessments of dunes

This appendix presents some examples of the longshore safety assessments. A manual assessment is applied to all subsequent cross-shore safety calculations in order to find out whether the failure of the first dune crest of a dune complex would induce an inundation of the hinterland. This could occur when a landward located dune crest behind a failing foredune (first dune crest) does not close off the dune valley in between those two dune crests adequately. In this case a breakthrough of the first dune crest might cause the inundation of the hinterland at a distant location where the second dune crest is insufficient.

Example 1

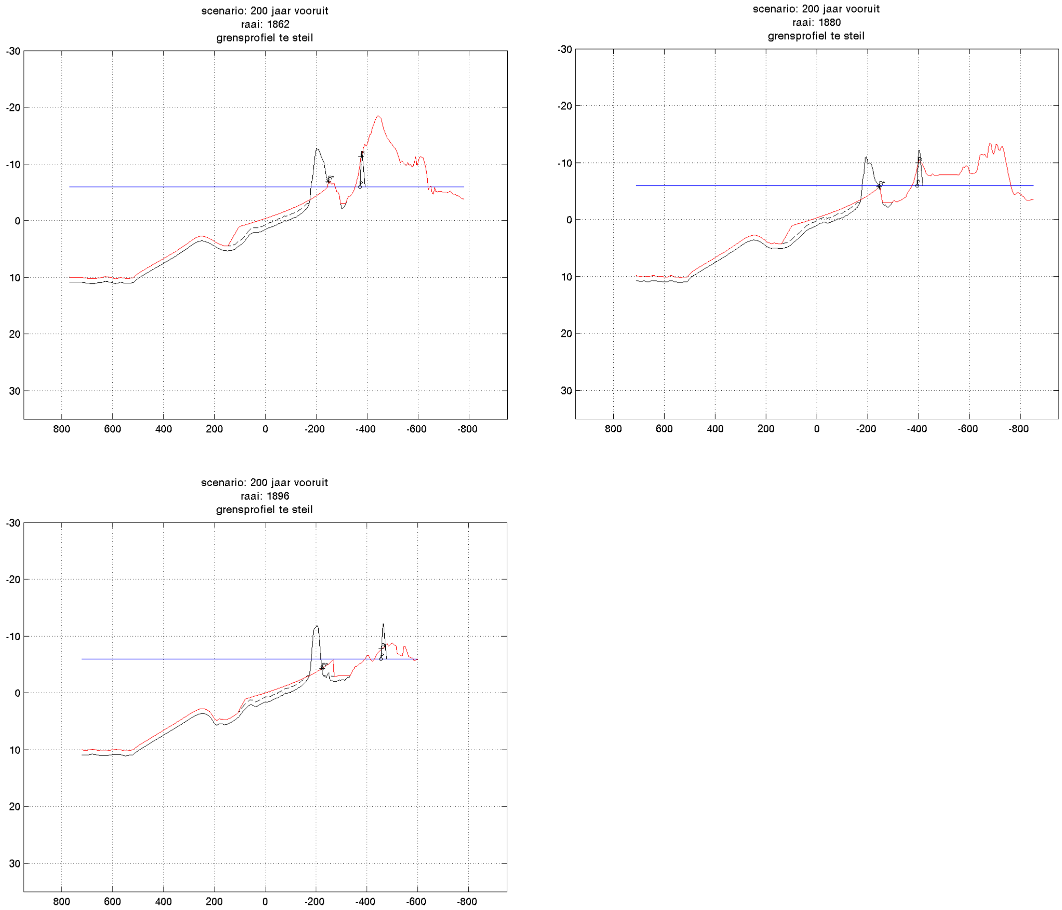


Figure 53: Erosion calculation results for the lower climate change scenario; cross-sections 1862, 1880 and 1896. Note: the dotted line in these graphs represent the beach (and the surfzone and shoreface) level rise caused by sand nourishments to maintain the Basal Coastline; the blue line represents the storm surge level.

In this example, the erosion calculations for the first two cross-sections do not show a safety problem since the boundary profile could easily be provided by the landward located dune crest. However, more to the south the height of the landward dune crest decreases and the boundary profile is not present anymore. A breakthrough of the foredune at the upper locations would cause the water to flow through the dune valley, causing an inundation of the hinterland at cross section 1896. Therefore, the first two cross-sections are said to fail too since both the additional erosion volume and the boundary profile do not fit in the foredune (so these sections are assessed orange according to the definition of Table 4).

Example 2

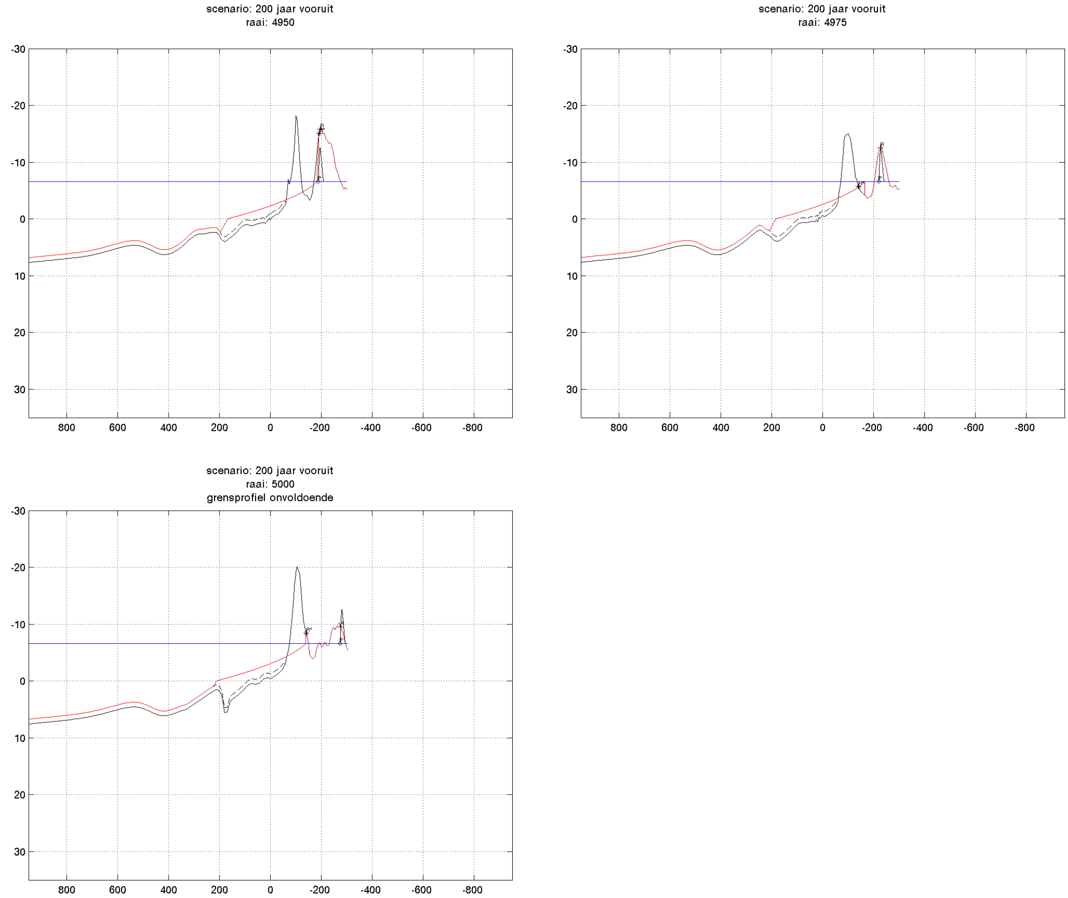


Figure 54: Erosion calculation results for the lower climate change scenario; cross-sections 4950, 4975 and 5000.

In this example, the dune configuration defers substantially from the configuration in example 1. However, the problem is the same. At cross-section 4950, there is no obvious problem in retaining the seawater. However, the first dune crest will erode and water will entrance the valley. At the same time, the second dune crest could not provide the boundary profile any more 500 m south of this location and an inundation of the hinterland will start. Therefore, the first two cross-sections are assessed negative too.

Example 3

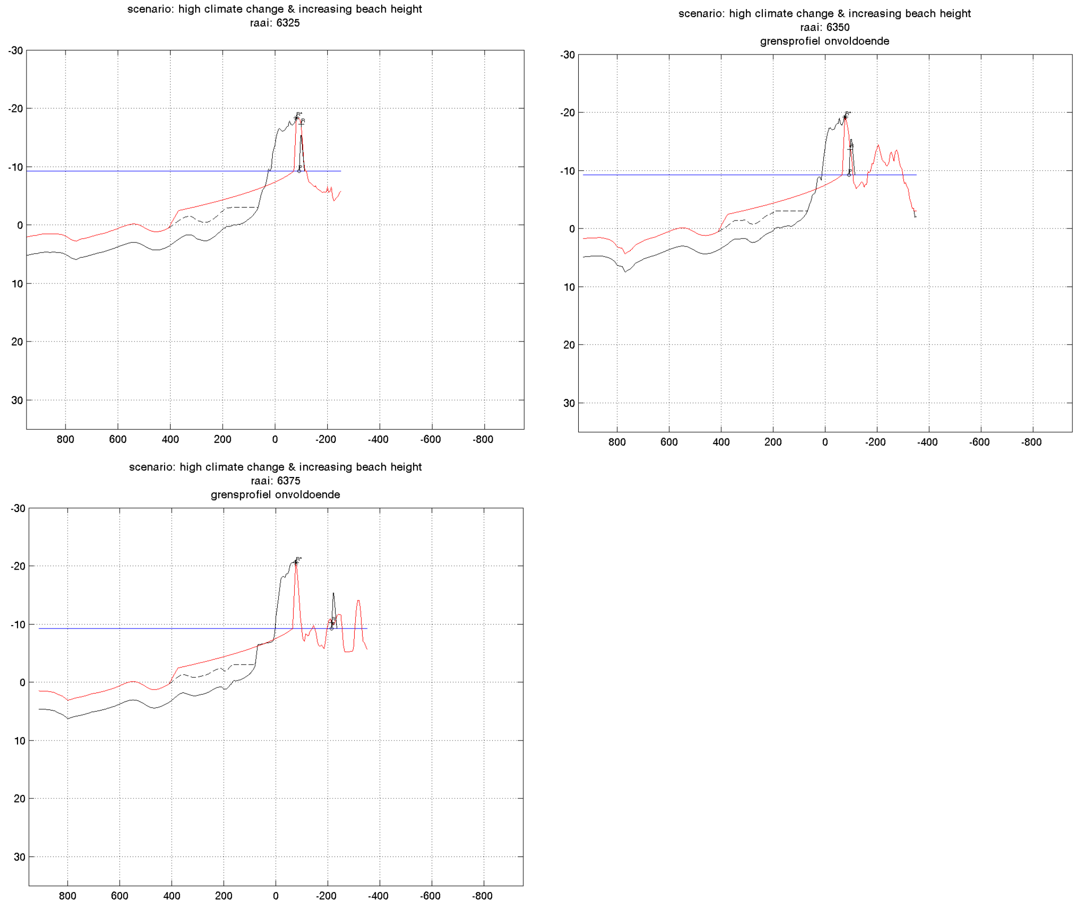


Figure 55: Erosion calculation results for the high climate change scenario; cross-sections 6325, 6350 and 6375.

This example shows a situation something different from the situations in the previous two examples. In this case, there is an open valley located behind the foredune since there is no second landward dune crest in cross-section 6325. However, at cross-section 6350 the boundary profile almost fits in the foredune so the assessment is only marginally negative (failure on boundary profile). At the same time, at cross-section 6375 even the additional erosion volume does not fit within the foredune and water could inundate the dune valley during a severe storm. At this cross-section, the problem is not caused by the boundary profile not being present in the second dune crest, as would be the assessment in a one-dimensional approach. In this case the assessment is determined by the additional volume of sand not being present in the foredune, causing the boundary profile to be shifted too far landward and the dune valley (and thus the hinterland) to inundate.

Example 4

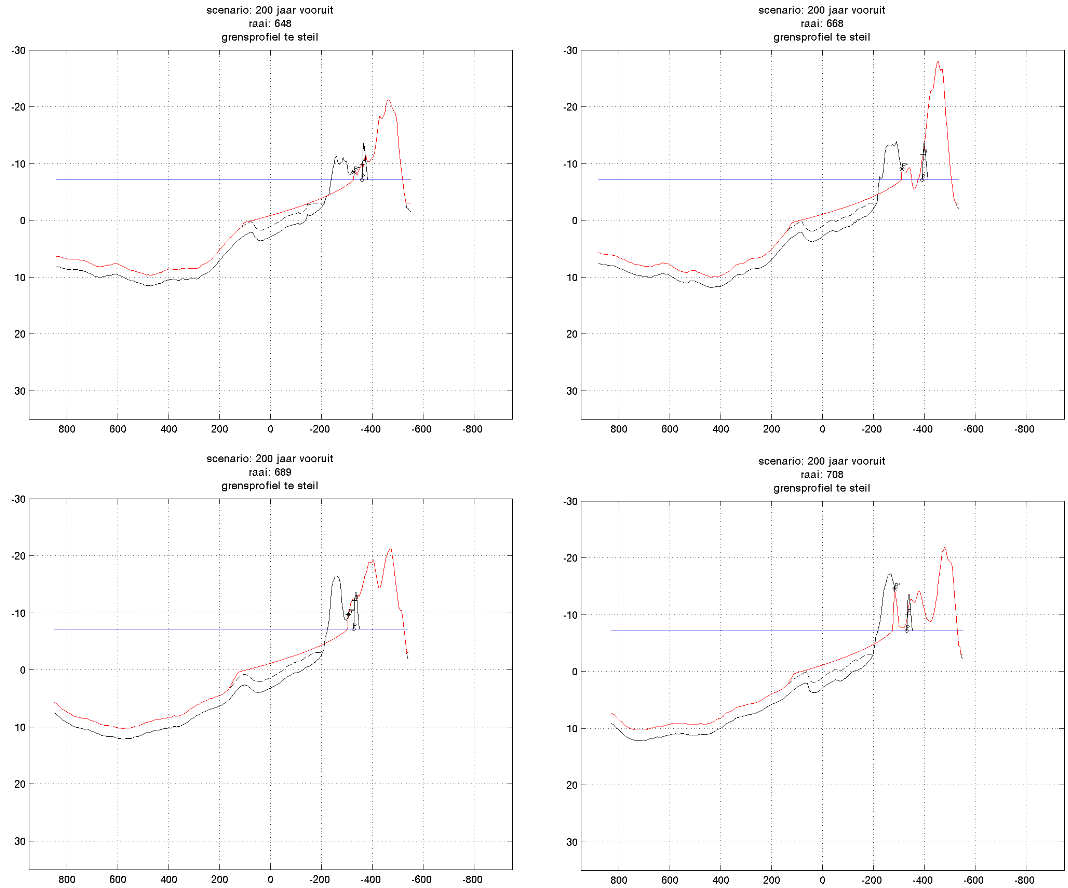


Figure 56: Erosion calculation results for the middle climate change scenario; cross-sections 648, 668, 689 and 708.

These cross-sections also show a failing first dune crest. However, the bottom of the valley behind has a higher elevation than the storm surge water level and the landward dune crests do not decrease in height. So the boundary profile could easily be shifted landward till it fits in the dune profile again and there is no probability of inundation of the hinterland. In this case, all sections are assessed safe (although the Matlab model gives another interpretation: ‘grensprofiel te steil’).

Example 5

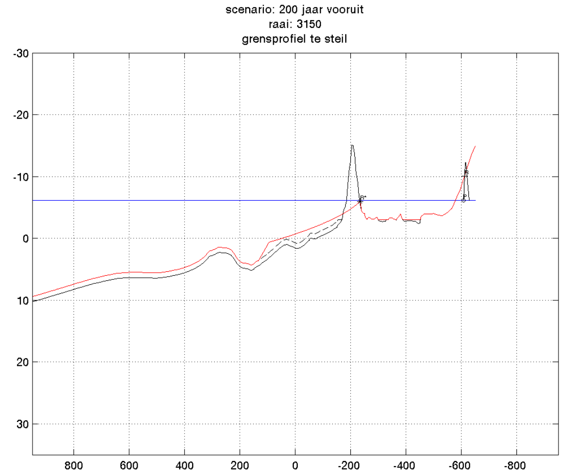
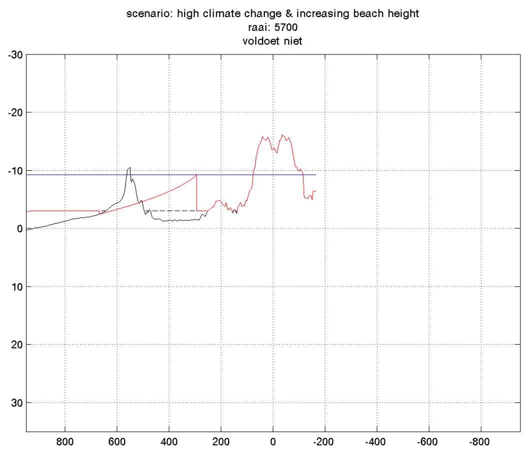


Figure 57: Erosion calculation results for the lower climate change scenario; cross-section 3150.

This example shows an exception. In this case, the first dune crest will totally erode resulting in a landward movement of the dune-toe of about 400 m. This recession of the dune-toe is supposed to be unacceptable since too much land (probably valuable nature) will be lost at once. Therefore, locations where the dune-toe recedes landward over a distance of several hundreds of metres at once are also assessed as insufficient (just like cases where the sand volumes in the dunes are insufficient for closing the sediment balance of the erosion profile). Note that this landward recession might still be acceptable from a safety point of view, as long as the erosion profile fits within the dunes (at some locations the dunes are several kilometres wide). This exception is merely based on a socio-economic perspective.

Example 6



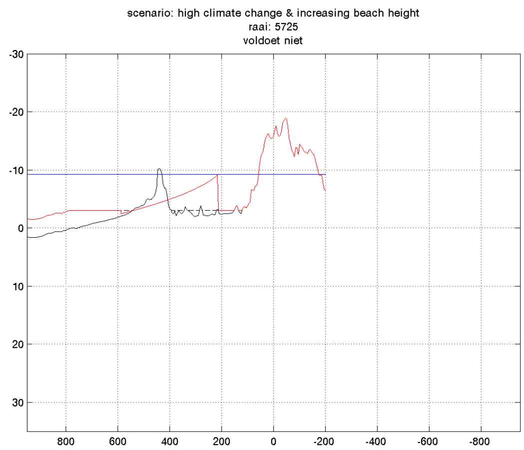
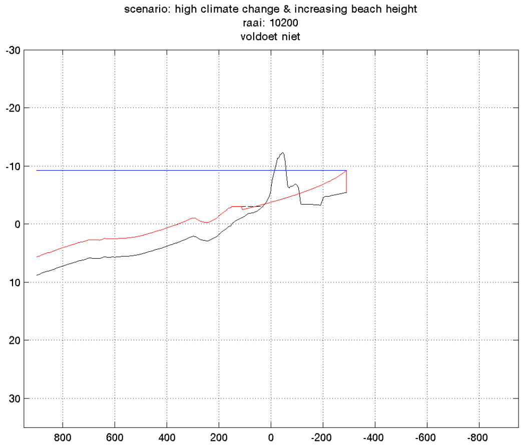


Figure 58: Erosion calculation results for the high climate change scenario; cross-sections 5700 and 5725.

This example presents some cross-sections of the coast at the east of IJmuiden. South and north of the harbour dams surrounding the canal mouth of the Noordzeekanaal the coast has extended in seaward direction. During a super storm, this area will be lost as could be seen in the calculated erosion profiles for cross-sections 5700 and 5725. However, this does not mean that the coastal defences are insufficient over here since the coastal plains are located outside the dike ring areas, so they are not protected. The dunes surrounding the horizontal origin of the cross-sections form the boundary of dike ring area 14 and, in combination with the presence of the coastal plain in front, their dimensions will be sufficient to protect the hinterland from being flooded. Therefore these cross-sections are assessed to be safe despite the fact that the Matlab script says that these cross-sections are not safe.

Example 7



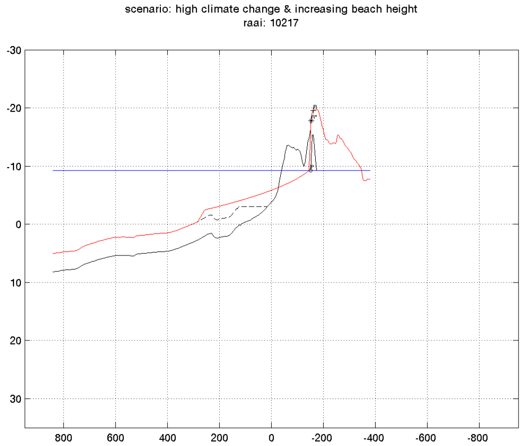


Figure 59: Erosion calculation results for the high climate change scenario; cross-sections 10200 and 10217.

This last example shows the problems occurring at insufficient connections between smaller and larger cross-shore profiles of coastal defences. The profile at cross-section 10200 is very small and entirely erodes during a severe storm event. The cross-shore profile at section 10217 (only 70 m to the north) is much larger and will not cause any problems during a severe storm event. However, erosion will shift the toe of the dune at cross-section 10217 to about 150 m landward. This is where the defence at cross-section 10200 has already stopped. So even when cross-section 10200 is improved (whether seaward or in vertical direction) water would be able to flow in longshore direction from the south (cross-section 10217) to the north (cross-section 10200) meanwhile passing the coastal defences. This is why cross-section 10217 should also be assessed negative.

I Available coastal management solutions

Lots of potential flood control solutions for future coastal management problems are available. These solutions can be divided into three main categories: seaward, landward or consolidating. The names of these categories indicate the locations of the solutions: seaward, landward or just at the same location of the present coastal defences respectively. This appendix summarizes all potential measures currently available. A short explanation of the main principles of every solution will be given, including some examples of existing plans related to the solution.

I.1 Seaward solutions

Seaward solutions incur coastal improvement activities in front of the existing defences (dunes or dikes). These solutions could be both ‘hard’ and ‘soft’. Hard solutions contain stones and/or concrete. Soft solutions are (mainly) consisting of sand. Table 26 contains the different hard and soft possibilities for seaward improvement of the coastal defences. These potential solutions are described in the subsequent subsections.

Table 26: Summary of hard and soft seaward coastal management solutions.

	Hard	Soft
Seaward coastal management solutions	- Islands - Artificial reefs - Offshore seawalls - Groynes	- Sandbanks - Dunes in front of existing defences - Reinforcing defences in seaward direction - Beach heightening and widening

I.1.1 Islands

Creating islands in frond of the Holland coast, will reduce wave attack at the mainland coast during severe storm events for all stretches located in the shadow area of the island. These islands could be realized at bottom levels of about 15 to 20 m below MSL. This means that they are located at several kilometres from the mainland coast. Islands should not be located too far seaward, since this will reduce the attenuation of wave characteristics at the mainland coast. At the same time, they should also not be located too close to the mainland coast since that would increase the negative impacts on the coastal view and some existing functions of the mainland coastal zone.

There are many possibilities for the outline of these islands. They could be constructed of sand with a surface entirely or partially above sea level. In the latter case, the island should be surrounded by dikes and a clay layer should prevent seepage of sea water. Multifunctional use of these islands could improve the profitability of such constructions.

Examples of plans for constructing islands in front of the Dutch coast are the plans of Bhalotra and Lievense. Bhalotra [1995] designed an extensive, multifunctional island in front of the southern coast of Zuid-Holland (from Hoek van Holland to Scheveningen) applied for housing and greenhouse horticulture (Figure 60). However, this plan would destroy the hydrodynamic processes in front of the mainland coast and the existing, valuable characteristics of this area will be lost. The plan of Lievense [2008] is about an island mainly used for hydropower (Figure 61). Again this function is combined with housing and industrial activities increasing multifunctional land-use. Recently, this plan is presented by the Dutch ‘Innovatieplatform’ as one of the key projects representative for the future of Dutch water management [Innovatieplatform, 2008].

A more convenient solution will consist of sandy islands feeding the sand river along the Dutch coast. This would prevent the mainland coast from structural erosion and would not affect the natural sand transport processes (the ‘building with nature’ principle). These islands could also be used for other functions, however these functions should be temporary. Sand supply should be the main function of these islands, implying that their location and shape is variable over time [Jorissen & Geldof, 2006].

Figure 60: The island design of Bhalotra in front of the coast between Hoek van Holland and Scheveningen [Bhalotra, 1995].

Figure 61: The energy-island design of Lievense, combining hydropower generation and other land-use functions in one island [Lievense, 2008].

I.1.2 Artificial reefs

In stead of islands, artificial reefs could also protect the Holland coast from high waves during severe storm events. The location of a reef could be the same as the location of the islands discussed above. They should be located at several kilometres seaward from the coastline where the sea bottom located at about 15 m below MSL (Figure 62). Preliminary designs of Royal Haskoning, who designed the reefs surrounding the new islands in Dubai, indicate that the top of these reefs will remain several metres below main sea level (opposed to the situation in Dubai). Behind the reef, wave heights are reduced and the occurrence of long waves decreases (Figure 63). Long waves are generated in the surf zone and especially these long waves cause large amounts of coastal erosion during storms [WINN, 2008].

A potential benefit of these reefs is the combination with recreational facilities for surfers for example.

Figure 62: Possible design for artificial reefs protecting the Holland coast [WINN, 2008].

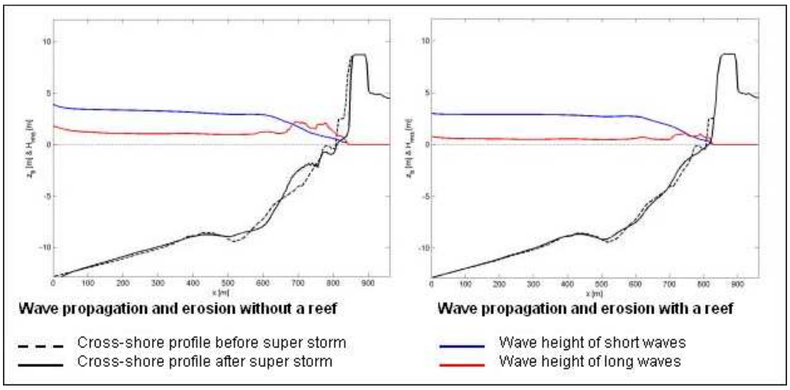


Figure 63: Effects of constructing an artificial reef before the coastline on wave heights and coastal erosion [WINN, 2008].

I.1.3 Offshore seawalls

Next to the artificial reefs with crest levels below mean sea level, another option is to construct some sort of seawall in front of the Holland coast. This seawall would resemble a narrow, elongated island and would create a lake in between this construction and the existing coastline. This idea is derived from the concept presented by Van den Haak and Stokman [2006], named the ‘Haakse’ seawall (Figure 64). In their design, this seawall is located at about 25 km seaward of the present coastline and the island structure is created with sand from the area behind the new seawall (Figure 65). Openings for main fairways are accommodated with cross-shore structures. The water levels in the newly created lakes are fully controlled in this solution.

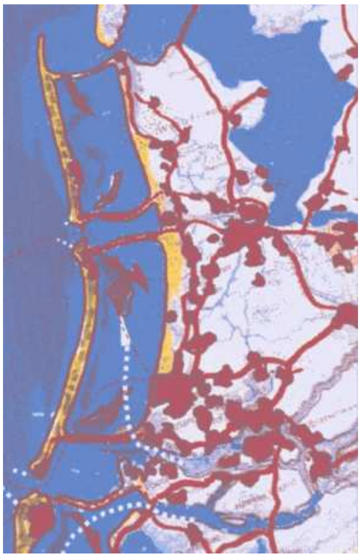


Figure 64: Artist impression of the Haakse seawall creating lakes in front of the Holland coast [Van den Haak & Stokman, 2006].

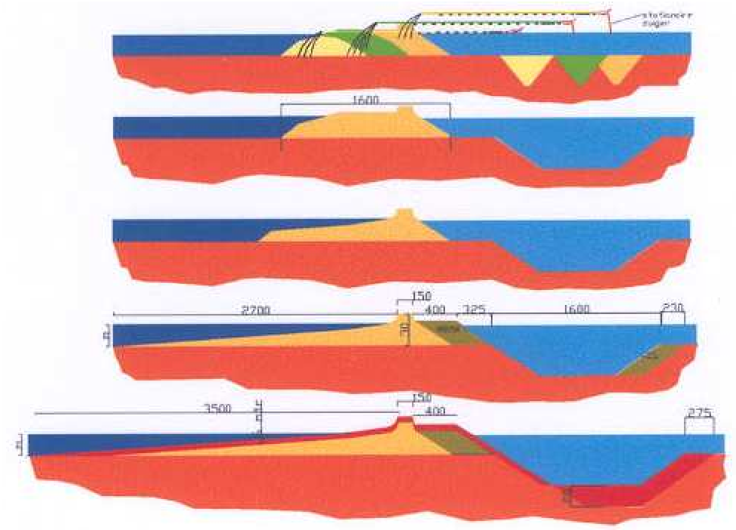


Figure 65: The seawall could be constructed with sand excavated from the lakes created behind these barrier islands [Van den Haak & Stokman, 2008].

An important disadvantage of this measure is the termination of all coastal dynamics. This will induce a slow degradation of the existing coast and the dunes. Moreover, the depth of the lake emerging behind the seawall will cause enormous problems in case the seawall itself fails during an extreme storm event. The weakened coastal defences will then be exposed to even higher waves. Construction by excavating the new lake between the seawall and the coastline also seems to be rather difficult during the construction period.

I.1.4 Sandbanks

A natural variant of creating artificial reefs, is the creation of sandbanks. These banks should be located further offshore than the sandbars generally found in front of the coastline and their dimensions should be much larger. They will resemble the sandy islands feeding the sand river, however their crest level will be located below mean sea level (Figure 66).

The use of these structures is twofold. First, they will supply sand to the coastal sand river, preventing the beaches and dunes from erosion. In stead, structural accretion might be stimulated. Next, the presence of these banks will attenuate waves attacking the coast, just like artificial reefs would do. It is supposed that these banks should be created where sea bottom levels are about 10 to 15 m below MSL, which implies a seaward distance from the coastline of a few kilometres. These depths are within the active coastal zone as defined by Mulder [2000]. Mulder also states that submerged sandbanks (shoreface connected ridges) are found at depths about 16 to 20 m below MSL, in front of the stable part of the Holland coast. However, the effects of these deeper sandbanks on the coastal stability are uncertain.

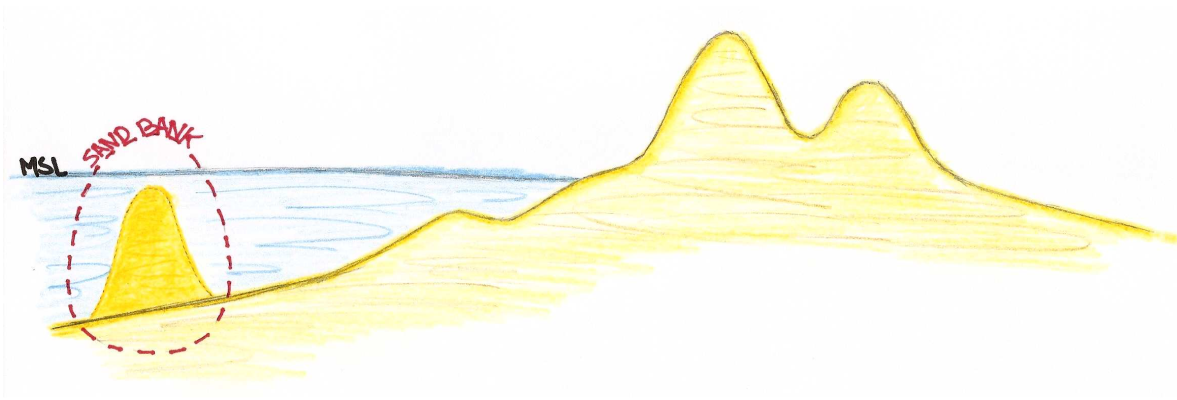


Figure 66: This figure shows the presence of sandbanks in front of the coastline, protecting the dunes from severe wave attack.

I.1.5 Dune in front of existing dunes/dikes

A more landward solution is the creation of a new dune in front of the existing dunes (or dike). This would generate a significant land extension since the beach will be shifted in seaward direction. A new dune will have a width of several tens of metres. Depending on the width of the newly created valley between the new dune and the existing dune front, the coastline will also be shifted several tens of metres in seaward direction (Figure 67).

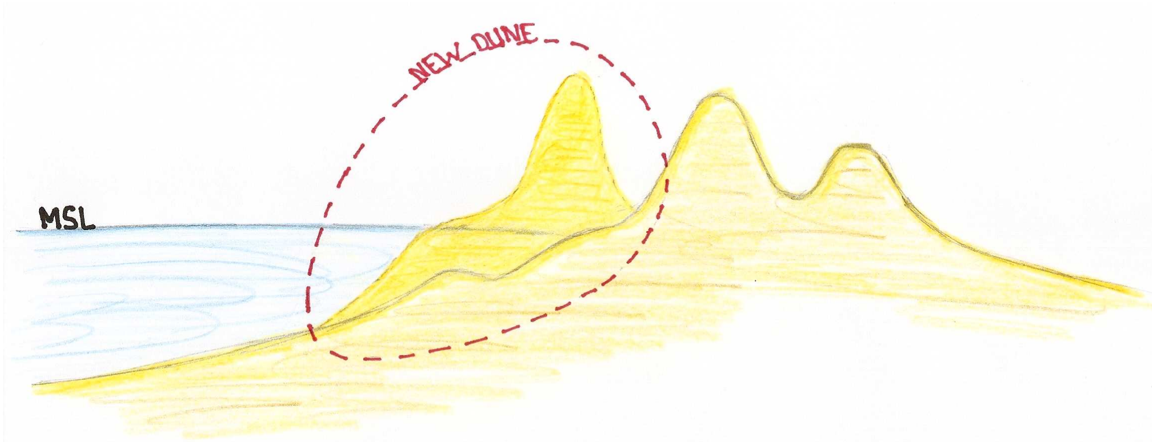


Figure 67: Creating a dune in front of the existing dunes will increase the retaining strength of the sea defences. A new dune valley (valuable nature) will be created by this measure.

This solution fits within the natural character of the majority of the Dutch coast. Moreover, extending the dunes will create opportunities for nature development and recreation. And when no marram grass ('helmgras' in Dutch) is planted on these new dunes for keeping its sand in place, new dynamics might emerge stimulating the natural development of the system.

The spatial scale is important in the application of this solution. When it is implemented on a small, local scale, the new coastline will show a wave-like irregularity that would increase the erosion of the parts extending into the sea.

Three examples are available of plans applying this solution's principle. Bos [2001] designed a wide coastal zone by extending the dunes along the entire Holland coast (Figure 68). Valuable, brackish nature could be developed in the seaward parts of these newly created areas. More landward, freshwater reservoirs could be developed. Next to that, economic activities are foreseen at certain locations closely related to current conglomerations. Harbours, companies and houses could be developed or extended here. Witteveen+Bos [2008] also foresees an extension of the Dutch coast with dunes (Figure 69). However, economic developments are not accommodated within this new area. The primary function of the new dunes is retaining water and next to that they could be used for nature development or for recreational activities. More concrete is the plan for applying this solution principle at the Delfland coast and at Kijkduin. Both locations are part of the current weak links in the coastal defences. The existing defences will be extended there by raising new dunes in front of the existing defences [Kustvisie Zuid-Holland, 2006]

Figure 68: Extension of the coastal defences according to Bos, also called the 'Bos-variant'. Dunes are significantly extended in seaward direction accommodating both nature and economic values [Bos, 2001].

Figure 69: Witteveen+Bos foresees a seaward extension of the Dutch coast in its Deltaplan 2008-2100. New dunes should be created in front of the present coastline [Witteveen+Bos, 2008].

I.1.6 Reinforcing first row of dunes/dikes in seaward direction

Instead of constructing new dunes the existing dunes (or dike) could also be strengthened by sand nourishments extending the width and height of the front dunes (Figure 70). In most cases, an extension of the front dune with several (tens of) metres, would suffice. Again, the coastline and thus the beach will be shifted in seaward direction by this solution. This will raise the need for additional nourishments in order to remain the present beach widths.

Since the extension of the dune area is relatively small with this solution, the potential for other functions to be developed is rather marginal. Currently, this measure is foreseen for Ter Heijde and for parts of the Noord-Holland coast, both parts of the weak link locations [Kustvisie Zuid-Holland, 2006] [Provincie Noord-Holland, 2008].

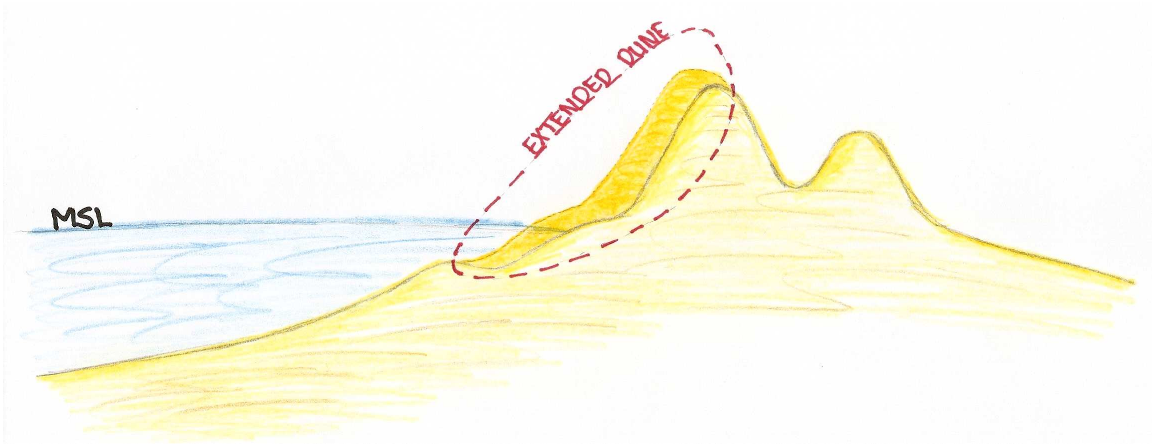


Figure 70: Dune extension in seaward direction increases the strength of the dunes. In case of dikes, a volume of sand will be added to the seaward side and on top of the structure.

I.1.7 Beach heightening and widening

By increasing the height of the beaches (Figure 71), the volume of sand in the coastal system will increase. This would reduce the landward shift of the erosion profile during a severe storm event. However, beach levels should be increased by several meters (unless the beaches are very wide of coarse) in order to cause a substantial reduction of dune erosion during a super storm.

A disadvantage of this measure is that the bottom steepness in front of the beach increases due to the higher level of the beach. This would cause more hydrodynamic activity at the coastline increasing structural erosion of the beach. Moreover, increasing wave activity could be negative for swimming.

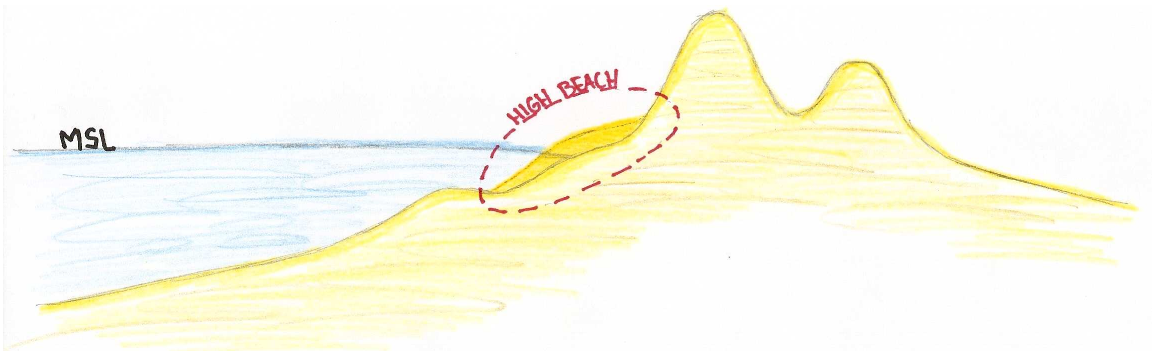


Figure 71: Heightening the beach will decrease dune erosion during severe storm events.

In stead of increasing beach heights, beaches could also be extended in cross-shore direction (Figure 72). This would also increase the volume of sand in the coastal system, thereby reducing the landward shift of the erosion profile during a super storm. Beaches should be widened with tens to hundreds of metres (unless very steep bottom slopes are found in front of the beach) in order to generate any substantial reduction of dune erosion.

A potential benefit of this measure is that the beach area is increasing, creating more space for recreational activities. At the same time, when beach widths are increasing, the typical sea-land interaction at the dunes becomes less distinct. Next, the disadvantage of an increasing steepness in front of the beach also occurs in case of horizontal beach extension. As stated before, this would cause structural beach erosion and it might affect the recreational value of the sea for swimmers.

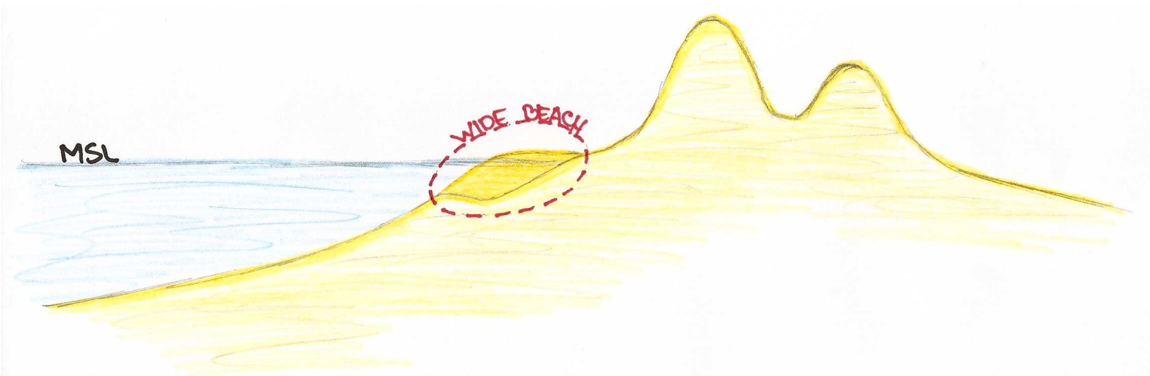


Figure 72: A wider beach decreases dune erosion during severe storm events.

I.1.8 Groynes

One of the few hard measures in order to reduce coastal erosion is building groynes in front of the dunes, protruding from the coastline into the sea. Groynes are stone or concrete structures constructed more or less normally to the coast. They have a length of several hundreds of metres and are located at several hundreds of metres up to one kilometre apart. The effect of these breakwaters is that the sand river, flowing from the south-west to the north-east along the Dutch coast, is shifted somewhat seaward. This reduces beach erosion and in stead structural accretion might occur between those structures (Figure 73). This might increase the volume of sand in the coastal system and otherwise sand could be nourished artificially to extend the coast between these groynes. The groynes would then keep this sand in place by their reducing effect on nearshore morphodynamics. By these measures, the landward shift of the erosion profile during a severe storm is reduced. However, north of the groynes structural erosion would occur due to sand deficits in the sand river reattaching the coast at this location.

Groynes were proposed as one of the potential measures for improving the weak links in the Noord-Holland coast (Figure 73). However, this measure was left in an early stadium of the design process. A disadvantage of this solution is that costs for construction and maintenance of the structures are relatively high compared to 'soft', sandy solutions. Next, coastal morphodynamics is changed and the natural character of the land-sea interface is lost. This would also affect the recreational value of the area [Weijers, 2005].

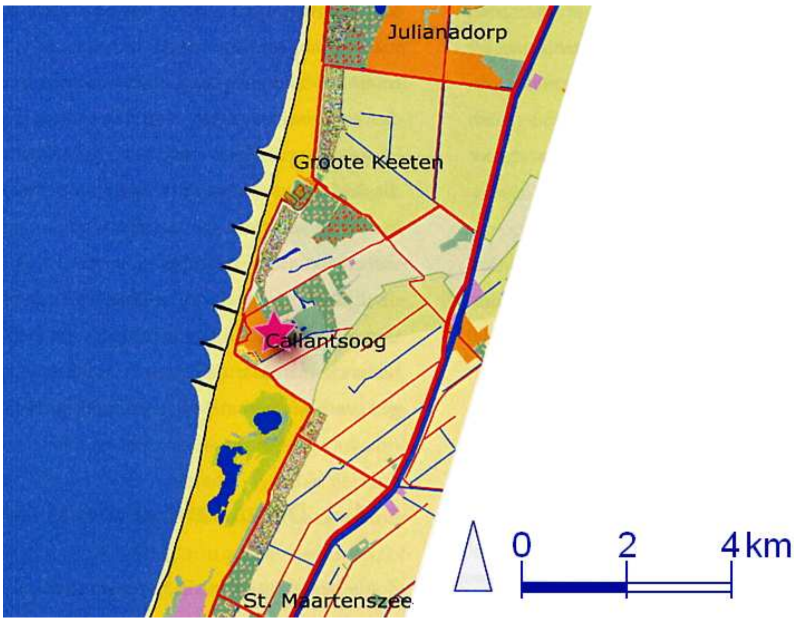


Figure 73: A design of the 'hard' solution variant for improving the weak link at Callantsoog by constructing groynes [Weijers, 2005].

I.2 Landward solutions

Landward coastal reinforcement measures incur improvement activities at the landward side of the existing coastal defences (dikes or dunes). Four solutions are distinguished within this category. Again, a difference could be made between hard and soft solutions depending on the materials applied for constructing the structures. Table 27 contains the potential landward solutions and whether they are hard or soft. Descriptions follow in the subsequent subsections.

Table 27: Summary of hard and soft landward coastal management solutions.

	Hard	Soft
Landward coastal management solutions	- Super levee - Withdrawal	- Dune behind existing dunes - Reinforcing defences in landward direction - Withdrawal

I.2.1 Dune behind existing dunes/dikes

The landward variant of the 'dune in front of existing dunes' solution is constructing a new dune or dike behind the existing defences (Figure 74). At locations with only one row of dunes or with a very narrow dune complex, creating a new dune (several tens of metres wide and about 5 to 20 metres high) behind the existing dunes could increase the safety level of the hinterland significantly. A new dune valley would originate between the old and the new dune.

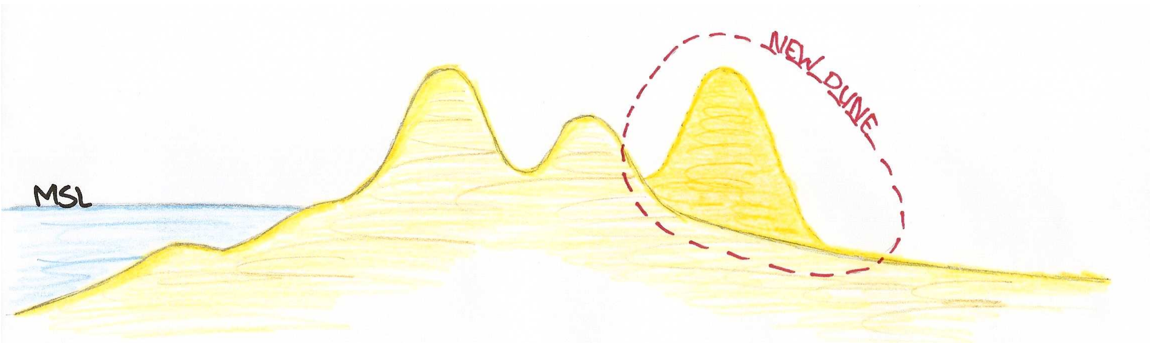


Figure 74: By creating a new dune behind the existing dunes (or dikes), a breakthrough of the original dunes in case of severe storms would not cause an inundation of the hinterland.

A major disadvantage of this type of solution is that, just like for all landward solutions, a strip of the area behind the dunes should be sacrificed for the safety of the entire hinterland. Functions present in this strip will be lost. Especially in case of houses and other buildings located close to the coastal defence the realization of this measure will be very difficult. However, in case the function of the area directly behind the coastal defence is of low value, this measure could be promising. No changes will be made to the existing coastline, so there are no hydrodynamic changes to be reckoned with. Moreover, an advantage of this solution is the increase of the dune area suited for nature development, especially the newly created valley. This new nature area is also applicable for recreational activities.

I.2.2 Reinforcing existing dunes/dikes in landward direction

In stead of constructing an entirely new dune landward of the existing dunes, it is also possible to extend the existing dunes (or dike) by increasing their width with tens to hundreds of metres and/or height with several metres of sand (Figure 75). This would increase the volume of sand within the cross-shore coastal profile and could prevent the erosion profile calculated for an extreme storm event to pass the landward boundary of the coastal defence.

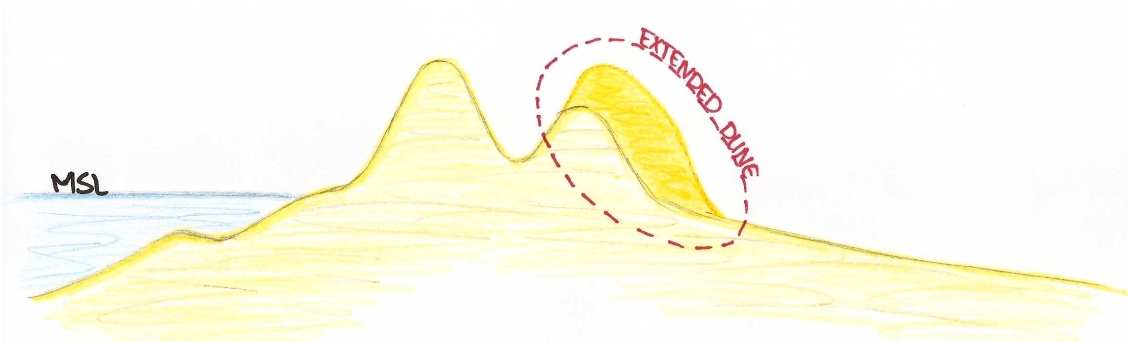


Figure 75: Dune extension in landward direction increases the strength of the dunes. In case of dikes, a volume of sand will be added to the landward side and on top of the structure.

The advantages and disadvantages of this measure are more or less the same as the effects of the construction of a new dune landward of the existing dunes. However, the strip needed for this measure will be narrower since no new dune valley is included in this solution. At the same time this decreases the potential value of this solution to nature development, but still the dune area increases (only the valuable valley is missing). This measure is part of the plan for reinforcing the weak link at the south-west of Walcheren [Witteveen+Bos, 2006].

I.2.3 Super levees

Another possibility for increasing the strength of the seawall along the Dutch coast is turning them into super levees (Figure 76). The super levee is an innovative idea of the Japanese in order to reduce the probability of flooding of the hinterland together with decreasing the risk of an inundation. Unless this solution is initially meant for strengthening river dikes, it would also be applicable to seawalls. The main characteristic of the super levee is the weak gradient of the inner slope of the dike that is about 1:30. This makes that super levees have widths of several hundreds of metres, dependent of the height needed. The weak gradient of the inner slope of the dike will prevent erosion of the dike in case of overtopping. Overtopping of a super levee thus would not lead to a breakthrough of the dike. Moreover, the robust dimensions substantially decrease the susceptibility of the dike to other failure mechanisms like piping and heave.

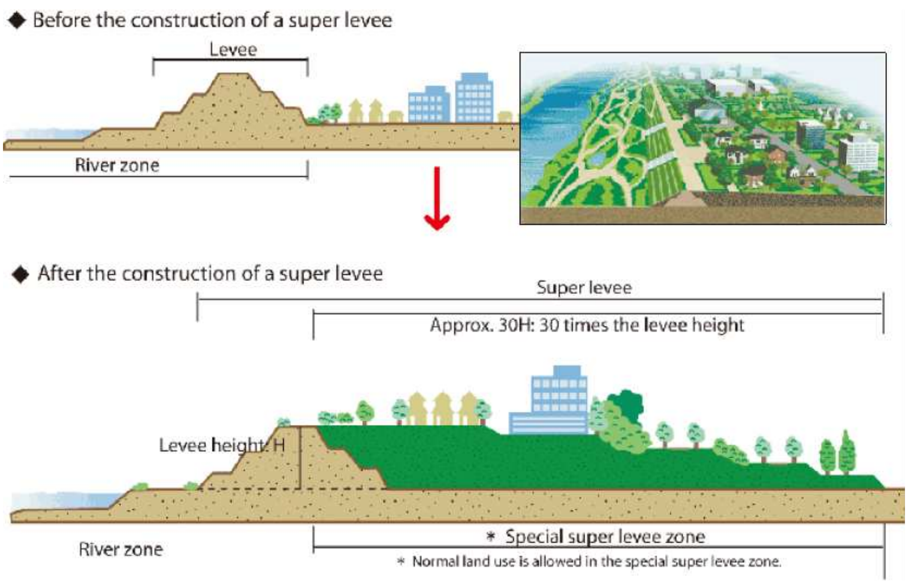


Figure 76: Artist impression of a multifunctional super levee along a river [Instituut SMO, 2007].

One of the major advantages of this structure is that it is possible to use super levees for spatial planning issues. Buildings and other functions could be located on the defences, integrating several spatial functions at the same location. People currently living close behind the defences, having a limited view, will have much wider views once their houses are located on the super levee. At the same time, the major disadvantage of this solution is that all buildings over several hundreds of metres behind the existing dike should be removed before constructions of the super levee will be possible. Locations along the coast that are protected by seawalls are mainly seaside resorts. These are specific locations where buildings are concentrated close to the coastal defence and where removal of all these buildings will be very expensive and where it will met large social resistance.

I.2.4 Withdrawal

Next to strengthening the coastal defence directly behind it's current location, it is also possible to retreat in landward direction. In this case, the existing dune or dike will be maintained or lowered and a new dike is constructed further landward at a distance of some hundreds of metres (Figure 77). The area between those two structures will inundate now and then, when heavy storms occur. The safety level of this area is lower than the safety to be maintained in the hinterland. However, most of the time, this are is not inundated. This type of solution resembles the management strategy applied to the rivers where a distinction is made between summer and winter dikes. The area in between, called the riparian land ('uiterwaard' in Dutch) could still be used when water levels are about the average. The ComCoast project is encouraging this type of solutions creating wider coastal defence zones in stead of the present single line defences.

Again, the major disadvantage of this measure is the amount of land lost by implementing this measure. A strip of several hundreds of metres wide would be sacrificed. However, less intensive land use functions like agricultural activities and recreational facilities could still be located within the coastal defence zone, as long as these functions are compatible with the possibility that the land inundates now and then. At the same time, valuable brackish nature could be developed in this zone creating a habitat for extraordinary species.

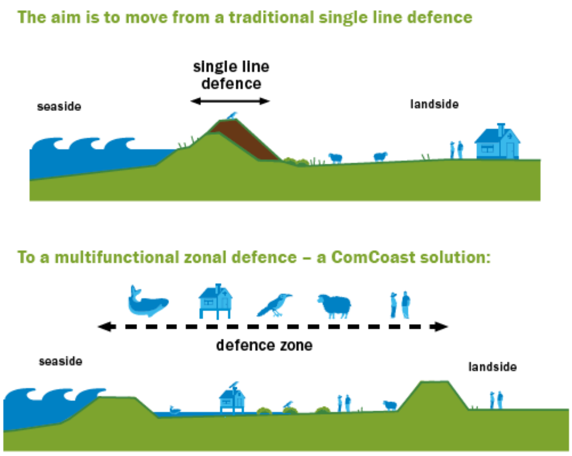


Figure 77: The ComCoast principle: changing single line defences to wider defence zones with opportunities for nature and recreation [ComCoast, 2007].

I.3 Consolidating solutions

The third and last category of measures is the option of consolidation. This means that the width of the coastal defences is not significantly extended. Improvements mainly occur in the vertical direction. There are four possible solutions (Table 28) that are described in the next subsections.

Table 28: Summary of hard and soft consolidating coastal management solutions.

	Hard	Soft
Consolidating coastal management solutions	- Dike in dune - Heightening dikes	- Heightening dunes - Natural growth of dunes

I.3.1 Dike in dune

One of the consolidating solutions is to construct a dike within the existing dune. In this case, the dune should be temporarily excavated. Meanwhile, a dike is constructed at the present location of the dune and afterwards the sand is relocated, covering the dike (Figure 78). Currently, this measure is being realized at Noordwijk, one of the weak links in the Zuid-Holland coast, in combination with a seaward extension of the dune.

A major advantage of this measure is that no additional space is available for reinforcing the coastal defences and that the existing functions within the area are not affected once the improvement is realized. However, the costs of excavating the existing dune and constructing a new dike are rather high. Next, existing nature will be destroyed during the construction process.

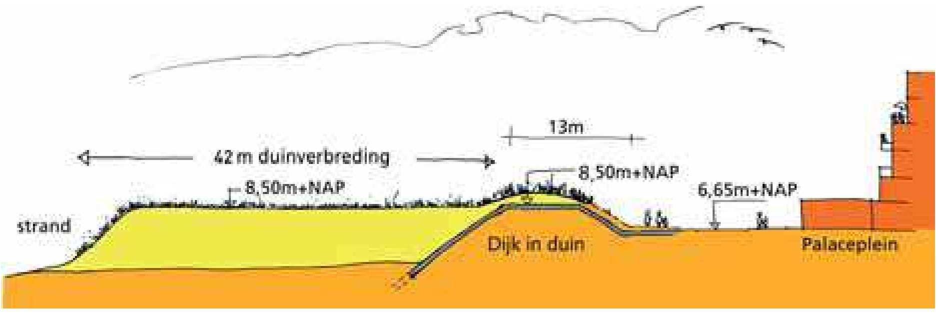


Figure 78: Design of the dike in dune solution, applied at the coast of Noordwijk [Rijnland, 2007].

I.3.2 Heightening dunes

Another consolidating solution is heightening the dunes at their present location. When only on row of dunes is present, this would be difficult. But when several rows of dunes are present in a dune area, it is possible to heighten the top level of (part of) these dunes (Figure 79). The amount of sand to be added strongly depends on the shortage faced in case of erosion during a super storm.

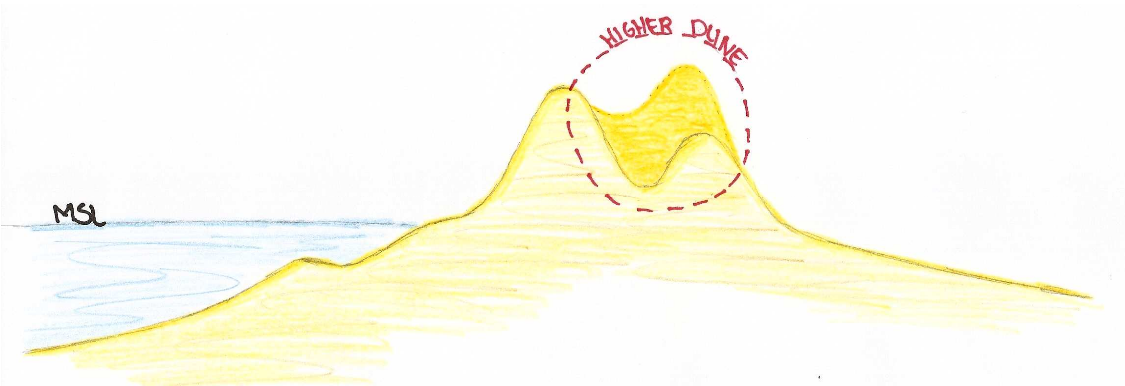


Figure 79: Heightening the dunes by adding sand to the existing dune area is a consolidating strategy for increasing the water retaining strength of the dunes.

Again, the advantage that no extra space is needed for this type of dune reinforcement is valid. However, (part of) the existing nature will disappear below the sand added to the system. Especially organisms living in dune valleys are very valuable. Moreover, transporting sand to a location within the dunes will be difficult, increasing the costs of this measure.

In stead of heightening the dunes by hand, it is also possible to leave this job to nature. Dynamic management of the dunes means that the sand of the dunes is allowed to move. Currently the dunefront is at its position by planting marram grass (helmgras) and other sand retaining objects.
When these retaining objects are removed and sand spray is allowed to occur, natural dynamics in dune development will return. These dynamics may cause the foredune to erode locally. However, fluctuations in the height of the foredune allow the sand (eroded from the foredune or blown from the

beach) to be transported further landward. This way, dynamic management enables the natural heightening of the entire dune complex (Figure 80) [Buiter, 2007]. A disadvantage of this management solution is the uncertainty on the actual strength of the foredune during a severe storm event. Therefore, this strategy is only applicable at location with wide dune areas consisting of several rows of dunes. An example of this management strategy is the pilot project named 'De Kerf' where an opening was created in the foredune [Buiter, 2007].

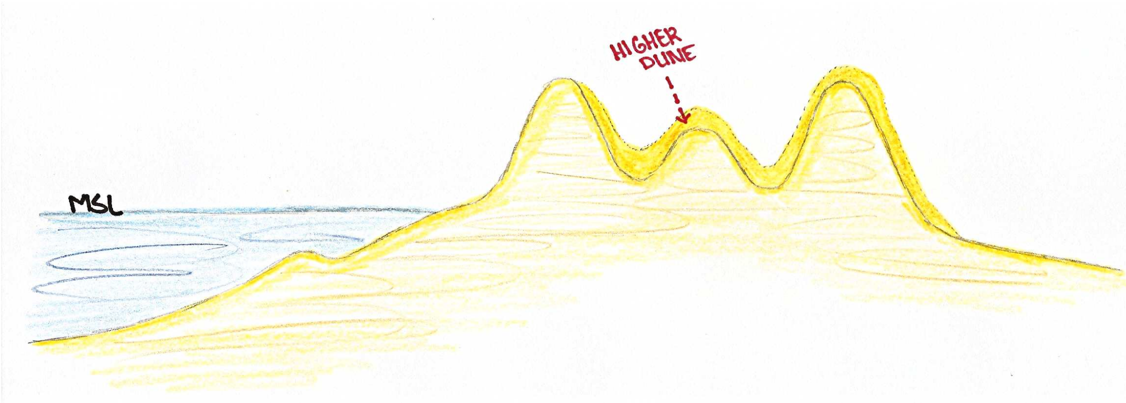


Figure 80: Heightening the dunes by dynamic management of the foredune is a natural variant for adding sand by hand, applicable in wider dune areas.

I.3.3 Heightening dikes

When no dunes but dikes are part of the coastal defence, dike heightening is the equivalent of dune heightening. In this case, a water retaining structure should be constructed on top of the existing dike (Figure 81). An example of this solution is the sheet piling constructed on top of the Hondsbossche sea defence after it was found that the safety level of this defence was far too low. Often heightening a dike incurs a substantial widening too in order to remain its stability. In this case the solution is not a purely consolidating one any more, but will still be defined as being consolidating.

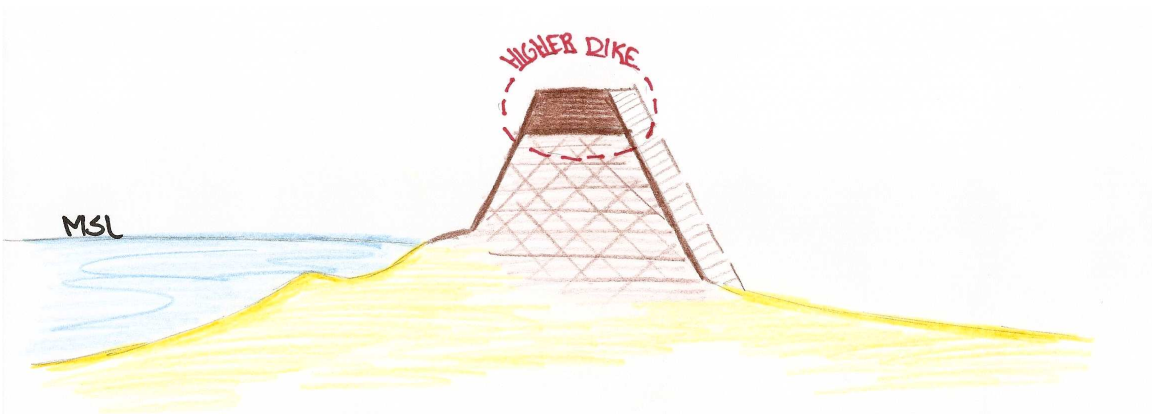


Figure 81: Heightening the dike will decrease the susceptibility of the hinterland for flooding during severe storm events. Often the dike should be extended in the horizontal direction in order to support a higher crest level.

Heightening dikes is said to be very inefficient nowadays (especially in river management). Increasing the height of dikes increases the dangers in case of failure. At the same time, dikes are susceptible to much more failure mechanisms (like overtopping, instability, piping and heave (sea appendix E.4.1)) than dunes (erosion and overtopping). Next, dikes are not resilient. Dikes don't have the ability to grow gradually and by natural processes. Costs for heightening dikes are much higher than costs for reinforcing coastal defences with sand. An advantage of dikes and heightening dikes is that the space needed for this type of defence and reinforcement is smaller than the space needed for dunes.

J Dimensioning coastal management strategies

This appendix presents a preliminary research into the dimensions of the coastal management strategies set-up for the year 2200. The goal of this study is not to present a detailed design of these measures, but to indicate possible effects and to compare the solutions given on the basis of global designs. In order to gather some knowledge on these effects, it is important to know the rough dimensions of the proposed solutions. This information is derived from both previous studies and from some quick Matlab calculations with the DUROS-plus model. These dimensions are based on the increased boundary conditions according to the higher climate change scenario presented in this study, as the measures will be initially compared for this scenario.

J.1 Uniform coast strategies

Concerning the large spatial scale, three potential coastal management strategies are proposed: islands, sandbanks and dunes in front of existing dunes.

J.1.1 Islands

Several designs for (multifunctional) islands in front of the Dutch coast are launched during the past decades. Some of these plans couple the designs of these islands to specific land use functions. The design of Lievense for example foresees a multifunctional island for hydro-power generation, industry and housing (see appendix I.1.1). However, this type of spatial development is beyond the scope of this study. Our main goal is to define the global dimensions of such an island.

The visionary plans of Adriaan Geuze (landscape planner) are most persistent concerning the creation of new islands. Together with the national Rijkswaterstaat and research institute TNO he developed a plan for the nicest and safest delta last year [Schreuder, 2007]. This plan contains a chain of islands in front of the North Sea coast, reaching from Calais to Callantsoog (Figure 82). This chain of islands should resemble the Wadden islands north of the Dutch mainland and one large island is foreseen in front of the Holland coast (with a narrow fairway in front of IJmuiden). An important feature of this design is that the outline of the islands does not affect the natural concave shape of the coastline. This would reduce the impact on morphodynamic impacts in longshore direction.

Figure 82: Artist's impression of the plan of Geuze describing a chain of islands in front of the Dutch and Belgian coasts [Havermans, 2007].

This section concentrates on the island in front of the Holland coast. Since it should resemble the Wadden islands, the features of these islands are studied. In general, these islands are located at 10 to 20 km seaward from the mainland coasts and they are about 2 to 6 km wide. To retain the concave shape of the shoreline, to the north the new island should become narrower and it should be located somewhat closer to the mainland coast. The offshore distance is supposed to be about 10 km. Sea bottom levels at this location are currently around 20 m below Amsterdam Ordnance Datum. The width of the island is supposed to decrease gradually from about 3 km in front of Hoek van Holland to about 1 km in front of Callantsoog.

The surface level of these islands could have an average of about 2.5 m above the mean sea level of the year 2200 (which would now be about 5.5 m +NAP). This is comparable to the surface level of major parts of the Wadden islands (Figure 83), which is about 2.5 m +NAP.

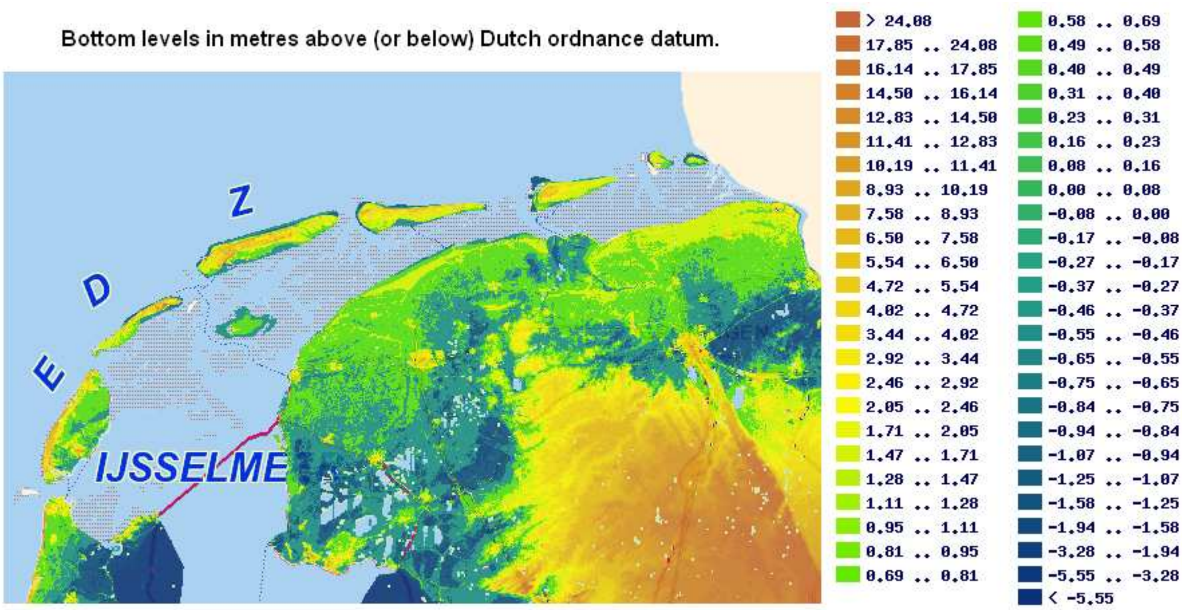


Figure 83: Bottom levels of the Dutch Wadden Islands [AHN, 2008].

Protection of the new islands could be provided by a row of dunes at their western coast. However, an important question is how safe these islands should be? It would not be efficient to copy the safety standards of central Holland to these new islands since this would ask for enormous investments for protecting these islands. On the contrary, these islands are the coastal protection of the central part of Holland. They should stop the long waves coming from the Northwest during severe storm events. So the safety levels of the islands should be much smaller than those of the mainland, about 1:500 for example. This would create possibilities for the investments in lower-valued land use functions like recreation and nature (and maybe even short-term housing). Another possibility is the integration of the plan of Lievense within this island.

In order to persist morphodynamic processes that will cause erosion of the island, it should be designed as a more or less static future (this is why it is called a hard engineering solution). This implies that the island will not just be a hump of sand in the North Sea, but its slopes should be protected by stones.

Concerning the protection of the mainland coast, it is not quite certain yet whether the construction of an island like this will be sufficiently effective in order to preserve the present safety levels of the dunes regarding the impeding boundary conditions. However, since the crests of these islands will be located at about 2.5 m above the future mean sea level, they will certainly damp out the long waves coming from the North Sea. The mainland dunes will then only be exposed to short waves and higher water levels. It is supposed that this will not lead to significant insufficiencies of the mainland coastal defences. Moreover, structural erosion of the mainland dunes might be decreased by the presence of these islands, since wave attack will be damped under almost all circumstances.

Another point of attention is the protection of the northern part of Noord-Holland, between Callantsoog and Den Helder (north of Jarkus cross-section 1300). Here the island has stopped already so coastal defences should be strengthened at the mainland. Since the northward transport of water and sediment in front of the Dutch coast would make it impossible to create a seaward extension of the mainland coast at this location where water is flowing through the relatively narrow opening between the mainland and the newly created islands. Therefore a seaward extension of the dunes is foreseen north of Callantsoog. This measure will also be applied to increase the strength of the dike at Den Helder.

The final configuration of this measure is presented in appendix K.

J.1.2 Sandbanks

Sandbanks are morphological features of the sea bottom that could be found in front of the Dutch coast (in the entire North Sea even). A distinction can be made between different types of seabed patterns (Table 29). The longshore bars are located closest to the coast, at about 100-1250 m offshore [Ruessink e.a., 2003]. However, their height is rather small compared to the present water depths of up to 10 m within this area. Shoreface connected ridges and sandbanks are very large patterns but are located even further offshore. The orientation of sand waves makes these features inapt for coastal protection. So it is concluded that none of these natural morphologic features is suited to be copied in order to decrease wave attack at the mainland coast.

Table 29: Overview of orders of magnitude of physical characteristics for large-scale seabed patterns [Hulscher e.a., 2005].

Bed pattern	Wavelength [km]	Orientation crests	Amplitude [m]	Migration
Tidal sandbanks	2-10	-30° to 0 ° to tide	2-20	no?
Sand waves	0.1-0.8	+/-90° to tide	5	yes
Shoreface connected ridges	5	0° to 30 ° to tide	2-5	no?
Longshore bars	0.075-0.25	90° to waves	0.5-1.5	yes

However, the principles of sandy features in front of the coast might still be very useful (see appendix I.1.4 for some advantages). This measure is closely related to the foreshore nourishments that are gaining more attention nowadays.

In order to create an effective structure, able to damp out wave attack at the mainland coast during severe storms we will copy the configuration of the artificial reefs (see appendix I.1.2). These reefs will significantly reduce long waves, however they are exponents of hard-engineering. However, hard measures decrease natural dynamics. This disadvantage could be reduced when the reefs are made of sand alone (no stones on top of it). Moreover, the sand available at these banks might feed the mainland coast causing a seaward extension of the existing defences over time. This would further improve coastal safety of the study area. However, it is still very uncertain whether the sand being eroded from these new sandbanks will be transported in coastward direction. It might also be transported in longshore direction or even towards the deeper waters seaward of these banks. Together, these wave-breaking and potential coastal-extension effects are supposed to increase the safety level of the study area to satisfy the legal preconditions.

Typical dimensions of these structures are thus copied from the artificial reefs. The width of the sandbanks has to be about 30 m at the top. These banks are located at 1.5 to 3 km offshore, where mean water depths are about 10 m, and their crest levels are about 1.5 to 3 m below mean sea level [Royal Haskoning, 2005]. Both the water levels and the bottom levels will increase with the same speed at these locations according to the predicted effects of the high climate change scenario and the autonomous developments. This means that these sandbanks on average will be about 8 m high (at the location of the crest). Once they are created, they are supposed to keep up with the sea bed rise of the surrounding area so that the distance between their crest and the mean sea level remains the same. The maximum slope of these sandbanks would be about 1:5 to 1:6 (expert judgement), so at the sea bed the width of these structures will be about 120 m.

Since the sandbanks are not protected by stones, the sand could be transported in both landward and seaward direction. For landward transport it is known that the maximum capacity of such a sand engine (‘zandmotor’) is about 225 m^3/m/year [Zijlstra e.a., 2007]. However, no knowledge is available on the seaward losses of sand from these banks. Independent of the amount of sand lost, this would raise the need for a maintenance programme in order to be sure that those banks are still present when a severe storm occurs.

Finally, it should be found out whether one long sand bank should be proposed or a chain of smaller sandbanks. In this case a chain of smaller sandbanks is chosen with the individual banks oriented the same way as the shoreface connected ridges (Figure 84). Although these new sandbanks are located closer to the coast than the shoreface connected ridges, it is assumed that this resembles some sort of morphologic equilibrium. Moreover, one long sand bank would not be stable since the water being transported in landward direction over the bank would increase the pressure behind the bank due to accumulation. This could result in the formation of so-called rip-channels (muigaten) within the bank with seaward flow velocities. This would locally increase erosion of the banks. By realising a number of shorter sandbanks with a larger spacing and oriented at an angle of about 30° to the coastline, this effect might be reduced since the accumulation of water landward of the sandbanks will decrease. Seaward transport of water is becoming easier but at the same time these banks are still able to break the most severe waves coming from the northwest (the major direction of storms being dangerous for the Dutch coast).

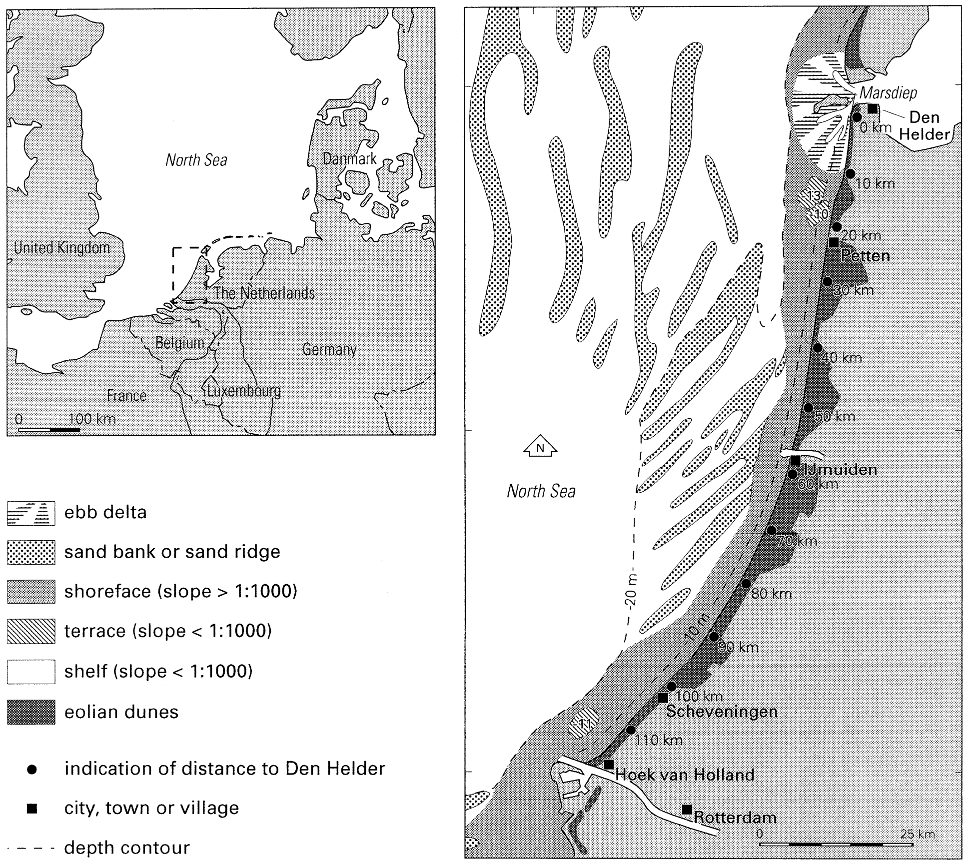


Figure 84: The configuration of the new sandbanks is deduced from the shoreface connected ridges in front of the Holland coast [Wijnberg, 2002].

A potential configuration of these sandbanks is sketched in appendix K.

J.1.3 Dunes in front of existing dunes

For designing the measure of building dunes in front of the existing dunes, some rough calculations are done with the DUROS-plus model. In order to assure that the coastal defences will be safe in the new situation (with a new row of dunes in front of the existing dunes), the aim of this measure is that the new dune absorbs the total erosion during a critical storm event (both the erosion volume and the additional erosion volume). In the new situation, the boundary profile should fit within the first row of dunes behind the existing dunes. This should prevent for complex situations with water flowing through dune valleys and entering the hinterland at a distant location as described in section 2.4.2 of this study. At locations where even the boundary profile does not fit within the existing foredunes, they should be heightened too in order to create one continue boundary profile landward of the new foredunes. Or the shortage in height of the foredunes should be compensated by the width of the existing foredunes (see appendix E.3.3, stating that other shapes of the dune could also satisfy the boundary profile).

In order to get some insight into the dimensions of the new foredunes, model calculations are made for a limited number of cross-shore profiles representative for large stretches of the studied coast. To find these representative profiles, we started by deriving larger stretches of the coast assessed more or less the same in Table 4. Next, for every section a representative cross-shore profile was selected. These representative cross-shore profiles are assessed relatively bad compared to the other profiles since the weakest link will determine the strength of the total defence of that section. But we didn’t select the weakest link of all since this would result in large overestimations of the needed extensions of the new foredunes for almost the entire coastline. This way, eleven cross-shore profiles were selected, representing the entire coast of the study area.

Finally, four of these profiles were selected for calculating the necessary dimensions of the new foredunes. In this case, we did (again) not select the worst cross-shore profiles since this would create an overestimation of the amount of sand needed for the new dunes. The selected profiles are ‘Jarkusraai’ 1708 (between Callantsoog and Petten), 2251 (Hondsbossche seawall), 8075 (Noordwijk) and 10996 (Delfland area). The situation at cross-section 2251 represents the situation at many coastal towns protected by small, rather low dunes and boulevards (being revetments) on top and just behind these sandy structures. The other three cross-section represent areas with narrow (1708) or much more extended (10996) dunes and lower (1708, 10996) and higher (8075) dunes. Each of these profiles is supposed to represent in an equal part of the total length of the coast.

Next, a first guess of the dimensions of the new dunes is derived from the existing foredunes along the Holland coast. It appeared that a crest level of 17 m above Amsterdam Ordnance Datum and a width of about 150 m resembles the dimensions of the existing foredunes. These new dunes are connected to the existing dunes at a height of 5 m above Amsterdam Ordnance Datum. The new dune is then modelled by a sinusoidal shape with the formula:

$$H = 5000 + 12000 * \left(\frac{2\pi}{300} * L \right)$$

Where H is the dune height in mm and L is the horizontal distance to the connection point in m (these somewhat remarkable units are due to the data input). Finally, the present toe of the dune, beach and foreshore, up to a depth of about 3 m below Amsterdam Ordnance Datum, are copied 150 m seaward and finally connected to the foreshore. This is done in order to retain current beaches.

Next, some model calculations have been made for the representative cross-shore profiles in order to determine the dimensions needed for the new foredunes in order to retain the present safety levels of the coastal flood defences when the boundary conditions intensify according to the worst climate change scenario. For this optimisation the crest level (C) and width (W) of the new dune have been varied, changing the previous formula into:

$$H = 5000 + (C - 5000) * \left(\frac{2\pi}{2W} * L \right)$$

Only a rough optimisation is executed due to the conceptual research of this study. Dune crest heights are optimized by changing crest levels by 1 m units and dune widths are increased in steps of 50 m. The necessary dimensions of the new dunes are summarized in Table 30.

Table 30: Dimensions needed for the new dunes in front of existing dunes to maintain coastal safety levels in the year 2200 according to the highest climate change scenario. Dimensions are calculated for four cross-sections representative for the entire coast of the study area.

Cross-section [kmr]	Foredune crest level [m +NAP]	Foredune width [m]
1708	17	150
2251	20	200
8075	17	150
10996	17	200

The changes to the cross-shore profiles implied by these dimensions are plotted in Figure 85. These plots show that current beaches (reaching from about 2 m –NAP to about 3 m +NAP [Mulder e.a., 2006]) are repositioned in front of the new foredunes. The results of the model calculations of these new cross-shore profile for their safety in 2200 according to the worst climate change scenario are presented in Figure 86. In the upper two windows of this figure the boundary profile does not fit entirely within the cross-shore dune profile. However, the dunes backing the new foredunes at cross-section 1708 are supposed to contain enough sand to obviate this problem (see before). At cross-section 2250 the Hondsbossche seawall is supposed to be sufficiently stable to supply the small missing volume of the boundary profile.

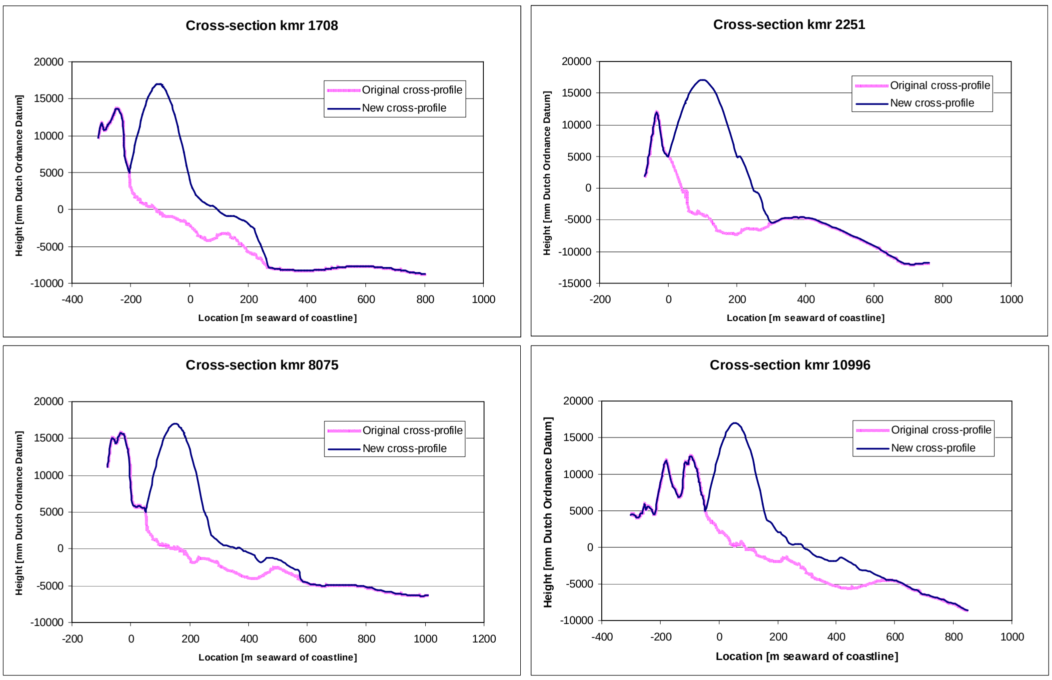


Figure 85: Schematic representation of the new dunes in front of existing dunes to maintain coastal safety levels in the year 2200 according to the highest climate change scenario.

In reality, by the year 2200 the cross shore profiles will be increased with about 3.15 m seaward from the toe of the dunes. However, this sea bed rise is part of the autonomous development and is therefore not included in these cross-sections. The DUROS calculation model adds this bed level increase automatically.

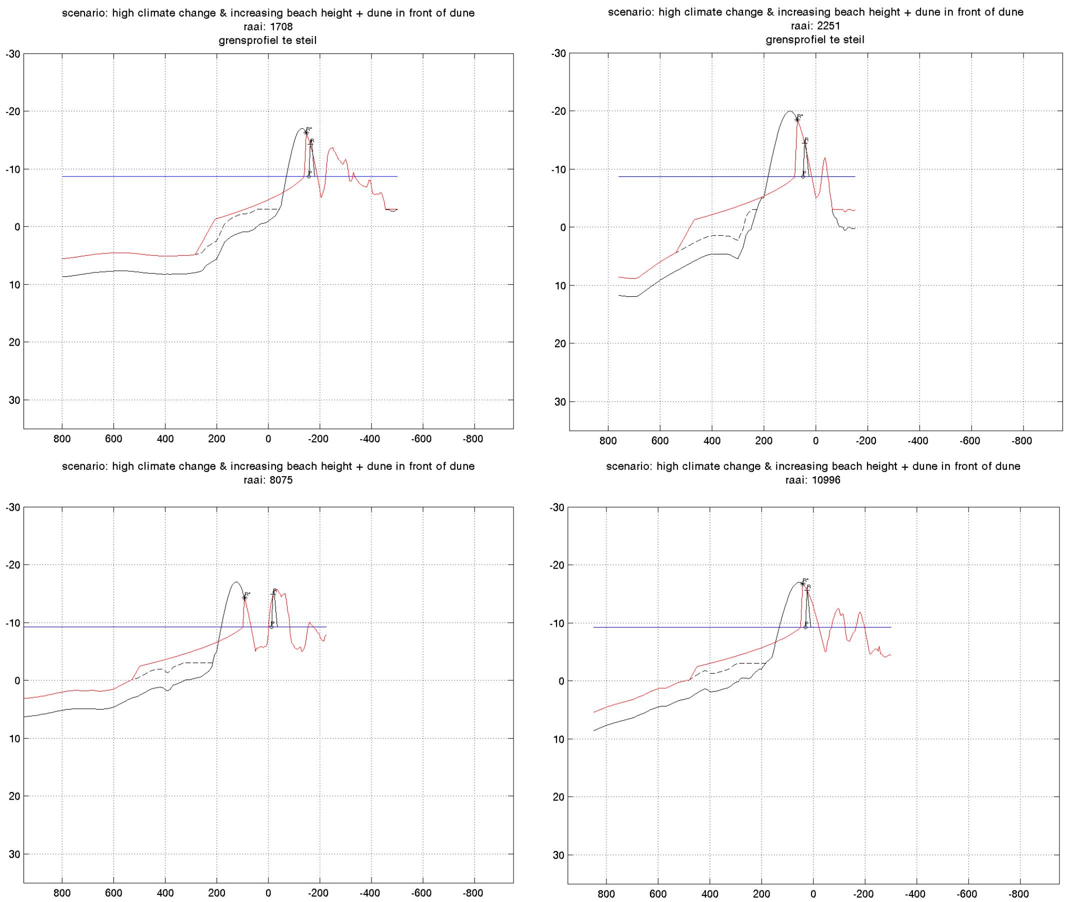


Figure 86: Results of model calculations for the new cross-sections with an additional dune in front of the existing foredune show that the optimized dimensions are effective and efficient for the representative cross-sections.

J.2 Large scale strategies

At this spatial scale, two different strategies are proposed. The dimensions of the solutions being part of these strategies are mainly copied from the dimensions of the uniform coast solutions.

J.2.1 Islands and dunes

The first solution covering the semi-large spatial scale consists of islands in front of the southern part of the study area (south of IJmuiden) and new dunes in front of the existing dunes (and dike) in the northern part of the study area. The dimensions of these measures are directly copied from the dimensions that where derived for the uniform coast solutions since nothing is changed to the situation to be improved. So this solution consists of the southern part of the island, up to the fairway at IJmuiden, and the dunes designed in section J.1.3 will be projected to the northern part of the coastline. The dimensions and configuration of both the island and the dunes will not be changed for this solution.

A preliminary configuration of this solution is drawn in appendix K.

J.2.2 Dunes and sandbanks

The second solution covering the semi-large spatial scale consists of dunes in front of the existing dunes for the southern part of the study area (up to IJmuiden) and sandbanks in front of the northern part of the Holland coast. Again, the dimensions and configuration of these measures are copied from the uniform coast solutions without any changes. A drawing of the outline of this solution can be found in appendix K.

J.3 Intermediate scale strategies

At the semi-small spatial scale again two strategies are proposed: a seaward and a landward variant.

J.3.1 Seaward strategy

The seaward strategy for enhancing the coastal defences is composed of several measures for increasing the strength of the dunes (or dikes) along the coast (Table 31). These measures are differentiated along the coast according to land use patterns at the intermediate spatial scale united in different sections. For every section with a characteristic land use a suitable measure is selected and dimensioned. These dimensions are very rough and only indicative and are based on the boundary conditions stated by the high climate change scenario. Dimensions are both derived from previous studies (as far as possible) and from new model calculations (for sandy measures).

Table 31: Seaward coastal management solution with an intermediate spatial differentiation. Notes: section numbers refer to Jarkus cross-section numbers and the colours in the assessment column refer to the colours in Table 4.

Section [#]	Section [kmr]	Representative cross-section [kmr]	Land use function	Assessment	Solution
1	0-2600	1524	agriculture	red	Dune in front of existing dune
2	2600-3300	2847	nature	orange	Sand bank (+ extended beach and dunes)
3	3300-4300	3550	agriculture	orange	Dune in front of existing dune
4	4300-5000	4900	nature	orange (red)	Sand bank (+ extended beach and dunes)
5	5000-5400	5050	greenhouses/industry	orange	Dune in front of existing dune
6	5700-7400	6725	nature	orange	Sand bank (+ extended beach and dunes)
7	7400-8100	7975	agriculture	orange	Dune in front of existing dune
8	8100-8800	8125	coastal towns	red	Artificial reef
9	8800-9200	9075	agriculture	green	-
10	9200-9900	9525	nature	yellow	Sand bank (+ extended beach and dunes)
11	9900-10800	10592	coastal towns	red	Artificial reef
12	10800-11850	10996	greenhouses/industry	orange (red)	Dune in front of existing dune

Section 1, 3, 5, 7, 12

The existing dunes within these sections are not sufficiently safe under the circumstances foreseen for the year 2200. These sections of the coastal defences will be enhanced by new foredunes to be built in front (=seaward) of the existing foredunes. The dimensions of these new dunes are derived at exactly the same way as in case of the uniform strategy. The dimensions found for the foredunes needed in these sections are summarized in Table 32. The new cross-sections and the results of the model simulations resemble those presented in Figure 84 and Figure 85.

Table 32: Dimensions needed for the new dunes in front of existing dunes to maintain coastal safety levels in the year 2200 according to the highest climate change scenario. Dimensions are calculated for five cross-sections representative for the intermediate scale spatial sections.

Section	Cross-section [kmr]	Foredune crest level [m +NAP]	Foredune width [m]
1	1524	17	150
3	3550	17	150
5	5050	17	150
7	7975	17	150
12	10996	17	200

Section 2, 4, 6, 10

These sections of the coastal defences will be improved by creating a sandbank in front of the coastline and by the natural growth of the beach and dunes due to the sand feeding by these banks. Since no calculations could be made on this measure, we just copy the planned configuration of the uniform coast and large scale solutions comprising sandbanks. So the preliminary dimensions of these sandbanks are equal to the dimensions presented in section J.1.2 of this appendix.

Section 8, 11

Constructing artificial reefs in front of the shoreline will enhance the coastal defence at the sections of these coastal towns. As stated above, preliminary studies into the effectiveness and effects of these reefs are currently studied by Royal Haskoning within the framework of water innovation resources project (Waterinnovatiebron, WINN). Two conceptual designs (Figure 87) were made for reefs in front of the coast of Scheveningen (cross-sections 9900-10300). The outcomes of this study are applied for indicating the features of these reefs.

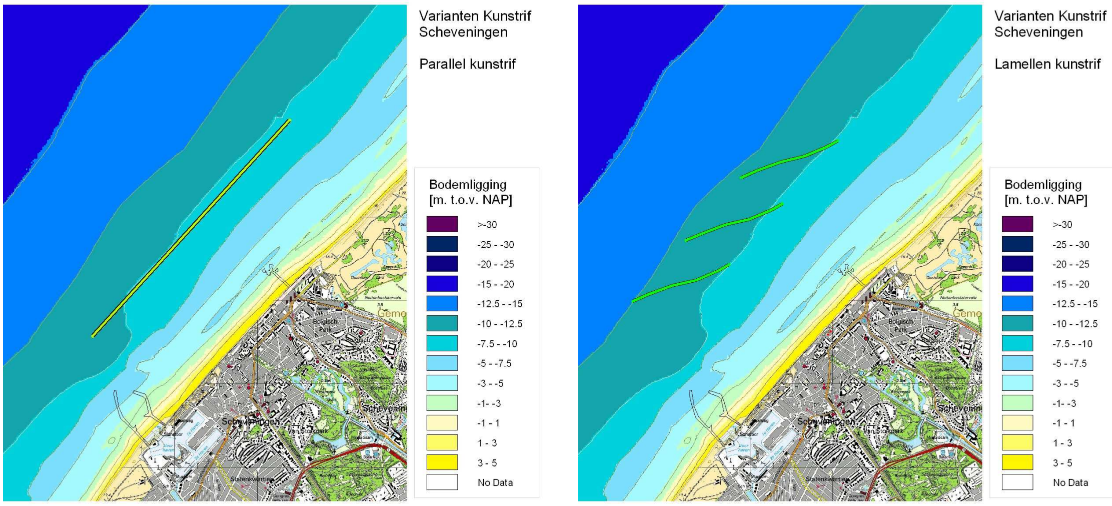


Figure 87: Two conceptual designs for artificial reefs in front of the Scheveningen coast: an elongated, longshore oriented design (left) and a design minimizing the impact on landward sediment transport directed to the north-east (right) [Royal Haskoning, 2008].

These reefs are projected at locations with an average water depth of about 10 m (bottom levels are at 10 m below MSL). This is said to be the seaward boundary of the morphologically active zone under normal conditions [Royal Haskoning, 2008]. There are also studies stating that the seaward boundary of morphological activity should be located at a bottom depth of 20 m beneath MSL. Nevertheless, this assumption is underwritten for this coastal enhancement alternative.

The crest levels of the reefs are designed at about 1.5 to 2 m below MSL and should have a width of 25 up to 30 m. The slopes at both sides of the reef will have an inclination of 1:1.5 and will be covered with stones. The length of the longshore variant in Figure 87 will be 3 km and the separated parallel reefs directing to the north-east will each have a length of about 1.3 km [Royal Haskoning, 2008]. For this study the concept of the parallel reefs from the right panel of Figure 87 is selected since this outline is less disrupting to the morphological processes transporting sand towards the coast stimulating the growth of both beaches and dunes.

From simulations it is concluded that constructing these reefs would reduce erosion of the mainland coast during a severe storm event by about 50% [Royal Haskoning, 2008]. This would increase the safety of the areas located in front of the coastal defences and at the same time the inundation risk of the hinterland will be reduced significantly. It is not certain whether this would solve the safety problems faced at both sections 8 and 11. However, redesigning the reefs would exceed the scope of this study and therefore these dimensions are copied and assumed to be sufficiently effective. It is supposed that redesigning would not significantly change the dimensions of the reefs. It should also be noted that the crest level of the reefs should be increased over time to keep up with the expected rates for sea level rise.

J.3.2 Landward strategy

This strategy is composed of landward directed measures that could be realized more or less in harmony with the land uses of the different sections distinguished at the intermediate spatial scale (Table 33). For every section with a specific land use a suitable measure is selected and dimensioned. These dimensions are very rough and only indicative and are based on the boundary conditions stated by the high climate change scenario. Dimensions are both derived from previous studies (as far as possible) and from new model calculations (for soft, sandy measures).

Table 33: Landward coastal management solution with an intermediate spatial differentiation. Notes: section numbers refer to Jarkus cross-section numbers and the colours in the assessment column refer to the colours in Table 4.

Section [#]	Section [kmr]	Representative cross-section [kmr]	Land use function	Assessment	Solution
1	0-2600	1524	agriculture	red	Extending dune in landward direction
2	2600-3300	2847	nature	orange	Dune behind existing dunes
3	3300-4300	3550	agriculture	orange	Extending dune in landward direction
4	4300-5000	4900	nature	orange (red)	Dune behind existing dunes
5	5000-5400	5050	greenhouses/industry	orange	Extending dune in landward direction
6	5700-7400	6725	nature	orange	Dune behind existing dunes
7	7400-8100	7975	agriculture	orange	Extending dune in landward direction
8	8100-8800	8125	coastal towns	red	Dike in dune + extending dune in seaward direction
9	8800-9200	9075	agriculture	green	-
10	9200-9900	9525	nature	yellow	Dune behind existing dunes
11	9900-10800	10592	coastal towns	red	Dike in dune + extending dune in seaward direction
12	10800-11850	10996	greenhouses/industry	orange (red)	Extending dune in landward direction

Section 1, 3, 5, 7, 12

Insufficient coastal defences in agricultural sections will be extended with sand at the landward side of the foredunes (or dike). However, at some locations (e.g. cross section 1524) it is inconvenient to locate these extensions further landward in case several dune crests are present in cross-shore direction since this would again create the problems with water flowing through the dune valleys in case of failing foredunes (see section 2.4.2).

Again we applied the DUROS-plus model to calculate what dimensions are needed to create coastal defences satisfying the increased boundary conditions for 2200 according to the higher climate change scenario. The width of the simulated dune extensions is varied with 10's of metres. Where necessary an increase of the crest level of the foredune is included to heighten crest levels to about 17 m above Amsterdam Ordnance Datum. This height is needed in order to satisfy the boundary profile on top of the extreme storm surge levels. Furthermore, extensions are designed according to the shape of the existing dunes (Figure 88).

Table 34 summarizes the dimensions needed for these landward extensions of the coastal defences. Figure 88 shows two examples of the changes of the cross-shore profile of the coastal defences due to this measure and Figure 89 presents the results of the safety calculations by DUROS-plus of these two cross-sections.

Table 34: Dimensions needed for extending the dunes in landward direction to satisfy coastal safety levels in the year 2200 according to the highest climate change scenario. Dimensions are calculated for five cross-sections representative for the intermediate scale spatial sections.

Section	Cross-section [kmr]	Landward extension [m]	Increase crest level [m]
1	1524	60	2
3	3550	40	-
5	5050	40	-
7	7975	40	-
12	10996	40	4

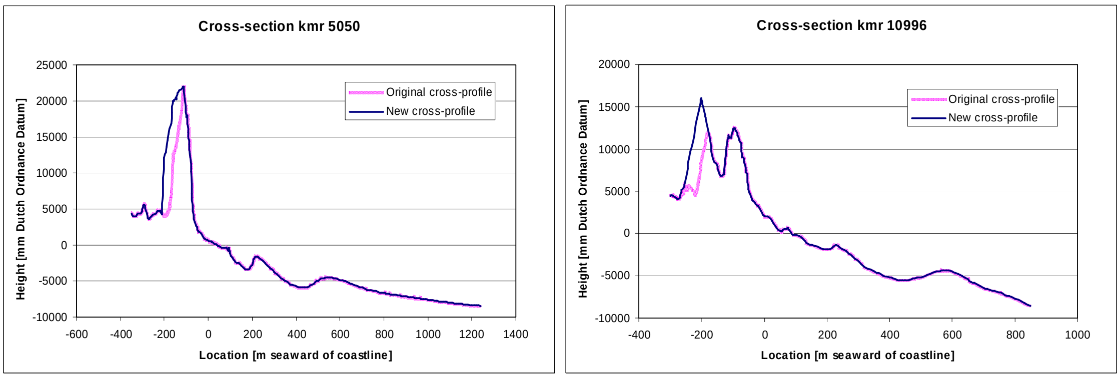


Figure 88: Schematic representation of the landward dune extension designed for Jarkus cross-sections 5050 and 10996 to maintain coastal safety levels in the year 2200 according to the highest climate change scenario.

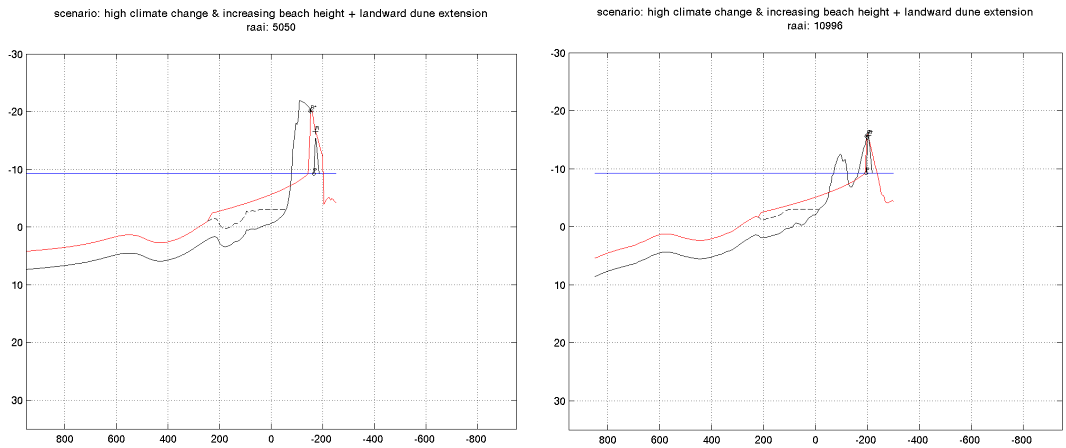


Figure 89: DUROS-plus safety calculation results for the landward extended cross-sections for the intermediate scale spatial differentiation.

Section 2, 4, 6, 10

The safety of the defences at these sections of the Holland coast will be improved by a new dune behind (landward of) the existing dunes. The dimensions of these dunes are derived by simulations with DUROS-plus and the shape of the dunes is again designed by a sinusoidal curve just like the dunes to be created seaward of the existing dunes. The crest level of the new dunes is the same for all sections: 16.0 m above Amsterdam Ordnance Datum. The width of the dunes is variable, according to the needs at the different representative cross-sections. The same is valid for the level where the new dune attaches to the existing dune, this depends on the local configuration. At the landward end of the new dune, a smooth connection to the existing cross-shore profile is designed.

After some steps of optimization, the dimensions of the new dunes are found. These are presented in Table 35. Figure 90 shows the present and future outlines of two of the representative cross-profiles of these sections. Figure 91 shows the erosion profiles calculated by DUROS-plus for the new cross-profiles including the new landward dunes.

Table 35: Dimensions needed for the new dunes landward of existing dunes to maintain coastal safety levels in the year 2200 according to the highest climate change scenario. Dimensions are calculated for four cross-sections representative for these intermediate spatial scale sections.

Section	Cross-section [kmr]	Crest level [m +NAP]	Width [m]	Level connection point [m +NAP]
2	2847	16	100	9
4	4900	16	75	8
6	6725	16	50	10
10	9525	16	30	13

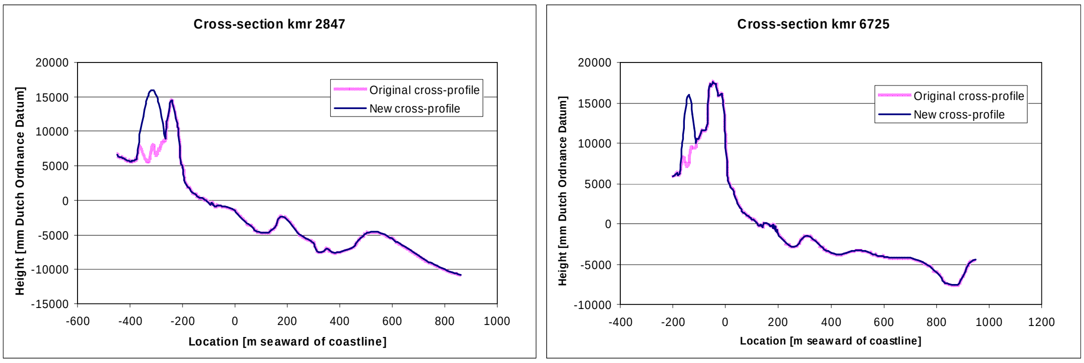


Figure 90: Cross-shore profiles showing the impact of a new dune to be realized landward of the existing (fore) dune at Jarkus cross-sections 2847 and 6725 to maintain coastal safety levels in the year 2200 according to the highest climate change scenario.

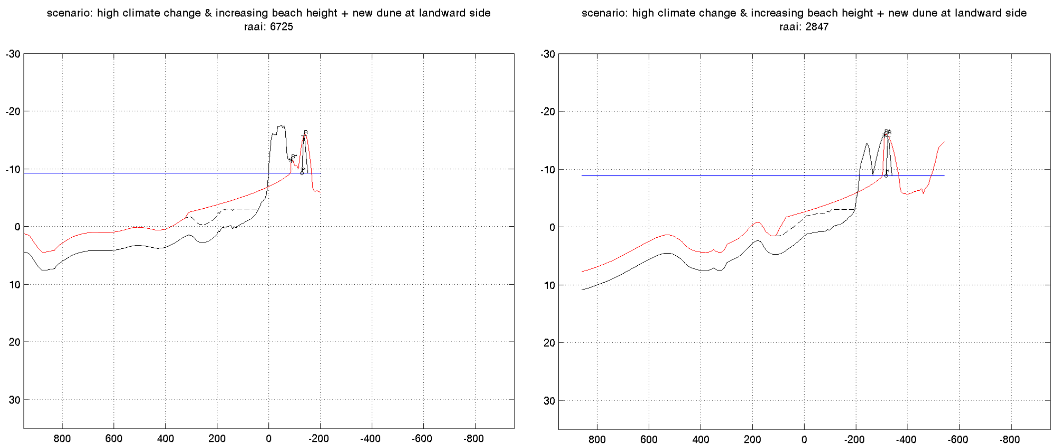


Figure 91: DUROS-plus safety calculation results for the cross-sections of the intermediate scale spatial differentiation being enhanced by a new dune behind the existing dune.

Section 8, 11

The coastal defences of these two coastal towns will both be improved by creating a dike within the existing but small dune and an extension of this dune in seaward direction. This solution is based on the project currently being realized at Noordwijk (Figure 92). However, the dimensions of this project are based on developments foreseen for the next 50 years (0.30 m sea level rise). For this short-term period, a crest level of 11.0 m above Amsterdam Ordnance Datum is designed for the northern part of this town and a crest level of 8.5 m +NAP for the southern part. The slopes of this internal dike are determined at 1:2 for the inner slope and 1:3 for the seaward slope. The new dunes in front of this dike are about 50 to 60 m wide and have a crest level of 8.5 m +NAP, on top of the dike this level would be some higher [Van Rijn, 2006]. Next, this study states that another seaward dune extension of about 10 to 30 m will be needed in order to facilitate a sea level rise of 1.70 m (and an increasing storm surge level of 0.40 m and 5% increase of wave heights) during the next two centuries.

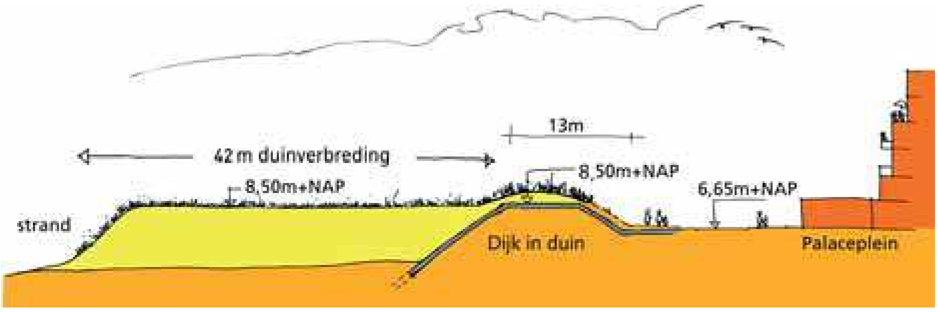


Figure 92: Design of the dike in dune solution, applied at the coast of Noordwijk [Rijnland, 2007].

However, our maximum scenario comprises a sea level rise of 3.15 m during the next two hundred years. Concerning the recreational function of these coastal towns, it is almost impossible to raise the dike within the dune any further. The starting document on this project stated that the maximum height of the construction should not exceed 10 m +NAP [Korzilius, 2005]. The dike of the current design with some sand on top of it will already reach this level. But the dune crest level could be heightened a little. So for the long term, the crest level of the dune is increased to 10 m +NAP and an additional seaward extension of about 40 m (adding up to a 120 m wide dune in front of the dike) is proposed. Together, these two changes to the current design are supposed to improve the coastal defences by the year 2200 to comply with the prescribed safety level.

These dimensions are based on the design for Noordwijk. However, from the hydraulic boundary conditions in Table 23 it follows that the boundary conditions for the other coastal towns south of Noordwijk are lower. So in principle the dimensions described above for the situation at Noordwijk will also satisfy for the other coastal towns within sections 8 and 11 (Katwijk, Scheveningen, Den Haag and Kijkduin). Therefore, these dimensions are without any changes applied to the entire length of these two sections.

J.4 Small scale strategy – the basic alternative

The small scale strategy represents the reference alternative of this study. Measures are selected on a local basis (small longshore sections), showing a large differentiation over the total length of the coast. Dimensions of these measures are partly derived from previous studies, for example those on the designs of the solutions for the weak link locations. For some other sections, model calculations are made with DUROS-plus to derive the dimensions of the planned measures. Table 36 summarizes the measures that are selected for this strategy.

Table 36: Basic alternative for coastal management solutions to preserve coastal safety up to the year 2200. Notes: section numbers refer to Jarkus cross-section numbers, the colours in the assessment column refer to the colours in Table 4 and the references refer to the resources where some measures for existing weak links were studied.

Section [#]	Section [kmr]	Represen-tative cross-section [kmr]	Land use function	Assessment	Solution
1	0-120	70	coastal town (Den Helder)	red	Dike heightening [RIKZ, 2004]
2	120-300	150	agriculture	orange	Extending dune in seaward direction [Provincie Noord-Holland, 2008]
3	300-700	608	agriculture	green	-
4	700-1300	928	agriculture	orange	Extending dune in seaward direction + increasing beach width [Provincie Noord-Holland, 2008]
5	1300-1400	1303	coastal town (Callantsoog)	orange	Increasing beach width [Provincie Noord-Holland, 2008]
6	1400-2040	1729	agriculture (dune)	orange	Extending dune in seaward direction + increasing beach width [Provincie Noord-

					Holland, 2008]
7	2040-2600	2300	agriculture (dike)	red	Dike heightening
8	2600-3150	2847	nature	orange	Extending dune in seaward direction + increasing beach width
9	3150-3250	3175	coastal town (Bergen aZ)	orange	Extending dune in seaward direction + increasing beach width
10	3250-3800	3550	agriculture	orange	Extending dune in seaward direction + increasing beach width
11	3800-3900	3900	coastal town (Egmond aZ)	green	-
12	3900-4300	4250	agriculture	yellow	Increasing beach width
13	4300-5000	4900	nature	orange (red)	Extending dune in seaward direction + increasing beach width
14	5000-5200	5050	greenhouses/industry	orange	Extending dune in seaward direction + increasing beach width
15	5200-5400	5300	greenhouses/industry	green	-
16	5700-6000	5950	nature	green	-
17	6000-6500	6125	nature	orange	Extending dune in seaward direction + increasing beach width
18	6500-6700	6550	coastal town (Zandvoort)	yellow	Dike in dune
19	6700-7100	6950	nature	orange	Extending dune in seaward direction + increasing beach width
20	7100-7400	7225	nature	green	-
21	7400-7900	7600	agriculture	green	-
22	7900-8100	7975	agriculture	orange	Extending dune in seaward direction + increasing beach width
23	8100-8350	8125	coastal town (Noordwijk aZ)	red	Dike in dune + extending dune in seaward direction [Kustvisie Zuid-Holland, 2006]
24	8350-8500	8450	agriculture	green	-
25	8500-8800	8650	coastal town (Katwijk)	red	Dike in dune + extending dune in seaward direction (weak link measure not yet known)
26	8800-9200	9075	agriculture	green	-
27	9200-9500	9350	nature	green	-
28	9500-9900	9525	nature	yellow	Increasing beach width
29	9900-10300	10075	coastal town (Scheveningen)	red	Water retaining structure in boulevard + increasing beach height [Kustvisie Zuid-Holland, 2006]
30	10300-10550	10461	coastal town (Den Haag)	green	-
31	10550-10800	10773	coastal town (Kijkduin)	orange	Extending dune in seaward direction + increasing beach width [Kustvisie Zuid-Holland, 2007]
32	10800-11100	10996	greenhouses/industry	orange	Extending dune in seaward direction + increasing beach width [Kustvisie Zuid-Holland, 2007]
33	11100-11250	11072	coastal town (Ter Heijde)	orange	Extending dune in seaward direction + increasing beach width [Kustvisie Zuid-Holland, 2007]
34	11250-11850	11356	greenhouses/industry	orange (red)	Dune in front of existing dunes + increasing beach width [Kustvisie Zuid-Holland, 2007]

Section 1

The dike at Den Helder should be heightened in order to maintain the coastal safety levels. According to a study after the options for improving the dike at Den Helder, the needed increase of the crest level of this dike is about 0.30 m in case of 0.45 m sea level rise and about 0.80 m in case of 0.85 m sea level rise by 2100. Both situations included increasing storm surge levels (0.40 m) and wave heights (5%), being the same as in case of the upper two scenarios applied in this study. This 0.80 m heightening of the dike implies a horizontal extension of the structure of 6.4 m (0.30 m heightening would imply a 2.4 m horizontal extension). This extension is planned at the landward side of the dike, since the seabed in front of the dike is very steep and flow velocities are large at that location [RIKZ, 2004].

This information is translated to the higher climate change scenario applied in this study. We assumed a sea level rise of 3.15 m (next to 0.40 m increasing storm surge levels and 5% increasing wave heights). Since storm surges and wave heights are not supposed to increase any further, it is assumed that the needed heightening of the dike equals sea level rise. So it is assumed that the crest level of the dike needs to be heightened with about 3.15 m. This comes down to a landward extension of about 25 m of the dike.

This project could be coupled to an impulse for the spatial quality in this area. In the study on possible multifunctional combinations for the new dike at Den Helder, three alternatives are available [RIKZ, 2004]:

- Building water retaining houses and buildings on the existing dike (dike city).
- Creating a horizontally extended dike with multiple functions on top of the landward slope (decreasing inundation risks for this area, terrace city).
- Increasing the recreational functions at the seaward side of the dike (sea city).

However, these multifunctionalities are not studied any further since the coastal defences at Den Helder are not assessed as a weak link anymore after the boundary conditions have been lowered recently. In this study, none of these multifunctional uses of the enhanced dike is foreseen since spatial planning is not the main aim of this study. However creating houses on top of the structure forming a 'dike city' should be considered as a serious option. These houses could be part of the water retaining body of the dike. This consideration is based on the fact that it is assumed to be realistic that multifunctional use of dikes is established in 200 years from now. It is considered to be unreal that this multifunctional space use will create public (and financial) support for large scale landward or seaward extension (and expenses) for realising ideas like 'terrace city' and 'sea city'.

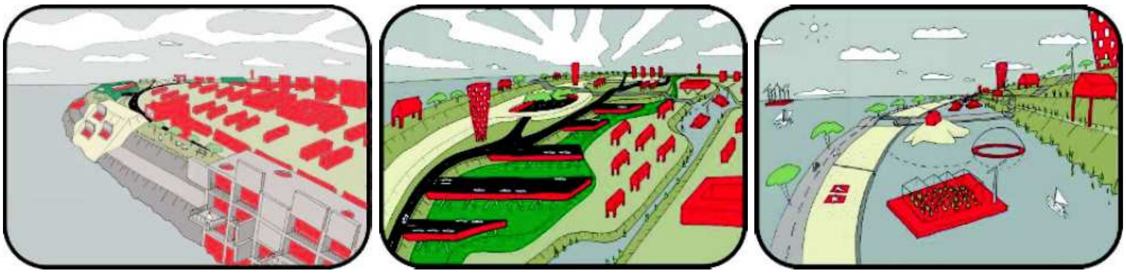


Figure 93: Impressions of the multiple dike use alternatives: dike city, terrace city and sea city from left to right [RIKZ, 2004].

Section 2, 4, 6, 8, 9, 10, 13, 14, 17, 19, 22, 31, 32, 33

Sea defences at all these sections along the coast will be improved by a seaward extension consisting of an extension of the existing dunes (the toe of the dunes is located at 3 m +NAP), sometimes combined with a widening of the beach (beaches are located from 2 m –NAP to 3 m +NAP). At some sections, the existing dunes are also rather low and insufficient for satisfying the boundary profile after erosion has taken place. At these sections, the seaward dune extension goes along with an increase of the crest level of the foredune. The shape of the extensions is adjusted to the initial cross-shore profiles.

The indicative dimensions of these dune and beach extensions needed for satisfying safety requirements in 2200 (according to the high climate change scenario) are determined by DUROS-plus calculations for the new cross-profiles. These dimensions are roughly optimized in order to prevent the measures from being inefficient.

Table 37 presents the dimensions found by this study for the extensions needed at the representative cross-sections. Four examples of the changed cross-sections due to these extensions are shown in Figure 94. Figure 95 show the results of the model calculations simulating the safety of these sections under the increased boundary conditions for 2200. It can be seen that in some cases the boundary profile still does not fit within the cross-shore profile. However, when the amount of sand landward from the projected boundary profile and above the storm surge level is rather large, these cross-sections are still assessed to be safe (see appendix E.3.3, stating that other shapes of the dune could also satisfy the boundary profile).

Table 37: Dimensions needed for extending the dunes and beaches in seaward direction to satisfy coastal safety levels in the year 2200 according to the highest climate change scenario. Dimensions are calculated for the cross-sections representative for the small scale spatial sections.

Section	Cross-section [kmr]	Seaward dune extension [m]	Increase dune crest level [m]	Seaward beach extension [m]
2	150	120	-	150
4	928	70	2	-
6	1729	70	2	100
8	2847	70	2	100
9	3175	40	-	100
10	3550	30	-	100
13	4900	40	-	70
14	5050	40	-	50
17	6125	40	-	60
19	6950	30	-	60
22	7975	30	-	50
31	10773	120	4	80
32	10996	100	4	100
33	11072	90	3	100

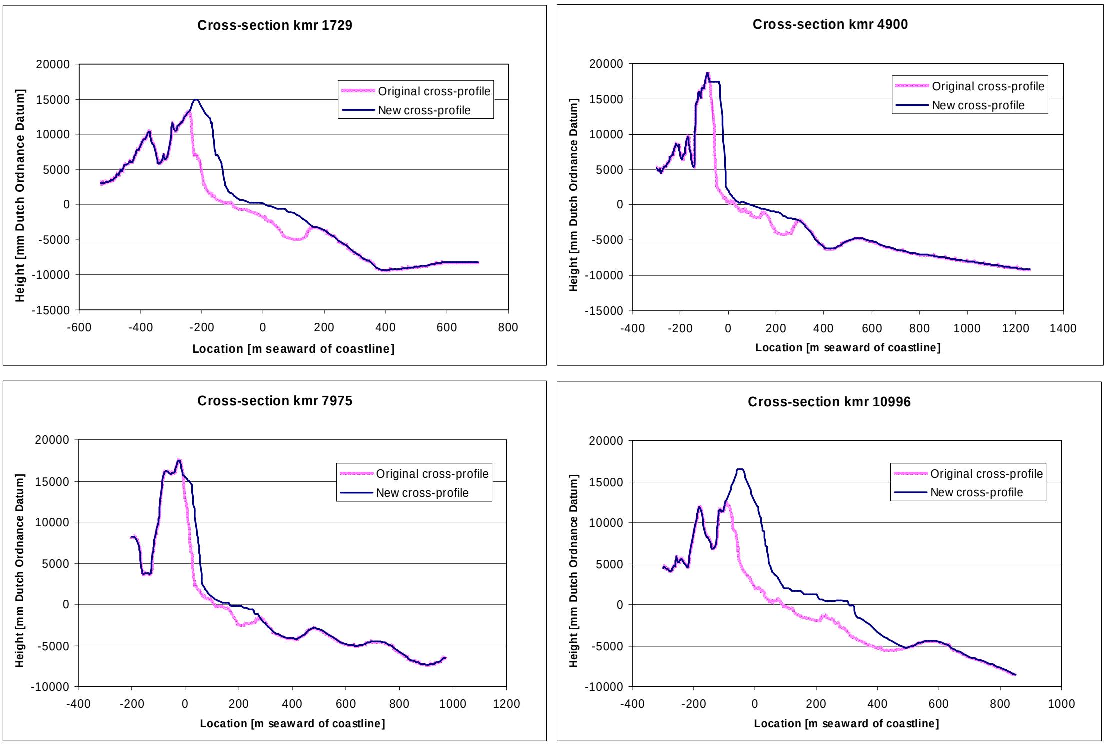


Figure 94: Representative cross-sections of the small scale sea defence sections being enhanced by seaward dune (and beach) extension for complying to the changed requirements in the year 2200 according to the high climate change scenario.

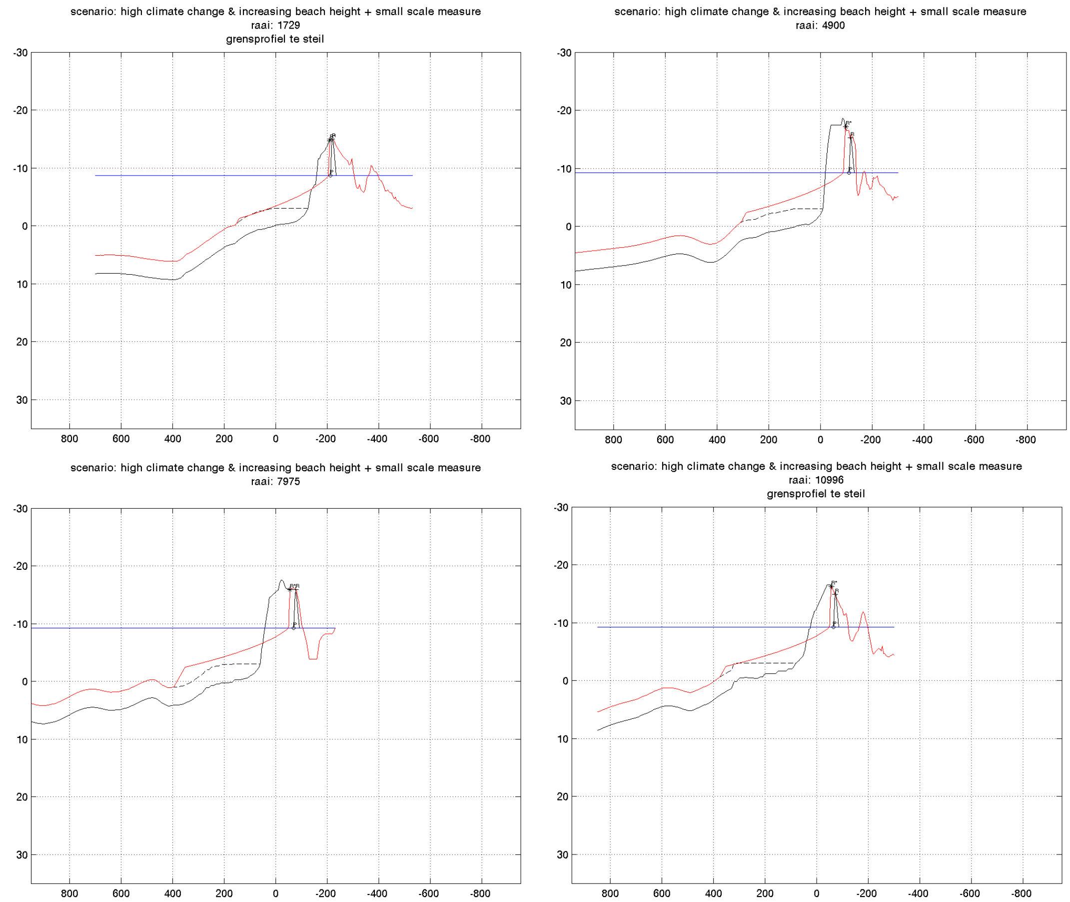


Figure 95: Results of the model simulations for the new cross-profiles of some of the representative defenses that are enhanced by extending dunes (and beaches) in seaward direction.

Section 5, 12, 28

For these three sections an extension of the beaches is foreseen in order to increase the strength of the coastal defence at these locations. Beaches are (by definition) located between 2 m –NAP and 3 m +NAP (toe of dunes). The distance between those two levels is increased by extending the beach in seaward direction just as it was done for the previous cross-sections (see Figure 94). Model calculations with DUROS-plus gave the results presented in Table 38.

Table 38: Dimensions needed for extending the beaches in order to satisfy coastal safety levels in the year 2200 according to the highest climate change scenario. Dimensions are calculated for the cross-sections representative for the small scale spatial sections.

Section	Cross-section [kmr]	Beach extension [m]
5	1303	150
12	4250	120
28	9525	150

Section 7

The Hondsbossche and Pettemer seawalls are assessed negative over their total length because of an insufficient crest level. Under the present studies for improving the coastal weak links, an initial report on alternatives for strengthening these seawalls was presented early this year [Hoogheemraadschap Hollands Noorderkwartier, 2008]. The basic alternative presented in this document implies raising the dike and extending the landward slope at the same time. Most other alternatives presented in this document (e.g. making the dike resistant to overtopping and increasing the height of the seabed in front of the dike) will affect the typical character of the existing dike. There is a widespread opinion that this character should remain unchanged. Moreover, this basic alternative might be introduced since it is supposed to be cheaper than the other alternatives.

The designs presented in this document are based on a sea level rise of 0.30 m for the next 50 years. It is stated that an average heightening of the crest levels of the dike of about 5.5 m is needed, inducing a landward extension of the dike of about 33 m (since the outer and inner slope of the dike have a 1:3 slope) [Hoogheemraadschap Hollands Noorderkwartier, 2008].

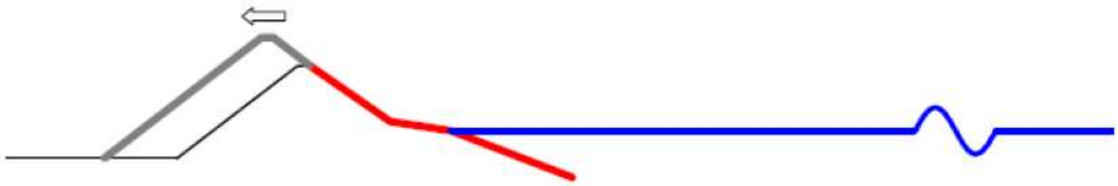


Figure 96: Schematic representation of dike heightening and the induced landward extension of the inner slope of the dike [Hoogheemraadschap Hollands Noorderkwartier, 2008].

For longer term calculations, the needed heightening of the dike increases significantly. When a period of 200 years is concerned with 1.70 m sea level rise and increasing storm surge levels (0.40 m) and wave heights (5%), an even larger averaged heightening of about 10.5 m will be needed [Steetzel, 2007]. This scenario is almost the same as the middle scenario of this study. The upper scenario however contains a relative sea level rise of 3.15 m in stead of 1.70 m. From the latter publication it is also derived that the additional dike height needed in case of an increase in sea level rise (within the boundary conditions of the stated maximum scenario) is about 2.5 times the observed increase in sea level rise. So in case of the upper scenario with a sea level rise of 3.15 m, this dike should on average be heightened with about 14 m. This induces that at the landward side, an average extension of the dike of about 84 m will be needed.

This large landward extension will certainly conflict with present land uses and buildings located close to the dike. However, when the resistance to overtopping of the dike is increased, these land uses and buildings would also be affected since a certain area behind the dike should be sacrificed for storing the water flowing over the dike. With the main aim of conserving the character of this dike unchanged, that is based on a widely accepted viewpoint, this measure is therefore still supposed to be realistic. Moreover, over a period this long, possibilities for removing existing functions from locations close to the dike will certainly increase.

Section 18

This section contains the coastal town of Zandvoort. Initially is was planned to increase the beach width at this location, but after a model simulation it appeared to be impossible to create a safe sea defence at this location by only increasing the beach width. Therefore it was decided to implement a measure resembling the dike in dune solution for Noordwijk aan Zee (section 23) and Katwijk (section 25). However, this section is initially assessed much better (yellow) than sections 23 and 25 (red) so extending the dune in seaward direction is left here. The measure for this section will only consist of constructing the dike within the existing dunes. The dimensions of this dike will just be copied (see section J.3.2 of this appendix). The dune at Zandvoort has a crest level of about 12 m above Amsterdam Ordnance Datum, so constructing this dike will not result in any problems since it fits easily within the dune cross-section.

Section 23, 25

These two sections contain the coastal towns of Noordwijk aan Zee and Katwijk. The solution for improving the strength of the coastal defences at these locations is the same as in the landward alternative of the intermediate scale alternative: creating a dike within the existing but small dune together with a seaward extension of the dune. The dimensions of this solution will be the same as the dimensions defined for sections 8 and 11 of the intermediate scale landward alternative described in section J.3.2 of this appendix.

Section 29
At Scheveningen, the existing coastal cross-shore profile will be insufficient for satisfying the future preconditions concerning the safety of the hinterland. This location is also part of the weak links that are currently investigated. Initial studies on the possibilities for strengthening this weak link indicated a preferred alternative. This alternative contains the construction of a water retaining structure (sheet piling) within the boulevard, combined with an increasing height of both beaches and boulevard (Figure 97) [Kustvisie Zuid-Holland, 2006].

Dimensions are given for both periods of 50 and 200 years, however on the short term the construction will only be designed for deteriorating conditions over a 50 years period. For a sea level rise of 0.30 m within 50 years (middle scenario of the present policy scenarios for climate change), a sheet piling with a crest level of 10 m above MSL is projected together with a beach heightening of about 0.60 m up to 300 m in seaward direction from the sheet piling [Arcadis & Alkyon, 2005]. The top level of this sheet piling is covered well by the existing level of the boulevard.

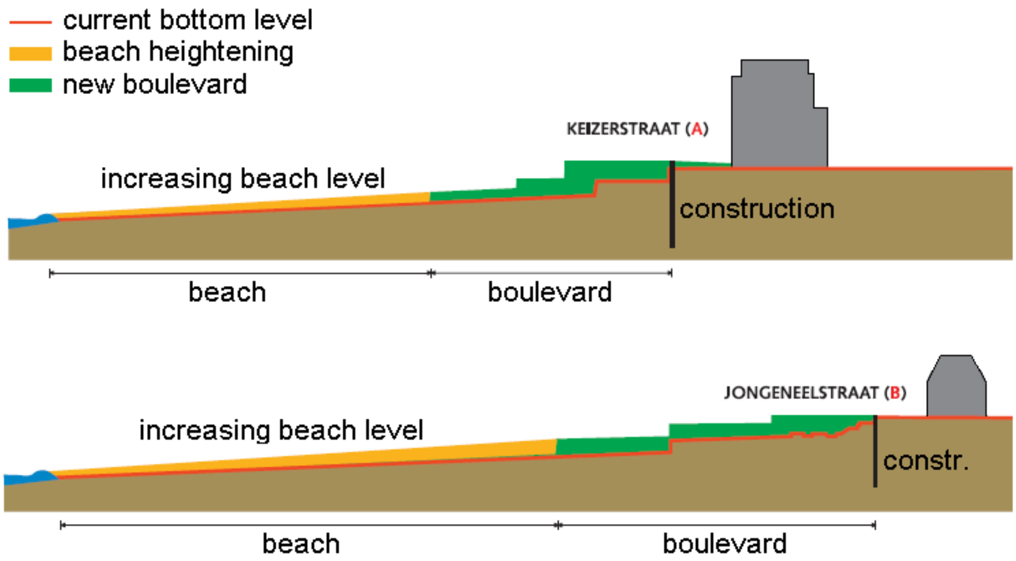


Figure 97: Side view of the solution principle selected as the preferred alternative for the Scheveningen coast.

A long term calculation (including 1.70 m sea level rise, 0.40 m increasing storm surge levels and 5% increasing wave heights according to the maximum policy scenario for climate change), indicates that an additional beach heightening of about 0.90 m will be needed without raising the sheet piling any further [Arcadis & Alkyon, 2005]. For the maximum scenario of this study a sea level rise of 3.15 m is foreseen, but the other boundary conditions are the same. Therefore it is supposed that another beach level rise of about 0.50 m will be needed in order to satisfy this worst case climate change scenario. So finally, a sheet piling with a crest level of 10 m +NAP and a beach heightening of about 2 m over a seaward distance of 300 m are needed by the year 2200.

Section 34
This section is located just north of the moles protecting the fairway towards the Rotterdam harbour. The coastal defences in this area are very small, but are protecting part of the valuable Delfland area with a very high density of greenhouses. Since this location is also part of the current weak link locations in the Dutch coastal defences, a preferred alternative has already been defined. For this area, a new dune in front of the existing dunes is foreseen. This measure is partly necessary, since new dunes should be created compensating the negative impacts on nature of the new ‘Maasvlakte’ project just

south of the harbour moles. Moreover, due to the sheltering effect of these moles, the new dune could be located further seaward so a wide new dune valley emerges between the existing foredunes and the new foredunes. According to the selected alternative, this valley could be up to 85 m wide (Figure 98) [Kustvisie Zuid-Holland, 2007].

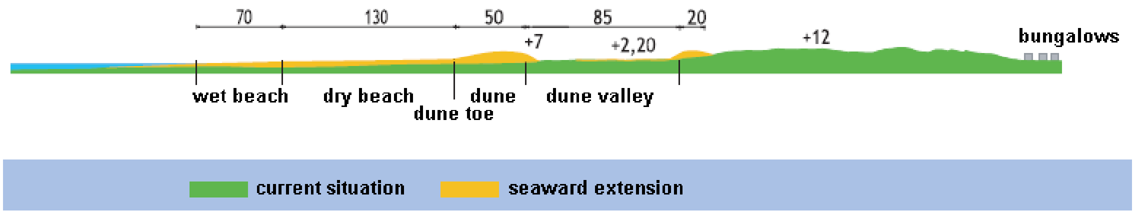


Figure 98: Seaward dune extension is preferred for improving the coastal defences in front of the southern part of the Delfland coast [Kustvisie Zuid-Holland, 2007].

Since this is a ‘soft’ engineering solution, dimensions will not be derived from previous reports but will be calculated roughly with the DUROS-plus model. We modelled a dune in front of the existing dunes in the same way as was done for the uniform coast and intermediate scale strategies: sinusoidal shape, crest level at 17 m +NAP and connecting to the existing dune at 5 m +NAP. We did not simulate the dune valley designed between the new and the existing foredunes, this is supposed to be optional. Furthermore, seaward of the new dune we copied the existing beach, extended it and created a smooth connection to the sea bed.

From these simulations it followed that a new dune is needed with a width of 200 m at the 5 m +NAP level and that the beach should be extended over 50 m (Figure 99). A measure with these dimensions could create a safe coast for the year 2200 supposing a high climate change scenario.

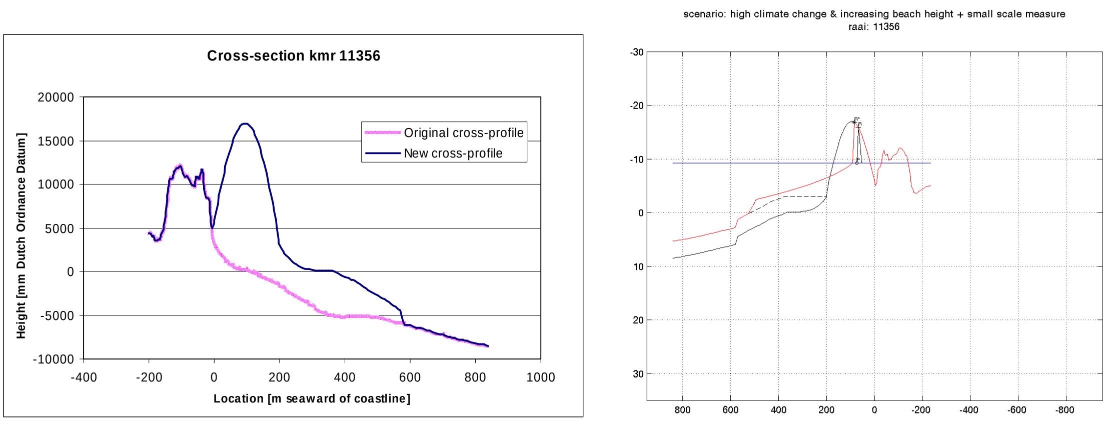


Figure 99: New cross-shore profile of the representative cross-section of section 34, strengthened by a new dune in front of the existing dunes and an extended beach (left); and the simulation results of a safety check for the boundary conditions of 2200 according to the high climate change scenario (right).

K Coastal management strategies for 2200

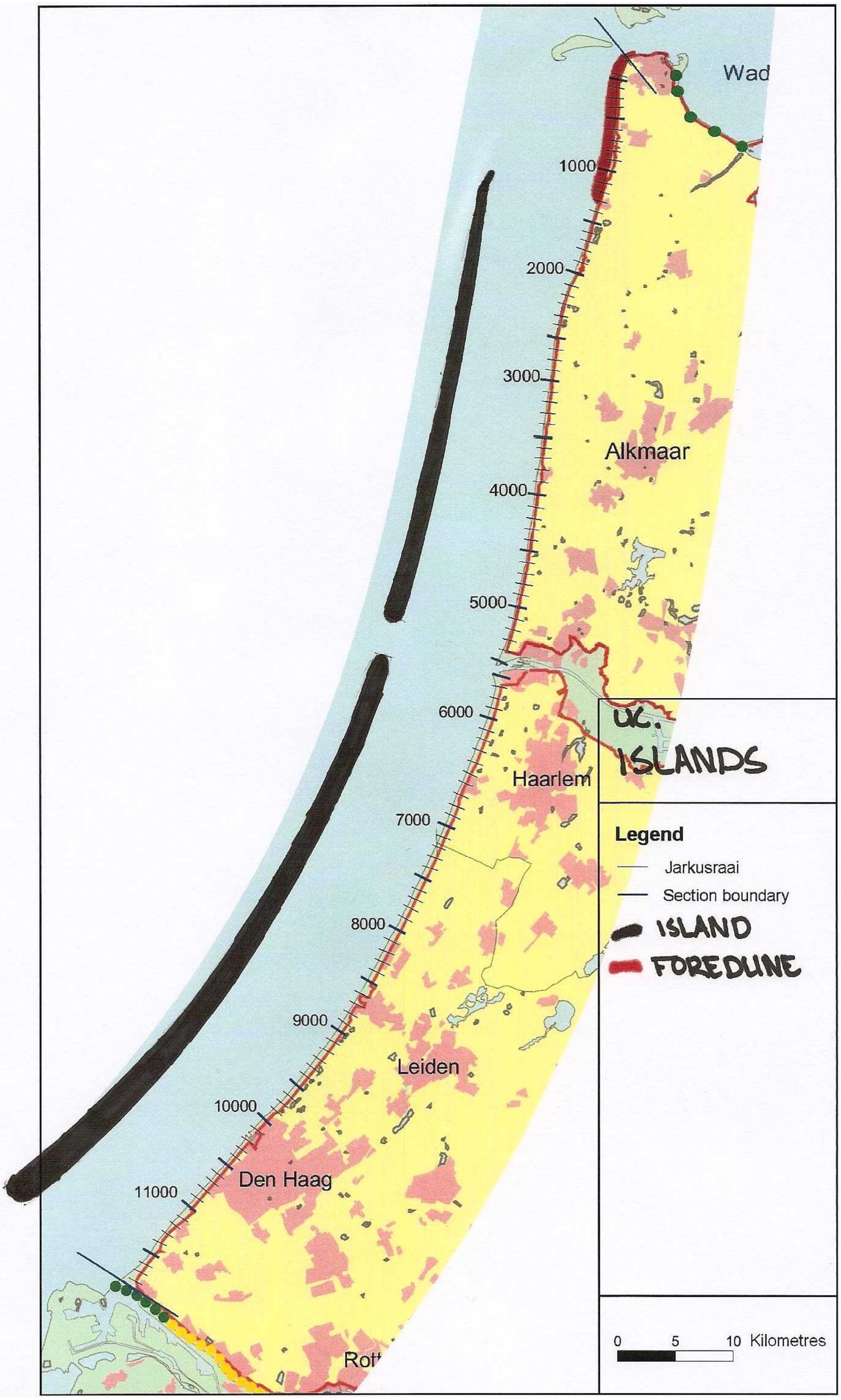


Figure 100: Preliminary design of the proposed uniform coast strategy with islands for maintaining the present safety levels up to the year 2200 for the highest climate change scenario.

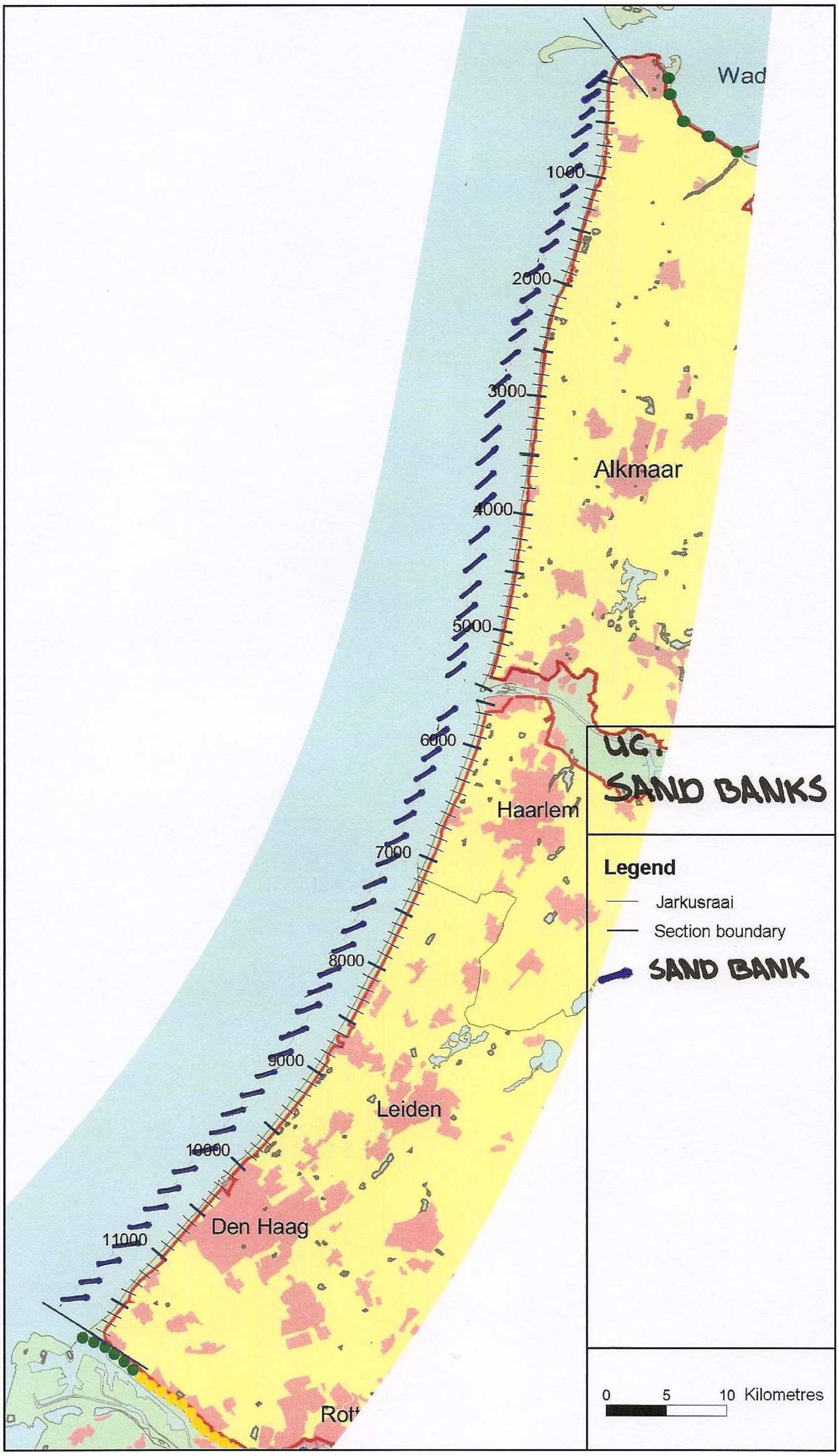


Figure 101: Preliminary design of the proposed uniform coast strategy with sandbanks for maintaining the present safety levels up to the year 2200 for the highest climate change scenario.

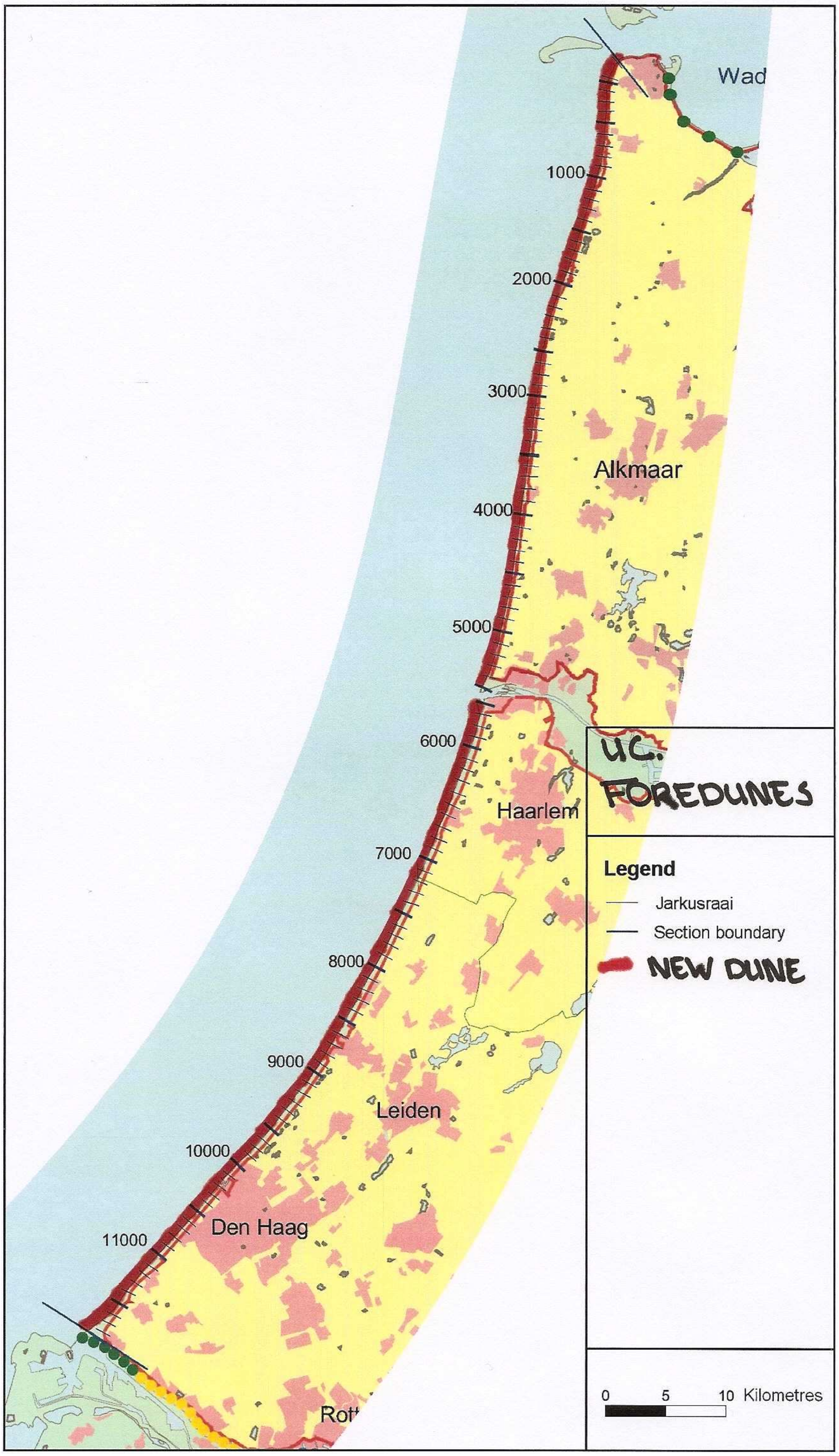


Figure 102: Preliminary design of the proposed uniform coast strategy with foredunes for maintaining the present safety levels up to the year 2200 for the highest climate change scenario.

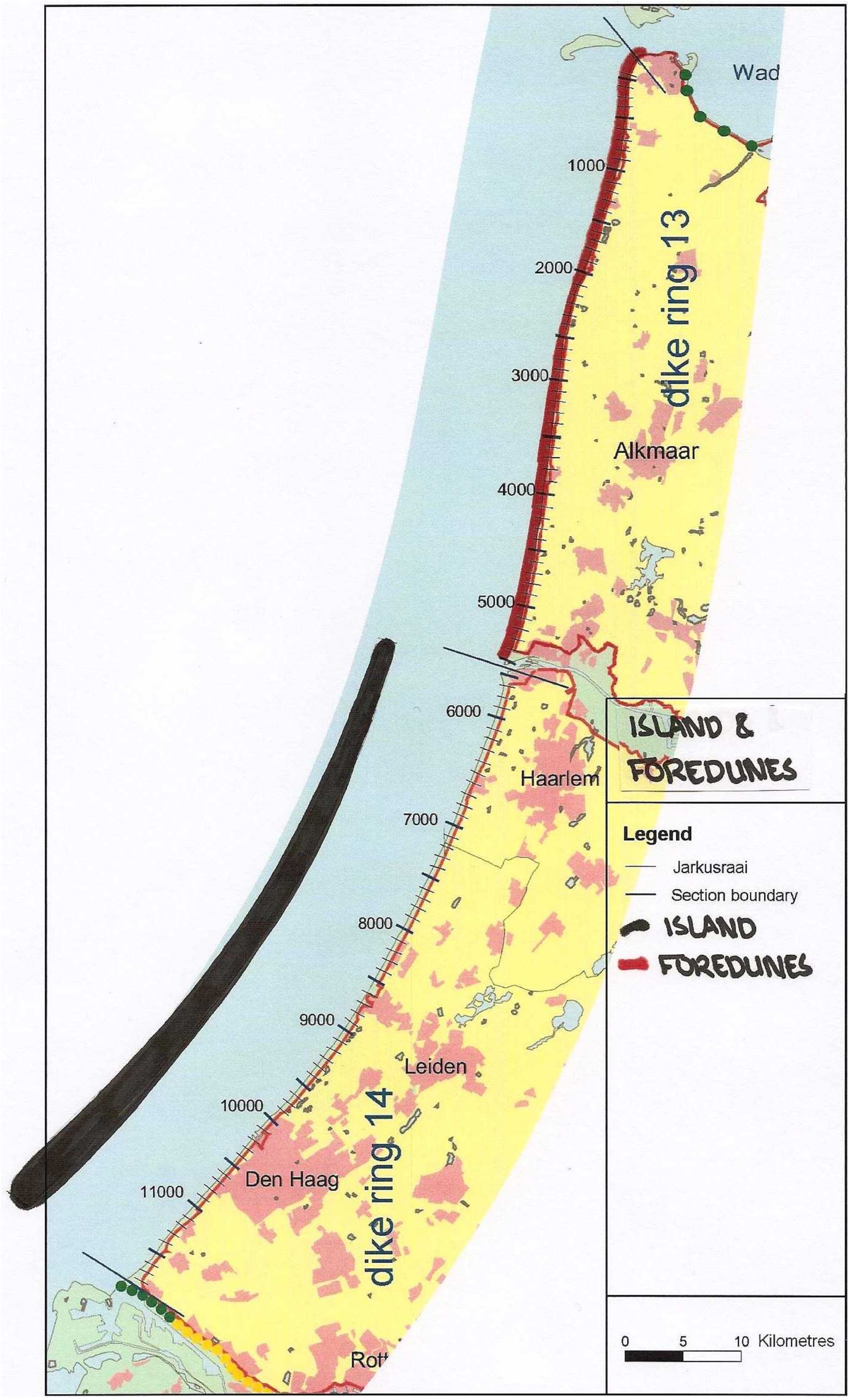


Figure 103: Preliminary design of the proposed large scale strategy with an island and foredunes for maintaining the present safety levels up to the year 2200 for the highest climate change scenario.

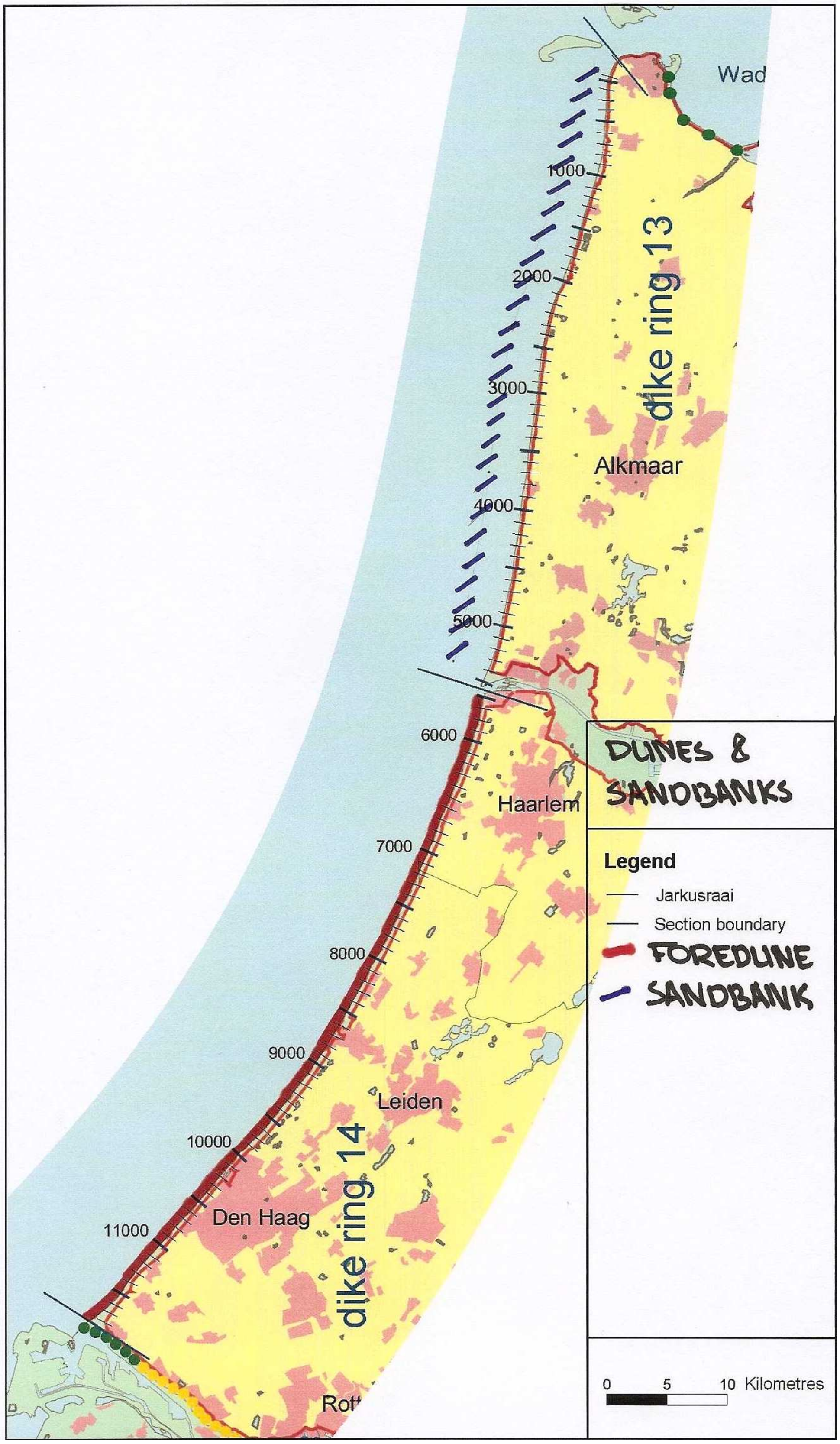


Figure 104: Preliminary design of the proposed large scale strategy with foredunes and sandbanks for maintaining the present safety levels up to the year 2200 for the highest climate change scenario.

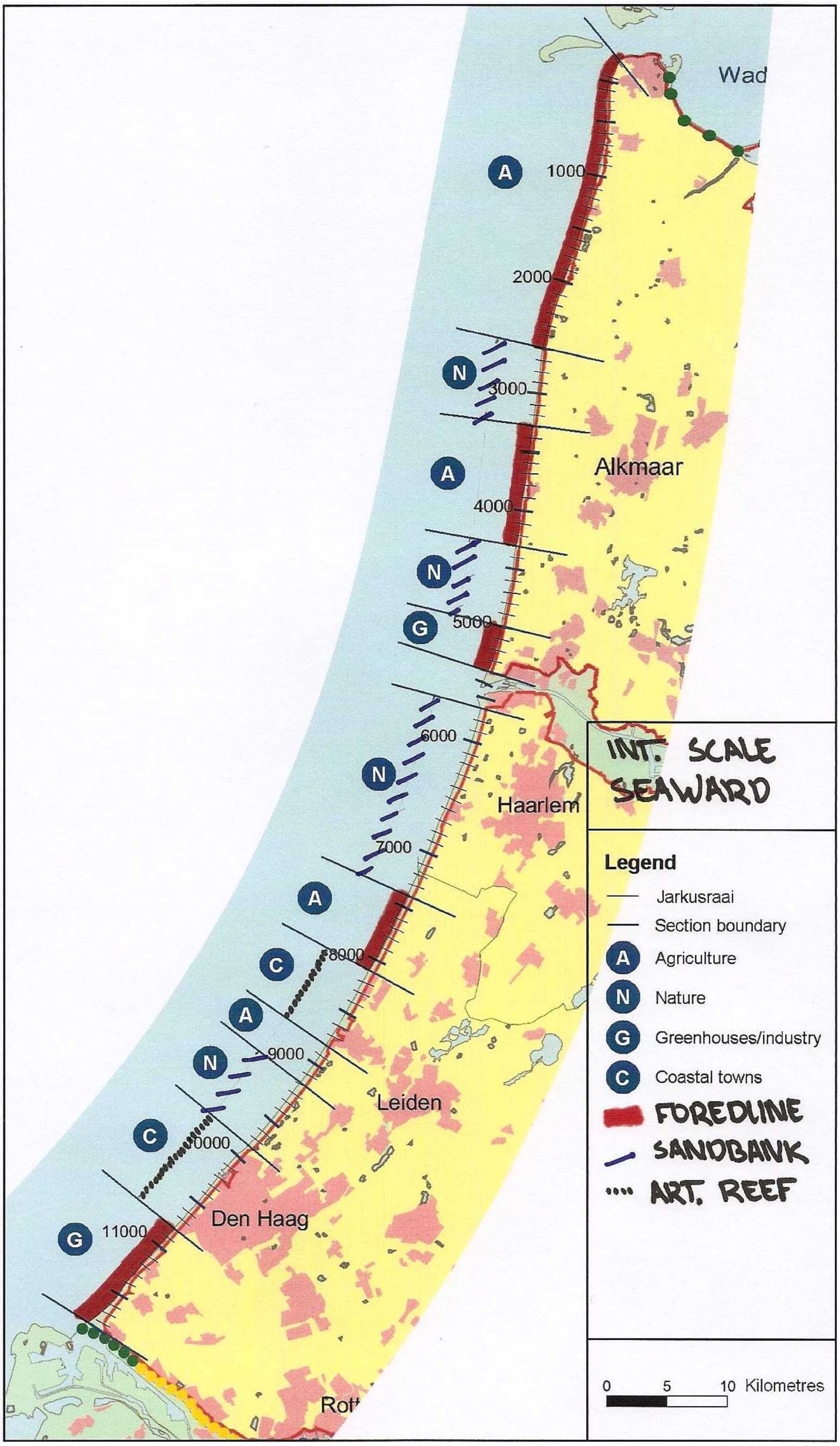


Figure 105: Preliminary designs of the proposed intermediate scale strategies for maintaining the present safety levels up to the year 2200 for the highest climate change scenario.

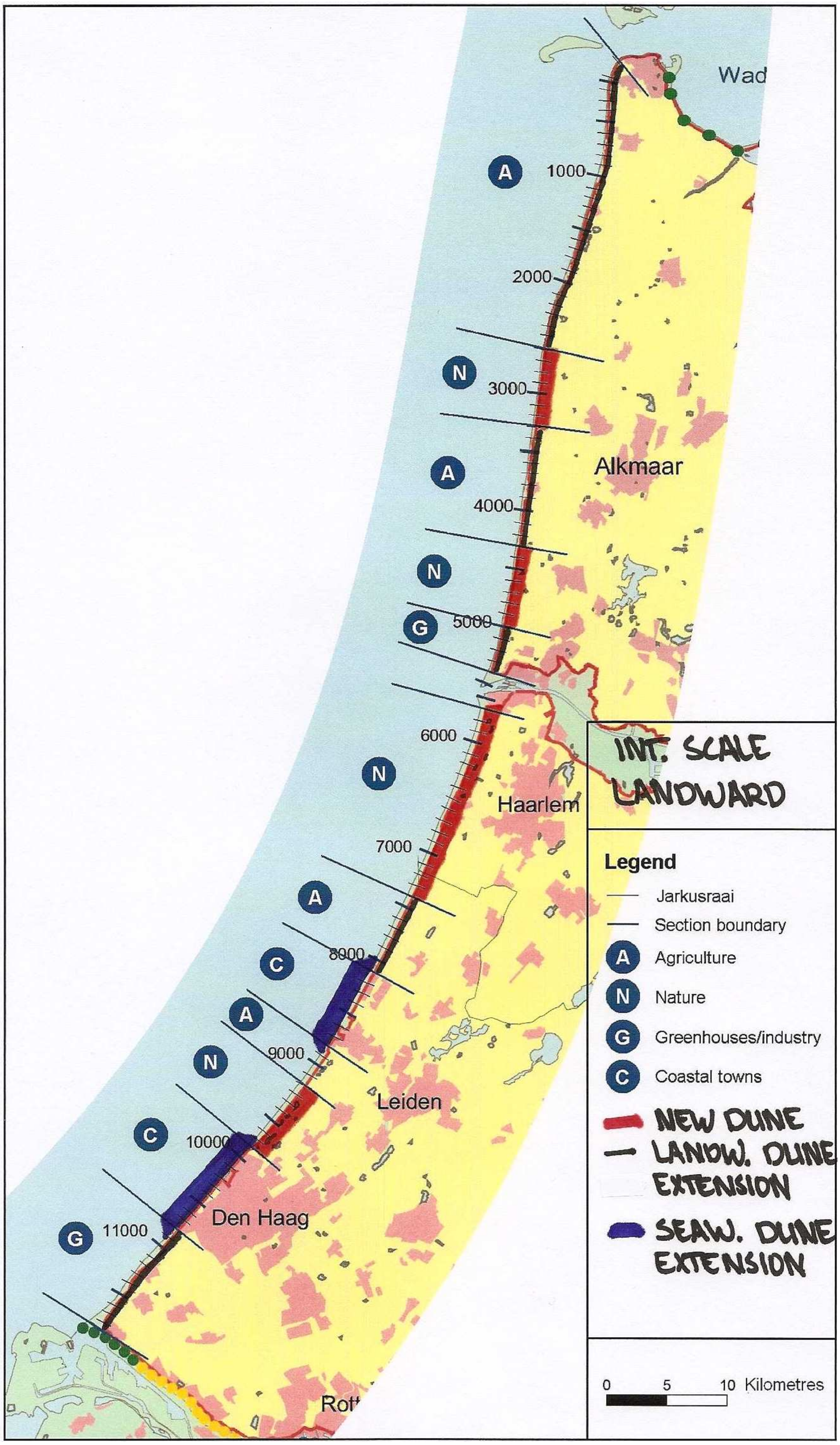


Figure 106: Preliminary designs of the proposed intermediate scale strategies for maintaining the present safety levels up to the year 2200 for the highest climate change scenario.

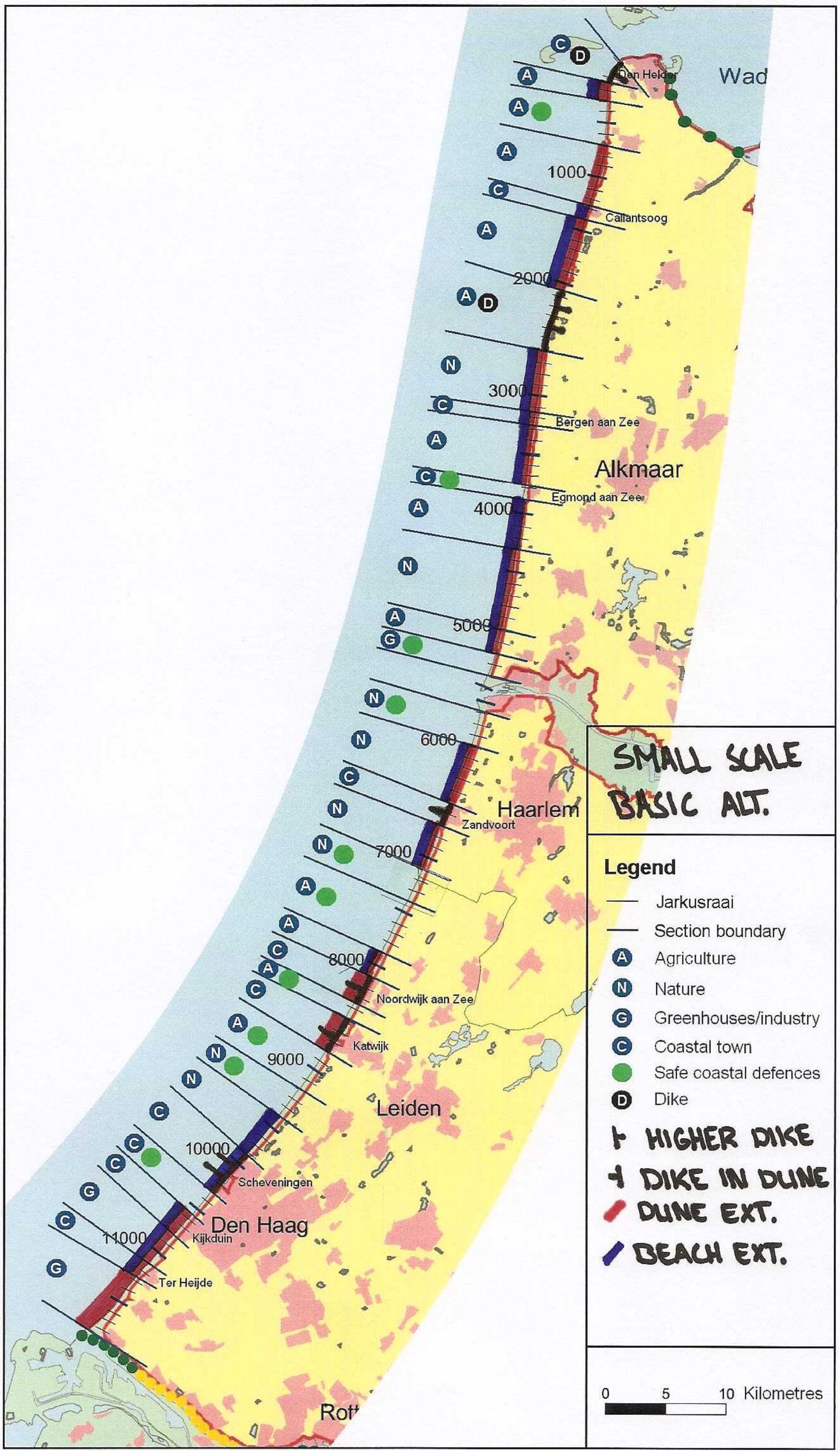


Figure 107: Preliminary design of the proposed small scale strategies for maintaining the present safety levels up to the year 2200 for the highest climate change scenario. This strategy represents the basic alternative.

L Assessment methodology

This appendix describes the derivation of the assessment method that is applied for assessing the coastal management strategies proposed in this study.

According to the assessment directive for water related projects ('de waterwaarderingswijzer') of the Dutch governmental organization for water management (Rijkswaterstaat), both multi-criteria analysis (MCA) and pre-feasibility cost-benefit analysis (CBA) are most suited for the assessment to be executed in this study [Rijkswaterstaat, 2003]. These two methods are preferred over some other types of cost-benefit analysis (e.g. a fully financial CBA) and methods for presenting potential impacts (e.g. scorecards).

Both methods of multi-criteria analysis (MCA) and cost benefit analysis (CBA) are introduced in this appendix. The final section describes how these two methods are derived in order to develop a comprehensive assessment framework that is suited to assesses the coastal management strategies that are proposed in this study.

L.1 Multi-criteria analysis

The starting point of every MCA is an impact matrix. This matrix represents the effects of the proposed measures on the different criteria. Applying several explicit criteria is the first characteristic of this assessment method. Next, the effects of the measures concerning these criteria could be expressed in their natural units or even in qualitative units. For example, the effect of a measure on nature could be rated by the area of nature that will be lost due to this measure (natural unit) or it could be qualitatively assessed, for example on a scale of -- (most negative effect) to ++ (most positive effect).

Finally, in order to summarize all those quantitative and qualitative effect scores, they should be standardized. This standardization equalizes the scales of the different assessments. The final score of each measure could then be calculated by multiplying the effect scores with the weights of all criteria and summarizing all these partial scores. The possibility of applying different weights to the assessment criteria is a third characteristic of MCA. These weights can represent different perspectives on what features are important for the measures to be assessed. The final scores determine the ranking of the proposed alternatives compared to each other and to the autonomous development (if this is defined as the basic alternative) [Pouwels, 1995] [Hellendoorn, 2001]. Thus MCA methodology is quite well suitable for ranking different alternatives for infrastructure projects.

L.2 Cost benefit analysis

Next to MCA, there is the possibility of applying CBA for the assessment of different measures. In CBA, the present and future advantages (benefits) and drawbacks (costs) of every measure are measured in monetary units. The scope of a socio-economic CBA is even wider and includes all changes in societal welfare by quantifying and monetarizing them as much as possible [Ruijgrok e.a., 2006]. Effects that could not be expressed in a monetary value, should be stated qualitatively in the CBA and can not be included in the final balance [Pouwels, 1995] [Hellendoorn, 2001].

From the year 2000, socio-economic cost benefit analysis is compulsory for assessing infrastructural investment decisions in the Netherlands. To ensure that these CBA's are executed similarly by different consultants, a national guideline was introduced [Eijgenraam e.a., 2000]. Next to the more common welfare effects of infrastructure (direct costs and benefits), this guideline also acknowledges the importance of including impacts on nature, water, soil, landscape and cultural heritage. Furthermore, a difference is made between a pre-feasibility CBA (kentallen kosten baten analyse) and a thorough CBA (diepgaande variant). Figure 108 shows how these two variants are located in the development process of infrastructure designs. The aim of the pre-feasibility type of CBA is to identify the most likely designs based on rough estimations of the potential effects that might be deduced from other studies. This type of assessment corresponds to part of the assessment framework of this study.

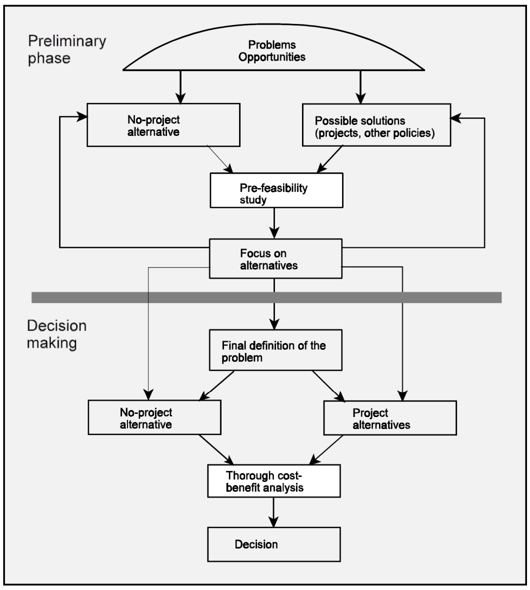


Figure 108: The two phases in the design of infrastructure projects do have their own specification level for analyzing costs and benefits [Eijgenraam e.a., 2000].

L.3 Combination of CBA and MCA

All economic, environmental and social impacts should be considered in assessments of potential measures for retaining the present safety levels of the Dutch coastal defences. A nature- and environment inclusive MCA contains all these aspects [Ruijgrok, 2005]. The valuation of an ecosystem falls apart in three different types: financial values, economic values and intrinsic values (see Figure 109). This distinction is also presented in an article of Ruijgrok on the valuation of nature [Ruijgrok, 2006]. However, no monetary value can be awarded to those intrinsic values and they are not included in the welfare effects to be assessed in the MCA. Moreover, there are some more impacts (like social acceptance) that can not be monetarized. These can be included in CBA's as impacts to be assessed (pro-memorie posten). In that case the score is a question mark (?) and is sometimes amplified by a qualitative indication of the potential impact (like + or -). These impacts can not be included in the final balance of the CBA.

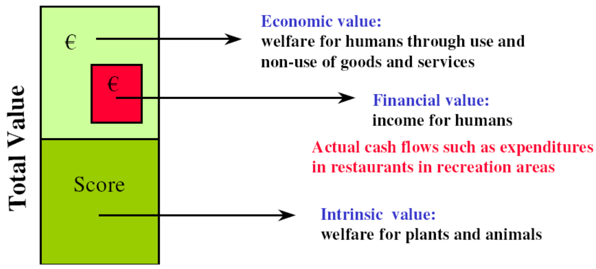


Figure 109: Representation of the three typical values of ecosystems. Only the upper two values are included in CBA's [Ruijgrok, 2005].

Still, we would like to include all (both monetary and non-monetary) environmental and societal impacts in our assessment method. Therefore, the ComCoast study into the comparison of the state of the art CBA methods in the UK and the Netherlands provides some interesting information [Ruijgrok & Kirchholtes, 2006]. Figure 110 shows that in the UK all monetary and non-monetary effects are included in a general MCA. Thereby, monetary social and environmental impacts are included in the economic impact assessment. In the Netherlands, a difference is made between welfare and non-welfare effects. Those welfare effects comprise both monetary and non-monetary impacts due to economic, social and environmental changes caused by the assessed project and are all included in a CBA. Non-welfare effects consist of the intrinsic value of nature and of other political values. Intrinsic nature values are only presented in the environmental impact assessment (which will be held in a premature stage of the project) and other political values are part of the political judgement.

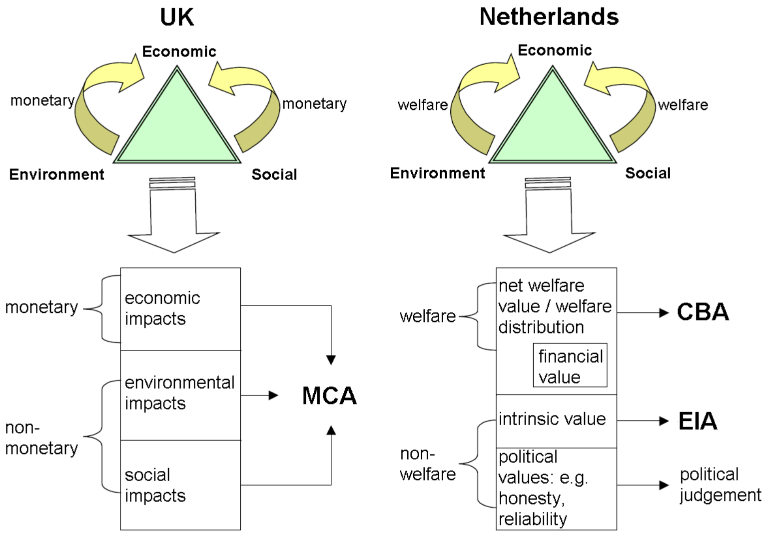


Figure 110: Differences in including economic, environmental and social impacts in project assessments in the UK and the Netherlands [Ruijgrok & Kirchholtes, 2006].

In this study, we want to separate the non-monetary welfare effects from the CBA since they could not be included in the final balance and that seems to decrease their importance in the final assessment. Moreover, we would like to include the non-welfare effects and some other criteria into the assessment method in order to create a full-scale representation of all impacts and characteristics in the final assessment. Therefore, a combination of both the UK and the Dutch approaches of Figure 110 is created in Figure 111. The important issue here is the separation of monetary impacts and impacts that can not be monetarized. For the first group, costs and benefits will be estimated according to the method presented in appendix M. These quantitative scores will subsequently be translated to some rather qualitative assessments (--/-/0/+/++). The non-monetary impacts are assessed qualitatively from the start. Except for some aspects that could be expressed easily in a quantitative natural unit (like nature area). These aspects are first assessed quantitatively and afterwards they are translated into the same qualitative assessment scale. Subsequently, all impacts are considered in order to come to a political judgement. Note that all costs and benefits will not be added into one figure to be included in the MCA, although this is recommended by Bel & Ruijgrok [2005]. This would reduce the transparency of the method and it would implicitly decrease the weight awarded to these costs and benefits since only one value representing different impacts, would be found in the overall assessment.

In the end, four categories of criteria are considered for this study:

- Costs;
- Welfare impacts;
- Non-welfare impacts;
- Other criteria.

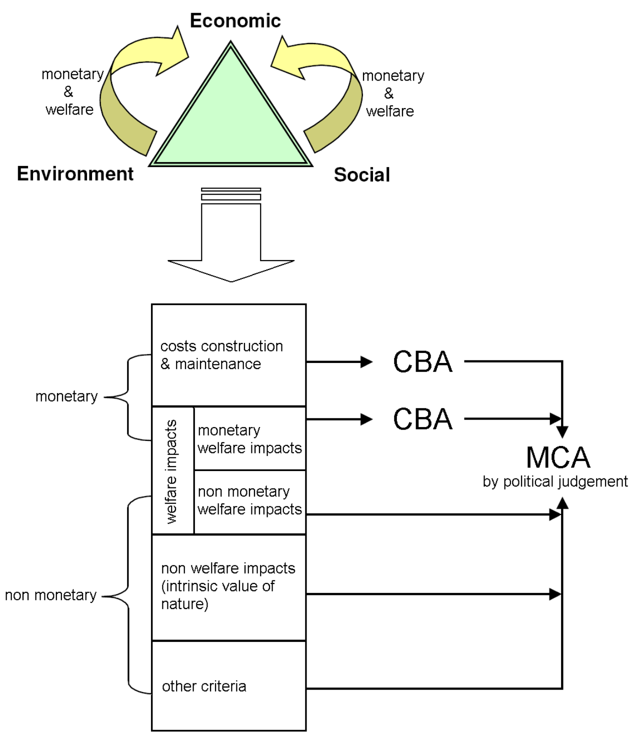


Figure 111: General set-up of the assessment method that is applied in this study.

M Assessing monetary impacts

This appendix explains the selection and assessment of the monetary impacts of the coastal management strategies proposed in this study. Monetary impacts are both costs and other welfare impacts that can be economically valued. This section starts with the selection of the monetary impacts for which the costs and/or benefits will be analysed. Next, the application of authorised values for impact assessment will be discussed. Finally, some attention will be given to the area and timeframe for which the welfare impacts should be considered and to the discounting of future costs and benefits.

M.1 Monetary impacts

In order to create an overview of all monetary welfare impacts that should be included in the assessment of the proposed coastal management strategies (next to the costs for construction and maintenance), the potential physical effects of the proposed plans should be considered first. For agriculture these effects could be the loss of farmlands for example and for recreation a possible effect is the increasing area of nature.

Next, these physical effects should be translated into welfare effects (Figure 112). Sometimes, this can be done directly (direct financial costs and benefits) like in case of the farmlands in the example above. The welfare effect of a decreasing farmland area is represented by the value of the crops grown on these lands. Otherwise, for natural and social values a conditional function might be needed for this step [Ruijgrok e.a., 2004] [Ruijgrok, 2006]. For example, when a certain area of forest is destructed, one of the conditional functions that will be affected is the assimilation of carbon. In this case, the service 'protection against climate change' will be affected. Those welfare effects should then be quantified and at last, these quantified impacts should be monetarized.

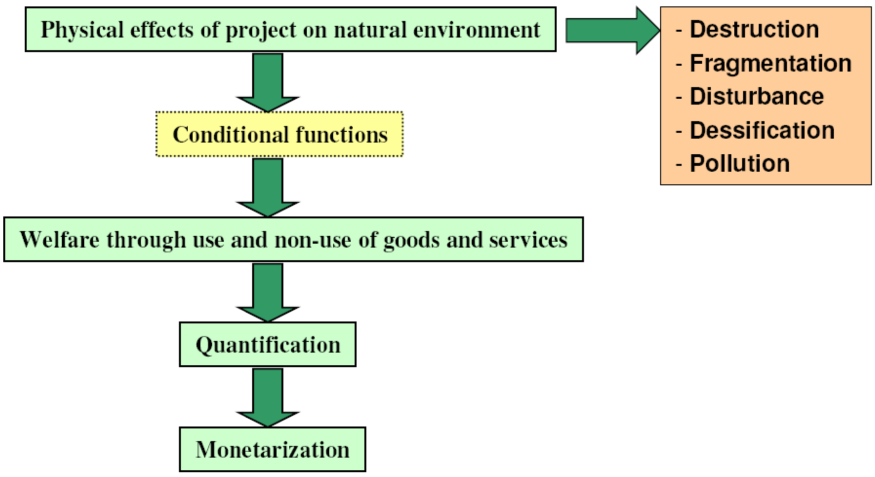


Figure 112: The translation process of physical effects into monetary values added or lost due to a proposed measure [Ruijgrok, 2005].

A preliminary inventory is made of the potential physical effects of the proposed coastal management strategies. Table 39 summarizes the relevant potential physical effects. For these physical effects, all related conditional functions are summed up with the help of the assessment manuals of Ruijgrok e.a. [Ruijgrok e.a., 2004] [Ruijgrok e.a., 2006]. The welfare effects of these conditional functions are aggregated in order to decrease the amount of impacts to be considered in the final analysis. Moreover, the welfare effects are grouped according to three general aspects: nature values, safety benefits and man-made functions.

Table 39: Physical effects and their related conditional functions and welfare effects to be included in the assessment of the welfare impacts of the proposed coastal management strategies.

	Physical effect	Welfare effect	Conditional function
Costs			
Construction and maintenance costs	Construction costs	Expenditure by national government	Costs
	Costs for maintenance and management	Expenditure by national government	Costs
Welfare impacts			
Nature values			
Environment & recreation	Changing foredune area	Environmental advantages dune vegetation	Filtering fine particulate matter
			Uptake of NO_x and SO_2
			Carbon assimilation
		Possibilities for exploitation	Day trips because of dunes
			Stay trips because of dunes
		Recreational perception	Presence of nature through dunes
		Non-use possibilities because of increasing biodiversity	Non-use possibilities because of increasing biodiversity
	Changing inner dune area	Environmental advantages dune vegetation	Filtering fine particulate matter
			Uptake of NO_x and SO_2
			Carbon assimilation
		Possibilities for exploitation	Day trips because of dunes
			Stay trips because of dunes
		Recreational perception	Presence of nature through dunes
		Non-use possibilities because of increasing biodiversity	Non-use possibilities because of increasing biodiversity
	Changing beach area	Possibilities for exploitation	Day trips because of beaches
			Stay trips because of sea
		Recreational perception	Presence of nature through beaches
Water supply	Drinking water filtration	Ground water quality	Drinking water filtration
Safety benefits			
Safety	Protection coastal towns in front of dunes	Decreasing risk of inundation of the coastal towns	Risk of inundation of the coastal towns
Man-made functions			
Housing	Changing location of housing related to environment	Enjoyment of coastal environment	Living with a view of the dunes and/or the sea
	Changing housing area	More houses in coastal area	Change housing area
Agriculture	Ground water quality for crops	Increasing harvests	Salinity ground water
	Changing agricultural area	Increasing harvests	Change agricultural area

M.2 Authorised values for impact assessment

The first step in specifying the measurement of the potential costs and benefits of the monetary impacts that are summarized in Table 39 is determining the units for quantifying the conditional functions of the welfare effects. At the same time, the units for monetarizing these quantities should be determined. These units are derived with the help of the guideline for the valuation of nature, water and soil in socioeconomic cost benefit analyses of Ruijgrok e.a. [Ruijgrok e.a., 2006]. The results of this step are included in Table 40.

Table 40: Physical effects, conditional functions and welfare effects to be included in the impact assessment and the units for quantifying and monetarizing these effects (WTP = Willingness To Pay for a certain benefit).

	Physical effect	Welfare effect	Conditional function	Unit for quantification	Unit for monetarization
Costs					
Construction and maintenance costs	Construction costs	Expenditure by national government	Costs		
	Costs for maintenance and management	Expenditure by national government	Costs		
Welfare impacts					
Nature values					
Environment & recreation	Changing foredune area	Environmental advantages dune vegetation	Filtering fine particulate matter	kg PM10 per ha per year	Price per kg PM10
			Uptake of NO_x and SO_2	kg NO_x per ha per year	Price per kg NO_x
				kg SO_2 per ha per year	Price per kg SO_2
			Carbon assimilation	kg C per ha per year	Value per ton C (in biomass)
		Possibilities for exploitation	Day trips because of dunes	# day trips per year	Profit by averaged spending per visitor
			Stay trips because of dunes	# overnight stays per year	Profit by averaged spending per visitor
		Recreational perception	Presence of nature through dunes	# visits per year	WTP per visit
		Non-use possibilities because of increasing biodiversity	Non-use possibilities because of increasing biodiversity	# households concerning about biodiversity	WTP / donations per household per year
	Changing inner dune area	Environmental advantages dune vegetation	Filtering fine particulate matter	kg PM10 per ha per year	Price per kg PM10
			Uptake of NO_x and SO_2	kg NO_x per ha per year	Price per kg NO_x
				kg SO_2 per ha per year	Price per kg SO_2
			Carbon assimilation	kg C per ha per year	Value per ton C (in biomass)
		Possibilities for exploitation	Day trips because of dunes	# day trips per year	Profit by averaged spending per visitor
			Stay trips because of dunes	# overnight stays per year	Profit by averaged spending per visitor
		Recreational perception	Presence of nature through dunes	# visits per year	WTP per visit
		Non-use possibilities because of increasing biodiversity	Non-use possibilities because of increasing biodiversity	# households concerning about biodiversity	WTP / donations per household per year

	Changing beach area	Possibilities for exploitation	Day trips because of beaches	# day trips per year	Profit by averaged spending per visitor
			Stay trips because of sea	# overnight stays per year	Profit by averaged spending per visitor
		Recreational perception	Presence of nature through beaches	# visits per year	WTP per visit
Water supply	Drinking water filtration	Ground water quality	Drinking water filtration	# m^3 clean ground water per year	Saved treatment costs per m^3
Safety benefits					
Safety	Protection coastal towns in front of dunes	Decreasing risk of inundation of the coastal towns	Risk of inundation of the coastal towns	Decrease inundation risk	Economic value coastal towns
Man-made functions					
Housing	Changing location of housing related to environment	Enjoyment of coastal environment	Living with a view of the dunes and/or the sea	# houses overlooking the dunes or sea*average purchase price	Additional value per house in %
	Changing housing area	More houses in coastal area	Change housing area	Increase housing area at the landward side of the dunes	Additional value per ha housing area
Agriculture	Ground water quality for crops	Increasing harvests	Salinity ground water	# ha with a certain % damage caused by saline ground water	Harvest per ha per year
	Changing agricultural area	Increasing harvests	Change agricultural area	Increase agricultural area at the landward side of the dunes	Value per ha agricultural area

The second step is to find out how large the (future) impacts (goods and services provided) of the proposed measure will be. This is what is done in chapter 4 where the proposed strategies are assessed, here we explain the methodology of the assessment. The impacts of the proposed strategies should be expressed in the units determined before.

The next step is to determine the prices or values to be used for monetarizing the quantified impacts. For construction and maintenance costs, this is very straightforward since one could apply prices of sand and so on. For the remaining welfare impacts, this is some more difficult. Goods and services provided by our environment can be monetarized by different valuation methods. These methods are: contingent valuation method, travel cost method, hedonic pricing method, averting behaviour method and avoided costs method. The method to be applied depends on the characteristics of the goods and services. A general overview of these methods is presented in the PhD thesis of Ruijgrok on the valuation of nature in coastal zones [Ruijgrok, 1999]. The result of applying these valuation methods is that a price is connected to each of the impacts. These prices are expressed per unit of quantification. For example: the unit of quantification for carbon assimilation by broad-leaved forests is the amount (in tons) of assimilated C per hectare per year. This unit should be multiplied by the area change of this type of nature in order to calculate the total change in carbon assimilation. Subsequently, this figure should be multiplied by a characteristic price for every ton of carbon (not) being assimilated. This results in a cost (in case of forest reduction) or benefit (otherwise) for one of the possible impacts of a new coastal management strategy.

It may be clear that determining the quantities of all impacts and applying the valuation methods to determine prices for these impacts will be quite a lot of work. However, in political decision making both time and money are lacking. A way to overcome those time and budget constraints is to work with sets of authorised values for both quantification and monetarization. In 2006, a first edition was published of the handbook with authorised values for the valuation of nature, water, bottom and landscape in socioeconomic CBA's [Ruijgrok e.a., 2006]. This handbook is based on numerous studies into the quantification and monetarization of these impacts and represents the state of the art for this research area.

The authorised values of this handbook are applied for deducing the potential welfare impacts of the coastal management strategies. Besides, other characteristic values (not related to nature, water, bottom or landscape) for determining impacts in the study area (Holland) were found in the report on the economic analysis of the Dutch coastline policy [Zijlstra e.a., 2007]. The values for the quantification and monetarization of the welfare impacts that were deduced from these studies are derived in a separate appendix, appendix N. A summary of these values can be found in appendix N.10.

M.3 Assessment area

An important step in performing CBA is the definition of the spatial scale of the study area. Some measures, like extending the foredune area, might increase the local welfare due to the increasing amount of tourists attracted by this natural beauty. However, on a national scale this welfare effect might disappear again since the local increase in visitors might be compensated by a decrease anywhere else. So in this case there is no national increase in welfare, it is a redistribution. It should be realised that this would only occur when no shortage of recreational facilities would exist within a country.

For this study, the coastal management strategies will be assessed by a national CBA. This spatial scale is most suitable since the costs of implementing a new coastal management strategy will be paid by the national government. So both costs and benefits should be considered on a countrywide scale.

M.4 Assessment period

Since the coastal management strategies proposed in this study should enhance the coastal defences over the next two centuries, the entire period up to the year 2200 will be concerned in the impact assessments. Some costs and benefits will recur annually from the moment of realization up to the end of our timeframe. Some other impacts will be incurred only once or at several moments over the entire period, like the construction costs. For comparing these impacts that are incurred at different moments in time, net present values of these costs or benefits should be calculated by discounting the future values of these amounts.

M.5 Discounting

One euro to be gained over one year will be valued lower than one euro to be gained today. This is due to the fact that interest would increase the value of the euro gained today in the year to come. So after one year, the euro gained today will be worth about 1.025 euro while the euro gained at that moment is still 1 euro. This effect should also be accounted for when adding the future costs and benefits of the coastal management strategies. These values should be discounted in order to calculate the net present values of these future impacts. This is represented by the equation:

$$net\ present\ value = \frac{value\ in\ year\ t}{(1+i)^t}$$

In this equation, i represents the real interest rate. Last year, the Dutch government lowered the real interest rate to be applied in CBA’s of public projects from 4% to 2.5% [Werkgroep Actualisatie Discontovoet, 2007]. In this study, net present values are calculated for the year 2008.

Next to this long-term influence of interest, the time might also increase the uncertainty of the amount of certain costs and benefits. Maybe some future benefits will not be gained at all and on the contrary they might also exceed the benefit expected. Uncertainties in future costs and benefits always result in a reduction of the valuation of these impacts. A standard risk correction rate of 3% is applied in the Netherlands [Commissie Risicowaardering, 2003]. However, in this study this risk correction will not be applied since its reducing effect on future costs and benefits will be too large. In that case benefits and costs that will be generated after the first 50 years will be negligible and that would reduce the significance of the long term perspective of this study.

N Values for quantification and monetarization of impacts

This appendix contains the derivation of the values for the quantification and monetarization of the monetary impacts of the coastal zone management strategies to be assessed. These values are mainly based on authorised values (kentallen) presented in the handbook 'Kentallen waardering natuur, water, bodem en landschap, hulpmiddel bij MKBA's [Ruijgrok e.a., 2006]. Besides, some values for functions like living and recreation in this study's area were specified in the report on the 'Economische analyse kustlijnbeleid, rapport fase 2: verkenning ex ante' [Zijlstra e.a., 2007]. In the sections below, these information is combined into typical values for quantifying the welfare effects that could be caused by changing coastal management strategies. Where possible, different impacts are combined into one welfare effect in order to reduce the amount of costs and benefits to be calculated.

N.1 Changing foredune area

The fore dunes are the front rows of the dunes, mainly consisting of young, growing dunes. In this study, these dunes could be formed by the impact of the proposed coastal management strategies. The potential impacts of an increase of the fore dune area are valued in the subsequent sub-sections. It is assumed that vegetation on the fore dunes (not the vegetation at the seaside of the dune front) consists of 50% foliage trees and 50% pine trees. Moreover, vegetation on fore dunes just started developing, so the potential impacts are supposed to be 30% of the impacts of full-grown trees [Zijlstra e.a., 2007].

N.1.1 Environmental advantages dune vegetation

Four effects of the presence of trees in fore dune forests should be considered here: filtering fine particulate matter, the uptake of NO_x and SO_2 and carbon assimilation.

Zijlstra e.a. [2007] have found that foliage trees filter about 50 kg PM10 (dust) per hectare per year and pine trees about 100 kg. This means that fore dune forests effectively filter 22.5 kg PM10/ha/yr. The benefit of this filtering is calculated form the potential health damage caused by PM10 in the air. For locations outside the built-up areas (like dunes are) the benefits of clean air are about € 70 per kg PM10 [Ruijgrok e.a., 2006]. The final result is a benefit of 1575 €/ha/yr.

According to the handbook of Ruijgrok e.a. [2006], both foliage and pine trees assimilate about 205 kg of NO_x per hectare per year. So fore dune vegetation assimilates about 61.5 kg NO_x/ha/yr. Outside the cities, the benefit of NO_x assimilation is rated at € 7 per kg based on the possible health damage caused by one kg of nitrogen in the air [Ruijgrok e.a., 2006]. The final result is a benefit of 431 €/ha/yr.

Next, for the uptake of SO_2 by trees, a general value of 178 kg per hectare per year could be assumed [Ruijgrok e.a., 2006]. This is converted into a efficiency of fore dune vegetation of 53.4 kg of SO_2 assimilated per hectare of this vegetation type per year. Outside the built-up areas, the value of this air cleaning function is assumed to be about € 4 per kg SO_2. This results in a benefit of the uptake of SO_2 of 214 €/ha/yr.

The last environmental advantage of the presence of dune vegetation is the protection against climate change by carbon fixation. Ruijgrok e.a. [2006] found that foliage trees assimilate a yearly amount of 1.37 tons of carbon per hectare. For pine trees, a value of 2.19 tons C/ha/yr is found. This results in an assimilation capacity of fore dune forests of about 0.53 tons C/ha/yr. The same source presents a benefit of € 49.5 per ton carbon fixated, which results in a benefit of carbon assimilation of 26 €/ha/yr.

All these environmental advantages of fore dune 'forests' are summarised (Table 41) and result in a total annual benefit of € 2246 per hectare fore dune forest added. Zijlstra e.a. [2007] only apply this value to the coastal areas located in Zuid-Holland and the southern part of Noord-Holland, since this are the only regions with serious air pollution and significant emission of the substances considered here. However, it might be expected that the northern part of Noord-Holland will face these problems too within the next decades due to the rapid urbanisation of the western part of the Netherlands. Since the temporal scope of this study is 200 years we therefore apply this benefit to the entire coast of the study area.

Table 41: Summary of the environmental advantages of forest-like vegetation on fore dunes, based on authorised values from previous studies.

Process	Authorised values for quantification		Effectivity of fore dune vegetation	Authorised values for monetarization	Costs/benefits
	Foliage trees	Pine trees			
Filtering fine particulate matter (PM10)	50 kg/ha/yr	100 kg/ha/yr	22.5 kg/ha/yr	70 €/kg	1575 €/ha/yr
Uptake of NO_x	205 kg/ha/yr	205 kg/ha/yr	61.5 kg/ha/yr	7 €/kg	431 €/ha/yr
Uptake of SO_2	178 kg/ha/yr	178 kg/ha/yr	53.4 kg/ha/yr	4 €/kg	214 €/ha/yr
Carbon assimilation	1.37 tons C/ha/yr	2.19 tons C/ha/yr	0.53 tons C/ha/yr	49.5 €/ton	26 €/ha/yr
Total benefit					2246 €/ha/yr[1]

[1] Since due forest is found at the landward side of new foredunes, this value should be halved when the total area of the new foredunes is calculated and multiplied by this benefit. It is then assumed that half of the new dune area is located landward of its crest and the other half seaward.

N.1.2 Possibilities for exploitation

For calculating possible benefits caused by exploitation of the increased area of the fore dunes, a difference should be made between day trips and stay trips (at least one overnight stay). Concerning these day trips, it is important to realise that on a national scale the generation of more day trips within the study area might decrease the number of day trips anywhere else. This would not result in a net national benefit. However, from the statistics on the supply and demand for day trips provided with the handbook of Ruijgrok e.a. [2006], it is deduced that the study area faces a large deficit in day trip facilities. Therefore, an increasing potential for day trips would increase the net national benefits, since more trips will be generated in stead of a redistribution of the existing amount of trips.
For overnight stay trips, this deliberation is something different. It is not expected that an increase in the facilities for stay trips would increase the number of inland stay trips. The number of stay trips in the Netherlands would not change, but the destination of the trips will be redistributed. This does not generate a net national benefit. On the other hand, the number of foreign tourists might increase due to the attraction of these new facilities. The contribution of these foreigners to the exploitation benefits should be included since this would increase the net national benefit.

For day trips it is assumed that every hectare of nature added to the fore dune area could attract 355 visitors per year in Noord-Holland and 968 visitors per year in Zuid-Holland. These values are presented as general figures for recreational possibilities of nature by Zijlstra e.a. [2007]. Next, Ruijgrok e.a. [2006] found that a walk in the dunes generates an averaged profit of € 0.152 for local entrepreneurs. Cyclists spend some more money during their day trips, an averaged profit of € 0.60 is assumed per trip. For this study, it is assumed that the numbers of walkers and cyclists are equal, so the averaged profit of a day trip is € 0.376. In this case an hectare of fore dune area added would generate 133 €/ha/yr in Noord-Holland and 364 €/ha/yr in Zuid-Holland.

For stay trips, several tourist regions are distinguished. Along the coast of our study area, two regions are of interest: the seaside resorts and the urbanised regions surrounding The Hague and Rotterdam. Ruijgrok e.a. [2006] deduced a number of overnight stays by foreigners per hectare of nature in these areas from present figures for day trips within these regions. For the seaside resorts a figure of 22 overnight stays per hectare of nature per year was found and for the urbanised regions a figure of 142 overnight stays per hectare of nature per year. The next step is the monetarization of these changes. Based on the prices for overnight stays at campsites, in bungalows, in hotels, in bed and breakfasts and in harbours, an average value for the price and profit per overnight stay is calculated. This value is found to be € 1.751 for seaside resorts and € 3.379 for the urbanised regions [Ruijgrok e.a., 2006]. This induces that the potential profits for an increase of overnight stays are 39 €/ha/yr for the seaside resorts and 480 €/ha/yr for the urbanised regions.

Furthermore, based on the present spatial distribution of the stay trip regions, it could be assumed that the urbanised regions cover one half of the Zuid-Holland coast. This means that an extra hectare of nature would incur an average profit of € 259. The Noord-Holland coast only consists of seaside resorts, so in this region an added hectare of nature incurs a profit of € 39. The total benefits of recreational exploitation add up to 172 €/ha/yr for Noord-Holland and 623 €/ha/yr for Zuid-Holland.

N.1.3 Recreational perception

Visitors of the coastal areas do have a positive perception of the area of nature at their destination. An extension of the dunes (no matter whether fore dunes or inner dunes are concerned) would therefore generate a positive benefit. Again, the visitor numbers of Zijlstra e.a. [2007] are applied: nature areas in Noord-Holland would attract 355 visitors per hectare and in Zuid-Holland they would generate 968 visitors per hectare. Ruijgrok e.a. [2006] found a willingness to pay for the presence of nature of € 0.45 per visit of the dunes. This results in a benefit of € 160 per hectare of fore dune area added in Noord-Holland and € 436 per hectare of fore dune area added in Zuid-Holland.

N.1.4 Non-use possibilities because of increasing biodiversity

These non-use possibilities of the nature present in the dunes are related to the valuation of the preservation of the existing biodiversity. These benefits should be deduced from the willingness to pay per household for preserving this biodiversity. However, the quantification and monetarization of this benefit is complex and the prices presented by Ruijgrok e.a. [2006] are uncertain. Moreover, the biodiversity or landscape diversity will not significantly be changed by most of the strategies proposed. And when it will be changed (due to new islands for example) it is rather difficult to estimate the valuation of this change and how many people would pay for it [Ruijgrok, 2006]. Therefore, this impact is not included in the cost-benefit analysis.

N.1.5 Conclusion

The potential welfare effects of a change in the fore dune area and the authorised values for calculating the costs and/or benefits of these welfare effects are summarised in Table 42 below. This table shows the potential benefits, in case of a loss of fore dune area, these benefits should be interpreted as costs due to the loss of the potential for gaining these benefits.

Table 42: Authorised values for monetarizing the potential welfare effects of a changing fore dune area.

Welfare effect	Benefits
Environmental advantages dune vegetation (trees)	2246 €/ha/yr
Possibilities for exploitation	
- Noord-Holland	172 €/ha/yr
- Zuid-Holland	623 €/ha/yr
Recreational perception	
- Noord-Holland	160 €/ha/yr
- Zuid-Holland	436 €/ha/yr

N.2 Changing inner dune area

The inner dunes are located at the landward side of the dunes and generally consist of older dunes. The area of these inner dunes might change too, when the sea defence is shifted in seaward direction and these dunes are cultivated for example. The benefits delivered by the inner dunes are summed up below.

N.2.1 Environmental advantages dune vegetation

Four effects of the presence of trees in inner dune forests (located at the landward side of the dunes) should be considered here: filtering fine particulate matter, the uptake of NO_x and SO_2 and carbon assimilation (the same effects as those stated for fore dune forests). In contradiction to fore dune vegetation, these trees are full-grown so the impacts of these forests do not need to be reduced.

Zijlstra e.a. [2007] have found that foliage trees filter about 50 kg PM10 (dust) per hectare per year and pine trees about 100 kg. This means that inner dune forests effectively filter 75 kg PM10/ha/yr. The benefit of this filtering is calculated form the potential health damage caused by PM10 in the air. For locations outside the built-up areas (like dunes are) the benefits of clean air are about € 70 per kg PM10 [Ruijgrok e.a., 2006]. The final result is a benefit of 5250 €/ha/yr.

According to the handbook of Ruijgrok e.a. [2006], both foliage and pine trees assimilate about 205 kg of NO_x per hectare per year. So inner dune vegetation assimilates 205 kg NO_x/ha/yr. Outside the cities, the benefit of NO_x assimilation is rated at € 7 per kg based on the possible health damage caused by one kg of nitrogen in the air [Ruijgrok e.a., 2006]. The final result is a benefit of 1435 €/ha/yr.

Next, for the uptake of SO_2 by trees, a general value of 178 kg per hectare per year could be assumed [Ruijgrok e.a., 2006]. This means an efficiency of inner dune vegetation of 178 kg of SO_2 assimilated per hectare of this vegetation type per year. Outside the built-up areas, the value of this air cleaning function is assumed to be about € 4 per kg SO_2. This results in a benefit of the uptake of SO_2 of 712 €/ha/yr.

The last environmental advantage of the presence of dune vegetation is the protection against climate change by carbon fixation. Ruijgrok e.a. [2006] found that foliage trees assimilate a yearly amount of 1.37 tons of carbon per hectare. For pine trees, a value of 2.19 tons C/ha/yr is found. This results in an assimilation capacity of inner dune forests of about 1.78 tons C/ha/yr. The same source presents a benefit of € 49.5 per ton carbon fixated, which results in a benefit of carbon assimilation of 88 €/ha/yr.

All these environmental advantages of inner dune forests are summarised (Table 43) and result in a total annual benefit of € 7485 per hectare inner dune forest added. Again, this benefit is applied to the entire coast of the study area, as discussed for the environmental advantages of fore dune vegetation.

Table 43: Summary of the environmental advantages of forest-like vegetation on fore dunes, based on authorised values from previous studies.

Process	Authorised values for quantification		Effectivity of fore dune vegetation	Authorised values for monetarization	Costs/benefits
	Foliage trees	Pine trees			
Filtering fine particulate matter (PM10)	50 kg/ha/yr	100 kg/ha/yr	75 kg/ha/yr	70 €/kg	5250 €/ha/yr
Uptake of NO_x	205 kg/ha/yr	205 kg/ha/yr	205 kg/ha/yr	7 €/kg	1435 €/ha/yr
Uptake of SO_2	178 kg/ha/yr	178 kg/ha/yr	178 kg/ha/yr	4 €/kg	712 €/ha/yr
Carbon assimilation	1.37 tons C/ha/yr	2.19 tons C/ha/yr	1.78 tons C/ha/yr	49.5 €/ton	88 €/ha/yr
Total benefit					7485 €/ha/yr

N.2.2 Possibilities for exploitation

Just like the extension of the fore dune area, the extension of the inner dune area would also generate some additional day trips and overnight stays. Since there is no significant difference between the recreational value of fore dunes and inner dunes, the benefits caused by recreational exploitation of the inner dune area are the same as those for the fore dunes. So again, the total benefits of recreational exploitation sum up to 172 €/ha for Noord-Holland and 623 €/ha for Zuid-Holland.

N.2.3 Recreational perception

Visitors of the coastal areas do have a positive perception of the area of nature at their destination. An extension of the inner dunes would therefore generate the same positive benefit as the extension of the fore dunes. So one should account for a benefit of € 160 per hectare of inner dune area added in Noord-Holland and € 436 per hectare of inner dune area added in Zuid-Holland.

N.2.4 Non-use possibilities because of increasing biodiversity

See section N.1.4.

N.2.5 Conclusion

The potential welfare effects of a change in the inner dune area and the authorised values for calculating the costs and/or benefits of these welfare effects are summarised in Table 44 below. This table shows the potential benefits, in case of a loss of fore dune area, these benefits should be interpreted as costs due to the loss of the potential for gaining these benefits.

Table 44: Authorised values for monetarizing the potential welfare effects of a changing inner dune area.

Welfare effect	Benefits
Environmental advantages dune vegetation (trees)	7485 €/ha/yr
Possibilities for exploitation	
- Noord-Holland	172 €/ha/yr
- Zuid-Holland	623 €/ha/yr
Recreational perception	
- Noord-Holland	160 €/ha/yr
- Zuid-Holland	436 €/ha/yr

N.3 Changing beach area

Next to the dunes, new coastal management strategies might also affect the area of the beaches. The beaches in the study area do have some important recreational functions. A change in the area of beaches will affect the benefits of these functions. The quantification and monetarization of these impacts is studied below.

N.3.1 Possibilities for exploitation

For calculating possible benefits caused by the exploitation of the increased area of the beaches, a difference should be made between day trips and stay trips (at least one overnight stay). The difference in the contribution of these two modes to the net national benefit is already explained in section N.1.2 of this appendix.

For day trips it is assumed that every hectare of nature added to the fore dune area could attract 355 visitors per year in Noord-Holland and 968 visitors per year in Zuid-Holland. These values are presented as general figures for recreational possibilities of nature by Zijlstra e.a. [2007]. Next, Ruijgrok e.a. [2006] found that a walk on the beach generates an averaged profit of € 0.152 for local entrepreneurs. In this case every hectare of beach added would generate 54 €/ha/yr in Noord-Holland and 147 €/ha/yr in Zuid-Holland. The average width of the beaches in the study area is about 150 m (based on a visual study of the map of the Netherlands). So these values could be translated to a benefit per metre of beach that is created. For Noord-Holland this results in a value of 0.8 €/m/yr and for Zuid-Holland it is 2.2 €/m/yr.

For overnight stay trips attracted by the sea (which is directly related to the beaches), the handbook of Ruijgrok e.a. [2006] makes no distinction between overnight stays of foreigners and of Dutch people. However, based on the information used for deriving the exploitation benefits of an increase in dune area presented in the same handbook, this distinction could still be made. Then it is found that the relevant number of overnight stays per metre beach length is 40 per year. The average profit of each overnight stay in these coastal regions is € 1.751. This is translated into a benefit of 70 €/m/yr.

These two aspects could be added, resulting in a yearly benefit of € 71 per metre beach created in Noord-Holland and € 72 per metre beach created in Zuid-Holland.

N.3.2 Recreational perception

Visitors of the coastal areas do also have a positive perception of the area of the beaches at their destination. An extension of the beaches would therefore generate a positive benefit. Again, the visitor numbers of Zijlstra e.a. [2007] are applied: nature areas in Noord-Holland would attract 355 visitors per hectare and in Zuid-Holland they would generate 968 visitors per hectare. Ruijgrok e.a. [2006] found a willingness to pay for the presence of beaches of € 1.40 per visit. This results in a benefit of € 497 per hectare of beach area added in Noord-Holland and € 1355 per hectare of fore dune area added in Zuid-Holland. Again, these values are translated to a value per metre of beach (assuming an average beach width of 150 m). For Noord-Holland, this results in a benefit of 7.5 €/m/yr and for Zuid-Holland a benefit of 20 €/m/yr is calculated. Benefits through the recreational perception of beaches are not related to the area of the beaches in this study but only to the length, since increasing beach widths might decrease the number of visitors due to a lower recreational perception of wide beaches where the distance to the sea could be rather large.

N.3.3 Conclusion

The figures found for the valuation of the benefits of an increasing beach length (or the costs of a decreasing beach length) are summarised in Table 45.

Table 45: Authorised values for monetarizing the potential welfare effects of a changing beach length.

Welfare effect	Benefits
Possibilities for exploitation	
- Noord-Holland	71 €/m/yr
- Zuid-Holland	72 €/m/yr
Recreational perception	
- Noord-Holland	7.5 €/m/yr
- Zuid-Holland	20 €/m/yr

N.4 Drinking-water filtration

Sandy grounds have a purifying effect on infiltrating rainwater (or infiltrated water from other sources). Therefore, ground water below the dunes is very clean and could be used for the production of drinking water. This filtering process induces the benefit of saved treatment costs in the production of drinking water. So when the area of dunes is extended, this would incur the benefit of saved costs for drinking water filtration.

Zijlstra e.a. [2007] assume an annual production of 7500 m^3 of drinking water per hectare dune area. Moreover, they found that the production of drinking water from this filtered ground water is 24% cheaper than the production of drinking water from surface water. This compares to a benefit of € 0.145 per m^3 of drinking water produced. So a benefit of 1088 €/ha/yr could be gained by extending the area for drinking water filtration in the dunes.

However, not the total dune area is used for drinking water filtration. Currently, 14,110 ha of the dunes in Noord-Holland and Zuid-Holland is managed by drinking water companies [Van Wijk, 2005]. The total area of the dunes in the Netherlands amounts to 48,000 ha [Kustgids.nl, 2008] and about half of this area is located within the study area. Based on these characteristics, it is estimated that at least half of the dune area in central Holland is applied for drinking water filtration.

Based on this information, it is assumed that 50% of the area by which the dunes are extended will be applied for drinking water filtration and this area will generate a benefit of 1088 €/ha/yr.

N.5 Protection coastal towns

Some coastal residences in the study area do have some areas that are not protected by the dunes or dikes. These areas are called ‘buitendijks’ (outside the dike) and are located outside the legally defined dike ring areas for which general safety levels are prescribed. On the contrary, for these areas outside the ‘dikes’ no legal safety prescriptions are determined and the inhabitants are responsible for their own safety [Commissie Poelmann, 2005]. The chances of inundation in these areas are much larger than inside the dike ring areas.

Zijlstra e.a. [2007] present a value of the assets within the coastal areas that are located outside the dikes of € 5.7 milliard. Zijlstra e.a. suppose that the total damage in case of inundation of these areas incurs 20% of this value: € 1.1 milliard. This figure should be increased annually with an economic growth rate of 1.7%.

Next to that, the present probability of inundation (or protection level) of these areas is estimated at about 1:250 per year [Zijlstra e.a., 2007]. The realisation of a new coastal management strategy might increase this safety level and thereby reduce the inundation risk to be included in the CBA.

N.6 Changing location of housing related to environment

The creation of new dunes or the extension of the existing dunes might improve the environment of existing houses near the dunes. When the dunes are extended landward for example, more houses might be located in a coastal environment. Moreover, Zijlstra e.a. [2007] found that the additional value of houses in a coastal environment is about 10%. The increasing value of these houses should be included as a benefit.

Assuming a density of about 20 houses per hectare [Zijlstra e.a., 2007] for coastal built-up regions and an average price for houses of € 218,000 [Ruijgrok e.a., 2006], the increasing value of the built-up areas upgraded to a coastal environment is about 436,000 € /ha. Note that this benefit could be applied only once, in contradiction to the annual recurrence of most other benefits.

N.7 Changing housing area

The creation of new dunes or the extension of the existing dunes might create possibilities for the development of housing projects at the landward side of the dunes (the inner dunes). In this case, it might be supposed that this would decrease the demand for houses at other locations, so there is only a shift in the production of new houses. However, houses in the coastal environment are valued higher than inland located houses. Zijlstra e.a. [2007] found that the additional value of houses in a coastal environment is about 10%. This additional value should be included as a benefit. On the other hand, it should be included as a cost if houses that are presently located in the coastal zone should be removed inland due to a landward extension of the dunes.

Assuming an averaged price for houses of € 218,000 [Ruijgrok e.a., 2006] and a density of about 20 houses per hectare [Zijlstra e.a., 2007], this turns into a benefit of about 436,000 €/ha. Note that this benefit could be applied only once instead of the annual recurrence of most other benefits.

Moreover, Zijlstra e.a. [2007] have inventoried the land use in a 2 km wide zone behind the coastal defences within the study area. They made a distinction between three different regions in Zuid-Holland (south, middle, north) and two regions in Noord-Holland (south, north). These values are roughly aggregated to two regions and are presented in Table 46. These land use percentages will also be applied when in some inner dune areas the existing nature could be replaced by man-made functions (due to the seaward extension of the coastal defences). So in this case, it could be assumed that in Zuid-Holland about 30% of this area will be dedicated to housing projects, while this function would only fill-up 10% of the area in Noord-Holland.

Table 46: Percentages land used for agriculture, housing and recreation in the coastal zone of the study area (2 km wide). The remainder of the space is dedicated to functions of minor economic importance.

Land use	Zuid-Holland	Noord-Holland
Agriculture	30%	60%
Housing	30%	10%
Recreation	2%	5%

N.8 Ground water quality for crops

Calculating the effects of increasing salinity of ground water is very complex. First, one should exactly know the area where the salinity of the ground water changes and what crops are cultivated in this area. Next, one should study the change in the salinity (the concentration of chloride in mg per litre ground water). Then the effect of this changing salinity on the cultivated crops can be calculated by applying some pre-defined functions and valuation figures. One of the difficulties in this procedure is the difference in the sensitivities of the different crops to changes in the salinity of ground water. Another difficulty is the spatial inequality in the distribution of the crops cultivated within the study area and the differences in the profits to be gained with these crops. Moreover, crops are improved to resist increasing salinity which lessens potential impacts and hampers the insights into the impacts of changing salinities even further.

After all, it is concluded that the inclusion of this effect in this CBA is far too complex compared to the aim of this study.

N.9 Changing agricultural area

Zijlstra e.a. [2007] present values on the distribution of the agricultural activities in a 2 km wide zone behind the current coastal defences and on the annual benefits of these agricultural activities. A significant difference exists between the distribution of the activities in the southern part of Zuid-Holland (mainly greenhouses in Delfland) and the activities in the remainder of the study area (mainly grass). When these information is aggregated, one would find a benefit of about 69,000 €/ha/yr for Delfland and of 3200 €/ha/yr for the remaining part of the coastal zone within the study area.

In this case, the land use of the present area behind the coastal defences will again be projected towards the newly available area in the inner dunes. From Table 46 it follows that in Zuid-Holland about 30% of this new area would be dedicated to agriculture. In Noord-Holland this percentage is even 60%.

Moreover, the inland locations that will not be used for the realisation of the houses that might be developed in the coastal zone (with the same area as the developed housing project in the coastal zone) will remain it’s agricultural function (assuming that no inland nature will be sacrificed for realising these houses). Zijlstra e.a. [2007] calculate an annual benefit of the inland agricultural areas of € 2640 per hectare.

N.10 Summary

The derived values for valuation of the welfare effects are summarized in the table below. Note that some values have been added up in order to reduce the amount of aspects and that no characteristic values can be given for the construction and maintenance costs. As stated in the previous sections, some other aspects are left out the final analysis method due to their uncertainty. No costs or benefits are allocated to these aspects.

Table 47: Translation of costs and welfare effects into monetary costs/benefits (dependent on the direction of change) based on authorised values. Note: NH = Noord-Holland, ZH = Zuid-Holland.

	Physical effect	Welfare effect	Cost/benefit
Costs			
Construction and maintenance costs	Construction costs	Expenditure by national government	To be calculated
	Costs for maintenance and management	Expenditure by national government	To be calculated
Welfare impacts			
Nature values			
Environment & recreation	Changing fore dune area	Environmental advantages dune vegetation	2246 €/ha/yr
		Possibilities for exploitation	NH: 172 €/ha/yr
			ZH: 623 €/ha/yr
		Recreational perception	NH: 160 €/ha/yr
			ZH: 436 €/ha/yr
		Non-use possibilities because of increasing biodiversity	-
	Changing inner dune area	Environmental advantages dune vegetation	7485 €/ha/yr
		Possibilities for exploitation	NH: 172 €/ha/yr
			ZH: 623 €/ha/yr
		Recreational perception	NH: 160 €/ha/yr
			ZH: 436 €/ha/yr
		Non-use possibilities because of increasing biodiversity	-
	Changing beach area	Possibilities for exploitation	NH: 71 €/m/yr
			ZH: 72 €/m/yr
		Recreational perception	NH: 7.5 €/m/yr
			ZH: 20 €/m/yr
Water supply	Drinking water filtration	Ground water quality	1088 €/ha/yr
Safety benefits			
Safety	Protection coastal towns	Decreasing risk of inundation of the coastal towns	€ 1.1×10^9 * change in annual probability of flooding
Man-made functions			
Housing	Changing location of housing related to environment	Enjoyment of coastal environment	436,000 €/ha
	Changing housing area	More houses in coastal area	436,000 €/ha
Agriculture	Ground water quality for crops	Increasing harvests	-
	Changing agricultural area	Increasing harvests	Delfland: 69,000 €/ha/yr Coastal zone: 3200 €/ha/yr Inland: 2640 €/ha/yr

O Assessing coastal management strategies

This appendix contains the assessments of the proposed coastal management strategies. Within this assessment, the effects of the strategies are considered for all criteria of the assessment method defined in section 4.1. Some of these effects are first expressed in monetary terms: costs for construction and maintenance and part of the welfare effects. The other effects are only expressed in qualitative terms based on a mutual comparison between the effects of the strategies. All assessments are then translated into a score on an assessment scale ranging from –2 to 2, with a positive score being positive and a 0 score indicating no or neutral effects.

These qualitative scores of the strategies on each criterion are awarded in comparison to the potential impacts of the basic alternative. Fist this comparative assessing is common practice. Second, weighting methods like interval standardization or vector normalization [Pouwels, 1995] in order to translate those quantitative assessments to a scale ranging from –2 to 2 are improper in this case. This is due to the fact that one or more of the strategies have rather large impacts at each of the criteria, making the difference between the impacts of the other strategies irrelevant. This loss of nuance in the final qualitative assessments could be avoided by this comparative method.

O.1 Construction costs

In this section we present some estimates of the construction costs of the proposed coastal management strategies. These estimates are based on rough calculations of the product of unit prices and volumes of sand needed. In some cases, constructions costs are derived from prices for coastal enhancement solutions from existing projects or studies. Moreover, an indication is given when these constructions should be realised in order to maintain present safety levels. An assumption is made on these temporal distribution:

- Sections assessed red in Table 4 will need to be improved at about 2025.
- Sections assessed mainly orange and slightly red in Table 4 will be improved at about 2050.
- Sections assessed orange in Table 4 will need to be improved at about 2075.
- Sections assessed yellow in Table 4 will need to be improved at about 2125.
- Sections assessed green in Table 4 will not need any improvement.

These are only assumptions since we do not exactly know how safety develops over time (we only did simulations for the year 2200). These assumptions only give an indication of the potential temporal distribution of the construction costs. Finally it is calculated what this means to the net present value of the construction costs. Other project costs for overhead, uncertainties and engineering are not included in these cost estimates but might add up to about 40% of the estimated costs [Briene & Wienhoven, 2006]. Other costs that should be incurred for related spatial planning developments (e.g. in case of new islands) are also not included in these costs since they are not directly related to the water retaining function of the planned structures.

O.1.1 Uniform coast; islands

The costs of constructing the islands with the dimensions stated in appendix J.1.1 are derived from the amount of sand (and stones) needed for construction. The islands are schematized as one prism with an upper plane at about 5.5 m above NAP and a lower plane at about 20 m –NAP. The width of the upper plane ranges from 3000 to 1000 m and from the lower plane it ranges from 3225 to 1225, since a 1:5 slope (see appendix J.1.2) of the sides of the island is supposed. The length of the island is about 105 km. About $5.7*10^9$ m^3 sand is needed to create this island. Planning dunes at the ocean-side of this island for protecting it against flooding by minor storm events (with a probability of occurrence of about 1:100, see appendix J.1.1), would not add significantly to this sand volume. The same is valid for the dune extension still needed at the mainland coast north of the island between Callantsoog and Den Helder. Together, about $0.1*10^9$ m^3 sand will be needed for these measures.

According to [Zijlstra e.a., 2007], underwater nourishments (below 2 m –MSL) cost about 2 €/m^3, while beach nourishments (above 2 m –MSL) cost about 4 €/m^3. Less than 1/3 of the calculated volume is located above 2 m –MSL, so a unit price of 2.6 €/m^3 is assumed. The total costs are thus calculated at € $15*10^9$. These costs should be incurred at once around 2025 since some locations along the studied coast will be insufficiently protected by then and from other viewpoints (morphologic, spatial planning) it would be rather difficult to split the construction of the islands in several phases. The net present value of the construction costs (applying a 2.5% discount rate) is about € 9.8 billion.

According to Jan de Nul dredging company [Jan de Nul, 2008], about $70*10^6$ m^3 of soil (sand, caprock, calcarenite, limestone) was used for the reclamation of Palm Jebel Ali, one of the palm islands in front of the Dubai coast. It's contract value was about USD $137*10^6$. For this project, about 80 times that amount of soil is needed. Multiplying the costs by the same amount results in about € 8 billion, being of the same order of magnitude as the calculated amount.

O.1.2 Uniform coast; sandbanks

A cross-section of these sandbanks resembles a parallelogram with a 30 m wide crest, a 120 m wide floor and being about 8 m high (bottom level at 10 m –NAP and crest level at about 2 m –NAP). Next, this solution covers the entire coast with a total length of 117.5 km. Since the banks will be oriented at an angle of about 30° towards the coast, it is supposed that the total length of the banks will be about 1.5 times the length of the mainland coast. This implies that about $106*10^6$ m^3 sand will be needed for constructing these banks. Since these banks can be built by underwater nourishments, this would cost about € $210*10^6$. From a morphological point of view, it is again assumed that it is better to realise this measure at once and then it should be realized around 2025 when the first weak links in the coastal defences would occur. The net present value of these construction costs is € 140 million.

O.1.3 Uniform coast; dunes in front of existing dunes

For this strategy, we did some model calculations to determine new cross-shore profiles that would satisfy safety requirements. Four representative cross-profiles were selected, each representing equal parts of the coast studied (see Figure 22). The amount of sand needed for constructing these new cross-sections is determined by integrating the difference between the cross-shore profile before and after construction.

At the same time, this measure is less exposed to morphodynamic processes since the new dunes are located closer to the coast. Therefore it is supposed that these new dunes are created gradually between 2025 and 2075, starting at the locations where coastal defences will be inadequate at first. The construction is therefore projected towards the year 2050, when autonomous developments (see section 2.2.2) will have caused both sea level and sea bed rise of about 0.75 m. This factor was still supposed being insignificant by the year 2025, but on this longer time span it could not be ignored any more. This sea bed rise only takes place seaward form the toe of the dune, located at 3 m +NAP, and is added to the existing cross-shore profile in order to calculate the (reduced) amount of sand needed to create these new foredunes. This was done for the four cross-sections and it was found that on average about 3200 m^3/m was needed for these new dunes.

Of these new dunes, about 80% is located above 2 m –NAP and should be created by beach nourishments (4 €/m^3), the other 20% could be created by underwater nourishments (2 €/m^3). The average cost is then 3.6 €/m^3 adding up to the construction costs being about € $1.3*10^9$. These costs are projected to 2050 and result in a net present value of € 470 million.

O.1.4 Large scale; islands and dunes

This strategy is composed from two of the uniform coast strategies. An island is planned in front of the coast of Zuid-Holland. It's dimensions are equal to those of the southern part of the larger, uniform coast island. So this one is about 61.5 km elongated, it's crest is 3 km wide at the south and 2 km wide at the north, the slopes have a 1:5 inclination, the bottom is located at about 20 m –NAP and the crest is located at 5.5 m +NAP. This requires a total amount of sand of about $4.1*10^9$ m^3. At 2.6 €/m^3, this would cost about € $11*10^9$. The construction is planned in 2025, just as for the uniform coast variant.

In front of the Noord-Holland coast, a seaward extension of the dunes is planned by creating a new row of dunes in front of the existing dunes. Just as in the previous section, these will be constructed between 2025 and 2075 and the costs are therefore concentrated in 2050. With an average sand need of about 3200 m^3/m for these new dunes, the 54 km long coast of Noord-Holland should be enhanced by $175*10^6$ m^3 of sand. Again, this would cost 3.6 €/m^3 and thus about € $631*10^6$ in total.

Together, the measures for creating this strategy have a net present value of € 7.3 billion.

O.1.5 Large scale; dunes and sandbanks

For this strategy, new dunes are planned to improve the coastal safety of the southern part of the study area. The assumptions on time (2025-2075 but projected towards 2050) and sand needed (3200 m^3/m) are again the same. For this 61.5 km long stretch of the studied coast, this means that $196*10^6$ m^3 sand will be needed to realise these new foredunes. This would cost about € 706 million (at a unit price of 3.6 €/m^3).

For the sandbanks planned to enhance the Noord-Holland coast, we took the conditions from the uniform coast sandbank strategy. With the same dimensions and orientation of the sandbanks, this 54 km long section of the coast would need about $50*10^6$ m^3 sand and it would cost € $99*10^6$ (at a 2 €/m^3 unit price). These sandbanks will again be constructed at once in 2025, since this would increase morphologic stability of the new features.

The total net present value of the costs for realizing this strategy is € 320 million.

O.1.6 Intermediate scale; seaward

This strategy consists of three different measures: dune in front of existing dune, sandbanks and artificial reefs. Costs for the first two measures are again calculated by multiplying sand volumes with unit prices. The sand volumes are calculated from the new cross-shore profiles determined in appendix J.3.1. For the latter solution, an estimate is made on the construction costs.

Section 1, 3, 5, 7, 12

The coastal defences in these sections will be improved by creating a new dune in front of the existing dunes. For each of these sections, the new cross-profiles were determined in section J.3.1. The volume of sand needed could then be derived from the difference between this new profile and the cross-shore profile at the moment of realization. These moments differ and are assumed to be interconnected with the assessment of each section as stated before. For the successive years it is supposed that:

- By 2025 no significant rise of sea and bed levels have occurred.
- By 2050 both sea levels and bed levels (seaward from the dune toe) will be 0.75 m higher.
- By 2075 both sea levels and bed levels (seaward from the dune toe) will be 1 m higher.
- By 2125 both sea levels and bed levels (seaward from the dune toe) will be 1.50 m higher.

Next, for every section the amount of sand needed to construct the new cross-profiles on top of the existing cross-profiles are calculated. These amounts are presented in the fourth column of Table 48. Multiplying these amounts by the length of the section and the unit price of sand nourishments for this measure (3.6 €/m^3), gives the total costs. Finally, the net present value of the investments for every section is derived by use of the year of investment. The resulting values are presented in Table 48.

Section 2, 4, 6, 10

At these section, sandbanks will be created in order to enhance the existing coastal defence, both by breaking waves and by their possible use as sand engine for the mainland coast. The dimensions of these banks are the same as in case of the uniform coast solution consisting of sandbanks. In this case, the amount of sea and bed level rise do not affect the dimensions of the sandbanks to be constructed (see appendix O.1.2). Again it is supposed that the total length of the sandbanks, showing a small angle to the coastline, is about 1.5 times the length of the mainland coast. By applying the unit cost (2 €/m^3), the total costs and the net present values of these investments can be calculated. The results are summarized in Table 48.

Section 8, 11
At these sections, accommodating coastal towns, artificial reefs are planned to increase the safety of the coastal defences. Since there are only executed some preliminary studies on the features of these reefs in front of the Holland coast, estimates on their costs are not yet available. According to expert judgement, the costs of artificial reefs will be about one order of magnitude higher than the costs of traditional coastal enhancement projects and the costs will be of the same order of magnitude as the costs of complex coastal enhancement projects like constructing a dike within the dune. Therefore we took the costs of the landward strategy for these two sections that will be improved by such a complex construction in case of this landward strategy. These costs are all translated to net present values (based on the year of investment) and the results are presented in Table 48.

The total net present value of the costs for realizing all measures within this strategy is about € 860 million.

Table 48: Calculation of the construction costs of the seaward intermediate scale strategy, based on sand volumes, unit prices and project information.

Section [#]	Length [km]	Solution	Amount of sand [m^3/m]	Unit cost [€/m^3]	Total cost [*10^6 €]	Year of investment	NPV [*10^6 €]
1	26	Dune in front of existing dune	2706	3.6	253	2025	166
2	7	Sandbank	600	2	13	2075	2.4
3	10	Dune in front of existing dune	2069	3.6	74	2075	14
4	7	Sandbank	600	2	13	2050	4.5
5	4	Dune in front of existing dune	2719	3.6	39	2075	7.5
6	17	Sandbank	600	2	31	2075	5.9
7	7	Dune in front of existing dune	2756	3.6	69	2075	13
8	7	Artificial reef	-	-	403	2025	265
9	4	-	-	-	-	-	-
10	7	Sandbank	600	2	13	2125	0.7
11	9	Artificial reef	-	-	518	2025	340
12	10.5	Dune in front of existing dune	3086	3.6	117	2050	41

O.1.7 Intermediate scale; landward

This strategy consists of three different measures: extending dune in landward direction, dunes behind existing dunes and a dike in dune solution including a seaward dune extension. Costs for the first two measures are calculated by multiplying sand volumes with unit prices. The sand volumes are calculated from the new cross-shore profiles determined in appendix J.3.2. For the latter solution, an estimate is made on the construction costs.

Section 1, 3, 5, 7, 12
The dimensions of the necessary dune extensions in order to maintain present safety levels are determined in section J.3.2 for some representative cross-sections. Integrating the difference between these new profiles and the existing profiles results in the amount of sand needed per metre length for improving the coastal defences.

Sand for these landward dune extensions is also extracted from the sea, but it needs to be desalinated before is could be used at the landward side of the defences. This is done by first bringing this sand to the beaches by beach nourishments and then it is left there for a certain time in order to reduce its salt content. Afterwards it is transported landward for construction activities. In this case sand production is more expensive and a unit price of 7 €/m^3 is found [Briene & Wienhoven, 2006]. The total costs and net present values found by these calculations are presented in Table 49.

Section 2, 4, 6, 10
In these cases, the costs are derived at exactly the same way as for sections 1, 3, 5, 7, and 12.

Section 8, 11
The measure for these two sections is derived from the plans presently being realized at Noordwijk. In the next section we find we find for the longshore section containing Noordwijk that it would cost about € 72*10^6 to create a dike with a crest level of 8.5 m +NAP within the existing dune and extending this dune with about 120 m in seaward direction, both over a length of 1250 m. These costs are translated to the length of the sections 8 and 11 and the net present values are determined. The results are presented in Table 49.

The total net present value of the costs for realizing all measures within this strategy is about € 720 million.

Table 49: Calculation of the construction costs of the landward intermediate scale strategy, based on sand volumes, unit prices and project information.

Section [#]	Length [km]	Solution	Amount of sand [m^3/m]	Unit cost [€/m^3]	Total cost [*10^6 €]	Year of investment	NPV [*10^6 €]
1	26	Extending dune in landward direction	596	7	108	2025	71
2	7	Dune behind existing dunes	634	7	31	2075	5.9
3	10	Extending dune in landward direction	438	7	31	2075	5.9
4	7	Dune behind existing dunes	422	7	21	2050	7.3
5	4	Extending dune in landward direction	657	7	18	2075	3.5
6	17	Dune behind existing dunes	275	7	33	2075	6.3
7	7	Extending dune in landward direction	480	7	24	2075	4.5
8	7	Dike in dune + extending dune in seaward direction	-	-	403	2025	265
9	4	-	-	-	-	-	-
10	7	Dune behind existing dunes	108	7	5.3	2125	0.3
11	9	Dike in dune + extending dune in seaward direction	-	-	518	2025	340
12	10.5	Extending dune in landward direction	374	7	27	2050	9.7

O.1.8 Small scale; basic alternative

This strategy contains a spectrum of different measures, all being applied over a relatively short longshore distance. For some of these sections (sections 1, 7, 18, 23, 25 and 29) the costs of constructing the proposed measures is derived from project studies into enhancing the weak links. These solutions are currently being realized or they are still under investigation. Costs for the sandy solutions in the remaining sections are calculated by multiplying sand volumes with unit prices. The sand volumes are calculated from the new cross-shore profiles determined in appendix J.4.

Section 1
For this section, no studies are available on the possible costs of heightening the dike protecting the city of Den Helder. However, some estimates are available on heightening the Hondsbossche and Pettemer sea walls located somewhat further to the south (see next paragraph). Heightening these sea walls with about 5 m (and an induced landward extension of 30 m) would cost $9*10^3$ €/m length [Steetzel, 2007]. This quite nearly resembles the dimensions of the dike improvement needed at this section: 3.15 m heightening and about 25 m landward extension. It is supposed that this dike enhancement project would cost about $7.5*10^3$ €/m length.

The total length of this section is 1.2 km and implies a total investment for the needed dike heightening of about € $9.0*10^6$. This project is planned for 2025. The net present value of these construction costs is € 5.9 million.

Section 7
The sea wall of this section will be enhanced by heightening the dike and at the same time extending it's width in landward direction. From a study into the possible measures for enhancing the Hondsbossche and Pettemer is sea walls (currently marked as weak link location) it is derived that heightening these sea walls with 5 m would cost about $9*10^3$ €/m length [Steetzel, 2007]. This value is averaged from the minimum and maximum values given for both sections of the sea wall. These costs are estimated based on an average heightening of the dike of about 5 m and the induced landward extension of the dike with about 30 m.

In this case a heightening of the dike of about 14 m was foreseen, so it would cost about $27*10^3$ €/m length of the dike. Since this section's total length is 5.6 km, this comes down to a total cost of € $151*10^6$. This investment will be planned in 2025 only, since it will be easier and less expensive (think of overhead costs and public nuisance) to realize this dike heightening project at once in stead of in several phases. The net present value of this investment is about € 99 million.

Section 18
At Zandvoort, the town located in this section, we only designed a dike to be constructed within the dune. In the next paragraph we find that constructing a dike (crest level about 9.5 m +NAP) within the dune and extending the dune about 30 m seaward would cost € $11.5*10^6$ for a section length of 1250 m. Based on these figures, it is assumed that only constructing the dike over a distance of 2000 m would cost about € $15*10^6$. The net present value of this investment, planned for 2125, is only € 0.8 million.

Section 23
At Noordwijk, the coastal town located in this section, a dike will be constructed within the existing dune together with a seaward extension of this dune. The costs of this project are derived from a preliminary study into the possibilities for improving coastal safety of this town [Korzilius, 2005]. This study states that constructing a dike with a crest level varying from 11 m to 8.5 m +NAP within the existing dune and extending the new dunes in front of the dike with about 50 to 60 m will cost about € $11.5*10^6$. In order to withstand a sea level rise up to 1.70 m (next to 0.40 m storm surge level increase and 5% wave height increase), the dune will be extended over another 30 m (about 255 m^3/m sand). According to Korzilius this addition would cost about € $20.5*10^6$.

In this case, we planned to extend the dune with another 40 m and to heighten the crest level of the entire dune up to 10 m +NAP. This would incur an amount of sand of about 490 m^3/m, assumed to add another € $40*10^6$ to the construction costs. Moreover, these cost estimates are based on a section length of 1250 m, but the length of section 23 is 2500 m. Total construction costs are thus adding up to about € $144*10^6$. Again, this project will be realised at once since this prevents for unnecessary nuisance at these important recreational areas due to phasing of the project. The net present value is calculated to be € 95 million.

Section 25
For this section, representing Katwijk, we designed exactly the same measure as for Noordwijk. However, the length of this section is 3 km, so the total investment costs add up to € 173*10^6 representing a net present value of about € 114 million.

Section 29
This section contains Scheveningen and it's coastal defences will be improved by constructing a water retaining structure within the boulevard and by heightening the beach in front of the boulevard over a seaward distance of 300 m. According to a preliminary study after the possibilities for enhancing the coastal defences at Scheveningen, constructing this structure and heightening the beach with 0.6 m would cost about € 20*10^6 for a section length of 3 km. Section 29 has a length of 4 km, so these costs are extrapolated to about € 27*10^6. Furthermore, an additional increase of the beach level of 1.4 m is foreseen. About 1.68*10^6 m^3 of sand would be needed to realize this beach heightening. This would cost about € 6.7*10^6 assuming the unit price for beach nourishment.

The total costs of this measure are thus estimated at € 34*10^6, resulting in a net present value of about € 22 million.

Remaining sections
The sea defences of these sections will all be extended with 'soft' sandy measures. The costs of these measures are again derived from the volume of sand needed and unit prices for nourishment. The needed sand volumes are derived by integrating the difference between the new cross-sections determined in appendix J.4 and the existing cross-sections. The bed levels of these existing cross-sections are increased according to the assumptions stated in section O.1 of this appendix. Next, these integrated differences are multiplied by the length of the section being represented by a certain cross-section. The resulting sand amounts are presented in Table 50.

The unit prices are somewhat variable. In case of sections 2 and 5, about half the sand volume is needed below the 2 m –NAP level and could be supplied by underwater nourishments, resulting in an averaged unit price of 3 €/m^3 (2 €/m^3 for underwater nourishment and 4 €/m^3 for beach nourishment). Sections 33 and 34 resemble the construction of dunes in front of the existing dunes and thus have a unit price of 3.6 €/m^3. The sand that is needed for the remaining cross-sections should mainly be supplied by beach nourishments with a unit price of 4 €/m^3. The results of these calculations are presented in Table 50.

The total net present value of the costs for realizing all measures within this strategy is about € 410 million.

Table 50: Calculation of the construction costs of the small scale strategy, based on sand volumes, unit prices and project information.

Section [#]	Length [km]	Solution	Amount of sand [m^3/m]	Unit cost [€/m^3]	Total cost [*10^6 €]	Year of investment	NPV [*10^6 €]
1	1.2	Dike heightening	-	-	9	2025	5.9
2	1.8	Extending dune in seaward direction	6812	3	37	2075	7.0
3	4	-	-	-	-	-	-
4	6	Extending dune in seaward direction + increasing beach width	958	4	23	2075	4.4
5	1	Increasing beach width	421	3	1.3	2075	0.2
6	6.4	Extending dune in seaward direction + increasing beach width	1148	4	29	2075	5.6
7	5.6	Dike heightening	-	-	151	2025	99
8	5.5	Extending dune in seaward direction + increasing beach width	1252	4	28	2075	5.3
9	1	Extending dune in seaward direction + increasing beach width	1248	4	5.0	2075	1.0
10	5.5	Extending dune in seaward direction + increasing beach width	632	4	14	2075	2.7
11	1	-	-	-	-	-	-
12	4	Increasing beach width	72	4	1.2	2125	0.1
13	7	Extending dune in seaward direction + increasing beach width	841	4	24	2050	8.3
14	2	Extending dune in seaward direction + increasing beach width	678	4	5.4	2075	1.0
15	2	-	-	-	-	-	-
16	3	-	-	-	-	-	-
17	5	Extending dune in seaward direction + increasing beach width	607	4	12	2075	2.3
18	2	Dike in dune + increasing beach width	-	-	15	2125	0.8
19	4	Extending dune in seaward direction + increasing beach width	566	4	9.1	2075	1.7
20	3	-	-	-	-	-	-
21	5	-	-	-	-	-	-
22	2	Extending dune in seaward direction + increasing beach width	445	4	3.6	2075	0.7
23	2.5	Dike in dune + extending dune in seaward direction	-	-	144	2025	95
24	1.5	-	-	-	-	-	-
25	3	Dike in dune + extending dune in seaward direction	-	-	173	2025	114
26	4	-	-	-	-	-	-
27	3	-	-	-	-	-	-
28	4	Increasing beach width	216	4	3.5	2125	0.2
29	4	Water retaining structure in boulevard + increasing beach height	-	-	34	2025	22
30	2.5	-	-	-	-	-	-
31	2.5	Extending dune in seaward direction + increasing beach width	2230	4	22	2075	4.3
32	3	Extending dune in seaward direction + increasing beach width	1757	4	21	2075	4.0
33	1.5	Extending dune in seaward direction	1890	3.6	10	2075	2.0
34	6	Dune in front of existing dunes + increasing beach width	3375	3.6	73	2050	26

O.1.9 Conclusion

Table 51 shows a summary of the results of these construction cost calculations. The calculated NPV's of the construction costs are subsequently translated into a qualitative assessment according to these criteria:

- NPV strategy X > 10x NPV basic alternative: -- (costs are an order of magnitude higher)
- NPV strategy X > 2x NPV basic alternative: - (costs are doubled)
- NPV strategy X < 2x NPV basic alternative & NPV strategy X > 0.5x NPV basic alternative: 0
- NPV strategy X < 0.5x NPV basic alternative: + (costs are halved)
- NPV strategy X < 0.1x NPV basic alternative: ++ (costs are an order of magnitude lower)

Table 51: Net present value of the construction costs for the proposed coastal enhancement strategies. These NPV's are subsequently assessed on a qualitative scale by comparing them to the NPV of the basic alternative.

Strategy	NPV 2008 [$*10^6$ €]	Qualitative assessment
Uniform coast; islands	9800	--
Uniform coast; sandbanks	140	+
Uniform coast; dunes in front of existing dunes	470	0
Large scale; islands and dunes	7300	--
Large scale; dunes and sandbanks	320	0
Intermediate scale; seaward	860	-
Intermediate scale; landward	720	0
Small scale; basic alternative	410	0

O.2 Maintenance costs

Maintenance costs for the proposed strategies for coastal enhancement strategies can now be estimated. These estimations will be based on expert judgements on the maintenance requirements for these strategies. In some cases, especially for hard engineering solutions, maintenance costs are estimated as a certain percentage of the construction costs. For soft engineering solutions, the maintenance requirement will mostly be expressed as ratio to the current maintenance effort for the Holland coast. From this perspective, it is noted that currently about $7*10^6$ m^3 of sand is annually nourished to the Holland coast [Nederbragt, 2005]. Since most of this sand is supplied by underwater nourishments, the annual costs of this maintenance policy are about € $14*10^6$ based on a unit price of 2 €/m^3 for underwater nourishments.

The next sub-section contain short explanations on the ratios used for calculating the maintenance costs. The results of these calculations are presented in the last sub-section.

O.2.1 Uniform coast; islands

Since these islands will be designed as static features (being hard engineering solutions), maintenance requirements will be limited. The island will however be less stable than for example the dikes at the mainland coast, since the protection level of the island is restricted to about 1:500 in stead of 1:10.000. This makes that the boundary conditions for the design of the island are less severe and that damage will occur more frequently (at less severe storm events).

For static features at the mainland coast, annual maintenance needs are supposed to be about 1% of the construction costs [Arcadis & Alkyon, 2005]. This is increased to an annual maintenance need of about 5% in case of these islands. Since these islands are planned to be realised around 2025, these maintenance costs will start by then. The net present value of these costs is calculated by assuming an everlasting cost (calculated by dividing the annual value by the discount rate) to be incurred in the first year of occurrence (2025 in this case):

$$NPV\ MC = \frac{annual\ MC / i}{(1+i)^{X-2008}}$$

With MC = maintenance costs, i = discount rate and x = year of construction.

Next, it is supposed that the present nourishment policy will go on until the islands are constructed. So the NPV is calculated of the annual recurrence of these annual costs, as stated above, until year X. Once the islands are constructed, erosion of the mainland coast will be decreased significantly and compensating maintenance efforts are neglected in this calculation. The resulting figures are stated in Table 52.

It should be noted that maintenance needs could increase significantly when some unpredicted developments emerge in the foreshore of the islands. This could occur since the islands would have an enormous impact on the coastal morphology and our knowledge on this morphological system is insufficient to predict all potential effects.

Finally, it should be noted that maintenance costs for the mainland coast may go on after the construction of the islands, but the maintenance requirement might also be reduced since structural wave-attack at the mainland coast is decreased by these islands. Due to this uncertainty, and the relative small contribution of these maintenance costs (only about € 14 million per year, which is less than 2% of the maintenance costs of the islands), these costs are neglected.

Table 52: Calculation of the NPV of the maintenance costs (MC) for some of the proposed strategies, based on relative maintenance needs expressed as a percentage of the construction costs or the present maintenance effort of the studied coast.

Strategy		Annual MC [% of constr. costs]	Annual MC [% of present nourishments]	Annual MC starting from year X [*10^6 €]				MC alternative [NPV 2008 *10^6 €]	MC before construction [NPV 2008 *10^6 €]	Total MC [NPV 2008 *10^6 €]
				2025	2050	2075	2125			
Uniform coast; islands		5%		745				19,584	206	19,790
Uniform coast; sand banks		50% 20%		106				2,787 1,115	206	2,992 1,321
Uniform coast; dunes in front of existing dunes			200%		28			397	375	773
Large scale; islands and dunes	islands	5%		535				14,064	109	14,173
	dunes		200%		13			187	177	365
Large scale; dunes and sandbanks	dunes		200%		15			210	198	408
	sandbanks	50% 20%		50				1,301 521	97	1,398 618

O.2.2 Uniform coast; sandbanks

As stated before, it is uncertain whether these sandbanks will be effective. Two possible directions for the coastal development are possible after implementing this strategy:

- The morphologic system in front of the coast adapts to the new situation and a new kind of equilibrium morphology emerges with a sand trap at the landward side of these banks (resembling the situation at the Wadden Sea).
- Or the sandbanks appear to be very unstable and are eroded on very short time scales. The sand might then be transported in seaward or in landward direction, the main direction of this sand transport is not known yet.

In both cases, maintenance needs of these sandbanks will be extensive since wave attack would affect these features even under normal circumstances. However, the stability of the sandbanks will vary significantly and therefore an annual maintenance ratio of 20% of the construction costs is supposed for the first case (being about the maximum maintenance need for soft but stable seaward engineering solutions [Steetzel, 2007]) and a ratio of 50% for the latter scenario.

The remaining calculations are again presented in Table 52. Moreover, for now it is supposed that the present nourishment policy is stopped after implementing this strategy. The resulting values stated in Table 52 show that the exact percentage of the maintenance rate of these sandbanks does not really matter that much when the outcomes are compared to the other values.

O.2.3 Uniform coast; dunes in front of existing dunes

This strategy creates a new, smooth coastline preventing for the occurrence of longshore sediment transport gradients causing erosion at certain locations. The increase of the maintenance efforts is thus very limited. However maintenance needs would still increase due to the seaward extension of the coast due to which the slope of the foreshore will increase. This will increase cross-shore sediment transport rates in the offshore direction. Over time, this morphologic abnormality (steep foreshore) might be stopped due to a redistribution of the sand within the system until a new morphologic equilibrium with a less steep foreshore is developed. To support this development, nourishments will be needed. These nourishments are supposed to be twice the amount of the present nourishments, due to the extra compensation needed for the steeper foreshores. The calculated results are again contained in Table 52.

O.2.4 Large scale; islands and dunes

Maintenance costs of the large scale strategies are derived from the maintenance costs of the uniform coast strategies. However, some changes will occur in the maintenance requirements due to the large-scale combination of two coastal management solutions within this strategy.

First, nothing will change to the maintenance requirement of the island planned to be realised in front of the southern part of the Holland coast. For this section, a proportional share is taken from the uniform coast solution. Next, north of the island erosion rates will increase due to the presence of the island in front of the southern part of the coast creating an upstream shortage of suspended sediment. However, this problem will only be faced by part of the northern section of this strategy and is not supposed to add significantly to the maintenance needs of this section. Therefore it is assumed that the new foredunes in front of the northern part of the coast will require two times the present maintenance efforts (just like the doubling of these efforts for the uniform coast strategy). Again the calculations are summarized in Table 52.

O.2.5 Large scale; dunes and sandbanks

For this large-scale combination of two different coastal enhancement measures, no significant effects on the maintenance requirements of both separate measures are supposed to occur. For the southern part of the coast nothing will change, considering maintenance requirements, compared to the uniform application of this measure. So a proportional share is taken of the maintenance costs for the uniform coast counterpart. The same is supposed to be valid for the sandbanks in front of the northern part of the coast. These calculations are presented in Table 52.

In fact, serious accretion might even occur at the transition between those two measures. According to the preliminary design, this transition is located at the North Sea Canal mouth. Accretion is undesirable at this location, so the accreted material should be removed by dredging or the design should be changed. However, this kind of optimization problems is out of the scope of this study and therefore it is only noted here.

O.2.6 Intermediate scale; seaward

Spatial differentiation increases within this strategy and seaward extensions of the coastal defences are variable in longshore direction. This increases the longshore gradients in sediment transport and causes erosion and accretion to occur at several places. The three measures within this strategy show different maintenance requirements.

The artificial reefs, planned in front of the coastal towns, are typical examples of hard engineering solutions. An annual maintenance requirement of about 1% of the construction costs is assumed for these static features [Arcadis & Alkyon, 2005].

Sections containing sandbanks according to this strategy do again show the same problems as in the uniform application to the entire coast of the study area. It is rather uncertain whether these bars will persist over time. Due to the spatial variation, relative maintenance requirements might even increase compared to the uniform coast strategy. Therefore we assumed the highest rate applied for calculating the maintenance costs of these sandbanks in the uniform coast strategy: 50% of the construction costs.

Those sections enhanced by new foredunes do extent less in seaward direction compared to the other measures applied in this strategy. However increased spatial variation would increase maintenance requirements of these new foredunes compared to the uniform coast strategy applying this measure. For this strategy it is assumed that the maintenance requirement will quadruple compared to the maintenance costs of the currently existing situation. This implies that these foredunes will need more maintenance than in case of the uniform coast counterpart (for which a doubling of the existing maintenance efforts was supposed) and the large scale counterpart (for which present maintenance efforts were tripled).

Moreover, the section that is assessed safe for the entire period will also show an increase in its maintenance requirement due to the increased gradients in longshore sediment transport. For this section, the same increase is supposed as for the sections with new foredunes.

Next to these assumptions on the maintenance costs of the measures to be realised, it is again supposed that present maintenance efforts (€ $14*10^6$ annually) will go on until the year of realisation of the measures. The calculations were the same as those presented in Table 52 (but are not presented) and result in a NPV of the total maintenance costs for the next two centuries of about € 1,400 million.

O.2.7 Intermediate scale; landward

By this strategy the spatial differentiation of the seaward extension of the coastal defences is reduced again. At most sections, the defences are planned to be extended in landward direction, except for two locations along the coast of Zuid-Holland.

For the sections extended in landward direction, the present maintenance requirement is supposed to remain valid. No changes are planned at the seaward side of the coastal defences in these sections, so no (increase of the) disturbance of the morphologic equilibrium state will occur.

Within this strategy, the seaward extensions at some coastal towns are significantly affecting the smooth coastline of the Holland coast by extending into the sea for more than 100 metres. This would increase longshore sediment transport gradients causing the southern and northern boundaries of these sections to be rather unstable. Moreover, this seaward extension would (at least temporarily) increase the slope of the foreshore due to which cross-shore sediment transport rates with an offshore direction will increase too. Due to these effects, it is supposed that the annual maintenance requirement of these sections will be five times larger than nowadays. Moreover, 1% of the construction costs is added to the annual maintenance costs since this measure contains a ‘hard’ dike within the ‘soft’ dune extension.

These calculations resulted in a total NPV of the maintenance costs for this scenario of about € 1,000 million.

O.2.8 Small scale; basic alternative

The same steps are repeated for determining the maintenance costs of the basic alternative. Spatial differentiation is even larger than in case of the intermediate scale seaward strategy. In this case however, the extensions are located direct in front of the existing defences. Therefore, annual maintenance requirements of the sandy seaward extensions of the coastal defences are supposed to triple compared to the present situation. This indicates that the maintenance needs are smaller than in case of the seaward intermediate scale strategy (for which the present maintenance costs were quadrupled), but are still higher than in case of uniform creation of new dunes in front of the entire coast (where present maintenance costs were doubled). This increase of the maintenance requirements is also applied to sections that do not need to be enhanced within the next two centuries. These sections will also suffer from increased morphodynamic activity due to the increase of the longshore gradients.

For all hard engineering solutions being part of this strategy (dike heightening, dike or construction in dune) we again applied an annual maintenance requirement of 1% of the construction costs.

Net present values are calculated for these annual recurring maintenance costs. Moreover, continuation of present maintenance practice is assumed for the period until the measures will realised. Altogether, this resulted in a NPV of the maintenance costs of this strategy of about € 1,300 million.

O.2.9 Conclusion

The results of the previous maintenance cost calculations are summarized in Table 53. Note that for most strategies, maintenance costs are an order of magnitude higher than the construction costs (Table 51). Subsequently, these net present values of the maintenance costs are translated into a qualitative assessment score according to the next rules:

- NPV strategy X > 10x NPV basic alternative: --
- NPV strategy X > 2x NPV basic alternative: -
- NPV strategy X < 2x & > 0.5x NPV basic alternative: 0
- NPV strategy X < 0.5x NPV basic alternative: +
- NPV strategy X < 0.1x NPV basic alternative: ++

These qualitative assessments are presented in the last column of Table 53. The maintenance requirements of the sandbanks appeared to have no significant effects on the qualitative assessments of the strategies containing this measure.

Table 53: Net present value of the maintenance costs for the proposed coastal enhancement strategies. These NPV's are subsequently assessed on a qualitative scale by comparing them to the NPV of the basic alternative.

Strategy	NPV 2008 [$*10^9$ €]	Qualitative assessment
Uniform coast; islands	19.8	--
Uniform coast; sandbanks	3.0/1.3	0
Uniform coast; dunes in front of existing dunes	0.8	0
Large scale; islands and dunes	14.5	--
Large scale; dunes and sandbanks	1.8/1.0	0
Intermediate scale; seaward	1.4	0
Intermediate scale; landward	1.0	0
Small scale; basic alternative	1.3	0

O.3 Nature values

Three sorts of nature values are assumed to be susceptible to changes in the dune area and beach length within the study area:

- Environment; the environmental benefits of dune vegetation are directly related to the dune area.
- Recreation; the possibilities for attracting tourists are directly related to the dune area and the beach length.
- Water supply; the new dune area could be used for the filtration of drinking water.

The benefits of these indicators are inventoried by the changes in dune area and beach length and the authorised values derived for these welfare effects. Environment and recreation are merged into one subsection since these calculations are almost the same. The last sub-sections contains the resulting benefits due to the changes of these indicators for the value of nature.

O.3.1 Environment & recreation

The costs and benefits of affecting or stimulating specific use functions of the coastal area are estimated by multiplying changes in the areas of specific types of nature by the authorised values for the costs and benefits of these functions. These authorised values are derived in appendix N. In this section, we will consider changes in the foredune and inner dune areas and beach lengths for all strategies and what this means to the yearly costs or benefits generated by a certain measure. For these areas and lengths we first consider the final situation in the year 2200.

Changes are calculated for the northern (above the North Sea Canal) and southern (below the North Sea Canal) region separately. For the sake of simplicity, these regions are called Noord-Holland (north) and Zuid-Holland (south) unless the real boundary between those two provinces is located somewhat further to the south. This assumption would do less harm to applying the authorised figures derived for the real provinces of Noord- and Zuid-Holland, since the southern part of Noord-Holland (below the canal) resembles Zuid-Holland very well. These calculations are presented in Table 54. The subsequent sub-sections describe the background of the changes in foredune and inner dune areas and beach lengths.

It should be noted in advance that these benefits could increase over time when population densities in the study area are growing. It should also be noted that the stated benefits of the islands are potential benefits that are strongly related to the development of the spatial planning of these islands. It is supposed that a major part of the island is applied land use functions like nature, agriculture and recreation.

Table 54: Benefits attributable to environmental and recreational values of new dune areas or new beaches. For every strategy the changes realised by the year 2200 are multiplied by the authorised values for the benefits of these changes. No net losses of dunes or beaches are found so all changes are positive.

Strategy	Foredune area				Inner dune area				Beach				
	Change		Benefit		Change		Benefit		Change		Benefit		
	NH [ha]	ZH [ha]	NH [€/ha/yr]	ZH [€/ha/yr]	NH [ha]	ZH [ha]	NH [€/ha/yr]	ZH [€/ha/yr]	NH [km]	ZH [km]	NH [€/m/yr]	ZH [€/m/yr]	Total [*10^6 €/yr]
Uniform coast; islands	820	1230	1455	2182	260	0	7817	8544	41	61.5	79	92	14.8
Uniform coast; sandbanks	480	540	1455	2182	0	0	7817	8544	0	0	79	92	1.9
Uniform coast; dunes in front of existing dunes	270	310	1455	2182	810	920	7817	8544	5.6	0	79	92	15.7
Large scale; islands and dunes	270	1230	1455	2182	810	0	7817	8544	5.6	61.5	79	92	15.5
Large scale; dunes and sandbanks	480	310	1455	2182	0	920	7817	8544	0	0	79	92	9.2
Intermediate scale; seaward	120	210	1455	2182	600	210	7817	8544	5.6	0	79	92	7.6
Intermediate scale; landward	210	220	1455	2182	0	40	7817	8544	0	0	79	92	1.1
Small scale; basic alternative	200	210	1455	2182	0	90	7817	8544	0	0	79	92	1.5

Uniform coast; islands

The two islands are separated by a canal being the continuation of the North Sea Canal. North of Callantsoog, about 13 km of new dunes are planned in front of the existing dunes. South of Callantsoog the northern part of the island has a length of about 41 km. The southern part of the island is about 61.5 km long. For the island, we also supposed that a (relatively) low dune would be created at the seaward coast.

The new foredunes at the mainland of Noord-Holland are about 200 m wide at their toes, just like the average cross-profiles of the existing foredunes. These existing foredunes will become inner dunes (+260 ha) and no net changes in the amount of foredunes takes place (0 ha). For the island we also supposed a base width of the dunes of about 200 m, resulting in additional foredune areas for the northern part (+820 ha) and the southern part (+1230 ha).

Finally, the creation of the islands will result in new beaches at both sides. However, the beaches at the seaside are supposed to be most attractive (think of the Wadden island coasts). So the northern part will give rise to 41 km of new beach and the southern part to 61.5 km.

Note that these values assume that some facilities will be developed, both for transporting people to the islands and for facilitating recreational visits. So we calculated potential benefits for the islands, since the development of such facilities is not included in our strategies.

These area changes will emerge once this strategy is completed.

Uniform coast; sandbanks
There is no direct use of the sandbanks for increasing the amount of dunes or beaches. However, sand eroded from these banks might be transported to the mainland coast giving rise to a seaward extension of the existing dunes. According to Zijlstra e.a. [2007], seaward extension of the dunes by natural dynamics is confined to a maximum of about 1 m per year.

This measure is supposed to be realised by about 2025, so dunes might grow over a period of 175 years and we assume half of the maximum speed. Along the Noord-Holland coast this would increase the foredune area by about 480 ha, along the Zuid-Holland coast by about 540 ha.

On contrary to the previous strategy, the changing dune area for this strategy emerges gradually. The mentioned areas could develop from the moment of realization of the sandbanks up to the year 2200.

Uniform coast; dunes in front of existing dunes
In this case new foredunes will be created in front of the existing foredunes, turning them into inner dunes. For the representative cross-sections presented in appendix J.1.1, the average width of the new dunes is about 200 m at their toe levels (3 m +NAP) and the average width of the existing foredunes is about 150 m at their basis. For Noord-Holland, this causes an increase of the foredune area of about 270 ha and the inner dune area would increase by about 810 ha. For Zuid-Holland these values are 310 and 920 ha respectively. These area changes will emerge once this strategy is completed.

Since new dunes will be created in front of the Hondsbossche and Pettemer seawalls, the beach length of Noord-Holland will also increase with about 5.6 km.

Large scale; islands and dunes
For this strategy the natural benefits of the southern island in front of the Zuid-Holland coast are just added to the benefits of creating new dunes in front of the Noord-Holland coast.

Large scale; dunes and sandbanks
Now we added the increase of the dune areas caused by creating new dunes in front of the Zuid-Holland coast to the dune extension caused by nourishing sandbanks in front of the Noord-Holland coast.

Intermediate scale; seaward
This strategy consists of three different measures: dunes in front of existing dunes, sandbanks and artificial reefs. The latter ones will have no effect on the area of dunes or the length of the beaches at

the mainland coast. The first two measures will change dune areas in both Noord-Holland and Zuid-Holland.

For the sections enhanced by new foredunes, the widths of the new and the existing foredunes are derived from the representative sections (see appendix J.3.1). Multiplied by the total section length, this difference between those two figures might induce a net gain or loss of foredune area.

For those sections enhanced by sandbanks, we again assumed a seaward extension of the foredunes of about 0,5 m per year due to the potential feeding effect of the sandbanks. This growth rate is multiplied by the period from the moment of realization (see appendix O.1.6) up to the year 2200. Subsequent multiplication by the section length gives the net gain in foredune area.

The calculated changes are all added for the two separate regions and for the two different types of dune (foredune, inner dune) and result in the figures presented in Table 54.

Finally, this strategy contains the creation of a dune in front of the Hondsbossche and Pettemer seawalls. Presently, there are no beaches in front of these seawalls, but there will be beaches after this measure is realised. This would induce an extension of the beach length of Noord-Holland by about 5.6 km.

Intermediate scale; landward

This strategy consists of three different measures: extending dune in landward direction, dunes behind existing dunes and a dike in dune solution including a seaward dune extension. Creating new dunes behind the existing foredunes is only planned for sections containing nature. At these sections, the existing dune areas are extensive and those new dunes will be located just landward of the existing foredunes, so no new area is added to the existing inner dune area. However, the other measures will generate some changes in foredune and inner dune areas.

At those sections where the dunes are extended in landward extension, the existing dunes mainly consist of only one row of dune crests so the landward extension (see appendix J.3.2) directly adds to the area of foredune nature. These gains are calculated by multiplying the landward extension of the dunes by the corresponding section lengths.

In one occasion, at section 12, the dune extension is being realised landward of the second dune crest not being the foredune. This is an exception, where the dune extension will add to the inner dune area in stead of the foredune area.

Finally, the seaward dune extension at two sections in Zuid-Holland also adds some new area to the existing foredune area. These areas are found by multiplying the seaward dune extension of about 120 m by the related section lengths.

Small scale; basic alternative

Within this strategy, there are only three types of measures that would (significantly) influence the nature values of the study area: seaward dune extension, dune in front of existing dune and dike in dune accompanied by a seaward dune extension.

For the sections where the dunes are enhanced by a dune extension in seaward direction, these extensions (see appendix J.4) are multiplied by the section length. The areas found will add to the foredune areas of Noord-Holland or Zuid-Holland depending on the location of the sections.

The only section where a new dune will be created in front of the existing dune is located at the southern end of Zuid-Holland. Here a new dune with a base width of about 200 m will be created in front of the existing foredune with a width of about 150 m (that would change into the new inner dune).

Since the length of this section is 6 km, this results in a net gain of about 30 ha of foredune area and 90 ha of inner dune area.

Finally, the seaward dune extension at two sections in Zuid-Holland again adds some new area to the existing foredune area. These areas are found by multiplying the seaward dune extension of about 120 m by the related section lengths.

The calculated changes are all added for the two separate regions and for the two different types of dune (foredune, inner dune) and result in the figures presented in Table 54.

O.3.2 Water supply

The newly created dune area could be applied for drinking water filtration. As described in appendix N.4 about 50% of the dunes within the study area is applied for drinking water filtration at present. By 2200 the dune area will be extended by some of the measures proposed, extending the areas available for drinking water filtration. However, it is supposed that foredunes are not suitable for this function since these are located to close to the sea where the intrusion of saline sea water still might affect the fresh drinking water to be filtered by the dunes. Only the extended inner dune area is therefore supposed to contribute to the area available for the filtration of drinking water. These areas were already calculated in section O.3.1 of this appendix. Multiplying half of these areas (50% allocation rate) by the unit value for fresh water supply derived before, results in the total benefit for this criterion. These calculations are presented in Table 55.

Table 55: New inner dune areas created by the proposed strategies could be applied for drinking water filtration. Assuming an allocation rate of 50% and authorised values for the benefits of this water supply facility generates the total benefits.

Strategy	New inner dune area			Benefit	
	NH [ha]	ZH [ha]	Total [ha]	Unit value [€/ha/yr]	Total [*10^3 €/yr]
Uniform coast; islands	260	0	260	1088	141
Uniform coast; sandbanks	0	0	0	1088	0
Uniform coast; dunes in front of existing dunes	810	920	1730	1088	941
Large scale; islands and dunes	810	0	810	1088	441
Large scale; dunes and sandbanks	0	920	920	1088	500
Intermediate scale; seaward	600	210	810	1088	441
Intermediate scale; landward	0	40	40	1088	22
Small scale; basic alternative	0	90	90	1088	49

O.3.3 Conclusion

The calculated values for the benefits raised by the increasing environmental and recreational values of the study area and the increasing area available for drinking water filtration are recurring every year after the implementation of a certain strategy. In order to translate every benefit to a net present value, it is supposed that an eternal benefit starts at the major year of construction. The value of an eternally ongoing benefit is calculated by dividing the annual benefit by the discount rate (2,5%). This value could then be discounted as usual.

The major year of construction is derived from the years mentioned in the first section of this appendix on construction costs. The major year is selected for each strategy by analyzing in which year those measures causing the majority of the impacts on these indicators are realised.

Table 56 shows the results of these calculations. The calculated NPV's are subsequently translated into a qualitative assessment according to these criteria:

- NPV strategy X > 10x NPV basic alternative: ++
- NPV strategy X > 2x NPV basic alternative: +
- NPV strategy X < 2x & > 0.5x NPV basic alternative: 0
- NPV strategy X < 0.5x NPV basic alternative: -
- NPV strategy X < 0.1x NPV basic alternative: --

Table 56: Calculation of the net present value of the benefits of the increasing value of nature for the proposed coastal enhancement strategies. These NPV's are subsequently assessed on a qualitative scale by comparing them to the NPV of the basic alternative.

Strategy	Total benefit		Major year of construction	NPV 2008 [*10^6 €]	Qualitative assessment
	Environment & recreation [*10^6 €/yr]	Water supply [*10^6 €/yr]			
Uniform coast; islands	14.8	0.14	2025	392	++
Uniform coast; sandbanks	1.9	0.00	2100[1]	8	-
Uniform coast; dunes in front of existing dunes	15.7	0.94	2050	236	++
Large scale; islands and dunes	15.5	0.44	2025	419	++
Large scale; dunes and sandbanks	9.2	0.50	2050[2]	138	+
Intermediate scale; seaward	7.6	0.44	2075	61	+
Intermediate scale; landward	1.1	0.02	2075	9	-
Small scale; basic alternative	1.5	0.05	2050	22	0

[1] Although these sandbanks are planned to be constructed by 2025, their positive effect on the extension of the dune area is only gradual so the full amount of benefits is supposed to start at 2100.
[2] The contribution of the sandbanks is rather small in this case, so assuming 2050 (mayor year of construction of the foredunes) as starting date for the full benefits does not incur a significant error.

O.4 Safety benefits

Safety benefits could occur when built-up areas presently located in front of the coastal defences are better protected against flooding after the implementation of one of the coastal management strategies.

At the level of detail of this study it is supposed to be sufficient to make some rough estimates on the future safety of these coastal towns located in front of the sea defences (seasonal and year-round beach resorts are not included in this criterion). Both the number and protection level of coastal towns facing an increasing safety differs over the proposed strategies. The coastal towns that have areas being located in front of the official sea defences are indicated in Figure 113. The protection level of these areas is about 1:250 compared to 1:10,000 for the hinterland. This 1:250 safety level is supposed to be maintained (as part of the autonomous development) since the advice of the Poelmann Advisory Committee recommended to do so [Commissie Poelmann, 2005].

Figure 113: Coastal towns of which parts are located seaward of the sea defences. These areas, called 'buitendijks' in Dutch, face higher chances of inundation than the landward areas being protected by the formal sea defences [Commissie Poelmann, 2005].

Determining whether these areas will face an increasing safety level is simple, determining new safety levels is less straightforward. Some assumptions are made on this.

- When the section of a coastal town with 'unprotected' area will be enhanced by new dunes or other measures that are located seaward of the existing built-up area and that will certainly be able to increase the safety level of the hinterland sufficiently, the new safety level will be 1:10,000.
- When islands are planned in front of these coastal towns, safety levels of the areas currently located in front of the sea defences are supposed to face an increasing safety level up to 1:1000. Since the islands will stop long waves from the North sea, wave attack at the mainland coast will be reduced significantly. However, water levels (and short waves) will still reach critical heights for the relatively weak defences of these areas. Thanks to the wave-reduction the safety of these areas is supposed to increase by a factor 4 but it will still be significantly lower than the safety of the hinterland.
- The sandbanks and artificial reefs will again be less effective than the islands for increasing the protection of the areas concerned for this criterion. These features will dissipate a major part of the energy of long waves. Since the crest levels of these features are found below sea level, the waves are not completely stopped and part of the waves coming from the North Sea will still directly attack the mainland coast. Due to these effects, the safety level of the areas in front of the sea defences is supposed to increase only by a factor two.

In Table 57 it is stated how much of the coastal towns will face an increasing flood safety for every strategy. From the plans of the strategies it is also derived which safety level could be connected to these areas for the final situation in 2200 by applying the above assumptions.

These new safety levels should be multiplied by the value at risk in these coastal towns. In appendix N.5 it is stated that the present value at risk in these areas is about € 1.1 milliard. By the year 2200 this will be increased to about € 28 milliard (assuming an economic growth rate of 1.7%). This amount is equally divided over the nine relevant areas.

The total annual inundation risk is subsequently derived by multiplying the values at risk by the safety levels for all relevant areas. These inundation risks are calculated for 2200, the final situation when all measures will be implemented. Finally, the benefit of these increasing safety levels of the coastal towns is derived by calculating the reduction of the annual inundation risk compared to the situation that safety levels remain the same (1:250) for all areas. The resulting annual safety benefits are summarized in Table 57.

Table 57: Calculation of potential safety benefits caused by increased safety levels for parts of coastal towns located seaward of the sea defences. These benefits are calculated for the year 2200, when all measures will be implemented.

Strategy	Coastal towns facing safety increase [#]	Coastal towns per safety level in 2200				Total annual inundation risk in 2200 [*10^6 €]	Annual safety benefit in 2200 [*10^6 €]
		1/250	1/500	1/1000	1/10000		
Uniform coast; islands	9			9		28	84
Uniform coast; sand banks	9		9			56	56
Uniform coast; dunes in front of existing dunes	9				9	3	109
Large scale; islands and dunes	9			7	2	22	90
Large scale; dunes and sandbanks	9		2		7	15	97
Intermediate scale; seaward	9		8		1	50	62
Intermediate scale; landward	4	5			4	63	49
Small scale; basic alternative	6	3			6	39	73

These annual safety benefits of the different strategies are compared to the safety benefit of the basic alternative. According to this comparison, a qualitative assessment is awarded to each strategy based on the next criteria:

- benefit strategy X > 5x benefit basic alternative: ++
- benefit strategy X > 2x benefit basic alternative: +
- benefit strategy X < 2x & > 0.5x benefit basic alternative: 0
- benefit strategy X < 0.5x benefit basic alternative: -
- benefit strategy X < 0.2x benefit basic alternative: --

The assessment results of this comparison are presented in Table 58. This table shows no differences in the qualitative assessment of the different strategies, which is due to the fact that the criteria for awarding a qualitative assessment are quite rough and are not tuned to the rather small differences in the annual safety benefits. However, from a preliminary sensitivity analysis it appeared that the inaccuracy of the estimated benefits makes it impossible to refine these criteria.

Table 58: Translation of the safety benefits into a qualitative assessment based on a comparison of the safety benefits to those of the basic alternative.

Strategy	Annual safety benefit in 2200 [*10^6 €]	Qualitative assessment
Uniform coast; islands	84	0
Uniform coast; sandbanks	56	0
Uniform coast; dunes in front of existing dunes	109	0
Large scale; islands and dunes	90	0
Large scale; dunes and sandbanks	97	0
Intermediate scale; seaward	62	0
Intermediate scale; landward	49	0
Small scale; basic alternative	73	0

O.5 Man-made functions

Man-made functions potentially affected or stimulated by these coastal management strategies are housing and agriculture. Impacts on these two indicators of this criterion are studied here. The last sub-section contains the conclusion based on the inventoried impacts.

O.5.1 Housing

This indicator consists of two welfare effects:

- More houses in coastal area
- Enjoyment of coastal environment

It is not possible to couple these two effects in advance, since they are related to other areas. The first effect considers the gain or loss of coastal area available for housing. The latter effect considers the housing area being located close to the coast, enjoying the coastal environment.

More houses in coastal area

The area available for housing projects in the coastal zone could be extended when the coastal defences are also extended in seaward direction. However, this could affect the effect of the proposed coastal enhancement strategy. Therefore it is assumed that the entire area newly created by any seaward extension of the coastal defences will become nature at the mainland coast.

At the same time, the landward extension of the coastal defences will decrease the area available for housing in the coastal zone. Some houses will have to be removed. It is supposed that they are moved to another location further landward. This problem is only faced at the landward intermediate scale strategy. In the sections with a natural land use function, no housing area will be lost. The same is true for the sections enhanced by a dike within the existing dune. In the remaining sections, some housing area will be lost due to the landward dune extension. The width of these extensions are described in appendix J.3.2 and are multiplied by the section length. Next, it is supposed that (see appendix N.7) about 10% of this area is dedicated to housing in Noord-Holland and 30% in Zuid-Holland [Zijlstra e.a., 2007]. The total area lost for housing can be calculated and multiplying it with the unit benefit of this land use function results in the net benefits (in this case costs).

The strategies containing an island in front of (the southern part of) the coast would also generate an extended new area, potentially available for housing. However, housing is not supposed to be the main function of the island since the safety against flooding will be much smaller than it is at the mainland. To give an indication of the potential benefits of this island for housing, it is assumed that about 10% of the total area of the island is available for housing. The value of these houses is assumed to be half the value of houses at the mainland due to the higher probability of flooding of the island.

The results of these calculations are presented in Table 59.

Table 59: Benefits caused by new area becoming available for housing projects. Note that these benefits are not annual but only occur once when the houses are built.

Strategy	Vacant housing area		Benefit		
	Mainland [ha]	Island [ha]	Mainland [$*10^3$ €/ha]	Island [$*10^3$ €/ha]	Total [$*10^6$ €]
Uniform coast; islands	0	2100	436	218	458
Uniform coast; sandbanks	0	0	436	218	0
Uniform coast; dunes in front of existing dunes	0	0	436	218	0
Large scale; islands and dunes	0	1500	436	218	327
Large scale; dunes and sandbanks	0	0	436	218	0
Intermediate scale; seaward	0	0	436	218	0
Intermediate scale; landward	-42	0	436	218	-18
Small scale; basic alternative	0	0	436	218	0

Enjoyment of coastal environment

Enjoyment of the coast and the sea being located close to the houses is not significantly affected by most measures contained by the proposed strategies. The only measure that would significantly affects this welfare effect is creating new dunes in front of the existing dunes. For calculating the costs of these welfare losses, it is supposed that in the present situation all houses located within a distance of

500 m to the coastline are subjected to this welfare effect. This distance resembles the cross-shore extension of most coastal towns. This benefit will completely be lost when new dunes are constructed in front of the existing coast.

These losses are calculated by multiplying the 500 m width with the length of the section affected due to the creation of new foredunes. The percentages of 10% for Noord-Holland and 30% for Zuid-Holland are subsequently applied to calculate what part of the total area is used for housing. Applying the unit prices then gives an indication of the losses due to this welfare effect. The results are presented in Table 60.

Table 60: Benefits caused by the additional value of houses located in a coastal environment. Note that these benefits are not annual but only occur once when the strategies are brought into effect.

Strategy	Coastal area affected		Coastal housing area	Benefit	
	NH [ha]	ZH [ha]	Mainland [ha]	Mainland [*10^3 €/ha]	Total [*10^6 €]
Uniform coast; islands	-650	0	-65	436	-28
Uniform coast; sandbanks	0	0	0	436	0
Uniform coast; dunes in front of existing dunes	-2700	-3075	-1193	436	-520
Large scale; islands and dunes	-2700	0	-270	436	-118
Large scale; dunes and sandbanks	0	-3075	-923	436	-402
Intermediate scale; seaward	-2000	-875	-463	436	-202
Intermediate scale; landward	0	0	0	436	0
Small scale; basic alternative	0	-300	-90	436	-39

Conclusion

The total costs and benefits incurred by a changing area and environment for housing, calculated in the previous sub-sections, are summarized in Table 61.

Table 61: Summarized benefits for housing due to the proposed coastal enhancement strategies. Note that these benefits are only incurred once, shortly after the emergence of the strategies.

Strategy	Benefits new houses [*10^6 €]	Benefits existing houses [*10^6 €]	Total [*10^6 €]
Uniform coast; islands	458	-28	429
Uniform coast; sandbanks	0	0	0
Uniform coast; dunes in front of existing dunes	0	-520	-520
Large scale; islands and dunes	327	-118	209
Large scale; dunes and sandbanks	0	-402	-402
Intermediate scale; seaward	0	-202	-202
Intermediate scale; landward	-18	0	-18
Small scale; basic alternative	0	-39	-39

O.5.2 Agriculture

To indicate the effects of the presented strategies on the added value of agriculture, being its harvests, it is studied how much agricultural area will be gained or lost within the different strategies. This is almost the same as in case of the determination the area being vacant for housing projects. Again, it is assumed that a seaward extension of the dunes would not increase the space available for agriculture. It might be possible to combine this natural land use with some extensive kinds of agriculture but this is more a chance than a real benefit that will certainly be generated.

As stated in table appendix N.9, in Zuid-Holland about 30% of the coastal zone is applied for agriculture an in Noord-Holland about 60%. Moreover, agriculture in the Delfland region (south of The Hague) is far more valuable than agriculture in the remaining part of the coastal zone.

The only strategy directly affecting the area available for agriculture is the landward intermediate scale strategy. The area lost in the coastal zone due to landward dune extensions is calculated the same way as was done for the housing area. Moreover, it was found that 42 ha of housing area was lost in the coastal zone due to this strategy. These houses will rebuild further inland and another 42 ha of agricultural area should be sacrificed for this reason.

Next, it is supposed that about 50% of the islands being part of two strategies might be applied for agricultural functions, resembling the distribution of agricultural functions in the coastal zone. These islands are less safe than the mainland but are still well-suited for agricultural use. Shifting agriculture from the mainland to these islands might create some new space at the mainland for building new houses, extending offices and industries or for improving the ecological infrastructure. Again, these indirect benefits are not included in this study, since they depend on spatial developments that are not planned nor studied for this project.

These calculations are summarized in Table 62. Since these benefits are derived from harvests, they are recurring annually.

Table 62: Benefits by extension of the area available for agriculture, note that in case of the landward intermediate scale strategy area is lost.

Strategy	New area available for agriculture			Benefit			
	Delfland [ha]	Coastal zone [ha]	Inland [ha]	Delfland [*10^3 €/ha/yr]	Coastal zone [*10^3 €/ha/yr]	Inland [*10^3 €/ha/yr]	Total [*10^6 €/yr]
Uniform coast; islands	0	10600	0	69	3.2	2.6	34
Uniform coast; sandbanks	0	0	0	69	3.2	2.6	0
Uniform coast; dunes in front of existing dunes	0	0	0	69	3.2	2.6	0
Large scale; islands and dunes	0	7700	0	69	3.2	2.6	25
Large scale; dunes and sandbanks	0	0	0	69	3.2	2.6	0
Intermediate scale; seaward	0	0	0	69	3.2	2.6	0
Intermediate scale; landward	-13	-130	-42	69	3.2	2.6	-1
Small scale; basic alternative	0	0	0	69	3.2	2.6	0

O.5.3 Conclusion

The calculated values for the benefits raised by the increasing area available for housing could only be achieved once. On contrary, the benefits raised by the increasing area available for agriculture are recurring annually. In order to translate the benefits of these two indicators to a net present value, it is supposed that an eternal benefit starts at the major year of construction. The value of an eternally ongoing benefit is calculated by dividing the annual benefit by the discount rate (2,5%). This value could then be discounted as usual. The benefits from housing are supposed to occur only once, in the year when the concerning strategy should be realized.

The major year of construction is again derived from the years mentioned in the first section of this appendix on construction costs. The major year is selected for each strategy by analyzing in which year those measures causing the majority of the impacts on these indicators are realised.

Table 63 shows the results of these calculations. The calculated NPV's are subsequently translated into a qualitative assessment according to these criteria:

- NPV strategy X > 5x NPV basic alternative: --
- NPV strategy X > 2x NPV basic alternative: -
- NPV strategy X < 2x & > -2x NPV basic alternative: 0
- NPV strategy X < -2x NPV basic alternative: +
- NPV strategy X < -5x NPV basic alternative: ++

Table 63: Calculation of the net present value of the benefits from housing and agriculture for the proposed coastal enhancement strategies. These NPV's are subsequently assessed on a qualitative scale by comparing them to the NPV of the basic alternative.

Strategy	Total benefit		Major year of construction	NPV 2008 [*10^6 €]	Qualitative assessment
	Housing [*10^6 €]	Agriculture [*10^6 €/yr]			
Uniform coast; islands	429	34	2025	1174	++
Uniform coast; sandbanks	0	0	2025	0	0
Uniform coast; dunes in front of existing dunes	-520	0	2050	-184	--
Large scale; islands and dunes	209	25	2025	785	++
Large scale; dunes and sandbanks	-402	0	2050	-143	--
Intermediate scale; seaward	-202	0	2075	-39	-
Intermediate scale; landward	-18	-1	2075	-14	0
Small scale; basic alternative	-39	0	2050	-14	0

O.6 Equity

The equity criterion is meant to assess the spatial distribution of the impacts of each strategy over the study area. The main question is whether both negative and positive impacts are equally or at least fairly distributed over the study area. When positive and negative impacts are not equally distributed over the area, both costs and benefits should at least emerge at the same locations so that those areas and people suffering from the negative impacts also benefit from the positive effects.

Sometimes, equity is also interpreted as intergenerational equity indicating the equal distribution of costs over subsequent generations. This however coincides with the ability to develop a strategy in several phases being spread over time and is already indicated by the criterion of phasing.

The basic alternative scores very well on this criterion since the measures planned for this strategy are at a rather small spatial scale attuned to the needs of the both the coastal area and the hinterland. Coastal towns keep their connection to the sea and land uses behind the dunes are maintained. However, potential benefits are still not optimized within this strategy. More areas could benefit of increasing the strength of the sea defences when the intermediate scale seaward strategy is realized. Next to maintaining existing land use functions, new functions are created. Artificial reefs are planned in front of the coast of some major coastal towns, creating opportunities for new recreation facilities. New dunes will be created in front of the coast at some areas were space for nature and recreational facilities is lacking in the hinterland. Furthermore, this strategy is still well attuned to regional preferences preventing the negative impacts from being unequally distributed. This strategy is assessed better than the basic alternative.

The islands are an example of a strategy with almost no impacts to existing land use functions. Only shipping might be hindered, but the design should be attuned to this function were the islands interfere with main fairways. Moreover, everybody could benefit of this development since new recreational facilities might be developed with a (inter)national market area. Even tax payers from the other side of the country might thus benefit from this development, and on a much larger scale then would be the case when only the dune area was extended with some hectares.

The uniform coast strategy with new foredunes on the contrary is assessed very negative on this criterion. Since this measure is applied to the entire coast, the coastal towns will loose their direct relation with the sea. This might seriously damage tourist industries within these cities, notwithstanding it was supposed in the calculation of the possible benefits that the new nature emerging at the new foredunes would attract more tourists. At the same time, some other areas will mainly benefit of this development, due to increasing tourism for example or just caused by the increase in nature area.
The same is valid for the sandbanks when they would cause a serious accretion of the mainland coast. In that case, this accretion would affect the recreational values of the coastal towns but at the same time the naturally accreted area is supposed to be too small to create some real benefits (new nature, more

facilities for recreation) at any other locations. In this case, sandbanks would be assessed negative. When however these sandbanks would not cause any accretion of the coast, these negative effects at coastal towns are prevented but other benefits are still missing. In this case, the sandbanks would be assessed neutral.

For the large-scale strategies, the assessments of the large-scale counterparts are combined. This time it is considered that the major coastal towns are located in the southern part of the study area. So the assessment of the measure for the southern area was of major influence for the total assessment of these strategies.

The landward intermediate scale strategy is also assessed negative, since the coastal towns will be saved while at other sections farmers will have to give up some of their grounds in favour of the landward extension of the sea defences. This extension might generate some benefits by extending recreational and nature values but the farmers will not benefit of that. Therefore, this strategy is assessed negative.

All assessments on this criterion are summarized in Table 64. The last column of this table contains a judgement comparing each strategy to the basic alternative. Note that the uniform coast strategy with islands remains its double plus score since it is still assessed very well on this criterion, even in comparison to the basic alternative.

Table 64: Results of a qualitative assessment of the equity of the distribution of costs and benefits by the strategies proposed.

Strategy	Equity	Equity relative to basic alternative
Uniform coast; islands	++	++
Uniform coast; sandbanks	-/0	-
Uniform coast; dunes in front of existing dunes	--	--
Large scale; islands and dunes	+	0
Large scale; dunes and sandbanks	--	--
Intermediate scale; seaward	++	+
Intermediate scale; landward	-	--
Small scale; basic alternative	+	0

O.7 Safety perception

All measures are designed to serve the goal of preserving a 1:10,000 safety level of the sea defences within the study area. However, this technical approach of the protection of the hinterland is only weakly related to the perceived safety by the inhabitants of the hinterland.

Many studies are available on risk perception, also related to floods. Most determinants found of interest for risk perception however are not related to the sea (or river) defences themselves (the safety component). Examples of determinants for risk perception are: perceived personal risk, fear evoked by the risk, familiarity to those exposed, likelihood of fatal consequences, frequency and also (although to a lesser extent) demographic variables like age and education level [Plapp & Werner, 2006]. At first sight, risk perception thus seems to be more or less independent from the water retaining structures itself. However, these structures are supposed to be important for the perceived personal risk. People have to trust the coastal defences in order to feel themselves safe living behind that defences.

It is difficult to derive valid indicators for this criterion. A separate psychological study could be done in order to find out what really matters in perceived safety levels of coastal defences. For this study, it is supposed that the extensiveness of the measure is a rather good indicator. The larger the dimensions of a protecting structure, the safer people would generally feel themselves. It is also supposed that people's perception of the safety of a measure is determined by the (scientific) knowledge available on the effectiveness and endurance of a certain measure. Of course, this knowledge should then be communicated effectively to the inhabitants of the hinterland. Although this comes very close to the robustness criterion, these two indicators are applied for determining the perceived safety of the proposed strategies.

The results of the assessment of the perceived safety for the different coastal management strategies are summarized in Table 65. A short explanation on these assessments is given below this table.

Table 65: Results of a qualitative assessment of the safety perception of the strategies proposed.

Strategy	Safety perception
Uniform coast; islands	+
Uniform coast; sandbanks	--
Uniform coast; dunes in front of existing dunes	++
Large scale; islands and dunes	+
Large scale; dunes and sandbanks	0
Intermediate scale; seaward	0
Intermediate scale; landward	+
Small scale; basic alternative	0

Starting with the islands, these will be rather large. On the contrary it is not quite sure yet, from a scientific point of view, whether these islands will be sufficiently effective in decreasing critical circumstances during a storm event to prevent the mainland defences from failure. At a first glance however, this strategy would look save.

Sandbanks, on the contrary, are invisible. Nevertheless, their presence and effectiveness could have been explained when there would be any evidence of their effectiveness in reducing coastal erosion during storm events. This knowledge is lacking until know, so it is supposed that there is less confidence in the effectiveness of this measure.

New foredunes combine positive characteristics on both indicators: they are rather large and clearly visible and moreover it is sure (scientifically proved) that this type of coastal enhancement would increase safety levels.

For the large scale strategies, the uniform coast assessments are combined equally since the personal perception will mainly depend on the area the inhabitant is living in and the measure planned to increase the protection of that area.

The intermediate scale seaward strategy consists of sandbanks, artificial reefs and new foredunes. The safety perceived from the sandbanks will also be perceived from the artificial reefs since their effectiveness has not been proved in reality until yet. So this strategy's assessment is the same as for the large scale strategy with dunes and sandbanks.

The intermediate scale landward strategy is assessed slightly positive on this criterion, since the effectiveness of landward and seaward (at the southern coastal towns) dune extensions is well-known. However, in general these extensions are rather small compared to the seaward extension by new foredunes. And the effectiveness of the dike in dune solution has not been tested before.

The basic alternative is not supposed to change the perceived safety. Planned seaward extensions of dunes and beaches are optimized and not very large. However it is known that these extensions will increase safety, which is also valid for increasing dike heights in the northern part of the study area. At the same time, knowledge on the effectiveness of dikes within a dune at the southern coastal towns is uncertain. It might also be rather difficult for people to understand why nothing will be done to certain sections when (extensive) measures are planned for neighbouring sections of the coastal defences.

Since the basic alternative is assessed neutral for this criterion, the assessments do not need to be translated to a relative assessment compared to the basic alternative.

O.8 Intrinsic value of nature

Next to the economic value of nature, comprised in the nature values criterion, there are also intrinsic values of nature. As explained in appendix L of this report, intrinsic values represent the welfare of animals and plants instead of the welfare of humanity. Three indicators are applied to derive the impacts of the proposed strategies on the welfare of the flora and fauna in the coastal region: the amount of nature area gained; the possibility to create ecological links between different nature areas; and the impact on those areas presently being protected by national or European legislation. The impact on these three indicators are shortly described in the next three subsections. Finally, one qualitative assessment is derived for the effect on the intrinsic value of nature.

O.8.1 Area

From the calculated increases in both foredune and inner dune area in section O.3.1 of this appendix, it follows that all strategies will result in an increase of the nature area. Although it would be possible, it is assumed that the seaward extension of the dunes will not result in a seaward extension of the built-up area behind the existing sea defences. It is also supposed that the value of the marine ecology lost due to seaward extension of the sea defences is insignificant compared to the ecological value of the dunes. The marine ecology might recover in the new (morphological equilibrium) situation. So the net increase of the nature area equals the increase of the dune area.

Table 66 summarizes the calculated dune area increase for the proposed strategies. The qualitative assessment is again based on the ratio to the area of the basic alternative. When the area doubles, one plus is awarded and two plusses are awarded when the ratio is larger than four.

Table 66: The calculated increases of both the foredune and inner dune areas from Table 54 are applied to derive a qualitative assessment for the change of the nature area.

Strategy	Increase foredune area [ha]	Increase inner dune area [ha]	Total [ha]	Qualitative assessment
Uniform coast; islands	2050	260	2310	++
Uniform coast; sand banks	1020	0	1020	+
Uniform coast; dunes in front of existing dunes	580	1730	2310	++
Large scale; islands and dunes	1500	810	2310	++
Large scale; dunes and sandbanks	790	920	1710	+
Intermediate scale; seaward	330	810	1140	+
Intermediate scale; landward	430	40	470	0
Small scale; basic alternative	410	90	500	0

O.8.2 Links

The second indicator for the intrinsic value of nature is the possibility to create (or disrupt) connections between nature areas. In this case, we only consider the coastal zone of the study area. Some dune areas with high ecological values are located within this zone, mainly those areas characterized by a natural land-use function in the intermediate scale spatial division of the study area. These areas are separated by sections where the dunes are very narrow or even absent. This occurs for example where industries or towns are located very close to the coast and where dikes or other ‘hard’ structures are present in stead of dunes. By this indicator it is specifically considered whether the proposed strategy is able to connect these longshore separated nature areas. It is also positively appreciated when measures of the strategy at least close part of the gap between different nature areas since this might create ecological stepping stones for both flora and fauna.

The islands are located too far offshore to have significant connections with the mainland nature, so its potential for linking nature areas at the mainland is completely absent. However, there are also no negative impacts on the connections between nature areas on the mainland. The sandbanks might cause some accretion of the mainland coast, stimulating natural dynamics and increasing dune area. However, the potential growth is limited (to about 1 m/year, see section J.1.2) and it is uncertain whether this effect will occur. Therefore this measure is still assessed neutral too. New foredunes on the contrary would create one large connection between all nature areas along the mainland coast.

The scores of the large scale alternatives can be derived from the uniform coast alternatives by taking the average score of the components of these strategies. At the intermediate scale, the seaward strategy is also assessed positive because part of the gaps between the nature areas is bridged by new foredunes and some other parts might benefit from the positive effects of the sandbanks. The landward strategy is also assessed positive since the planned landward extensions will contribute to the connection of the separate nature areas.

The basic alternative is assessed neutral since it mainly consists of minimal (optimized) dune and beach extensions. These beach extensions will not significantly contribute to linking the nature areas. And the impact of the marginal dune extensions will be rather small. The large longshore differentiation of this strategy and the preservation of the dikes in Noord-Holland make that the possibility to connect the separate nature areas is not utilized. Although, this strategy does also not affect any existing connections between nature areas and therefore it is assessed neutral on this criterion.

The results of this assessment are summarized in Table 67. These scores are subsequently translated to a relative score in comparison to the basic alternative. The score of the large scale strategy on dunes and sandbanks is not increased since this would affect the ratio to the uniform coast counterparts of this measure.

Table 67: Results of a qualitative assessment of the potential of the different strategies to create links between the longshore separated nature areas.

Strategy	Potential to link nature areas
Uniform coast; islands	0
Uniform coast; sandbanks	0
Uniform coast; dunes in front of existing dunes	++
Large scale; islands and dunes	+
Large scale; dunes and sandbanks	+
Intermediate scale; seaward	+
Intermediate scale; landward	+
Small scale; basic alternative	0

O.8.3 Protected areas

The final, but not less important, indicator of the impacts on the intrinsic value of nature concerns the compliance with those areas protected by nature preservation legislation. Currently, there are three main legislations on the preservation of natural values in The Netherlands: the ecological main framework (Ecologische Hoofd Structuur = Natura 2000), the birds and habitat directive (Vogel en Habitat Richtlijn) and the law on nature preservation (Natuurbeschermingswet). These legislations are protecting different areas which are also located in the coastal zone of the study area. In Figure 114 all areas protected by these directives are marked green.

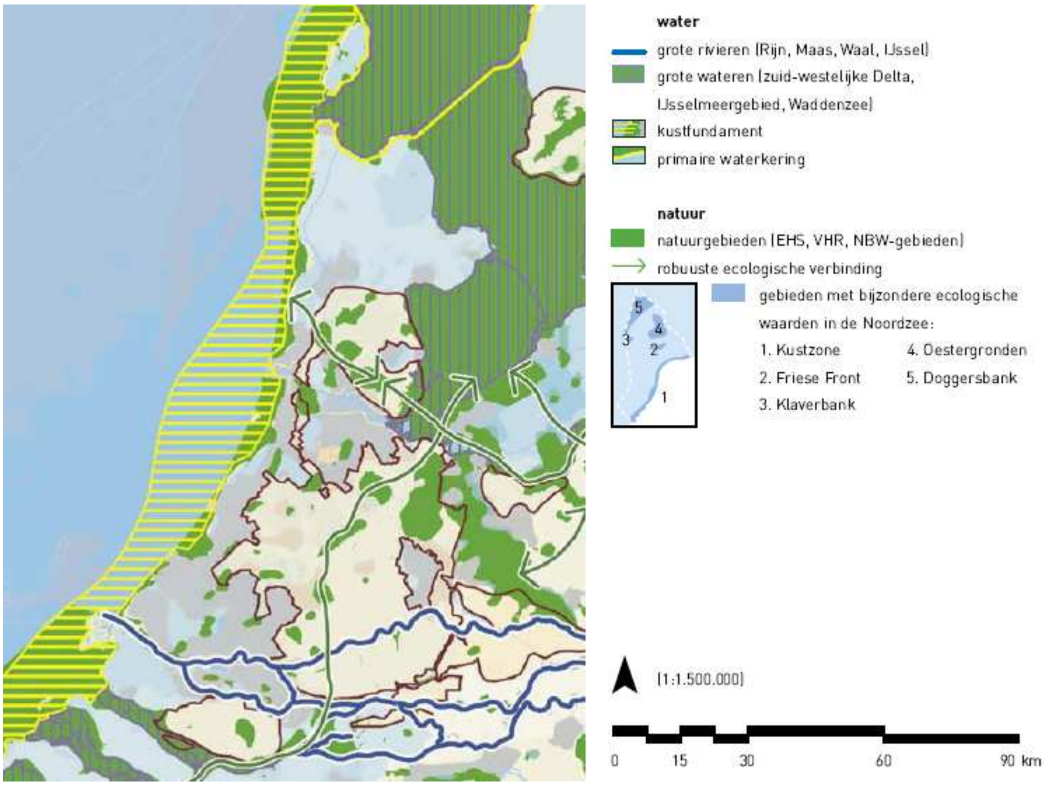


Figure 114: Protected nature areas are indicated in green [Min VROM, Min LNV, Min V&W & Min EZ, 2005].

For assessing the alternative strategies on this criterion it is considered how the proposed measures are located compared to these protected and valuable nature areas.

Starting with the uniform coast strategy with islands, these islands would seriously protrude the protected part of the North Sea at Noord-Holland. For the remainder of the coast, no negative impacts are foreseen. This strategy is assessed slightly negative. The same reasoning is valid for the sandbanks and also for the new foredunes. However, the new foredunes are connected to the mainland coast and are far less extensive than the islands or the sandbanks so its impact is assessed neutral.

In case of the large scale island and dunes strategy, it are again dunes protruding the protected area of the North Sea. The strategy concerning dunes and sandbanks plans sandbanks within this area. The scores for both these strategies are derived from this difference.

The intermediate scale seaward strategy will also preserve the protected dune areas at the mainland coast, but again the protected part of the North Sea will be affected by new foredunes in front of the coast. Thanks to the relative small dimensions of these new dunes, this strategy is assessed neutral again.

The landward counterpart on the other hand would seriously affect some of the nature areas along the mainland coast. This is mainly due to the fact that new dunes should be created within the existing dune areas. A very negative assessment is concluded.

The basic alternative compares to the seaward intermediate scale strategy. The preserved dune areas will not be seriously affected, but again the protected part of the North Sea faces some seaward extensions of the dunes and/or beaches.

The assessments on this criterion are summarized in Table 68. Since the basic alternative is assessed neutral, a translation in to comparative scores is not needed.

Table 68: Results of a qualitative assessment of the impact of the different strategies on protected nature areas.

Strategy	Impact on protected nature
Uniform coast; islands	-
Uniform coast; sandbanks	-
Uniform coast; dunes in front of existing dunes	0
Large scale; islands and dunes	0
Large scale; dunes and sandbanks	-
Intermediate scale; seaward	0
Intermediate scale; landward	--
Small scale; basic alternative	0

O.8.4 Conclusion

The qualitative scores on the three indicators determining the impact on the intrinsic value of nature by the proposed strategies are summarized in Table 69. From these partial assessments, an average assessment is derived for the final assessment on this criterion

Table 69: Summary of the results of the assessments of the coastal management strategies on three indicators for their impact on the intrinsic value of nature. The average scores are presented as the final assessments on this criterion.

Strategy	Nature area increase	Potential to link nature areas	Impact on protected nature	Intrinsic value of nature
Uniform coast; islands	++	0	-	0
Uniform coast; sandbanks	+	0	-	0
Uniform coast; dunes in front of existing dunes	++	++	0	+
Large scale; islands and dunes	++	+	0	+
Large scale; dunes and sandbanks	+	+	-	0
Intermediate scale; seaward	+	+	0	+
Intermediate scale; landward	0	+	--	0
Small scale; basic alternative	0	0	0	0

O.9 Technical complexity

This criterion is meant to indicate feasibility of realizing a certain strategy, or the components of that strategy. Technical complexity is related to the knowledge available for designing a strategy and the facilities available for constructing it. When knowledge and/or facilities are lacking, it would be rather complex to realize that strategy. Technical complexity of a strategy increases too when more difficult connections have to be designed and constructed for transitions between different coastal enhancement solutions being part of a certain strategy.

In general it is supposed that the measures contained in the proposed strategies are well attainable. Designing and constructing sandy features in front of the coast or just before or behind the coastal defences is very well feasible. Although, bringing sand to the landward side of the coastal defences will be some more difficult than just nourishing it at the beach or under the water level. This is due to the desalination and transportation processes needed for constructing landward dune extensions.

Constructing an artificial reef or a dike within an existing dunes are also more complex than the general, established coastal enhancement strategies. Unless these differences in technical complexity, there are no measures within these strategies that seem to be not feasible at this moment concerning the current state of the art on designing knowledge and construction facilities.

Finally, the number of transitions within a strategy does influence the technical complexity of the total plan. The more different solutions are included within one strategy, the more transitions should be designed. Designing these transitions is rather difficult, surely where ‘soft’ and ‘hard’ engineering solutions are meeting. Knowledge on the stability of these transitions is limited.

Since no real gaps in available knowledge or construction facilities could be found for each of the measures being part of the strategies, none of the strategies is assessed negative on this criterion. Due to the large number of transitions and the dike in dune solutions, the basic alternative scores neutral. All other measures are supposed to be less complex and thus score positive on this criterion. The less positive score of the intermediate scale strategies is also caused by the drawback of containing more transitions than the remaining strategies and by the complex solutions included in these strategies (artificial reef and dike in dune). These assessment results are summarized in Table 70.

Table 70: Results of a qualitative assessment of the technical complexity of the strategies proposed for improving the coastal defences in the study area.

Strategy	Technical complexity
Uniform coast; islands	++
Uniform coast; sandbanks	++
Uniform coast; dunes in front of existing dunes	++
Large scale; islands and dunes	++
Large scale; dunes and sandbanks	++
Intermediate scale; seaward	+
Intermediate scale; landward	+
Small scale; basic alternative	0

O.10 Robustness

The robustness of the strategies is represented by two indicators: the uncertainty about the effectiveness and the development of a certain measure; and the flexibility of a measure indicating its long term sustainability.

O.10.1 Uncertainty

The uncertainty of a strategy, or the components of a strategy, is derived from the degree to which it has proved to be effective in the past. This could be deduced from positive experiences in the past or from a clear understanding of the mechanisms determining the effectiveness of the strategy. First, this is related to the knowledge on how and to what extent a certain measure impacts the failure modes and frequencies of the coastal defences. Second, this criterion is related to the knowledge on the evolution of an implemented measure through time caused by natural dynamics (water and wind). When knowledge on one or both of these aspects is insufficient, it will be uncertain whether the effectiveness of a proposed strategy is realistic and whether it will persist over time. The assessment of the strategies on this indicator is presented in Table 71.

Table 71: Results of a qualitative assessment of the uncertainty of the strategies proposed for improving the coastal defences in the study area.

Strategy	Uncertainty
Uniform coast; islands	-
Uniform coast; sandbanks	--
Uniform coast; dunes in front of existing dunes	++
Large scale; islands and dunes	+
Large scale; dunes and sandbanks	0
Intermediate scale; seaward	0
Intermediate scale; landward	+
Small scale; basic alternative	0

The sandbanks are most uncertain of the measures proposed. It is not at all sure whether their presence will dissipate a sufficient part of the wave energy in order to prevent critical erosion at the mainland coastal defences (the same is true for the artificial reefs). At the same time, it is not sure whether these sandbanks will persist over time (whether a new morphologic equilibrium emerges) or whether natural dynamics would impose enormous maintenance needs. At a shorter timeframe, it is even uncertain whether these banks will persist one storm duration. They might be eroded during the first hours of a severe storm event and be ineffective during part of the storm duration.
These points are also valid for the islands, however the design of these islands would be better adapted to natural dynamics since this measure is part of the category of 'hard' engineering solutions. But it remains uncertain whether their presence would effectively reduce wave attack at the mainland coast during storm events.

On the contrary, the effectiveness of the new foredunes is quite certain and it is supposed that this strategy would be stable when applied to the entire coast of the study area since this would reduce longshore sediment transport gradients (important drivers for local erosion of the coast).

The large scale strategies are combinations of these three measures and are assessed accordingly. The same is valid for the seaward strategy, however this strategy also contains artificial reefs. As stated before, their effectiveness is yet as uncertain as the effectiveness of the sandbanks. Over time, artificial reefs are supposed to be more stable than sandbanks since they contain large amounts of stones.

The landward dune extensions of the landward intermediate scale strategy will also be very effective and stable over time, since erosion is limited to a small amount of wind erosion at the landward side of the dunes. The only drawbacks of this strategy are the dike in dune solutions supplemented by seaward dune extension. It is not exactly known how effective this combination (dike + dune) would be. Moreover these dune extensions, being located in front of the surrounding dunes, will be subjected to large eroding forces by longshore transport.

Concerning the basic alternative, most weak sections will be extended in seaward direction. In this case the longshore differentiation in the seaward extensions of the existing coast increases erosion by longshore sediment transport gradients. On the other hand, the effectiveness is still well known for most solutions being part of this alternative. Only for the 'innovative' dike in dune solution and the many transitions it is difficult to interpret their effectiveness. Together, this caused the neutral assessment of the basic alternative. Because the basic alternative is assessed neutral, it is not necessary to translate the assessment on this criteria to a relative assessment comparing the scores of the other strategies to the assessment of the basic alternative.

O.10.2 Flexibility

The flexibility of a strategy, or the components of a strategy, is derived from both its sustainability and its resilience. First, the sustainability component of this criterion tells us how well a measure could be extended when even worse conditions would be faced in the future. Second, the resilience of a measure indicates its self-restoring capabilities once it is damaged due to some natural impacts. In general, 'soft' engineering measures built with sand are more capable to restore themselves and are more suited to be extended any further in the future than their 'hard' counterparts. The assessments of the strategies on this criterion are summarized in Table 72. Some explanation is given below. In the last column of this table, these scores are translated to a relative score comparing the strategies to the basic alternative.

Table 72: Results of a qualitative assessment of the flexibility of the strategies proposed for improving the coastal defences in the study area.

Strategy	Flexibility	Flexibility relative to basic alternative
Uniform coast; islands	--	--
Uniform coast; sandbanks	-	-
Uniform coast; dunes in front of existing dunes	++	++
Large scale; islands and dunes	0	+
Large scale; dunes and sandbanks	+	++
Intermediate scale; seaward	0	+
Intermediate scale; landward	0	+
Small scale; basic alternative	-	0

Concerning flexibility, creating new dunes in front of the existing dunes over the total length of the studied coast would be the best solution. It would be very well possible to extend these dunes any further when future circumstances create the need to do so. Next, a smooth and sandy coastline will be created with the capacity to restore possible damaging impacts over time.

When concerning the islands, they are far less sustainable and resilient. Islands could be extended (this extension would mainly be needed for its height) after some time but it is uncertain whether this would reduce the impact of storm events on the mainland coast any further. Moreover, creating an island in front of the mainland coast might affect the existing mainland coastal defences since the cross-shore landward sediment transport component will be affected while at the same time eroding forces of the tidal longshore transport will persist. This is also why the resilience of the mainland coastal defences would be affected. The resilience of the island itself is also questionable since it strongly depends on the possibility that a new morphologic equilibrium state will be developed around the island. When a static island is designed it will be less susceptible to morphodynamic impacts and it would not need its resilience that much. However, the safety level the island will be much smaller than that of the mainland, so this hard structure will be more susceptible to natural eroding forces than hard structures at the mainland coast and still needs its lacking resilience.

For the sandbanks, the same arguments are valid as for the islands (except for the latest one since sandbanks are not at all static features). However, the sandbanks would not affect the mainland coast, they might even supply sand to the coastal defences by cross-shore transport. But it is uncertain whether a further extension of the banks would increase its effectiveness and whether some kind of morphologic equilibrium state will be developed supporting the sandbanks' resilience.

The large scale combinations of these measures are assessed according to the relevance and assessment of their components. The intermediate scale seaward strategy is mainly based on new dunes and sandbanks too, but is assessed neutral due to the lacking resilience of the artificial reefs and the loss of self-restoring capacity due to the larger spatial variation in longshore direction.
The landward intermediate scale strategy is assessed neutral too. Its sustainability is somewhat better since the landward dune extensions could well be extended. And an increase of the strength of the dike

in dune solution by further extending the dunes seems also realistic. At the same time, its resilience is a little worse since self-restoring capacities are limited at the landward side of the foredunes and the seaward extensions at some of the coastal towns might be subjected to structural erosion.

The basic alternative applies seaward extension of dunes and/or beaches for improving the coastal defences at many sections. These measures are very well extendible and their own resilience is quite good. The static components of this strategy, being the concepts of dike heightening and dike in dune constructions might be less suitable for further extension. Extending these static structures any further would be very expensive. Moreover, the additional spatial differentiation of the seaward extensions of the measures within this strategy affects the resilience of the overall concept of this strategy. And this differentiation might increase further when future circumstances ask for additional extensions. Longshore sediment transport gradients will increase thereby causing increased erosion rates of the seaward extensions. Due to this effect, the self-restoring capability of this strategy will strongly depend on the longshore location (whether it shows net erosion or accretion). Altogether, this basic alternative is assessed (slightly) negative.

O.10.3 Conclusion

In Table 59 the assessments on the uncertainty and flexibility of the strategies are summarized and a final assessment for the strategies' robustness is derived.

Table 73: Concluding assessment of the robustness of the strategies proposed for improving the coastal defences in the study area.

Strategy	Uncertainty	Flexibility	Robustness
Uniform coast; islands	-	--	--
Uniform coast; sandbanks	--	-	--
Uniform coast; dunes in front of existing dunes	++	++	++
Large scale; islands and dunes	+	+	+
Large scale; dunes and sandbanks	0	++	+
Intermediate scale; seaward	0	+	+
Intermediate scale; landward	+	+	+
Small scale; basic alternative	0	0	0

O.11 Phasing

This criterion is meant to give an indication on the suitability of a phased implementation of the proposed measures. When the implementation is realized at one longshore location after another (several stages in the longshore construction process), this would imply beneficial effects for the investment risk and the development of social acceptance. First, when the construction of a measure is divided into several phases, knowledge developed during one stage could be applied in the next phase. By doing so, the risk of making mistakes in both the design and the construction is reduced over time. This could cause an optimisation of the costs and benefits of a project. Moreover, a gradual implementation is generally better accepted by society than one enormous project emerging all at once. This is caused by the fact that a phase-wise implementation creates the opportunity to get used to the changes planned.

However, the possibility to implement those strategies in several phases is limited by the morphological effects of the longshore differences coming into play when measures are only partly realised.

Concerning the new island, it would be very well possible to create this strategy in several phases. Since the islands will be developed as more or less static structures at an offshore distance of about 10 kilometres, their susceptibility to erosion will not increase significantly when they are only partly realised. This creates the possibility to start the creation of the islands at those locations where the need to improve coastal defences is highest. The investment of the construction costs could then be spread out over time and future innovations might be applied in the construction process as soon as they become available.

On the contrary, splitting up the realisation of the sandbanks or the foredunes along the entire coast would cause a significant increase in their vulnerability. When these measures are realised in different phases, longshore differences will increase erosion rates at the newly created defending structures. This would impede the development of a new equilibrium situation, as was also stated in section O.10.2 of this appendix where the flexibility of the basic alternative is described. It is not impossible to split the construction of these uniform strategies into several longshore stages, but it would cause a significant increase in the maintenance requirements. And since this is valid to both components, the same assessment is applied to the large scale alternative consisting of dunes and sandbanks.

The second large scale alternative is a combination of the islands, which could well be developed in several phases, and the dunes that are less appropriate for a phased implementation. Since the island will cover the largest part of the coast, this strategy is assessed still slightly positive.

The different measures comprised by the seaward intermediate scale strategy would also increase maintenance requirements when realized in different phases. Again, this is due to the emergence of longshore variations creating additional erosion at those parts that are already strengthened and that extend further seaward than the surrounding sections. But again it is still possible to create this strategy in different phases at the cost of increasing maintenance requirements.

For the landward strategy, this drawback is invalid since almost all coastal enhancement activities are planned at the landward side of the existing sea defences. This prevents the parts that will be constructed first in a phased construction from being exposed to and affected by hydrodynamic impacts. The seaward extensions of this strategy do already face high maintenance requirements and this would not significantly increase any further when construction is split up in several phases.

The latter argument is also valid for the basic alternative. In the final situation the longshore differentiation is still rather large, causing a relatively high maintenance requirement. This spatial variation will be increased somewhat when the measures at each section would be constructed in several phases. It is not supposed that this would significantly increase maintenance costs, so this strategy is assessed neutral.

Since the basic alternative is assessed neutral, it is not necessary to translate these assessments to new scores comparing the different strategies to the basic alternative. The results of this assessment are summarized in Table 74.

Table 74: Results of a qualitative assessment of the suitability of the strategies proposed for being implemented in several phases.

Strategy	Suitability for phasing
Uniform coast; islands	++
Uniform coast; sandbanks	-
Uniform coast; dunes in front of existing dunes	-
Large scale; islands and dunes	0
Large scale; dunes and sandbanks	-
Intermediate scale; seaward	-
Intermediate scale; landward	++
Small scale; basic alternative	0

O.12 Governmental complexity

One could find that governmental difficulties in realising one of the proposed measures should not influence the selection of the optimal strategy. The political framework is then supposed to change in order to facilitate the realization of the selected strategy. This assumption might be true for a timeframe of 200 years.

However, large parts of the proposed strategies might need to be realised or at least preparation for realisation might need to be started rather soon. In this case, existing administrative structures will not change significantly and complexities might occur. These complexities might come into play when several administrative levels (e.g. ministries and waterboards) should be incorporated and/or when several administrative bodies at an equal level (e.g. two provinces) should cooperate. How much governments should cooperate at the same level largely depends on the longshore extension of the measures of a strategy, the longer the areas where the same measure should be implemented the more governmental bodies should be incorporated representing the same administrative level.

In Table 75 the assessments of the proposed strategies on this criterion are summarized. It appeared to be rather difficult to differentiate between good and better (and bad and worse) within this criterion. Therefore we only applied a positive (+) and negative (-) score next to the neutral assessment. An explanation of these assessments is given below the table.

Table 75: Results of a qualitative assessment of the governmental complexity related to the implementation of the coastal management strategies.

Strategy	Governmental complexity
Uniform coast; islands	+
Uniform coast; sandbanks	+
Uniform coast; dunes in front of existing dunes	-
Large scale; islands and dunes	0
Large scale; dunes and sandbanks	-
Intermediate scale; seaward	0
Intermediate scale; landward	-
Small scale; basic alternative	0

The basic alternative is assessed neutral on this criterion since it is supposed to be a prolongation of present coastal management practice. First, the relatively small spatial scale of the solutions within this strategy prevents the need for coordination between different bodies at the same political level. At the same time, these measures are all planned close to or even right at the existing defences where many governmental bodies at different administrative levels have their responsibilities and interests. These two characteristics are assumed to outweigh each other, resulting in a neutral assessment.

The seaward intermediate scale alternative is assessed the same, however the features on both indicators are somewhat different compared to the basic alternative. Those sections that are planned to be enhanced by sandbanks or artificial reefs are exposed to less governmental complexity since they are located further offshore where only national governments are at stake. Those sections to be improved by new foredunes on the contrary are extended in longshore direction. Lots of political stakeholders should be incorporated there, both at different governmental levels (foredunes are located close to the existing coast where many governments have their duties) and at equal levels (different municipalities responsible for the beaches).

In case of the landward intermediate scale strategy, governmental complexities do increase since all measures of this strategy are planned within or just before or behind of the existing sea defences. Moreover, the lengths of the sections where the same measure should be realized are rather long. So over the total length of the coast, many different governmental bodies representing different administrative levels should be incorporated. The same is true for the strategy planning new foredunes to the entire length of the coast (uniform coast).

Both uniform coast strategies containing islands and sandbanks will be less hindered by governmental bumps in their road to completion. Since these measures are located offshore, the only governments at stake are at a national level. Some different ministries should cooperate, for example those responsible for spatial planning and water management. However, they are incorporated in all projects related to the coast since they are responsible for funding these projects. So this is not adding to the governmental complexity of these measures.

The large scale strategy based on the combination of an island and dunes is assessed neutral, being the combination of the assessments of the uniform coast counterparts. The second large scale strategy, combining dunes in front of the Zuid-Holland coast and sandbanks for the Noord-Holland coast, is still assessed negative just like the uniform coast strategy with new foredunes. This is due to the fact that the southern part of the study area contains more administrative bodies (two waterboards, more municipalities) than the northern part (one waterboard, less municipalities). Moreover, much more people are living in Zuid-Holland, increasing the political relevance of this area. Therefore the increase in the administrative complexity in the southern part is much larger than the decrease of this complexity in the northern part of the study area when this strategy is compared to the other large scale strategy.

P Impact lower climate change scenario

The coastal management strategies that are designed and assessed in this study are based on the specific requirements in case the upper climate change scenario would come true. However, this is the worst case scenario and there are two less severe scenarios defined in section 2.1.2 that might also come true. The results of the safety assessment of the coastal defences for the year 2200 have shown that the reduction of the expected climate changes causes shorter longshore coastal sections to be assessed insufficient. The reduction of the climate changes implies a reduction of the boundary conditions (e.g. water level) and therefore those sections that are still assessed insufficient would require less extensive measures than in case the upper climate change scenario will come true.

The question to be answered in this appendix is whether reducing the boundary conditions for the coastal management strategies would change the assessment results and the final ranking of the strategies as presented in section 4.4 of this study.

The time available for this study is not long enough to repeat the entire process of dividing the study area in longshore sections according to different spatial scales, designing coastal management solutions to improve the safety of these sections and assessing several strategies composed of these solutions as was done for the upper climate change scenario. Therefore this sensitivity analysis of the assessment results to the expected climate change impacts is done on the basis of some rough estimates that cause some significant differences to the coastal management strategies initially designed for the highest climate change scenario. Now the lowest climate change scenario will be considered.

In this appendix we will first consider the (length of the) sections for which enhancement strategies would still be needed in case of the lowest climate change scenario. Then some assumptions will be made on the dimensions of the coastal management solutions for those sections that still require some improvement. Finally, this will be translated into a new assessment table stating the effects of all strategies on the range of criteria. From this table it can be derived whether some significant change occur in the ranking of the strategies.

P.1 Longshore changes

In case the lower climate change scenario comes true in stead of the most extreme scenario, the number of cross-shore sections that is assessed insufficient reduces as can be seen in Figure 19. This will definitely change some of the coastal management strategies. However the spatial scale of the designs of the coastal management strategies determines how well they could be adapted to these changing requirements.

For both the uniform coast and the large scale spatial strategies, the lengths of the sections are rather long and make it almost impossible to take these changing requirements into account. Some 'red spots' are still present along the coasts of both dike ring areas. In order to improve the safety of these coastal defence sections assessed insufficient, the proposed measures of these strategies should still be applied over the full length of their sections (being the entire coast or one of the dike ring areas). A local application of these measures at those 'red spots' is not considered here since this would create some new intermediate scale alternatives that are not considered in this study. Moreover, this would introduce all negative side-effects of the strategies designed at smaller spatial scales to those strategies designed for larger spatial scales (e.g. increasing maintenance, less new nature).

Concerning the intermediate spatial differentiation, some sections that would require strengthening of the sea defences for the most extreme climate change scenario appear to be safe under the lower climate change scenario. As for the section ranging from cross-sections 8800 up to 9200 (that was assessed safe even at the upper climate change scenario) no measures need to be planned for these sections. The observed changes due to the lower climate change scenario are:

- For both sections ranging from cross-section 3300 to 4300 (section 3 in Table 76) and from cross-section 4300 to 5000 (section 4), no enhancing strategies for the coastal defences are needed up to 2200 when the outer boundaries are shifted over a few kilometres. For convenience however, these boundaries are not changed but it is assumed that the existing sections do not need to be enhanced.
- No measures are required any more at both the sections ranging from cross-section 7400 to 8100 (section 7) and ranging from cross-section 9200 to 9900 (section 10).
- The extended longshore section ranging from cross-section 5700 to 7400 (section 6) only faces two rather small ‘red spots’ (both 1 km long) that require measures in order to prevent the safety level of the sea defences to become insufficient by the year 2200. When these problems are solved locally, the remainder of this longshore section might remain unaffected. For this sensitivity analysis, looking after potential differences due to decreasing climate change expectations, it is supposed that no measures are planned for this entire section since this would cause a larger difference to the original situation.

The same is valid for the small scale spatial differentiation. Some sections that initially needed coastal management solutions for enhancing their defences do not need these measures any more when the lower climate change scenario would approximate the reality. It is observed that:

- The sections located between cross-sections 3900 and 4300 (section 12 in Table 78), between cross-sections 6000 and 6500 (section 17), between 7900 and 8100 (section 22) and between cross-sections 9500 and 9900 (section 28) do not need any measures up to the year 2200 for the lower climate change scenario.
- The longshore section ranging from 4300 to 5000 (section 13) also would not require any measures when the southern boundary is shifted somewhat to the north.
- The static measures planned to enhance the coastal defences at the sections ranging from 6500 to 6700 (section 18, Zandvoort) and from 8100 to 8350 (section 23, Noordwijk) only need to be half as long in case of the lower climate change scenario.
- The hard (= static) engineering solution planned at the section ranging from cross-section 8500 to 8800 (section 25, Katwijk) can be reduced in length by one-third.

The implications of these observations for the intermediate scale and small scale coastal management strategies are summarized in the three tables below. Moreover, the assessment-columns of these tables have been changed according to the safety assessment results for the lower climate change scenario as they are presented in Table 4.

Table 76: Seaward coastal management solution with an intermediate spatial differentiation. Notes: section numbers refer to Jarkus cross-section numbers and the colours in the assessment column refer to the colours in Table 4.

Section [#]	Section [kmr]	Represen-tative cross-section [kmr]	Land use function	Assessment	Solution
1	0-2600	1524	agriculture	red	Dune in front of existing dune
2	2600-3300	2847	nature	orange	Sand bank (+ extended beach and dunes)
3	3300-4300	3550	agriculture	green	-
4	4300-5000	4900	nature	green	-
5	5000-5400	5050	greenhouses/industry	orange	Dune in front of existing dune
6	5700-7400	6725	nature	green	-
7	7400-8100	7975	agriculture	green	-
8	8100-8800	8125	coastal towns	orange	Artificial reef
9	8800-9200	9075	agriculture	green	-
10	9200-9900	9525	nature	green	-
11	9900-10800	10592	coastal towns	orange	Artificial reef
12	10800-11850	10996	greenhouses/industry	orange	Dune in front of existing dune

Table 77: Landward coastal management solution with an intermediate spatial differentiation.

Section [#]	Section [kmr]	Represen-tative cross-section [kmr]	Land use function	Assessment	Solution
1	0-2600	1524	agriculture	red	Extending dune in landward direction
2	2600-3300	2847	nature	orange	Dune behind existing dunes
3	3300-4300	3550	agriculture	green	-
4	4300-5000	4900	nature	green	-
5	5000-5400	5050	greenhouses/industry	orange	Extending dune in landward direction
6	5700-7400	6725	nature	green	-
7	7400-8100	7975	agriculture	green	-
8	8100-8800	8125	coastal towns	orange	Dike in dune + extending dune in seaward direction
9	8800-9200	9075	agriculture	green	-
10	9200-9900	9525	nature	green	-
11	9900-10800	10592	coastal towns	orange	Dike in dune + extending dune in seaward direction
12	10800-11850	10996	greenhouses/industry	orange	Extending dune in landward direction

Table 78: Basic alternative for coastal management solutions to preserve coastal safety up to the year 2200.

Section [#]	Section [kmr]	Represen-tative cross-section [kmr]	Land use function	Assessment	Solution
1	0-120	70	coastal town (Den Helder)	red	Dike heightening
2	120-300	150	agriculture	orange	Extending dune in seaward direction
3	300-700	608	agriculture	green	-
4	700-1300	928	agriculture	yellow	Extending dune in seaward direction + increasing beach width
5	1300-1400	1303	coastal town (Callantsoog)	orange	Increasing beach width
6	1400-2040	1729	agriculture (dune)	orange	Extending dune in seaward direction + increasing beach width
7	2040-2600	2300	agriculture (dike)	red	Dike heightening
8	2600-3150	2847	nature	orange	Extending dune in seaward direction + increasing beach width
9	3150-3250	3175	coastal town (Bergen aZ)	orange	Extending dune in seaward direction + increasing beach width
10	3250-3800	3550	agriculture	yellow	Extending dune in seaward direction + increasing beach width
11	3800-3900	3900	coastal town (Egmond aZ)	green	-
12	3900-4300	4250	agriculture	green	-
13	4300-5000	4900	nature	green	-
14	5000-5200	5050	greenhouses/industry	orange	Extending dune in seaward direction + increasing beach width
15	5200-5400	5300	greenhouses/industry	green	-
16	5700-6000	5950	nature	green	-
17	6000-6500	6125	nature	green	-
18	6500-6700	6550	coastal town (Zandvoort)	yellow	Dike in dune (for half this section's length)
19	6700-7100	6950	nature	yellow	Extending dune in seaward direction + increasing beach width
20	7100-7400	7225	nature	green	-
21	7400-7900	7600	agriculture	green	-
22	7900-8100	7975	agriculture	green	-
23	8100-8350	8125	coastal town (Noordwijk aZ)	yellow	Dike in dune + extending dune in seaward direction (for half this section's length)
24	8350-8500	8450	agriculture	green	-
25	8500-8800	8650	coastal town (Katwijk)	orange	Dike in dune + extending dune in seaward direction (for two-third of this section's length)
26	8800-9200	9075	agriculture	green	-
27	9200-9500	9350	nature	green	-
28	9500-9900	9525	nature	green	-

29	9900-10300	10075	coastal town (Scheveningen)	orange	Water retaining structure in boulevard + increasing beach height
30	10300-10550	10461	coastal town (Den Haag)	green	-
31	10550-10800	10773	coastal town (Kijkduin)	orange	Extending dune in seaward direction + increasing beach width
32	10800-11100	10996	greenhouses/industry	orange	Extending dune in seaward direction + increasing beach width
33	11100-11250	11072	coastal town (Ter Heijde)	orange	Extending dune in seaward direction + increasing beach width
34	11250-11850	11356	greenhouses/industry	orange	Dune in front of existing dunes + increasing beach width

P.2 Cross-shore changes

Concerning the dimensions of the measures planned for the remaining sections that still require some coastal improvement works in case the lower climate change scenario would come true, some rough assumptions are applied. According to Table 2 in the main report, sea level rise (and thus also autonomous sea bed rise) would be 0.95 m for this scenario in stead of 3.15 m for the highest climate change scenario. Moreover, storm surge levels and wave heights are not supposed to increase any further (storm surge level was supposed to increase by 0.40 m for the highest scenario, and wave height by 5%).

These reduced boundary conditions are translated into some 'quick and dirty' rules for calculating the new dimensions of the proposed measures integrated in the different strategies:

- The height of the islands is supposed to be decreased with about 2.5 m while the width and the length will remain the same since they are not related to the hydraulic boundary conditions. This will induce a decrease of about 10% of the total volume of sand needed for these islands since their total height from the sea bottom to the surface is about 25 m.
- Sandbanks and artificial reefs being constructed in front of the coast might also be designed with crest levels that are about 2.5 m lower due to the reduced sea level rise that will be faced in 2200. This would reduce the total volume of these features with about 30% since their initial height should be about 8 m.
- All other soft engineering measures like new foredunes or extending the existing dunes in seaward or landward direction, are supposed to show a decrease of the required sand volumes of about two-third due to the reduced climate change effects. This 67% decrease of the volume of sand that is required is supposed to imply that the horizontal dimensions (mainly the cross-shore width) of these measures will decrease with about 50%.
- The assumption applied to the remaining static structures that are part of the coastal management strategies like dike heightening and constructing a dike within the existing dunes is somewhat less favourable: construction costs will decrease by 50%. Since expected sea level rise is less than one-third of the sea level rise expected according to the highest climate change scenario, it should be possible to decrease the dimensions of these structures with at least 50% (for simple dikes it might be more, for dikes within dunes it might be less).

It should be noted that these assumptions are not based on any kind of safety calculations for the coastal defences. They are just based on some rough ratios first thoughts of the author. Nevertheless, it should be possible by applying these assumptions to find out whether a decreasing severance of the expected climate changes would (significantly) change the assessment of the proposed coastal management strategies.

P.3 New assessments

Now the impacts of these changes, as described in the previous sections, on the assessment of the coastal management strategies should be considered. First it is shortly described what effects would possibly change through the decrease of the extensiveness and the dimensions of the measures incorporated in the coastal management strategies. Finally, new tables will be presented summarizing all new impact assessments both quantitatively and qualitatively.

P.3.1 Costs

Concerning the construction costs, we just applied the assumptions on the new dimensions of the coastal enhancement measures to the dimensions that were derived for the higher climate change scenario. It is supposed that those volume decreases cause an equal decrease in the construction costs, as is understandable since most construction costs are derived by calculating and prizing sand volumes. For the static features (like dikes and reefs) it is just assumed that the ratio of decrease of the required height equals the ratio of the cost reduction. Moreover, the years that certain measures should be constructed (derived in the same way as was done for the initial strategies, see appendix O.1) are changed in accordance with the new assessments of the coastal defences for the lower climate change scenario.

As far as maintenance costs are related to the construction costs (mainly for static structures and for sandbanks) they will decrease somewhat in case of this reduced climate change scenario. In all other cases, maintenance requirements are mainly based on longshore differentiations (from which the ratio to present maintenance requirements is estimated). As can be seen in section P.1, this longshore variation does not decrease significantly. At the same time, the moment of construction changes for some sections, causing the maintenance requirements to change at different moments than in case of the highest climate change scenario.

In all cases, also for the other impacts, the criteria for translating the calculated costs into a qualitative assessment remain the same as those applied for assessing the strategies to cope with the highest climate change scenario.

The results of these calculations and valuations are summarized in Table 79 at the end of this appendix.

P.3.2 Welfare impacts

Concerning the nature values (environment & recreation and water supply) and the man-made functions (housing and agriculture), the rule of thumb of a 50% decrease of the surface needed for extending the dunes is applied. This causes that the new foredune area available for nature and recreation to decrease, but at the same time the area lost at the landward side of the dunes in case of landward dune extension is reduced too and creates some benefits. Meanwhile, the new foredunes will still affect the enjoyment of the coastal environment by those people presently living very close to the sea. These effects will not be reduced when the new foredunes are less voluminous. For the islands and the sandbanks, no changes are foreseen. In order to calculate the net present values of these benefits, the major year of realization of the basic alternative is also changed in accordance with the years of construction found in Table 78 (2075 in stead of 2050 for the higher climate scenario).

When the safety benefits are calculated for this new situation, some changes are faced since several coastal towns will not benefit from an increased safety level anymore. This is due to the fact that certain sections do not require the initially planned coastal enhancement measures in this new situation. These effects do only occur at the intermediate and small scale strategies, but do also change the scores of the other strategies since these scores are derived in comparison to the basic alternative. However, on the qualitative assessment scale for this criterion almost none of these changes results in an adjusted assessment in comparison to the higher climate change scenario.

Concerning the equity criterion, no large changes are found. In general, the effects of the different coastal management strategies affecting equity do not change significantly for the uniform coast strategies, nor for the large scale and small scale strategies. At the intermediate scale, some changes are found due to the fact that no measures are planned anymore for rather large sections. In case of the seaward strategy, this means that some of the benefits of the seaward extensions by dunes and sandbanks are lost and therefore this strategy is assessed slightly less positive than in case of the full-scale implementation. The landward counterpart on the contrary is assessed slightly more positive than in case of the full-scale implementation for the highest climate change scenario since the space lost for dune extensions is reduced along those sections where no measures are required anymore.

Finally the perceived safety of the proposed measures is supposed to be the same since the principles of the measures will not change. And when the impacts of the climate changes are rather low, people will certainly understand that it is not necessary to improve the coastal defences over it's total length.

The results of these considerations are summarized in Table 79 at the end of this appendix.

P.3.3 Non-welfare impacts

The impacts on the intrinsic value of nature do change somewhat too. In the first place the new nature area is reduced due to the fact that the new dunes and dune extensions do not need to be as wide anymore as they should be in case of the highest climate change scenario. But still the increase of the inner dune area is supposed to be the same, since a new row of foredunes will cause the existing foredunes (of a certain width) to become inner dunes. Based on the assumption of a decrease of 50% of the additional dune area, new values are calculated.

At the same time, the reduction of the number of sections facing a seaward or landward extension in the intermediate scale strategies causes a decrease of the potential to connect different nature areas. Therefore, these strategies are now assessed the same on this indicator as the small scale strategy.

The negative impact of the landward intermediate scale strategy on the protected nature areas also decreases due to the fact that some sections containing these protected areas do not need improvements of the coastal defences in the new situation.

Altogether, these changing impacts cause almost no changes in the qualitative assessment table as can be seen in the last sub-section of this appendix.

P.3.4 Other criteria

The remaining criteria are not related to the dimensions of the solutions, but to the principles for their effectiveness and their general characteristics (e.g. past experiences, flexibility for extending dimensions, possibility for phased implementation). Since these characteristics do not change for a lower climate change scenario, the assessments on these criteria remain unchanged.

P.3.5 Conclusion

From the contemplations in the previous sub-sections, two new assessment tables are derived for the situation that the lower climate change scenario would come true. Table 79 states the scores (both quantitative and qualitative) of the different strategies on all criteria, Table 80 presents the qualitative scores derived in comparison to the basic alternative. Those impacts that have been changed compared to the initial assessment of the strategies for the highest climate change scenario, are marked in both tables. As can be seen, not all changes in the absolute scores of the strategies presented in the first table are recurring in the comparative assessment as presented in the second table where all effects are assessed qualitatively and in comparison to the basic alternative. Moreover, improvements of the absolute (quantitative and qualitative) scores in Table 79 can still lead to an impeding qualitative assessment in Table 80. This occurs when the impact of the basic alternative is relatively more improved on criterion X than the impact of the other strategy, which causes a decreasing qualitative assessment of the other strategy in comparison to the basic alternative.

Table 79: Summary of the results of the impact assessments of the proposed coastal management strategies and the basic alternative for the lower climate change scenario. Some criteria are assessed by quantitative calculations based on authorised values. The remaining criteria are not suited for quantitative assessment and the effects are assessed on a qualitative scale ranging from -- (very negative effect) to ++ (very positive effect). The effects marked in green have been changed positively compared to the effects of the strategies designed for the higher climate change scenario, those that are marked red have been changed negatively.

Criterion	Uniform coast; islands	Uniform coast; sandbanks	Uniform coast; dunes in front of existing dunes	Large scale; islands and dunes	Large scale; dunes and sandbanks	Intermediate scale; seaward	Intermediate scale; landward	Small scale; basic alternative
Costs								
Construction costs; NPV 2008 [$*10^6$ €]	8800	100	160	6400	130	200	100	90
Maintenance costs; NPV 2008 [$*10^9$ €]	17.8	2.2/1.0[1]	0.8	13.1	1.4/0.9[1]	1.1	0.8	0.9
Welfare impacts								
Nature values								
- Environment & recreation; NPV 2008 [$*10^6$ €]	389	7.7	215	402	126	38	5.1	8.1
- Water supply; NPV 2008 [$*10^6$ €]	3.7	0	13	12	7.1	2.3	0.2	0.4
Safety benefits; annual benefit by 2200 [$*10^6$ €]	84	56	109	90	97	31	49	55
Man-made functions								
- Housing; NPV 2008 [$*10^6$ €]	282	0	-184	138	-143	-26	-1.3	-7.5
- Agriculture; NPV 2008 [$*10^6$ €]	892	0	0	648	0	0	-5.0	0
Equity	++	-/0	--	+	--	+	0	+
Safety perception	+	--	++	+	0	0	+	0
Non-welfare impacts								
Intrinsic value of nature								
- Area [ha]	2300	1000	2000	2200	1600	600	200	300
- Links	0	0	++	+	+	0	0	0
- Protected areas	-	-	0	0	-	0	-	0
Other criteria								
Technical complexity	++	++	++	++	++	+	+	0
Robustness								
- Uncertainty	-	--	++	+	0	0	+	0
- Flexibility	--	-	++	0	+	0	0	-
Phasing	++	-	-	0	-	-	++	0
Governmental complexity	+	+	-	0	-	0	-	0

[1] The maintenance requirements of sandbanks are rather uncertain since it is uncertain whether coastal morphology will develop into a new stable state. If this would be true, the lower values are valid. If the sandbanks appear to be rather unstable, maintenance requirements might increase enormously resulting in the higher estimates.

Table 80: Summary of the results of the impact assessments of the proposed coastal management strategies and the basic alternative for the lower climate change scenario. All strategies are assessed in comparison to the basic alternative. The difference of the impacts or effects between the strategies is stated in a qualitative score ranging from -- up to ++. The final row of this table presents the total assessment of the different strategies compared to the basic alternative, based on equal weights for all criteria. The effects marked in green have been changed positively compared to the effects of the strategies designed for the higher climate change scenario, those that are marked red have been changed negatively.

Criterion	Uniform coast; islands	Uniform coast; sandbanks	Uniform coast; dunes in front of existing dunes	Large scale; islands and dunes	Large scale; dunes and sandbanks	Intermediate scale; seaward	Intermediate scale; landward	Small scale; basic alternative
Costs								
Construction costs	--[1]	0	0	--[1]	0	-	0	0
Maintenance costs	--	0	0	--	0	0	0	0
Welfare impacts								
Nature values	++	0	++	++	++	+	0	0
Safety benefits	0	0	+	0	0	0	0	0
Man-made functions	++	0	--	++	--	-	0	0
Equity	++	-	--	0	--	0	-	0
Safety perception	+	--	++	+	0	0	+	0
Non-welfare impacts								
Intrinsic value of nature	0	0	+	+	+	0	0	0
Other criteria								
Technical complexity	++	++	++	++	++	+	+	0
Robustness	--	--	++	+	+	+	+	0
Phasing	++	-	-	0	-	-	++	0
Governmental complexity	+	+	-	0	-	0	-	0
Total assessment	8	-4	5	7	2	-1	3	0

[1] It should be noted that although the comparative scores of these strategies on the construction costs criterion do not change, the ratios of their construction costs to the costs of the basic alternative are about four times higher than the same ratios found for the highest climate change scenario.

Q Ranking coastal management strategies

This appendix contain the table containing all rankings of the proposed coastal management strategies for both the lower and the upper climate change scenarios and according to six different views each awarding different weight to the criteria of the impact assessment. The results presented in this table are discussed in section 4.4 of the main text.

Table 81: Rankings of the proposed coastal management strategies for both the lower (L) and higher (H) climate change scenarios, based on different weighting strategies. The total scores from the assessments according to a certain view are indicated by [#].

Position	Non-weighted		Leading criteria		Spatial development view		Risk averting view (financial)		Socially acceptable view		Sustainable view	
	L	H	L	H	L	H	L	H	L	H	L	H
1	UI [6]	UI [6]	UD LID IL [3]	UD LID [3]	UI LID [10]	UI LID [10]	IL [8]	IL [8]	UI [6]	UI [6]	UD [12]	UD [12]
2	LID [5]	LID [5]	LDS [2]	IL [1]	UD IL [2]	UD [1]	UD [2]	UD [2]	IL [2]	LID IS [1]	LDS [8]	IS [7]
3	UD [4]	UD [3]	UI SBA [0]	UI IS SBA [0]	LDS [1]	IS SBA [0]	LDS SBA [0]	LDS SBA [0]	UD LID [1]	UD SBA [0]	IL [6]	IL [5]
4	IL [3]	IS [2]	IS [-2]	LDS [-2]	SBA [0]	IL [-1]	IS [-2]	IS US [-2]	SBA [0]	IL [-1]	IS [4]	LDS [4]
5	LDS IS SBA [0]	IL [1]	US [-3]	US [-3]	US [-1]	US [-3]	US [-4]	UI [-5]	IS [-2]	LDS [-6]	LID [3]	LID [3]
6	US [-3]	SBA [0]			IS [-2]	LDS [-4]	UI [-5]	LID [-6]	LDS [-4]	US [-7]	SBA [0]	SBA [0]
7		LDS [-2]					LID [-6]		US [-7]		US [-9]	UI US [-10]
8		US [-3]									UI [-10]	

Note: UI = Uniform coast; islands
US = Uniform coast; sandbanks
UD = Uniform coast; dunes in front of existing dunes
LID = Large scale; islands and dunes
LDS = Large scale; dunes and sandbanks
IS = Intermediate scale; seaward
IL = Intermediate scale; landward
SBA = Small scale; basic alternative

R Sensitivity analysis

In order to find out how the potentially differing assessments, all stated in Table 15, will influence the assessment results, a random simulation should be applied. During this simulation, all uncertain impact assessments should be changed randomly according to their ranges identified in this table. This will cause variations in the outcomes of the assessments for all strategies and for every single view for weighting the criteria.

This random calculation process is executed by applying a special Excel tool for sensitivity and uncertainty analyses: @RISK. Distributions of input parameters can easily be defined in a standard Excel worksheet. In this specific case, discrete distributions are inserted since the values of the impact assessments can only be -2 (--), -1 (-), 0, 1 (+) or 2 (++). Graphs are shown for each distribution inserted within the worksheet. Examples of some of these graphs are included in Figure 115.

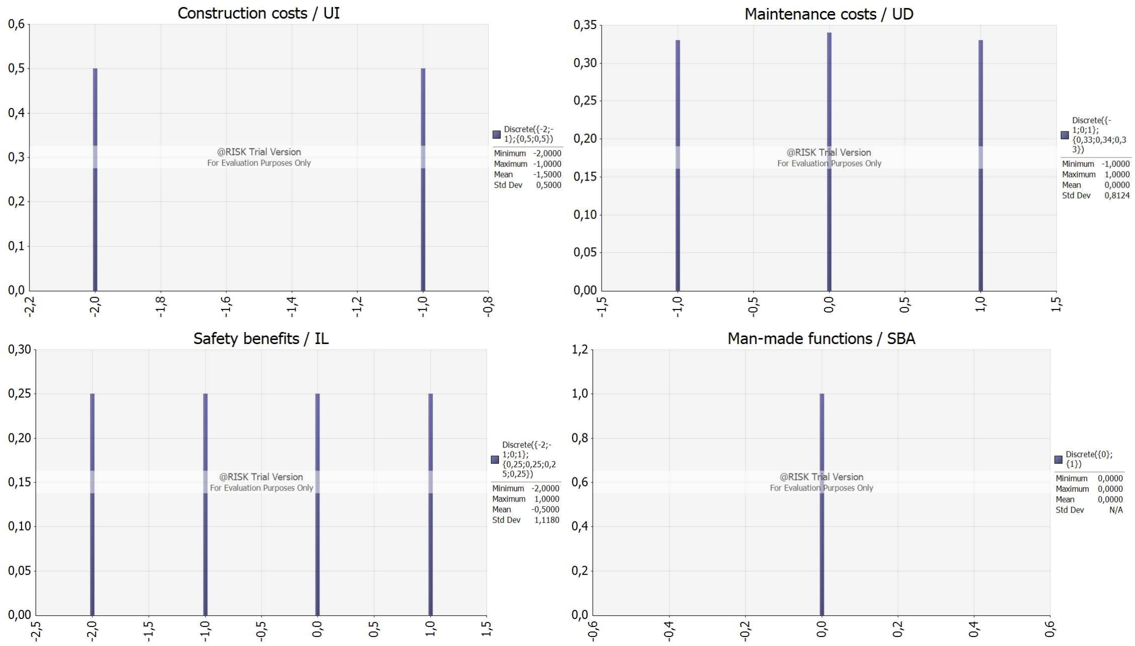
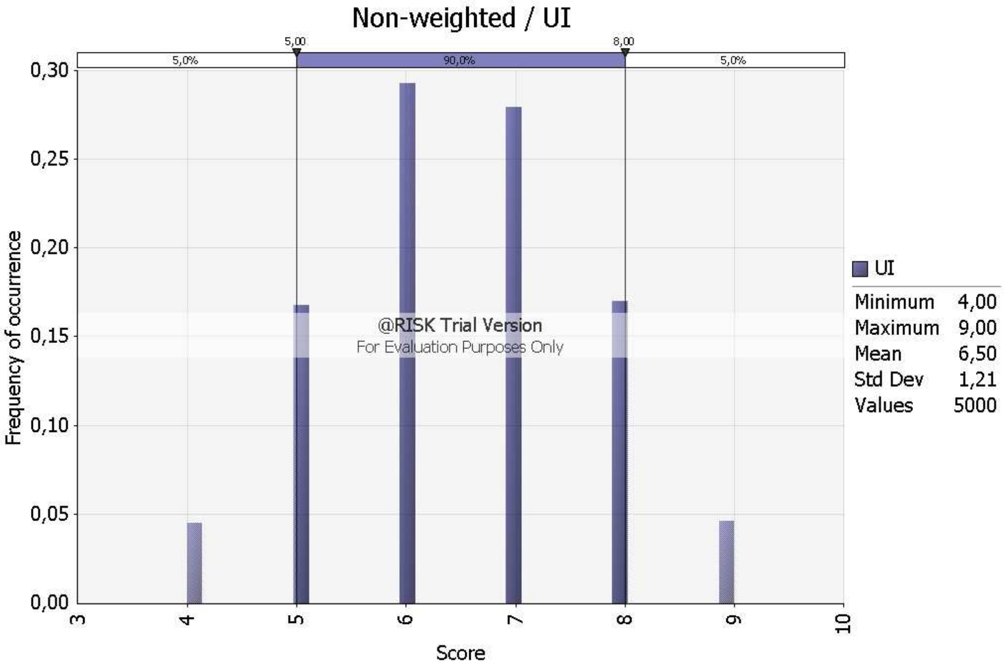


Figure 115: Input in @RISK for running the sensitivity analysis of the assessment results.

Subsequently, after inserting all uncertainty distributions of the impact assessment, the model is run. One model run contains 5000 iterations and for every iteration the scores of the uncertain impact assessments are randomly determined from the defined input distributions by Latin Hypercube sampling. And for each of these iterations the scores of the different strategies are calculated for all views (for all sets of weights) of the total assessment. At the end of all iterations, the resulting distributions of the scores over all iterations are summarized per strategy and per view. Two graphs presenting some of these results for the non-weighted view are presented in Figure 116.



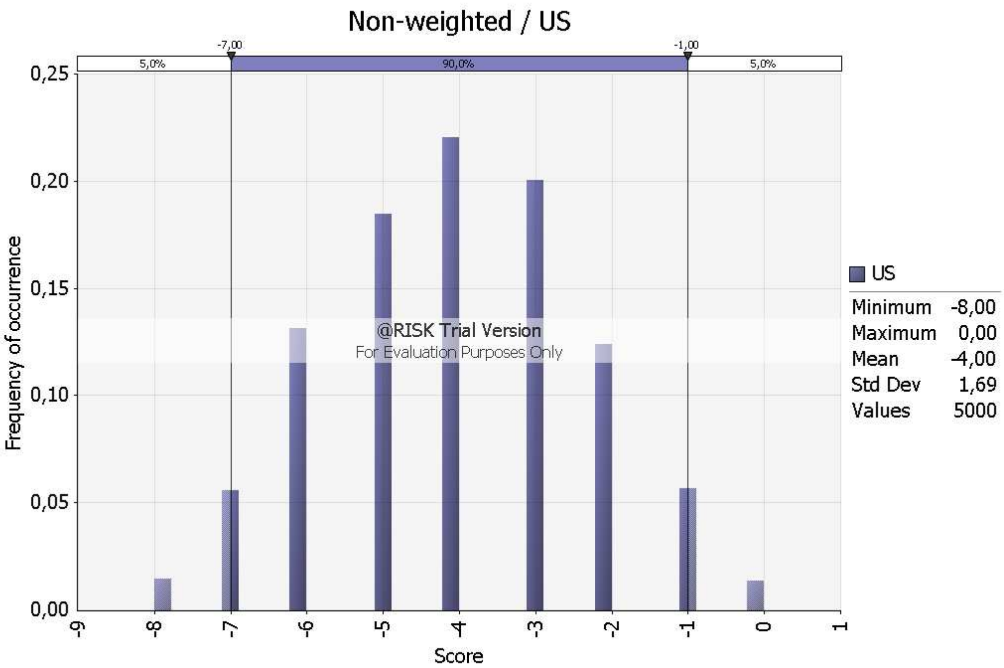


Figure 116: Distributions of the scores of two of the coastal management strategies (uniform islands and uniform sandbanks) after an @RISK simulation including all stated uncertainties within the separate criteria assessments.

The resulting distributions for all strategies can be summarized in separate box plots for every view of the assessment and for both the upper and the lower climate change scenario. These box plots are included in the figures below (the first one for the highest climate change scenario, the second for the lower climate change scenario) and clearly show the sensitivity of the ranking of the different strategies to the uncertainties inherent in the impact assessments of these strategies. Each of the boxes shown in these plots represents 50% of the scores calculated for the strategies within the 5000 @RISK simulations. The bars below and above these boxes indicate the 90% intervals of the distributions of these scores. Mean values of the distributions of the calculated scores are indicated within the boxes.

These box plots should be interpreted as follows: When a major part (more than half) of the depicted box of a strategy overlaps with another box for another strategy with a lower mean score, no clear distinction can be made on which of the concerned strategies scores significantly better. This is caused by the fact that the remaining chance that the one strategy with the higher mean score is indeed assessed better than the other strategy with the lower mean score is smaller than 50%. However, when the boxes of two strategies do not overlap but only the bars surrounding the box do so, the remaining chance that the actual score of the strategy with a higher mean score still turns out to be better than the actual score of the strategy with the lower mean score increases. The impacts of strategies could best be distinguished when neither the boxes, nor the bars are overlapping. In that case, the probability for a misinterpretation of the results due to the uncertainties inherent in the impact assessments is smaller than 5%.

Note that for some box-plots no lines are depicted above and below the box. In these cases, the 50% interval of the assessment results coincides with the 90% interval. This can occur when only a few possible final scores are found in the sensitivity analysis and each of these scores has a relatively large probability of occurrence.

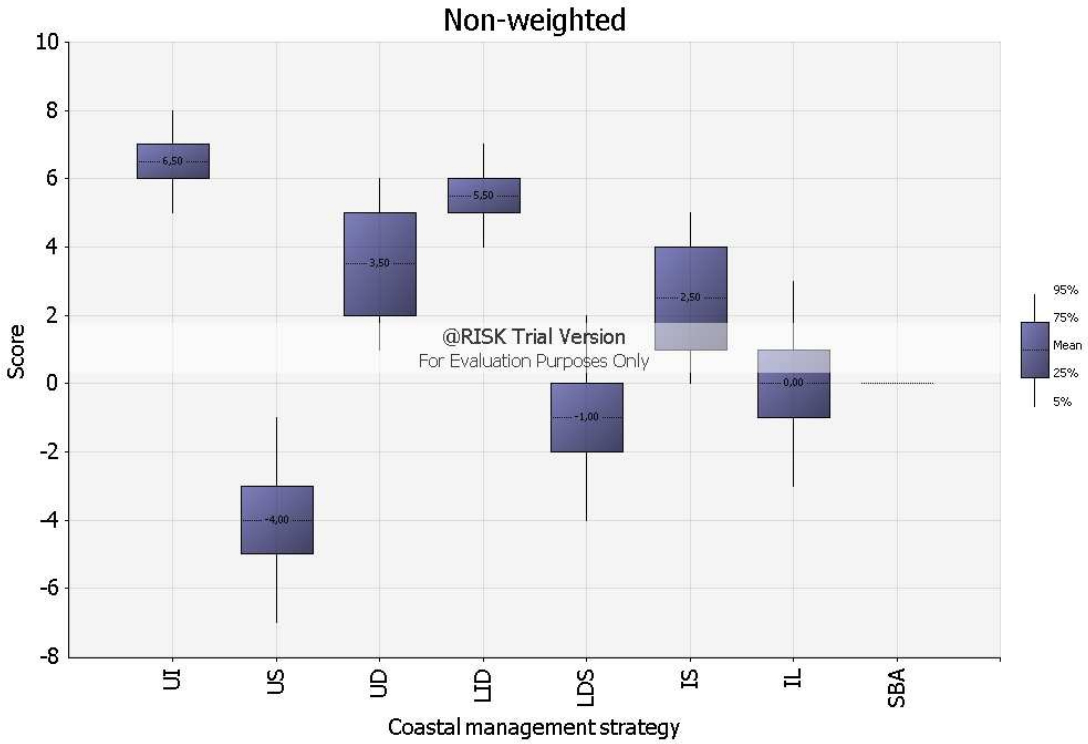


Figure 117: Resulting box plot of the sensitivity analysis of the total scores of the proposed coastal management strategies for the **highest** climate change scenario according to the non-weighted assessment perspective.

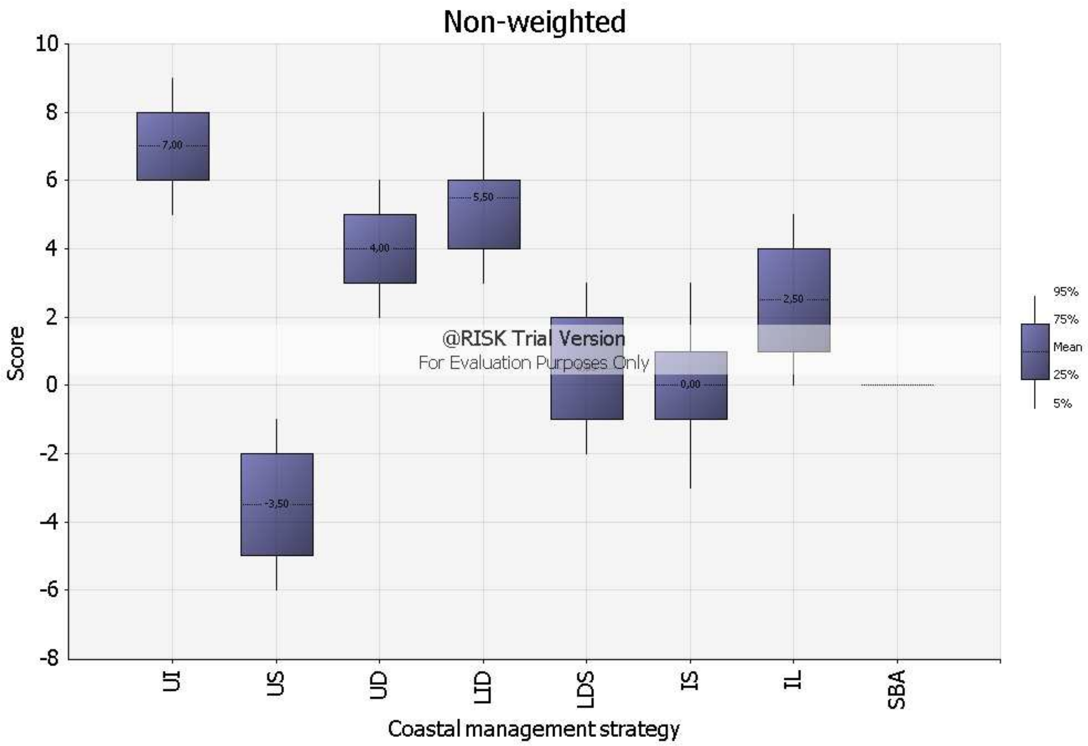


Figure 118: Resulting box plot of the sensitivity analysis of the total scores of the proposed coastal management strategies for the **lowest** climate change scenario according to the non-weighted assessment perspective.

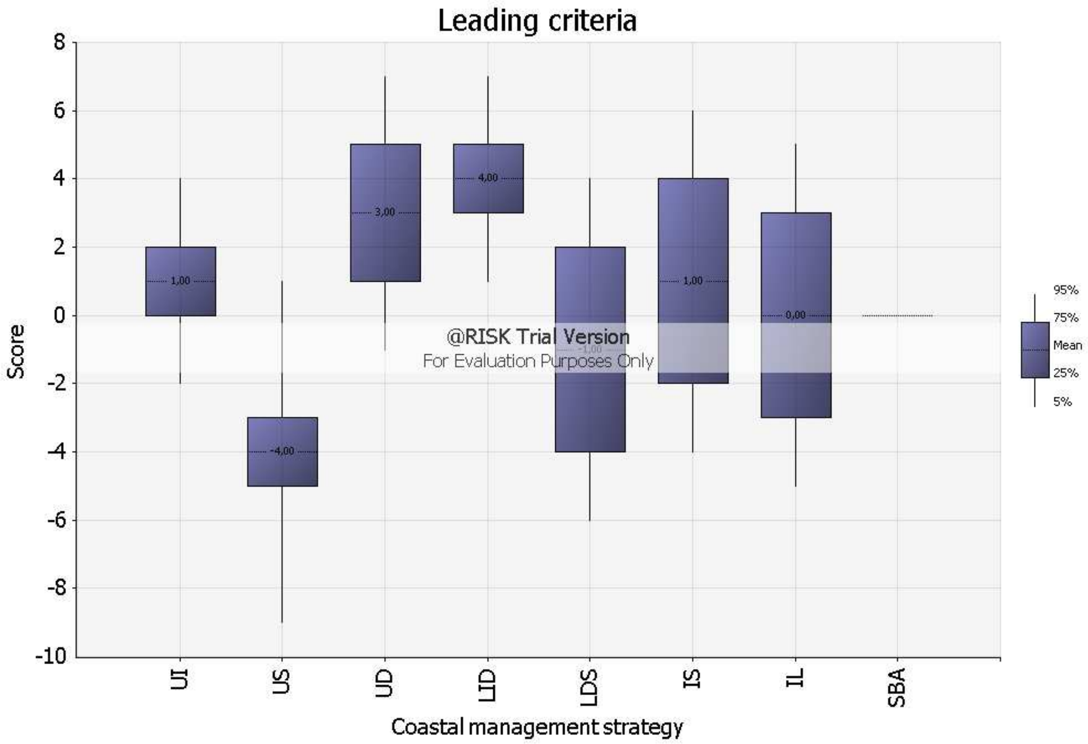


Figure 119: Resulting box plot of the sensitivity analysis of the total scores of the proposed coastal management strategies for the **highest** climate change scenario according to the technical assessment perspective.

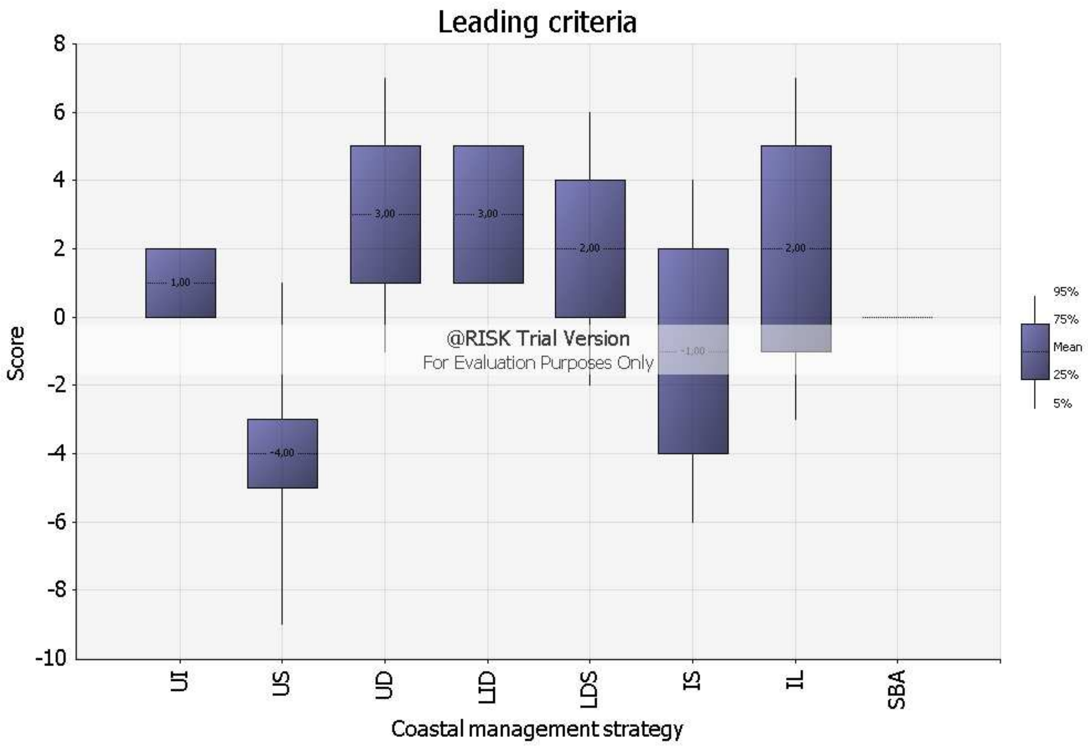


Figure 120: Resulting box plot of the sensitivity analysis of the total scores of the proposed coastal management strategies for the **lowest** climate change scenario according to the technical assessment perspective.

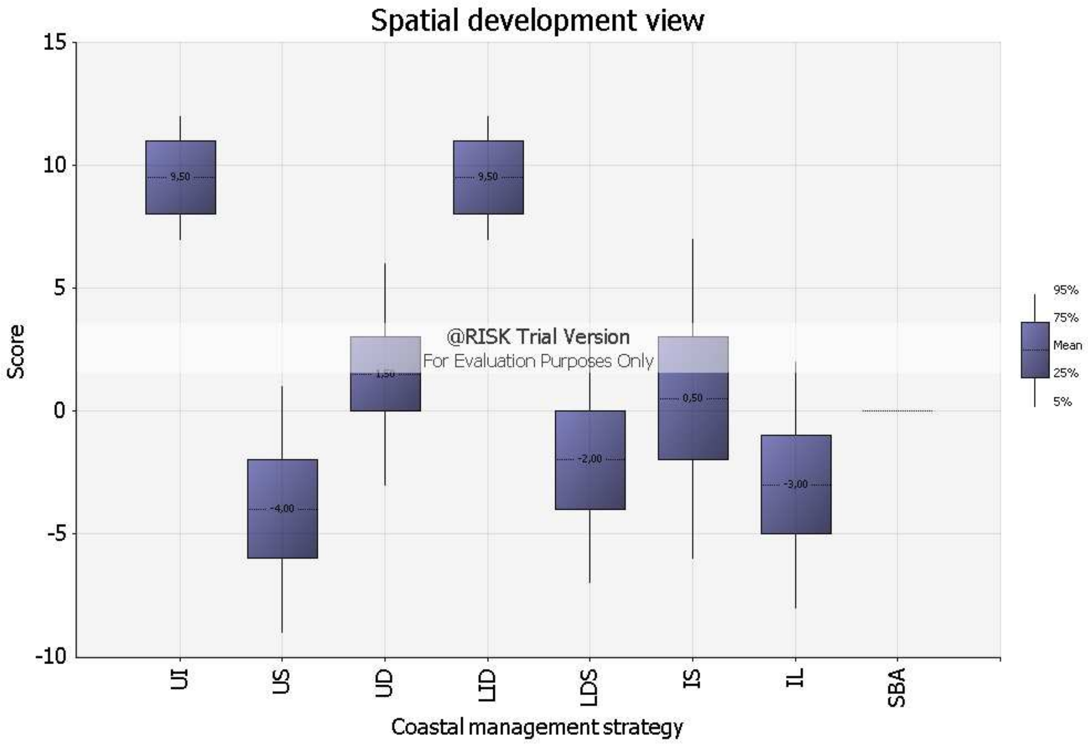


Figure 121: Resulting box plot of the sensitivity analysis of the total scores of the proposed coastal management strategies for the **highest** climate change scenario according to the spatial development assessment perspective.

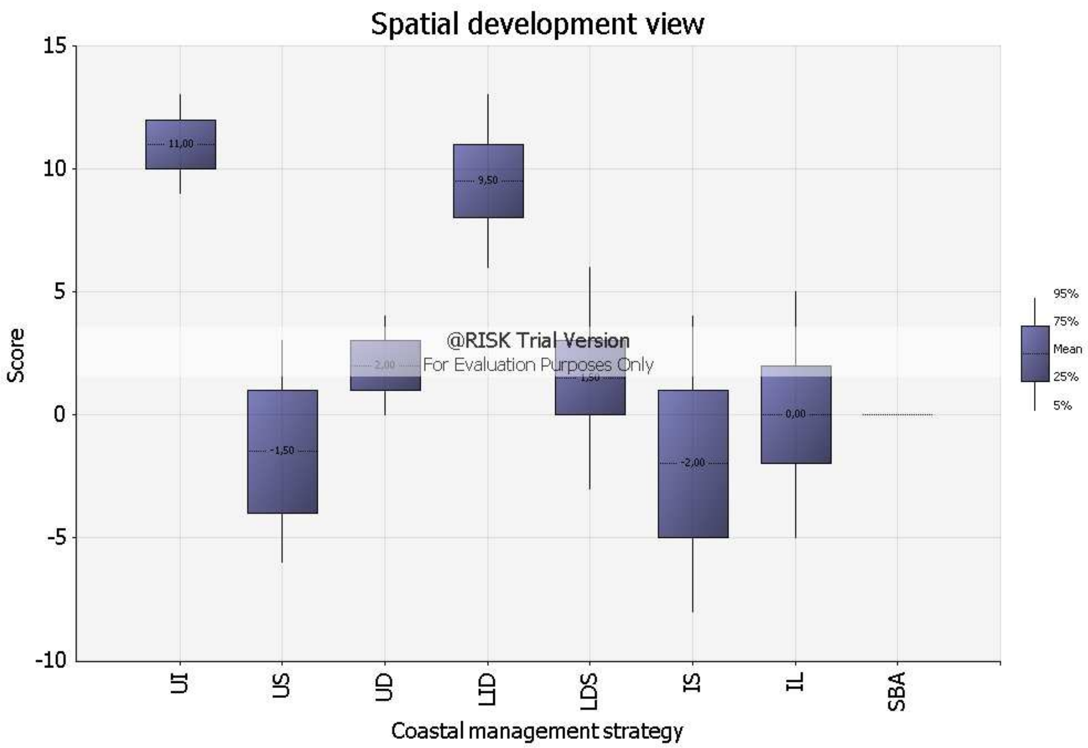


Figure 122: Resulting box plot of the sensitivity analysis of the total scores of the proposed coastal management strategies for the **lowest** climate change scenario according to the spatial development assessment perspective.

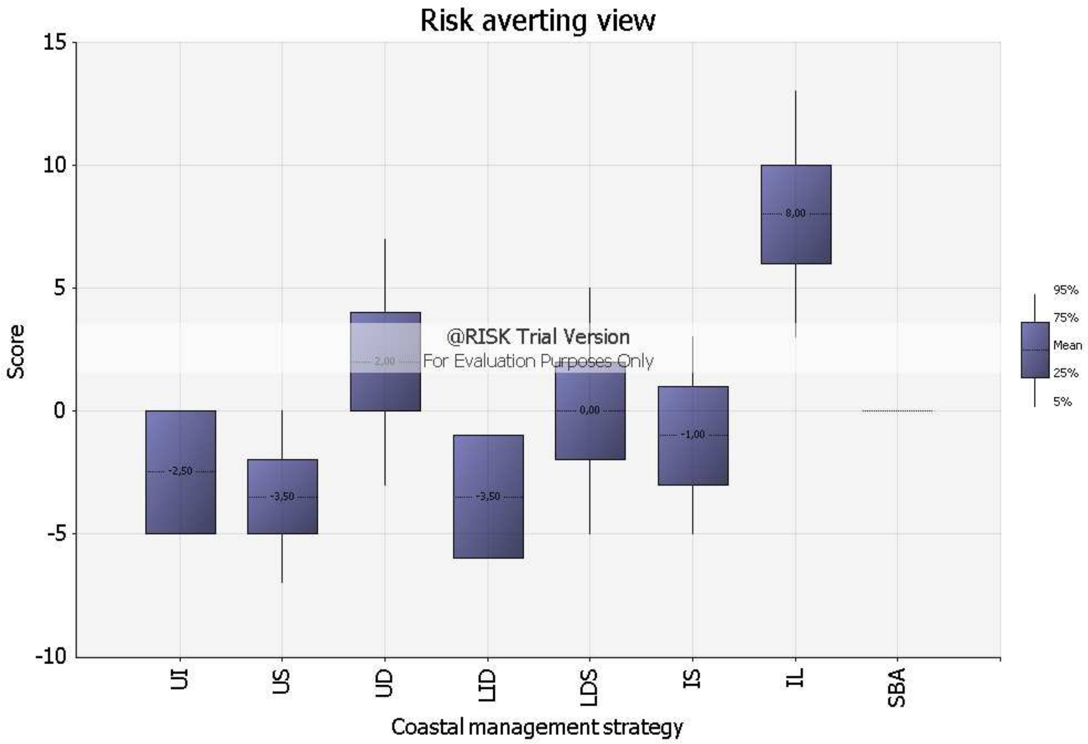


Figure 123: Resulting box plot of the sensitivity analysis of the total scores of the proposed coastal management strategies for the **highest** climate change scenario according to the risk averting assessment perspective.

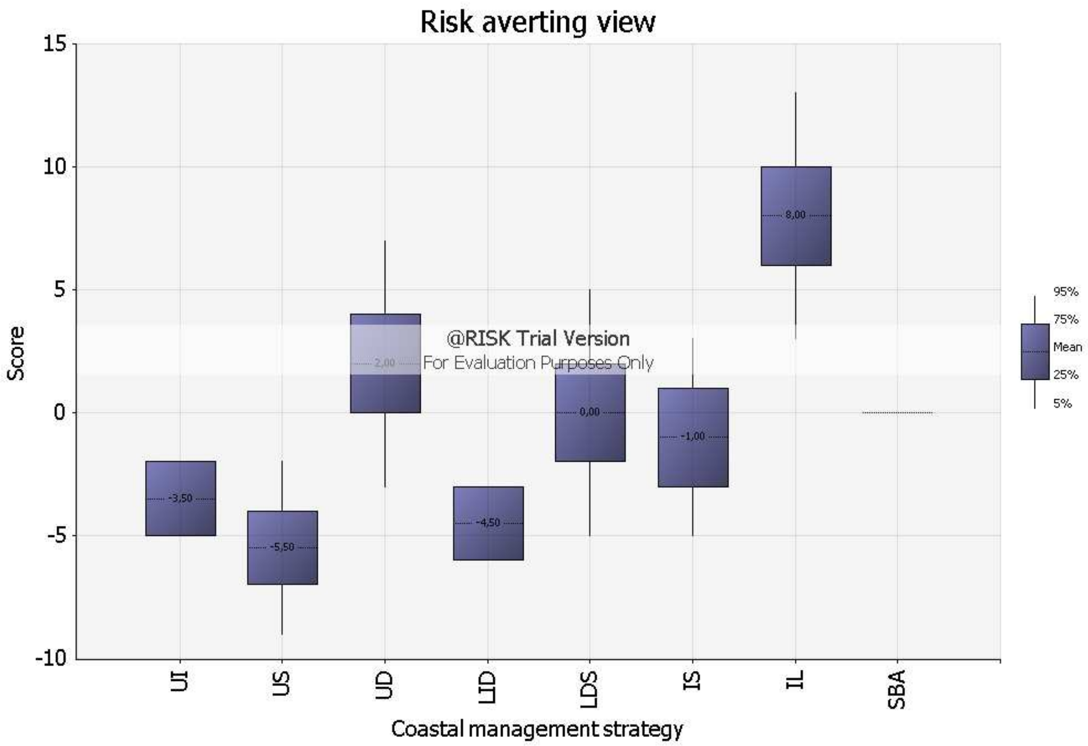


Figure 124: Resulting box plot of the sensitivity analysis of the total scores of the proposed coastal management strategies for the **lowest** climate change scenario according to the risk averting assessment perspective.

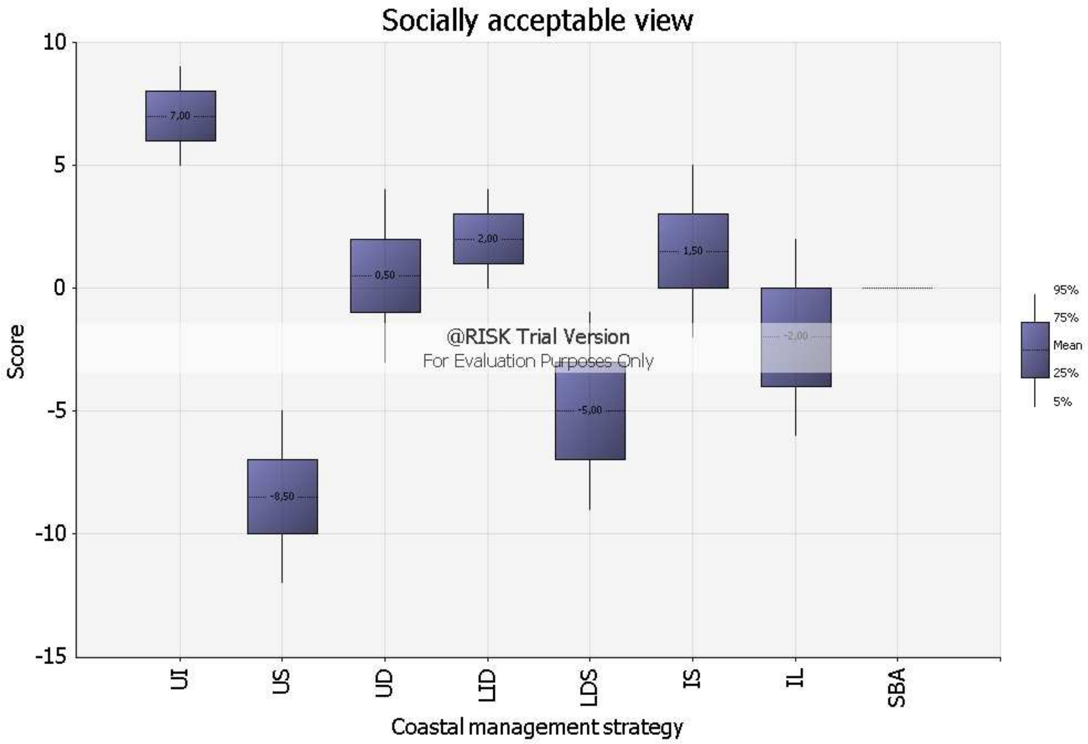


Figure 125: Resulting box plot of the sensitivity analysis of the total scores of the proposed coastal management strategies for the **highest** climate change scenario according to the socially acceptable assessment perspective.

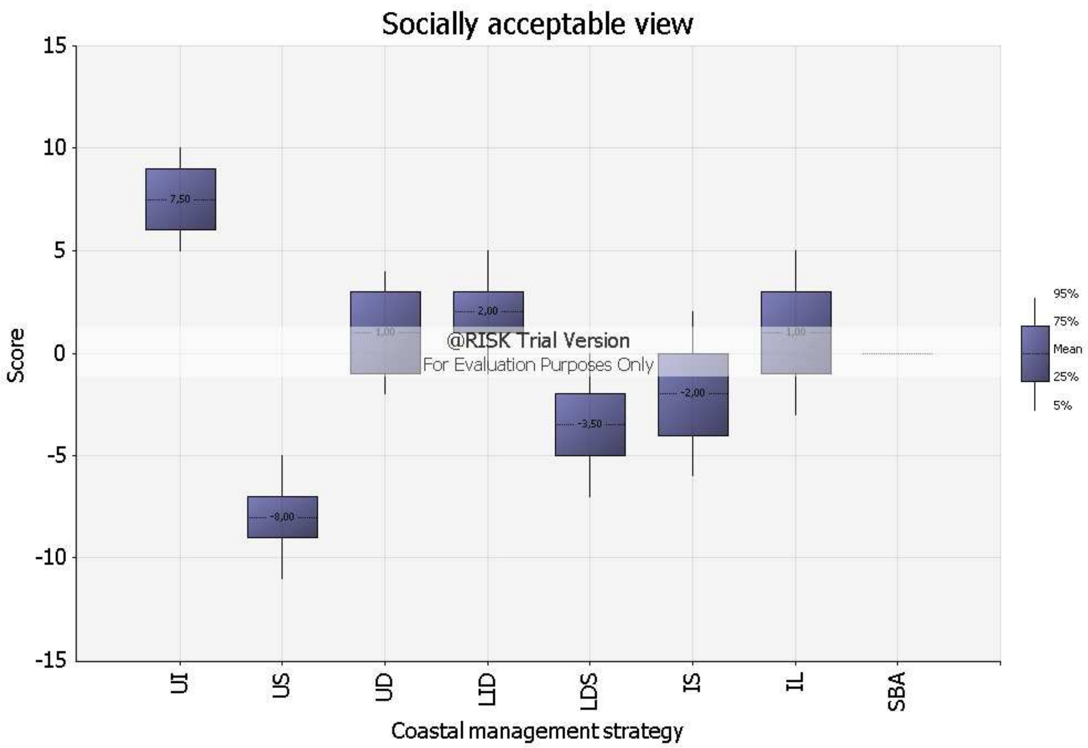


Figure 126: Resulting box plot of the sensitivity analysis of the total scores of the proposed coastal management strategies for the **lowest** climate change scenario according to the socially acceptable assessment perspective.

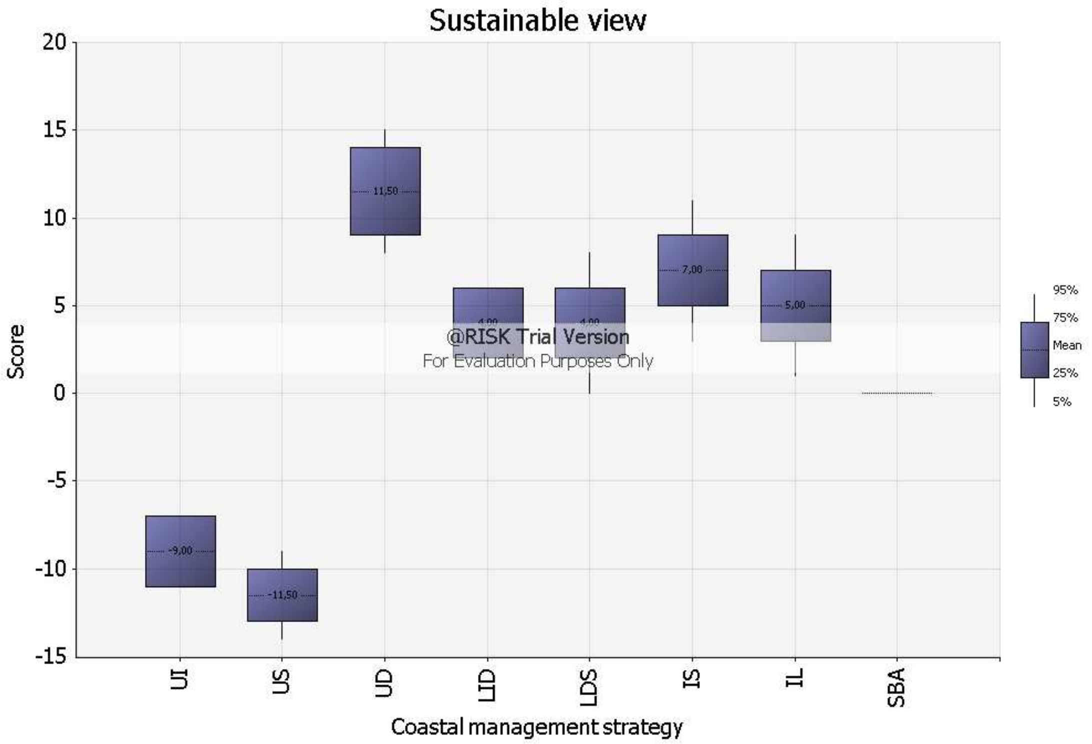


Figure 127: Resulting box plot of the sensitivity analysis of the total scores of the proposed coastal management strategies for the **highest** climate change scenario according to the sustainable assessment perspective.

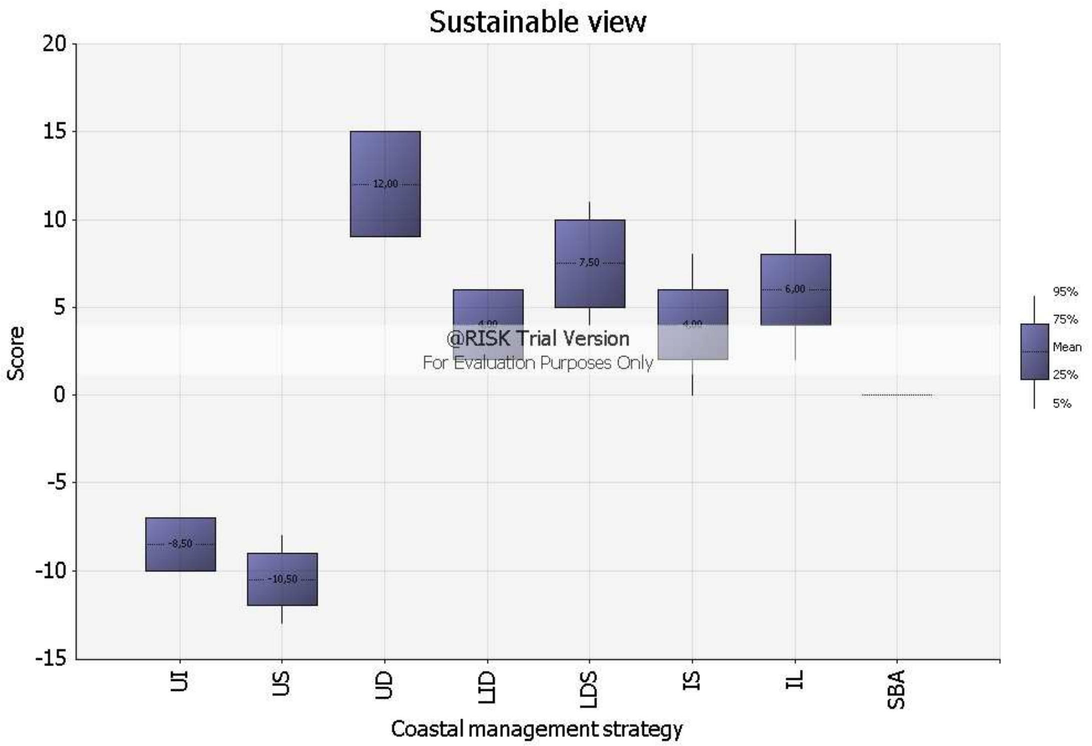


Figure 128: Resulting box plot of the sensitivity analysis of the total scores of the proposed coastal management strategies for the **lowest** climate change scenario according to the sustainable assessment perspective.