Knowledge for Climate

Exploring adaptation pathways

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Content

Summary

A flood risk management strategy encompasses measures which reduce the flood risk to an acceptable level. The problem though, is that the future flood risk can never be determined without some degree of uncertainty. Decision makers therefore struggle in choosing an appropriate flood risk management strategy. To overcome this problem several methods have recently become available that aid in developing strategies which require dealing with some degree of future uncertainty. A promising method is the Adaptation Pathway method.

For the unembanked area within the Feijenoord neighbourhood and Noordereiland in the city of Rotterdam, adaptation pathways have been developed. Information on the effectiveness over time of possible measures gained through a tipping point analysis, acted as building blocks to the development of the pathways. The current urban design was taken as the reference situation and compared to a situation with implementation of measures.

The results from the adaptation pathway method can aid policy makers in making a choice in long term flood risk management approach. The method results in an insight into the urgency to adapt to climate change, insight into the effectiveness over time of the possible measures and visualizes the link between long term policy approaches and the possible measures

1 Introduction

1.1 Making decisions for an uncertain future

The Rotterdam region has the ambition to transform the unembanked areas into high density residential and office areas. Most of these areas are elevated to a level where inundation is very unlikely to occur. Some of the lower parts encounter inundation along the edges once every few years. In future, inundation of these unembanked areas could occur more frequently though as a result of a rising sea level and increasing river discharges. When developing these areas, this fact will need to be taken into account, however it is yet highly uncertain to what extent the frequency of inundation will increase over time. It is therefore essential to develop a flood risk management strategy for these areas which takes this uncertain future into account.

A flood risk management strategy encompasses measures which reduce the flood risk to an acceptable level. The choice for an appropriate flood risk management strategy is often based on an area's present flood risk as well as the projected future flood risk due to climate change. With this information flood risk reducing measures are selected, addressing the identified flood risk in the area under consideration. The problem with this approach though, is that the future flood risk can never be determined without some degree of uncertainty. Decision makers therefore struggle in choosing an appropriate flood risk management strategy. To overcome this problem several methods have recently become available which aid in developing strategies which require dealing with some degree of future uncertainty. A promising method is the Adaptation Pathway method (AAP) which also incorporates the Tipping Point Analysis method (TPA). Adaptation pathways show how long a strategy would be effective and if and when a switch could be made to another strategy.

Within the context of the Knowledge for Climate project 'Adaptive development strategies in unembanked areas of the Rotterdam hotspot region' (HSRR31), adaptation pathways have been developed. The objective was to aid decision makers by providing insight into the effectiveness of different flood risk management approaches over time as well as the available flexibility to switch to other approaches. The adaptation pathways were also developed as an exercise on the use and application of the method within the context and scale of an urban planning development.

1.2 Adaptation pathways and tipping point analysis

Adaptation pathways describe a sequence of water management policies (or measures), enabling policy makers to explore options for adapting to changing environmental and societal conditions (Haasnoot et al, March 2012). Elements of the method such as the 'visualisation of moment to switch' and 'the possibility to explore options' aid in making choices which involve taking uncertainties into account.

An important building block to the development of the adaptation pathways is the information on the effectiveness over time of possible measures. A *tipping point analysis* defines the moment (or period) in time when climate change effects (e.g. increasing water levels or flood frequencies) reach such an extent that certain policy objectives can not be met anymore and thus give an indication of the urgency for adaptation. A tipping point analysis can be applied to assess current policy as well as give insight into the effectiveness of proposed flood risk reducing measures in view of climate change. Kwadijk et al (2010) define a tipping point as:

"point where the magnitude of change due to climate change or sea level rise is such that the current management strategy will no longer be able to meet the objectives. This gives information on whether and when a water management strategy may fail and other strategies are needed."

1.3 Approach and context

The Knowledge for Climate project 'Adaptive development strategies in unembanked areas of the Rotterdam hotspot region' (HSRR31) aims to obtain a deeper understanding of the problems, possibilities and obstacles in developing adaptive strategies for the urbanised unembanked areas within the Roterdam region. The KfC 3.1 project will contribute to further development of a Rotterdam adaptation strategy.

As a first step in developing possible flood risk management strategies for the Rotterdam area, a vulnerability analysis identified the areas where flood risks are high (work package 1) and through a design research exercise, (packages of) possible measures to reduce the flood risk within the case study areas were identified (work package 2). A tipping point analysis evaluated the sustainability of the current policy as well as the proposed flood risk reducing measures. This information was used as input for the development of the adaptation pathways. The analysis resulted in a series of adaptation pathways which provide insights for policy makers into options, lock-in possibilities and path dependencies, thus providing a valuable starting point for decision makers on short term policy actions, while keeping options open and avoiding lock-ins (Haasnoot et al, June 2012).

1.4 Research scope

The vulnerability analysis focussed on the unembanked part of the Feijenoord neighbourhood and the Noordereiland. The vulnerability analysis identified the Kop van Feijenoord and Noordereiland as most vulnerable areas within this region (Veerbeek et al, 2012). These areas were therefore selected for further analysis of possible measures and strategies.

1.5 Reader

A brief introduction to the study area and a summary of the Identified flood vulnerability and risks is given in Chapter 0. Chapter 3 explains how the adaptation tipping point method and adaptation pathways were applied within the research project. The results of the tipping point analysis are presented in chapter 4 (current situation) and chapter 0 (implementation of measures). The results on the development of the adaptation pathways can be found in chapter 6. Chapter 7 presents the overall conclusions and further recommendations.

2 The Feijenoord neighbourhood and the Noordereiland

2.1 Flood hazard and vulnerability within the study area

The KfC 3.1 project focuses on the unembanked area within the Feijenoord neighbourhood and the Noordereiland. The study area is not protected by flood defences and flooding of the study area is caused by high water levels in the adjacent river.

A first assessment carried out under the KvK project HSRR02 (Veerbeek et al, 2010) assessed the current and future flood hazard resulting in information on flood water extent and depth for the highly urbanised unembanked Rotterdam region along the Meuse River. The results reveal a diverse pattern of flood characteristics within the study area. Based on the flood characteristics 'flooding-frequency', 'water depth' and 'flood duration', five homogeneous sub-areas are detected with similar flood characteristics. These areas are illustrated in Figure 2.1. An overview of the five sub-areas is also given in Table 2.1.

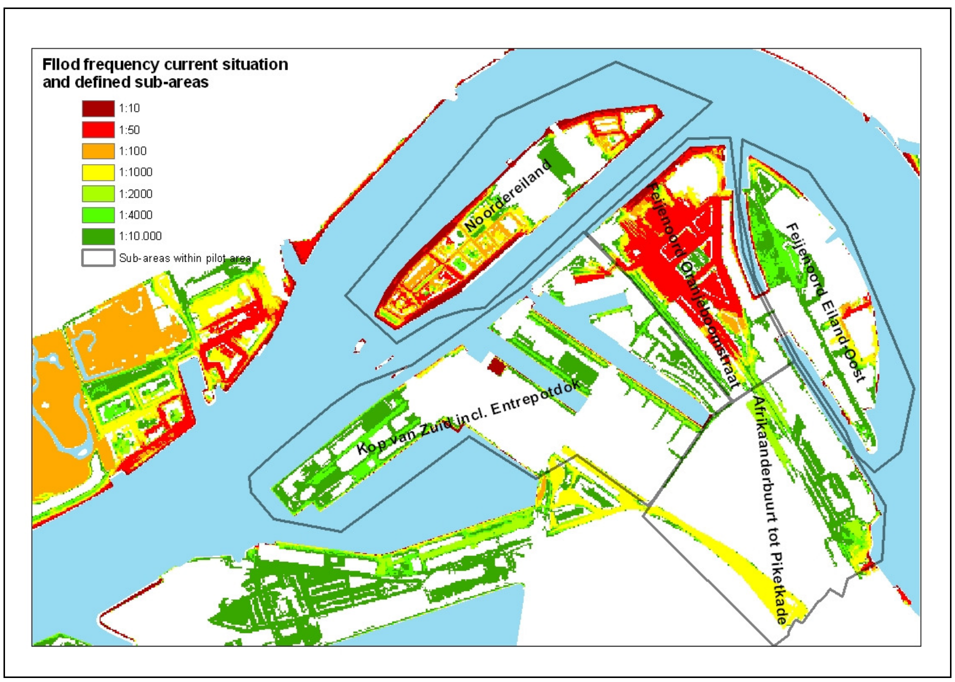

Figure 2.1 **Defined sub-areas according to the flood characteristics**

Table 2.1 Overview and description of the homogeneous flood areas within the unembanked Feijenoord region and Noordereiland

Name	**Description**	**Area type**
Noordereiland	A low-lying island with high flood frequencies. Medium water depths could be reached.	Low island
Kop van zuid including Entrepotdok	A high peninsula. Flooding does not occur frequently. Water depths are small.	High (is)land
Kop van Feijenoord (Feijenoord Oranjeboomstraat)	A deep basin prone to flooding.	Deep basin
Afrikaanderbuurt tot Piketkade	A high area not prone to flooding.	High (is)land
Feijenoord Eiland Oost	A high island not prone to flooding	High (is)land

Within the context of the KvK 3.1 project, a vulnerability analysis was performed, looking into the flood damages to buildings and infrastructure and into critical infrastructure (Veerbeek et al, 2012). The results identified the Kop van Feijenoord and Noordereiland as vulnerable areas to flooding.

The Noordereiland has low ground levels and frequent flooding of the island (> 1:10 years) is foreseen, although the water depths are not expected to be very high (< 30 cm). Flooding of the Noordereiland area proceeds gradually from the perimeter to the centre of the island. Currently, the perimeter (i.e. the quays) flood frequently, with return periods of 1:10 years or less (Veerbeek et al, 2012). The Kop van Feijenoord is a basin shaped area prone to flooding (approximately 1:50 years) where water depths of 1 – 1,5m can be reached.

More detailed information on the river water levels and climate change effects for the study area is included in appendix 9.1.

2.2 Current policy approach for dealing with flood risks

Noordereiland

Currently no specific flood risk management strategy is followed other than a prescribed raised ground level for new developments (which are rare) and prevention of casualties through evacuation. Many of the buildings on the Noordereiland were build in a time when flooding occurred more frequent and often these older buildings were developed with dry-proofing measures such as raised floor levels or a dry-proof plinth. With the construction of the Maeslant flood defence, flooding became rare. The preceding years though on several occasions the water levels have reached a level which caused flooding of the quays.

Kop van Feijenoord

The current strategy in dealing with flood risk in the area Kop van Feijenoord is equal to the strategy followed for the Noordereiland. New developments are build on elevated ground levels and citizen safety is attained through evacuation. This policy has led to a diversity in ground levels throughout Kop van Feijenoord because the prescribed ground level increased through the years. From a spatial planning point of view this is not a desirable situation, so other solutions to deal with the flood risks are necessary. It should therefore be noted that in this area it is not only the increase in flood risk triggering the call for other solutions as an alternative to the current strategy.

3 Tipping point analysis and adaptation pathways further explained

3.1 Overview of the approach

The results from the vulnerability analysis (WP1) (Veerbeek et al, 2012) give insight into the flood impacts and risk development over time. They give detailed information on the extent of the impacts and risk for different neighbourhoods within the Rotterdam unembanked area, such as information on damages to housing and interior or the locations of vulnerable infrastructure. The results show which areas encounter the highest impacts and risks and which the lowest. From this information, it could be concluded that the areas with the highest impact and risks require immediate action and the areas with relatively low impacts and risk do not require any actions. But what if the highest encountered impacts and risk are considered acceptable, or encountered lower impact and risk are beyond an accepted limit? This illustrates that to be able to take decisions on appropriate actions, it is required to define up to which impacts and risk values the flood consequences are considered acceptable. The selected limits can be seen as objectives and can be used to assess to what extent an area is in compliance with these objectives.

A tipping point analysis assesses for an area the moment in time at which the maximum acceptable limits are reached due to climate change. This point in time is called the tipping point. A tipping point analysis was performed for the unembanked areas of the Feijenoord neighbourhood and the Noordereiland. The next step was to assess the list of possible (packages of) measures (WP2) (Doepel et al, 2012). Implementation of measures will result in a reduction of flood impacts and risk and therefore stretch the moment in time at which the tipping point is reached. Some measures will be more effective in moving the tipping point than others.

The results from the tipping point analysis, an overview of the effectiveness of the possible measure, act as building blocks for the development of adaptation pathways. The adaptation pathways visualise the possible flood risk management measures through time and indicate if and when a switch should be made to another measure when due to climate change the effectiveness of a measure reduces.

The tipping point analysis and the adaptation pathways development were undertaken within the context of the work packages 1 and 2. The results from these work packages acted as input for the tipping point analysis and adaptation pathways development. This is illustrated in Figure 3.1.

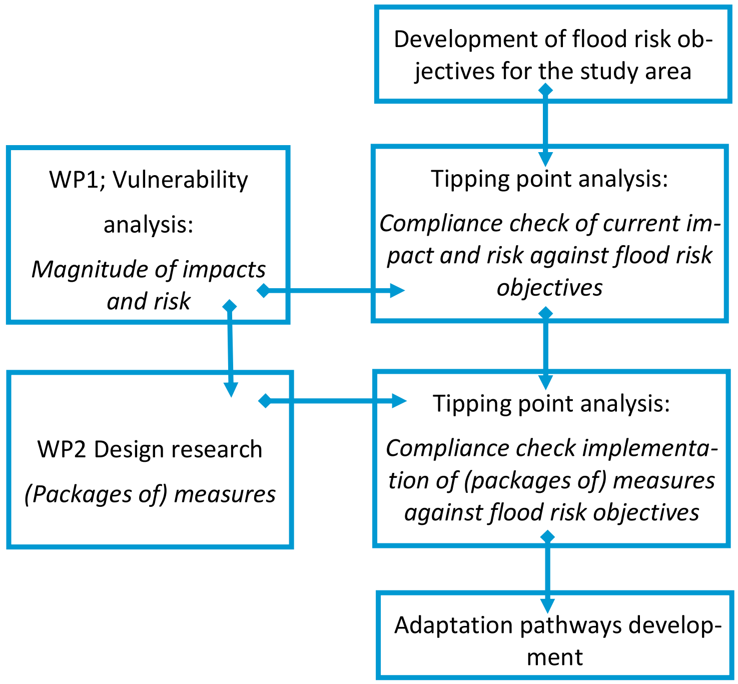

Figure 3.1 **Overview of the approach and linkage with work packages 1 and 2.**

3.2 Flood risk objectives

For the areas unprotected by flood defences, at present policy is only in effect for newly developed areas. These areas are elevated to a height equal to the current 1:10.000 water level. At present the Province of South Holland is developing alternative policy for new urban developments based on a maximum tolerated flood risk to people and social disruption. Within the context of the KvK 3.1 research project, objectives and threshold values have been defined in line with the policy of the Province. The objectives set by the province have been extended though with objectives and threshold values for damage to buildings and infrastructure. This paragraph provides an overview of the defines objectives. A full explanation on the objectives can be found in appendix 9.2.

Objective 1: social disruption

Certain urban functions are essential elements of daily life or are crucial during an emergency situation and failure of these urban functions will result in social disruption. A selection of urban functions have been identified as crucial and may not fail even during extreme flood events (up to a probability of 1:10.000 years). Table 3.1 gives an overview of these functions.

Table 3.1 Urban functions with may not fail even during extreme flood events (≥ 1: 10.000 years).

Urban functions	**Remarks**
Electricity substation	
Communication	Not addressed by the Province of South-Holland
Evacuation and emergency services routes	
Metro including the metro stations	High damages expected and long recovery time
Train including the train stations	High damages expected and long recovery time
Ground floor bound living (single floor)	
Hazardous activities	Appraised higher then the Province , loss of income
24-hour medical care	

Objective 2: Damages to the urban area

The objectives for damages to the urban area have been grouped in three categories:

1. *Damages to existing buildings*: No damages are tolerated (including the interior) for flood events up to a frequency of once in a 100 years. Damages are accepted for less common floods.

2. *Damages to newly build and renovation*: No damage are tolerated (including the interior) for flood events up to a frequency of once in a 1000 years. Damages are accepted for less common floods.

3. *Damages to public space*: No damages are tolerated for flood events up to a frequency of once in a 100 years. Damages are accepted for less common floods.

Objective 2: Risk of casualties

A measure used to express the risk of casualties is the Local individual risk (LIR). The Local Individual Risk is defined as:

The probability that an unprotected person could die as a result of a flood in one specific location within a period of one year, taking into account the possibilities for evacuation.

The LIR may not exceed a value of 10^{-6} for 95% of the area. This threshold has been adopted from the policy that is being developed by the Province of South Holland and is based on the values for safety applied in the field of external safety.

For the evaluation of risk of casualties, use was made of risk maps developed with use of a tool developed by the Province of South Holland (Huizinga et al, 2011). The tool only allows to assess the risk of casualties for a situation with a sea level rise of 35 cm and more, thus no insight is available on the casualty risk under current conditions. The tool also does not provide functionality to assess the effectiveness of measures on reducing casualty risks. Therefore the measures and Packages of Measures were not assessed for this target.

3.3 Tipping point analysis

The tipping point method can be applied to either assess current policy or to compare and weigh alternative solutions (te Linde and Jeuken, 2011). Within the context of the vulnerability analysis, the tipping point method was applied to assess the impacts and flood risk of the case study area in time and thus gain an indication of the urgency for adaptation. A tipping point analysis was also executed to assess the effectiveness of implementation of measures. A tipping point analysis is performed according to the following steps:

1. *Define scope*. Defining the scope includes defining the area and climate hazard to assess.

2. *Define indicators (objectives) and threshold values*. The next step is to outline the objectives and threshold values. This process includes discussion and coming to agreements on acceptable levels for flood impacts and risk.

3. *Assess the systems threshold*. The objective and threshold values are then assessed. This gives an indication of the extent of climate change effect at which the set objectives can not be met anymore.

4. *Define the time range in which the threshold is expected to occur*. The final step is to assess the moment in time at which the objectives can not be met anymore.

3.4 Adaptation pathways

Often several flood risk management strategies can be identified depending on the policy one wants to follow. For example, does a municipality take full responsibility or aim for a shared responsibility with building owners, are costs a limiting factor or are the measures integrated in an overall urban development plan, does one seek to implement a long term solution or rather focus on the urgent flood risk issues and implement further measures when more insight into the climate change effects are available?

During a workshop with stakeholders and specialists, several adaptation pathways were developed. with different policy approaches as a starting point. Thus each adaptation pathway was developed within the context of a certain policy approach. A simplified version of the workshop process as described in Roosjen (2012) was followed. By following this method the participants were stimulated to an ‘adaptive way of thinking’ through elements such as the diversity of future perspectives and the possibility to switch to other measures or adaptation pathways (Roosjen, 2012). For the development of the adaptation pathways, the following steps were applied. Steps 1 and 2 were executed preceding to the workshop . Steps 3 to 5 were implemented at the workshop.

1. *The urgency to adapt*. Determine the tipping point, the moment in time where climate change effects reach such an extent that the objectives can not be met anymore (Chapter 4).

2. *The effectiveness of implementation of measures*. Assess to what extent the implementation of measures will stretch the time of reaching the tipping point (Chapter 0).

3. *Definition of policy approaches (PA's)*. Define the policy approaches (PA's) as a starting point, e.g. keep water out or full responsibility citizen (Chapter 6).

4. D*evelopment of the PA based adaptation pathways*. For each case study area select from the overview which shows the effectiveness of the possible measures, a measure (or group of measures) in line with the policy approach. Determine at which point the measure does not meet the objectives (end of the line) and consider which alternative measures, in line with the policy approach, could be switched to. Repeat this exercise until no alternatives are required or available. This step results in the adaptation pathway which correspond to the specific policy analysis (Chapter 6).

5. *Overall picture of the adaptation pathways* (Chapter 6). Integrate the individual PA based adaptation pathways into one picture and determine:

    a. which path(s) make most sense and why

    b. What are the pros and cons, which contribute most effectively in reaching the objectives, what other advantages can be identified (e.g. costs, responsibility, spatial quality)

    c. Which external factors could affect the chosen strategy

4 The urgency to adapt

4.1 Introduction

For each of the homogeneous flood areas within the Feijenoord neighbourhood (see paragraph 2.1) it was determined to what extent the area is in compliance with the objectives which were defined within the context of this research project. First an assessment was made as to which of the objectives are relevant to the case study areas, e.g. is a subway system present within the area etc.. The next step was to analyze the vulnerability of study areas according to the defined threshold values. This exercise provides a more detailed insight into the urgency to adapt within the area. It indicates at which point in time implementation of measures is required to be able to meet the objectives.

4.2 Results of the tipping point analysis

4.2.1 Social disruption

For the objective on social disruption, the urban functions marked as crucial or essential, should at least remain functioning for floods with a return period of 1:10.000 years. Figure 4.1 shows the flooded area for a 1:10.000 flooding event at the current situation and after a 60 and 130 cm sea level rise.

The following paragraphs discuss the functioning of the urban functions under extreme flood conditions. The functions ‘evacuation and emergency services routes’ and 24 hour medical care’ do not occur within the case study area and are therefore left out of the discussion.

Figure 4.1 1:10.000 flooded area for a range of sea level rises. 1 = entrance to metro station, 2 = metro shunting yard, 3 = railway tracks and location where tracks submerge to underground rail tunnel.

Electricity substations and communication network

Within the study area many electricity substations are found (see Figure 4.2) as well as other electrical devises such as lamp posts. If a flood is foreseen with a water depth of at least 20 cm, the electricity network is shut down to prevent short circuit. But even so, the substations and other electrical devises will suffer damages from a water depth of approximately 30 cm's and higher. This water depth is also the critical limit for the cable and telephone network. The cable network is one of the communication media to provide the public with essential crisis information, although other means of communication are available as well which are less flood prone. It should be noted that if electricity is shut down to prevent short circuit, this could also affect many other functions within the area.

For the areas Noordereiland and Kop van Feijenoord, water depths of 30 cm's already occur from a river water level of 3,04m +NAP onwards. This corresponds to a 1:50 flood frequency in the current situation. For these areas the threshold has already been passed. For the other areas water depths of 30 cm occur for a larger part of the area (not just along the edges) when the river level is approximately NAP +3,75 or higher. This corresponds to a sea level rise of approximately 35 cm (see Figure 9.2, the 1:10.000 year line).

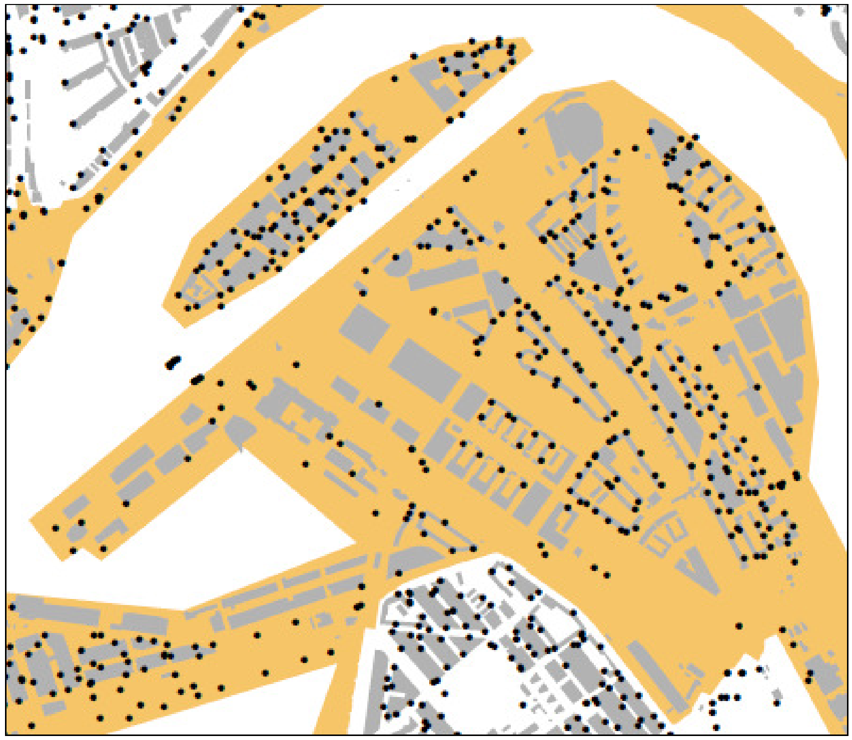

Figure 4.2 Electricity substations within the case study area (De Kort, 2012)

Train and metro system

The metro entrance located in the 'Kop van Zuid – entrepotdok' (Station Wilhelminaplein, see Figure 4.1 no.1) floods approximately at a river water level ranging from 4,21 m +NAP to 4,37 m +NAP. This coincides approximately with a sea level rise in the range of 70 to 90 cm (see Figure 9.2, the 1:10.000 year line). According to the flood maps, within this area the metro tunnel entrance and shunting-yard (see Figure 4.1 no.2) is also prone to flooding at frequencies higher than the set threshold value for the current situation, but the metro tunnel is protected against flooding with flood doors and the shunting area is currently under construction and being transformed into living area.

A very vulnerable location is found in the 'Parkzicht tot Piketkade' area where the train tracks emerge from the underground tunnel (see Figure 4.1 no. 3). According to the flood maps, both the tracks and the entrance to the tunnel at present already flood at frequencies higher than the set threshold value. But one should note that for the train tracks and tunnel additional measures are in place to prevent the tracks and the tunnel to become flooded.

Ground floor bound living

At present flooding at a frequency of 1:10.000 or more is expected for all the areas. Any Ground floor bound living area will be flooded in these areas. For these areas the threshold is already exceeded.

Hazardous activities

Hazardous activities are located in the areas 'Feijenoord eiland Oost', 'Kop van Feijenoord' and Noordereiland (Figure 4.3). These locations lie in an area where at present flooding at a frequency of 1:10.000 or more is expected. For these areas the threshold is therefore already exceeded..

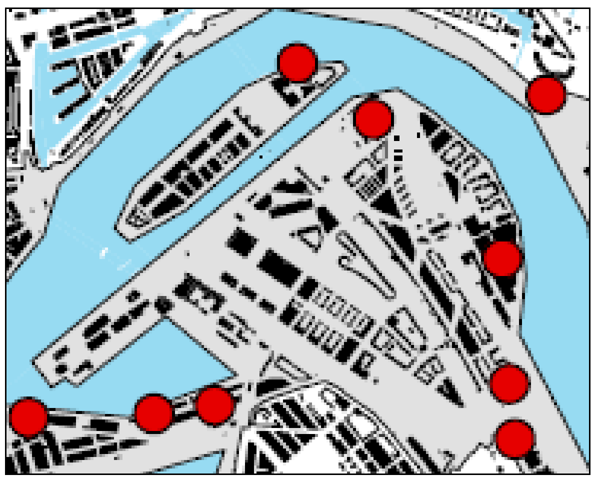

Figure 4.3 Locations of hazardous activities within the case study area (De Kort, 2012).

4.2.2 Direct damages

For housing and infrastructure, the potential damages have been assessed for a range of river water levels. The results for the study area are shown in Figure 4.4 and Figure 4.5. Damages to infrastructure start occurring at river water level of approximately +2,75 m +NAP Damage to buildings start occurring at water levels of approximately +2,85 m +NAP. The absolute damages to buildings are higher than those for the infrastructure.

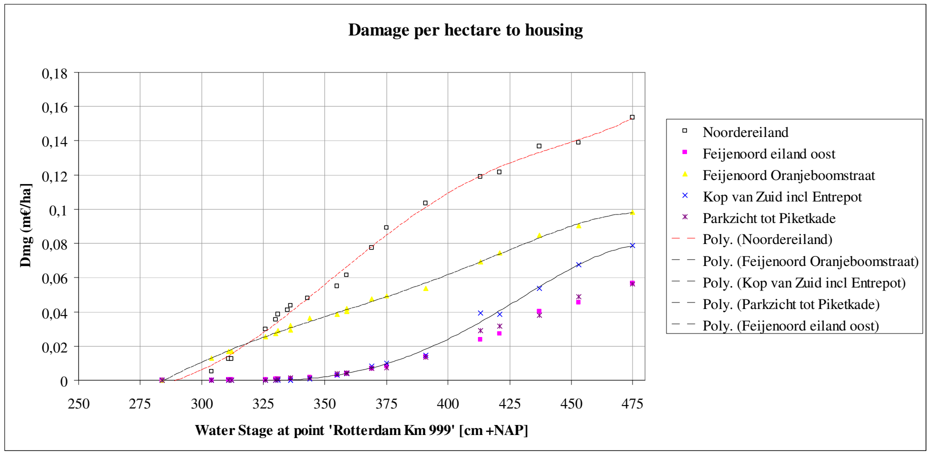

Figure 4.4 Damage to housing for different river water levels in MEuros/ha.

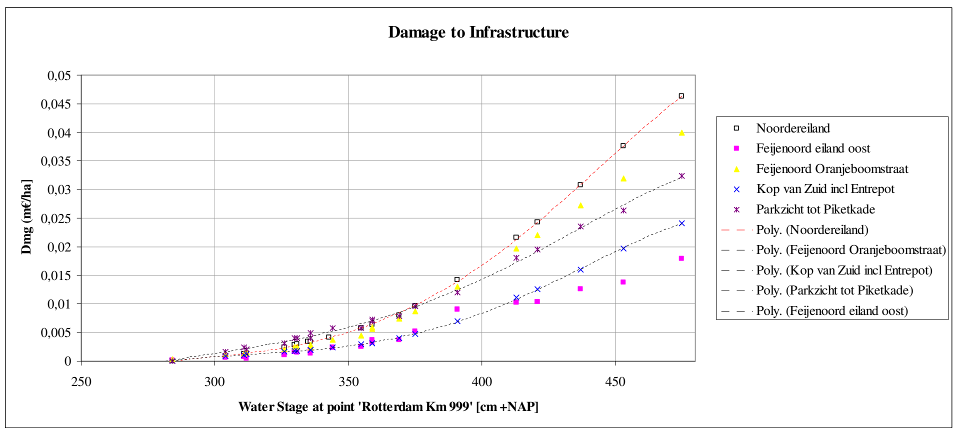

Figure 4.5 Total damage to infrastructure for different river water levels in MEuros/ha with equal vertical scale range as for damage to housing.

The threshold objective for existing buildings and public space is set at 0 Euros for a 1:100 years flood. For this project, the infrastructure is assumed to be the only item of loss in the public space as no additional information on damages in the public space is available. For each area the approximate river water level at which damages start to arise can be derived from these damage graphs. From Figure 9.2 the corresponding sea level rise can be depicted from the 1:100 frequency line. This gives the threshold value at which the objective is passed for the different areas.

From the graphs it was seen that damage to infrastructure already occurs at the lower water levels. Damages start to arise as soon as water floods the public space, even if only the quays are flooded. Therefore the threshold value is exceeded for all of the areas in the current situation.

A diverse outcome on damages to existing buildings is observed for the different areas. The threshold value is only exceeded at present for the areas 'Kop van Feijenoord' and 'Noordereiland'. For the remaining areas the threshold is not exceeded up to a sea level rise of 60 cm or higher.

Although no detailed information is available on planned developments in the area, the objective 'damage to new buildings' was assessed by determining the river water level at which the built area will start to flood. Parts of the built area within the areas 'Kop van Feijenoord', Noordereiland and 'Feijenoord eiland Oost' are inundated at a current 1:1000 flood and therefore do not comply with the objectives. Flooding at frequencies of 1:10.000 of the built up area for the 'Kop van zuid incl Entrepot' becomes problematic at sea level rises of 40 cm's. The 'Parkzicht to Piketkade' will reach the tipping point at a sea level rise of 65 sm's.

4.2.3 Loss of life

The loss of life is expressed as the individual risk. The individual risk for the study area is depicted in Figure 4.6 (35 cm sea level rise) and Figure 4.7 (60 cm sea level rise). This information is not available for the current situation.

Figure 4.6 Loss of life individual risk for a sea level rise of 35 cm.

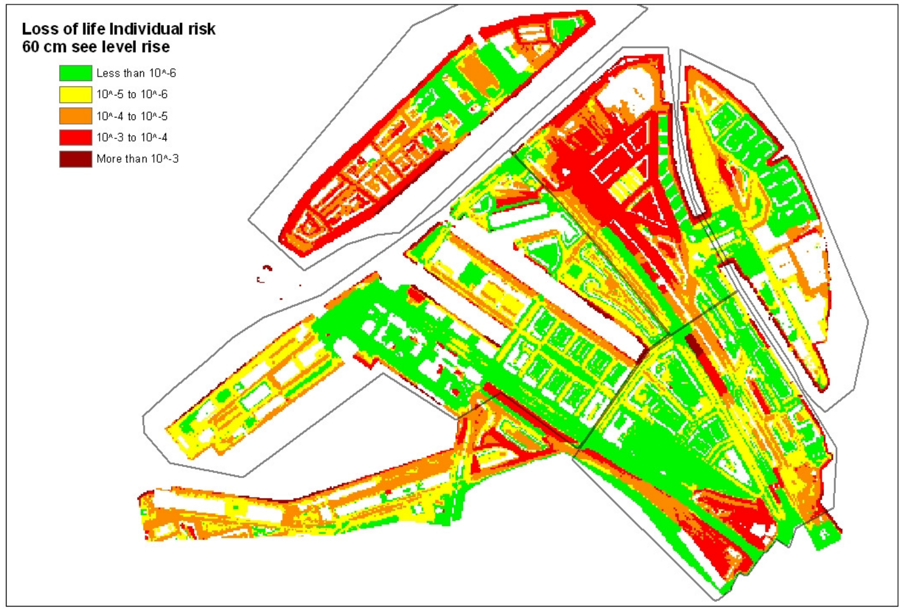

Figure 4.7 Loss of life individual risk for a sea level rise of 60 cm.

The objective is to reach an individual risk ≤ 10-6 for 95% of the area. From the histograms (Figure 4.8 and Figure 4.9) it is seen that this percentage is not reached for any of the areas from a sea level rise of 35 cm and higher. Through extrapolation of the percentages for 35 and 60 cm sea level rise, a rough estimate was made of the percentage of area for which the LIR is less than 10-6 at present. From this exercise it is assumed that only the area 'Kop van Zuid incl Entrepot' will comply with the set objective.

In addition a more lenient threshold value of 10-5 was evaluated. This resulted in a similar outcome where for the present situation only for the area 'Kop van Zuid incl. Entrepot' the objective is reached.

Figure 4.8 Individual risk within the study area for a sea level rise of 35 cm

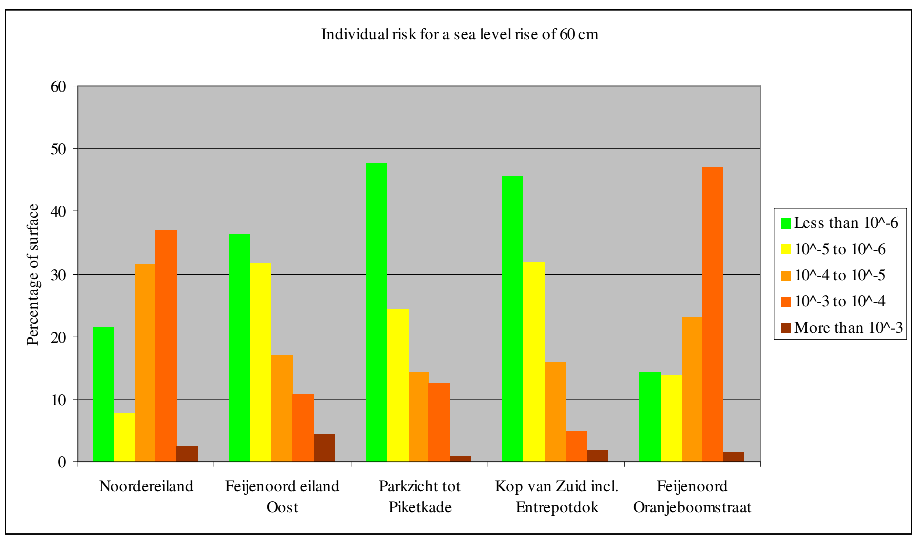

Figure 4.9 Individual risk within the study area for a sea level rise of 60 cm

4.3 Summary of tipping point analysis results

The overall results of the tipping point analysis are presented per objective in Figure 4.10. Damage to existing built is limited as is seen for the recently developed area ‘Kop van Zuid inclusief entrepotdok’. The areas ‘Feijenoord eiland Oost’ and ‘Parkzicht tot Piketkade’ are high areas and show limited damages as well. These areas will not exceed the threshold within the following 50 years. For the lower lying areas ‘Kop van Feijenoord’ and ‘Noordereiland’ the objective of ‘no damage for a 1:100 year or more frequent flood’ is not reached and reducing the damage to existing buildings, is an urgent matter. One should then also consider changing the ground floor bound residences into two story houses or changing the function of the ground floor level from a living function to a less vulnerable function. Throughout the study area with the exception of ‘Kop van Zuid – Entrepotdok’ ground floor bound living is encountered in areas where at present flooding is foreseen with a frequency higher than 1:10.000 years. Hazardous activities are encountered only sporadic within the study area, but also mainly in locations where at present flooding is foreseen with a frequency higher than 1:10.000 years. Electricity substations are encountered throughout the area and thought should be given to the locations of these substations.

It seems that thought has been given to the location of the metro entrances. For metro entrances no measures need to be taken for at least the first 50 years. The railway tunnel entrance and metro shunting yard seem vulnerable and based on these results it would be recommended to take measures as soon as possible. However, further research into the flooding hazard of these areas is advised and could change the tipping point analysis results in a positive way.

The infrastructure threshold as well as the casualties risk threshold are exceeded at present throughout the study area, but this is probably as a result of the damage and casualties assessment methods. E.g. the damage assessment method assumes damage to infrastructure as soon as the public space is flooded even if this concerns public space resistant to flooding (the quays). The casualties assessment method takes evacuation to nearby embanked areas into account, but does not consider the possibility of evacuation to high grounds within the area.

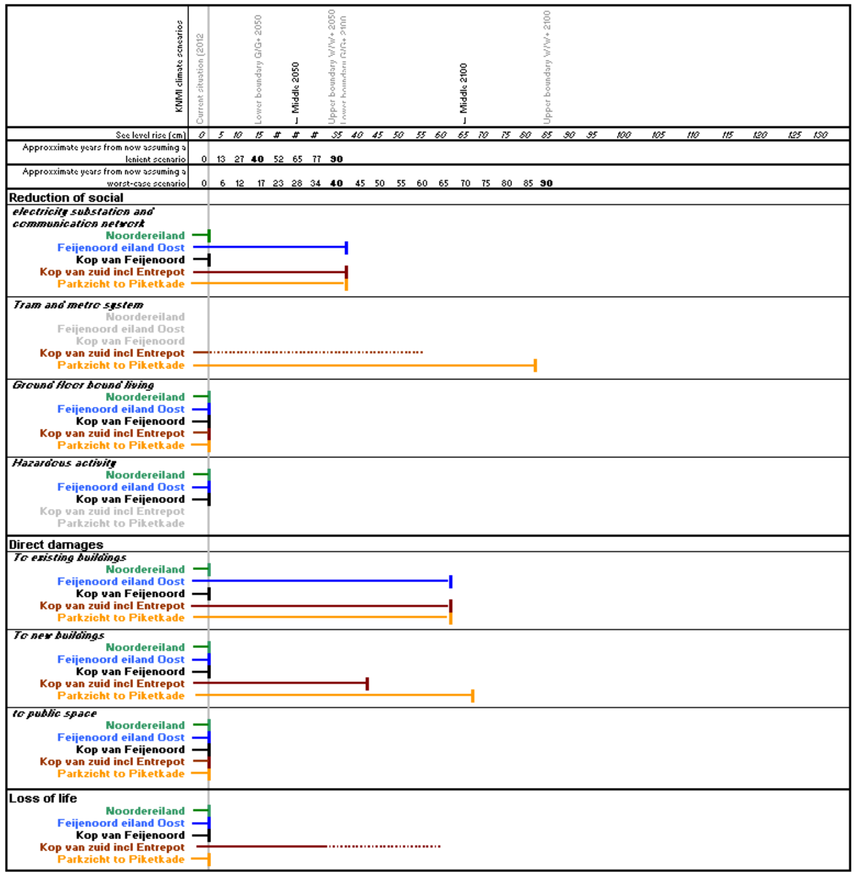

Figure 4.10 Overview of tipping point results for case study area Feijenoord and Noordereiland.

An overview of the results for the areas which were identified as highly riskfull ‘Kop van Feijenoord’ and Noordereiland’ is shown in Table 4.1. The tipping point analysis for the Noordereiland and the Kop van Feijenoord showed that none of the objectives are reached already under current climate conditions. The objectives for the risk of casualties could only be assessed for a situation with a sea level rise of 35 cm and more. The risk of casualties is unacceptably high in this situation.

From the tipping point analysis it is therefore seen that measures are required which address the objective Social disruption (electricity substation, communication network, single floor living and hazardous activity) and Damage to existing and new buildings as well as to public space and reduce the risk of casualties

Table 4.1 Overview of the results of the vulnerability study for the case study areas 'Noordereiland' and 'Kop van Feijenoord'.

	Social disruption								Damages			Casualties
	Electricity substation	Communication	Evacuation and emergency services routes	Metro including the metro	Train including the train sta-	Ground floor bound living	Hazardous activities	24-hour medical care	Damage to existing buildings	Damage to new buildings	Damage to public space	Risk of casualties
Noordereiland	•	•				•	•		•	•	•	•
Kop van Feijenoord	•	•				•	•		•	•	•	•

•	Criteria applicable to the area and expected to become problematic now or in future as a result of climate change.
•	Criteria applicable to the area but not expected to become problematic now or in future (flood proof).
	Function does not occur within the area.

5 The effectiveness of implementation of measures

5.1 Overview of possible measures

Through a design research exercise (WP2) a list of possible measures was developed. The design research focussed on the two areas which were identified as most risk full, the Kop van Feijenoord and Noordereiland. The results from the design exercise, including the lists of measures, is described in the WP2 report (Doepel et al, 2012). The design exercise included an analysis of the coping reach of measures within the case study areas. The coping reach of a measure was expressed as a maximum water level for which the measure can be applied within the case study area. Beyond this water level the measure is not effective in reducing flood risks. Through the tipping point analysis, this information has been translated to a maximum sea level rise (Climate Change) at which the objectives on social disruption, damage and casualties are still met if the specific measure were to be implemented in the case study area.

For the Noordereiland the objective on reducing damages to new buildings was not evaluated. No new developments are planned within this area and therefore the list does not encompass any measures aimed at reducing damages to new buildings.

5.2 The impact of measures on the defined objectives

Measures are applied with the intention to reduce the flood risk of an area. Table 5.1 gives an overview of the 'promising' measures and their contribution to reducing the flood risk of an area in respect to social disruption, damages and casualties. As is seen from the table, only a limited number of the measures have an effect on all of the objectives. To meet all objectives one can therefore choose to implement one single measure or a combination of measures.

Table 5.1 Overview of measures applicable to the case study areas and their impact on the objectives.

	Social disruption					Damages			Casu-alties
	Electricity substation	Communication	Evacuation and emergency services routes	Ground floor bound living	Hazardous activities	Damage to existing build-ings	Damage to new buildings	Damage to public space	Risk of casualties
Measures on buildings (new and/or existing)									
Dry-proofing plinth *				•	•	•	•		•
High ventilation registers *				•	•	•	•		•
Water resistant flood walls *				•	•	•	•		•
Dry-proof 'erfafscheiding'				•	•	•	•		•
Wet proofing of the interior						•	•		
Displacement of single floor liv-ing				•					•
Displacement of single floor dwellings				•					•
Measures on new buildings									
Building on stilts				•	•		•		•
Elevated issue level	•	•	•	•	•		•	•	•
Heavy foundation							•		
Self sustaining energy supply									•
Self sustaining drinking water supply									•
Measures in public space									
Retaining wall	•	•	•	•	•	•	•	•	•
'superdike'	•	•	•	•	•	•	•	•	•
Water in public space (wet-proofing public space)								•	
Wet-proofing of emergency services (including vulnerable elements)	•	•						•	•
Temporary flood defences	•	•	•	•	•	•	•	•	•
Temporary filling of street openings **	•	•	•	•	•	•	•	•	•
Temporary filling of embankment openings ***	•	•	•	•	•	•	•	•	•

*) The measures ‘Dry proofing plinth’, ‘High ventilation registers’ and ‘Water resistant flood walls’ (all dry-proofing of a building) will only have an effect if applied in combination.

**) The measure ‘Temporary filling of street openings’ only has an effect on the buildings and public space behind the barrier. To also protect the buildings and public space not-protected by the barrier and thus exposed to the flooding water, one should combine this measure with dry or wet-proofing of buildings and public space.

***) temporary filling of embankment openings can only be applied if one chooses to apply a measure for embankment.

5.3 Results on effectiveness assessment of the individual measures

For each measure, the maximum applicable water level up to which the measure is effective within the case study areas, has been determined (Doepel et al, 2012). Each measure was evaluated on their effectiveness in meeting the objectives under current and future climate conditions.

An overview of the measures is presented in Figure 5.1 and Figure 5.2 where the effectiveness in relation to the sea level rise is illustrated for the set objectives on social disruption and damage. For each measure a line indicates up to which sea level rise the measure is effective in reaching the objectives. The measures which remain effective with considerable sea level rise, can be noted as robust measures. Measures with possibilities to switch to other measures, can be noted as flexible measures. The following symbols were applied:

Red line = effectiveness of the measure on social disruption (assessed for a 1:10.000 flood). If a measure reduces social disruption as well as damages but no orange or green line is drawn, then the red line also illustrates the damage reduction.

Orange line = effectiveness of the measure on new buildings (For Noordereiland no new developments are planned) (assessed for a 1:1.000 flood).

Green line = effectiveness of the measure on damage to existing buildings and public space (assessed for a 1:100 flood)

5.3.1 Noordereiland

Figure 5.1 gives an overview of the effectiveness in time of the measures applicable to the Noordereiland. The measures have only been assessed on their effectiveness on improving social disruption (red lines) and on reducing damages to existing buildings and public space (green lines).

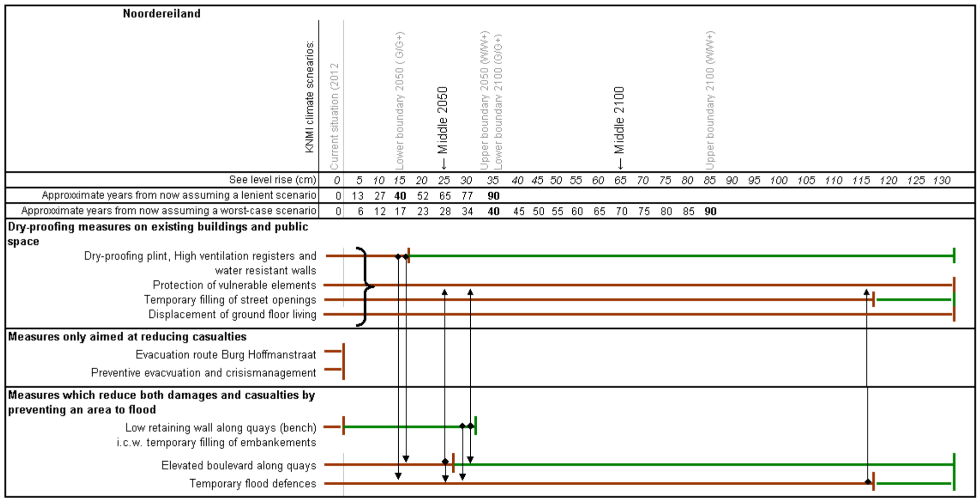

Figure 5.1 Effectiveness of flood risk reducing measures for the case study area 'Noordereiland' on reducing damage to existing buildings and public space (green lines) and reducing risk of social disruptions as well as damage to existing buildings (red line). The arrows indicate the possibilities to switch to other measures.

Damage to existing buildings (green lines)

All the measures aimed at reducing damages, have an effect on reducing damage to existing buildings. All these measures except for the measure 'Low retaining wall' are effective in reducing damages to buildings up to a sea level rise of 130 cm, thus highly effective for a long period of time. The measure 'Low retaining wall' is effective up to a sea level rise of 30 cm which is expected to be reached at the earliest in approximately 35 years from now.

Damage to public space (green lines)

The measures aimed at preventing the area from flooding (walls, embankments e.g.) all reduce damages in the public area and are highly effective up to a sea level rise of 130 cm. The retaining wall reduces damages up to a sea level rise of 35 cm. In addition the measure 'protection of vulnerable elements' is highly effective in reducing damages (up to a sea level rise of 130 cm) and will aid in increasing the effectiveness of evacuation operations by keeping the critical infrastructure (communication and electricity networks) active during the operation.

Social disruption (red lines)

Reducing social disruption for single floor living, requires that these quarters are prevented from flooding. This is achieved by dry-proofing buildings or preventing an area from flooding. Although these measures are equal to those highly effective for reducing damages to buildings, the measures are less effective when assessed against the objectives set for social disruption. This is due to the fact that a more stringent objective was chosen for the social disruption criteria, where the criteria objective for damages to existing buildings was set at a once in 100 years flood versus a once in a 10.000 years for social disruption.

It is seen that the measure 'low retaining wall' is not sufficient and that the dry-proofing of building measures (plinth and ventilation register) are only effective up to a sea level rise of 15 cm, which in the worst case (a rapidly increasing sea level) will be reached in approximately 15 years from now. The measures ''Elevated boulevard along quays' and 'Temporary filling of embankment' will be effective for a slightly longer period, up to 25 cm of sea level rise which in the worst case is expected to occur in approximately 30 years from now. The other measures, 'Temporary flood defences' and 'Temporary filling of street openings', are highly effective in reducing social disruption for a long period of time.

5.3.2 Kop van Feijenoord

Figure 5.2 gives an overview of the effectiveness in time of the measures applicable to the Kop van Feijenoord. The measures have only been assessed on their effectiveness on improving social disruption (red lines) and on reducing damages to new buildings (orange lines) and existing buildings and public space (green lines).

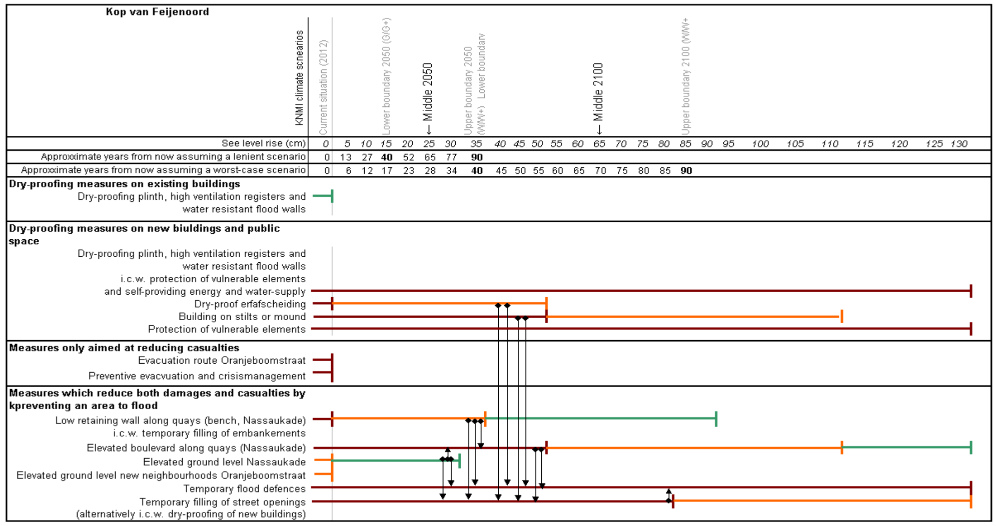

Figure 5.2 Effectiveness of flood risk reducing measures for the case study area 'Kop van Feijenoord' on reducing damage to existing buildings and public space (green lines), reducing damage to all buildings (orange lines) and reducing risk of social disruptions as well as damage to all buildings (red line). Note that measures aimed at reducing damages to new developments will not have an effect on reducing damages to existing buildings. The arrows indicate the possibilities to switch to other measures.

Damage to existing buildings (green lines)

Measures highly effective for reducing damages to existing buildings are mainly of the type which prevent the area from flooding, e.g. retaining wall, boulevard, flood defences. Dry-proofing measures such as a dry-proofing plinth and high ventilation registers, are not effective due to the larger water depths which can occur in this area, although water resistant flood walls proof do be a highly effective measure.

Damage to public space (green lines)

Similar as for the damages to existing buildings, the measures aimed at preventing the area from flooding reduce damages in the public space and depending on the choice of measure, can be effective up to a sea level rise of 130 cm. In addition the measure 'protection of vulnerable elements' is highly effective in reducing damages (up to a sea level rise of 130 cm) and will aid in increasing the effectiveness of evacuation operations by keeping the critical infrastructure (communication and electricity networks) active during the operation.

Damage to new buildings (orange lines)

For reducing damages to new buildings, the measures which prevent the area from flooding are effective, but less effective than for reducing damages to existing buildings and public space. This is as a result of the stricter objective for new buildings. Measures on new buildings which aim specifically at reducing damages are shown to be highly effective with the exception of the measure 'Dry-proofing plinth'.

Social disruption (red lines)

Reducing social disruption for single floor living requires that these quarters are prevented from flooding. This is achieved by dry-proofing buildings or preventing an area from flooding. Although these measures are equal to those highly effective for reducing damages to buildings, the measures are less effective when assessed against the objectives for social disruption. This is due to the fact that a more stringent objective was chosen for the social disruption criteria, where the criteria objective for damages to existing buildings was set at a once in 100 years flood versus a once in a 10.000 years for social disruption.

But even for the strict objective, the measure 'Temporary flood defences' is still highly effective and the measure 'Elevated boulevard along quays' is effective for at least another 55 years. For existing buildings only the dry-proofing measure 'Water resistant flood walls' will aid in providing safe ground floor living possibilities. For new buildings a selection of measures is available which make safe single-floor living possible.

Reducing social disruption due to failure of electricity and communication systems can be effectively accomplished with the measure 'Protection of vulnerable elements'. In addition the measure 'Elevated boulevard along quays (Nassaukade)' shows to be effective by preventing vulnerable element to become flooded.

5.4 Assessment of the Packages of Measures (PoMs)

For each of the two case study areas, three packages of measures (PoM) have been developed (Doepel et al, 2012). Each PoM follows a different strategy, e.g. prevention of flooding, water in etc. The PoM's have been assessed according to their effectiveness in reaching the objectives. For the measures suggested in the packages, a minimum as well as a maximum variant is given. The assessment assumes a minimum variant, but the maximum variant is also illustrated in the figures with a dashed line.

5.4.1 Noordereiland

The PoM's have been assessed according to the defined objectives for the area. A summary of the results is given in Figure 5.3.

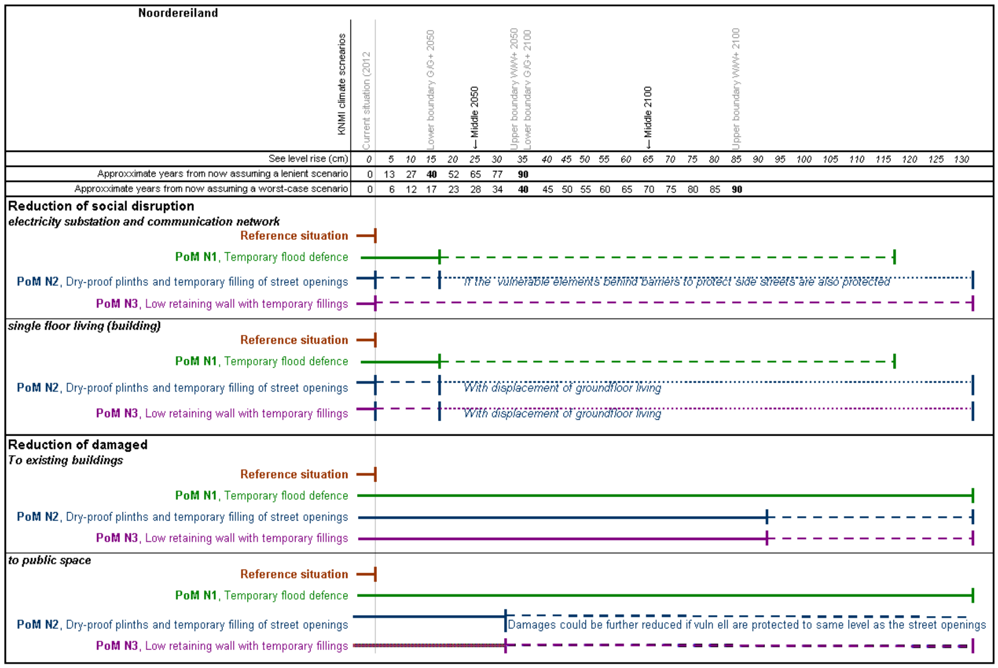

Figure 5.3 Overview of the effectiveness of the PoM's for Noordereiland in regard to the objectives. The dashed lines illustrate the effectiveness of the PoM's if the maximum variant for the measures is implemented.

PoM N1; Temporary flood defence

PoM N1 encompasses only one measure, 'Temporary flood defence', which aims at preventing the area from flooding. The minimum variant is sufficient to reach the objectives on reducing damages, but only reduces social disruption sufficiently for 15 to 40 years (worst-best case.). It is therefore recommended to choose a slightly larger variant, to be able to cope with social disruption for a longer period of time.

PoM N2; Dry proof plinths and temporary filling of street openings

This PoM uses a combination of measures which each address one or several criteria objectives. A drawback of the PoM is the fact that the minimum variant for the measures particularly focus on the reduction of damages of the public space and buildings. The minimal variant of the measures aimed at reducing social disruption due to ground floor living and due to failure of electricity and communication, are not effective. The maximum variant of these measures are highly effective. Dry-proofing will also effect ground-floor living, but is only effective for a maximum variant and even then only up to 15 cm sea level rise (15 – 40 years from now).

Damage prevention of buildings by dry-proofing in combination with the filling of street openings is very effective, and in combination with protection of vulnerable elements also effective in reducing damages to the public space.

PoM N3; Low retaining wall with temporary fillings

Up to a certain water level, this PoM firstly aims at preventing the area from flooding. Beyond this water level, the PoM aims at reducing damages and social disruption by displacement of ground floor dwellings and dry-proofing of buildings. The chosen minimum variants of the measures are effective in reducing damages, but are not sufficient in reducing social disruption. It is therefore recommended to choose a larger variant or add measures to the PoM.

To reduce damages on buildings and public space, the retaining wall is effective for at least approximately 35 years from now. Dry-proofing is effective for a longer period of time, up to al least 90 years from now.

5.4.2 Kop van Feijenoord

The PoM's have been assessed according to the defined objectives for the area. A summary of the results is given in Figure 5.4.

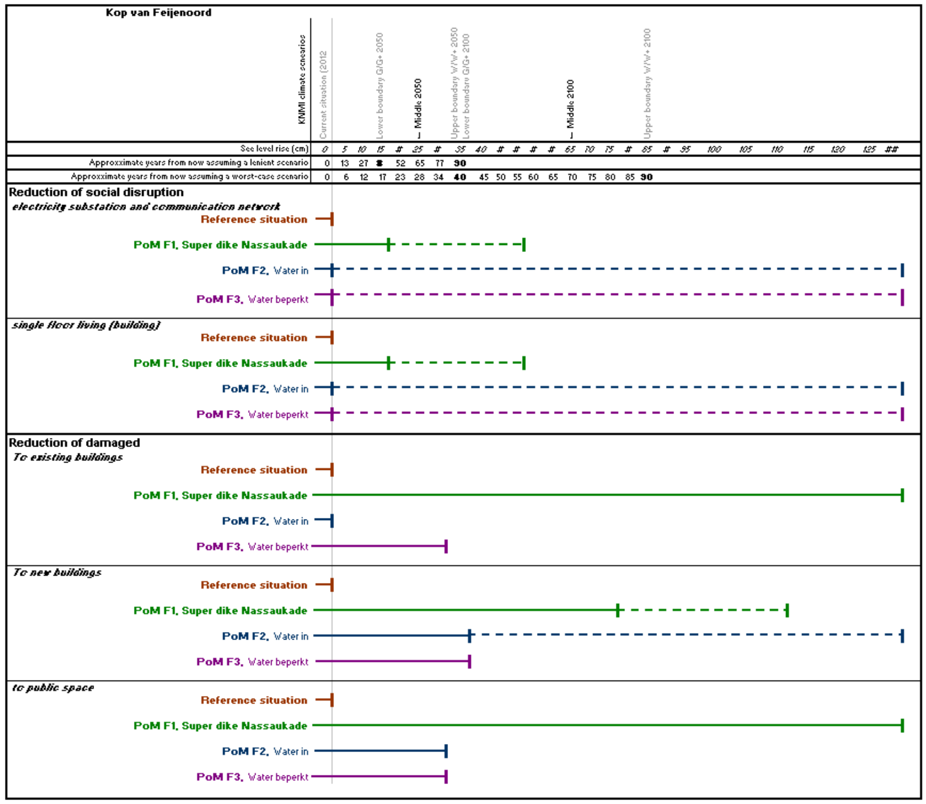

Figure 5.4 Overview of the effectiveness of the PoM's for kop van Feijenoord in regard to the criteria objectives. The dashed lines illustrate the effectiveness of the PoM's if the maximum variant for the measures is implemented.

PoM F1; Super dike Nassaukade

This PoM prevents the area from flooding, up to a water level of 3,70 m +NAP (minimum variant). For the criteria social disruption, this provides a prevention of flooding against a 1:10.00 years flood, and thus no social disruption, for a period of 15 to 40 years (worst and best case). The PoM is also highly effective in reducing damages.

PoM F2; Water in

The PoM F2 is a compilation of a series of measures aimed mainly at dry-proofing of existing and new (renovated) buildings. In addition a measure to protect vulnerable elements is included. Two variants for protection vulnerable elements is suggested; one of them focussing on extremely vulnerable elements. It is assumed that this measure protects the communication and electricity network. The minimum variant is not sufficient though to reduce social disruption under future climate conditions. It is therefore recommended to choose a larger variant for protecting vulnerable elements.

The suggested measures also are not sufficient to enable ground floor living. Ground floor living requires the dry-proofing of existing buildings up to a level which is not feasible for existing buildings. Displacement of ground floor living is the only applicable measure, but required that a variant larger than the minimum variant is implemented.

The suggested measures are also not sufficient to prevent damages to existing buildings. The foreseen water depths exceed the maximum level of dry-proofing measures on existing buildings. The measures aimed at reducing damages to new buildings and public space are effective for 35 to 80 years from now (worst and best case).

PoM F3; Ground elevation along Nassaukade

Similar to the PoM N3 for the Noordereiland, this PoM firstly aims at preventing the area from flooding up to a certain water level. Beyond this water level, the PoM aims at reducing damages and social disruption by displacement of ground floor dwellings and dry-proofing of buildings.

The performance of this PoM on social disruption, is equal to the effectivity of PoM F2. The measures which have an effect on social disruption are similar to those proposed for PoM F2. Like for PoM F2. it is recommended to choose a larger variant for protecting vulnerable elements and displacement of ground floor living.

The only measure which prevents damages to existing buildings, is the prevention of flooding by elevated ground levels up to 3,20m +NAP. This is sufficient to obtain the objectives for the coming 35 to 80 years. By elevating new building up to a level of 3,40m +NAP, the objectives are reached for the coming 40 to 90 years. But the dry-proofing of renovation buildings is not effective and other measures are therefore required for renovation buildings.

5.5 Summary of results on effectiveness of the measures

For the Noordereiland the figure shows that dry-proofing measures are highly effective (robust), although these measures do require implementation as a package. The effectiveness of the flood defence measures depend on the height of the flood defence, although even with a low retaining wall the objective for damages to existing buildings will still be met for at least another 35 years. Due to their robustness, the dry-proofing measures do not require to switch to other measures. From the flood defence measures it is possible to either switch to the dry-proofing measures or to a higher flood defence. Measures aimed at reducing casualties could not be evaluated.

For the Kop van Feijenoord, dry-proofing measures on existing buildings will not be sufficient to meet the objectives, but measures on new developments are highly effective. Flood defence measures are as effective as the dry-proofing measures and will also reduce damages to existing buildings. Switching to a (higher) flood defence measure seems more obvious than switching to a dry-proofing measure. Measures aimed at reducing casualties could not be evaluated.

6 Exploring adaptation pathways for Noordereiland and Kop van Feijenoord

6.1 Introduction

This chapter presents the results of the workshop on adaptation pathways. Paragraphs 6.2 and 6.3 give an oiverview of the policy based adaptation pathways for the Noordereiland and the Kop van Feijenoord. Paragraph 6.4 discusses the external factors which could influence the choice in strategy. In paragraph 6.5 a summary of the results is given.

6.2 Policy approach specific pathways Noordereiland

PA1; Focus on citizen safety

The current policy is to focus on the safety of the citizens where the municipality is responsible for the crisis management and safety of the citizens. The municipality is not directly responsible for damages to privately owned buildings, although regulation on floor level height is issued by the municipality for new developments. If this policy approach were to be continued, the municipality would need to invest only in measures which aim at reducing casualties (preventive evacuation and crisis management). Optional the municipality could invest in measures which prevent damages to the public space and critical infrastructure. The latter would be in support of the crisis management.

This approach remains effective even under extreme climate change conditions and switching to another approach is not necessary. Note that only the citizen safety is set as an objective. The objectives social disruption and damages are not met through this policy approach. If required a switch can be made either to a flood defence approach or a dry-proofing approach. This approach focuses on prevention of casualties but if flooding becomes more frequent and citizens suffer more damages, public support for this policy approach could decrease.

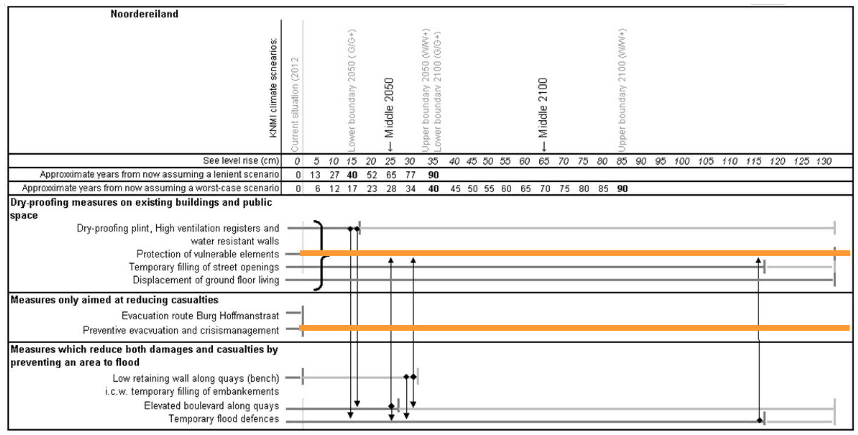

Figure 6.1 Adaptation pathway Noordereiland PA1

PA2; Prevention of flooding for the long term

Within this policy approach, the municipality takes full responsibility through measures which prevent the area from flooding. The starting point is the construction of an elevated boulevard along the quays which can withstand an extreme water level (1:10.000 years flood) for at the least the first 30 years, and more frequent floods (up to 1:1000 years flood) are kept out for at least the coming 90 years. On the elevated boulevard an additional temporary flood defence can be erected if necessary, to be able to withstand the extreme floods in future as well. An important advantage of this approach is that this will require significant reshaping of the landscape which provides opportunities to improve the spatial quality of this area. This in turn is also the draw back of the approach as it will be a costly exercise.

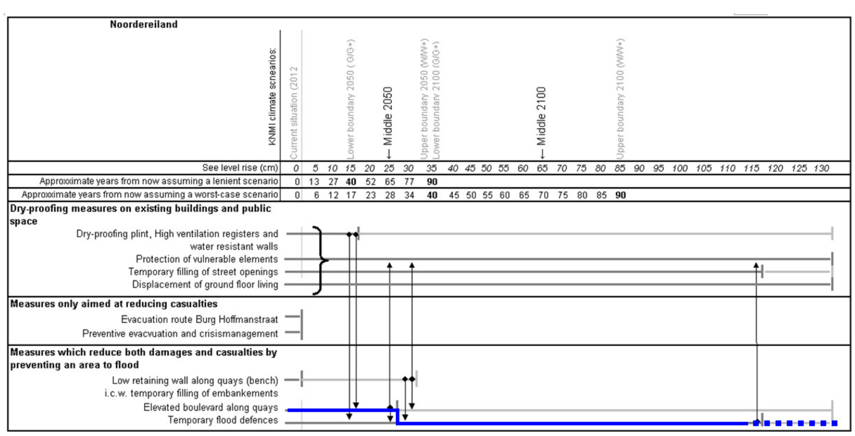

Figure 6.2 Adaptation pathway Noordereiland PA2

PA3; Reactive prevention of flooding

This policy approach is similar to PA2 as it focuses on prevention of flooding and the municipality taking full responsibility. But instead of choosing for a permanent measure which is integrated within the urban landscape, this approach applies a flood defence measure which is not part of the urban landscape. The starting point is the temporary flood defence which is only erected when a flood threat occurs. Temporary systems can be built up to a considerable height and switching to an alternative measure in future will not be necessary. This solution could turn out to be quite costly as the length for application of the flood defence is considerable. In addition it will require frequent testing of the system and training of personnel.

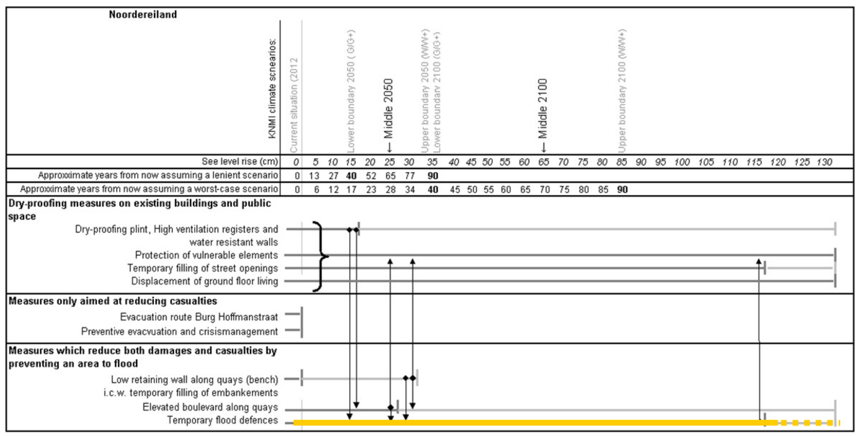

Figure 6.3 **Adaptation pathway Noordereiland PA3**

PA4; Allow partly flooding of area, shared responsibility

This approach accepts flooding of the quays up to the adjacent buildings. Flooding is prevented for the adjacent side streets by temporary filling of the street openings (temporary flood defences) and the public quay area, and buildings are dry proofed to prevent damages, social disruption and casualties. The number of buildings to which this applies at first is limited, as many buildings were traditionally already (partly) dry-proof build. With future increasing sea level rise and water levels, more buildings will need to be dry-proofed. With this approach the responsibilities (and costs) are shared between the municipality and building owners. This approach does not require switching to other measures.

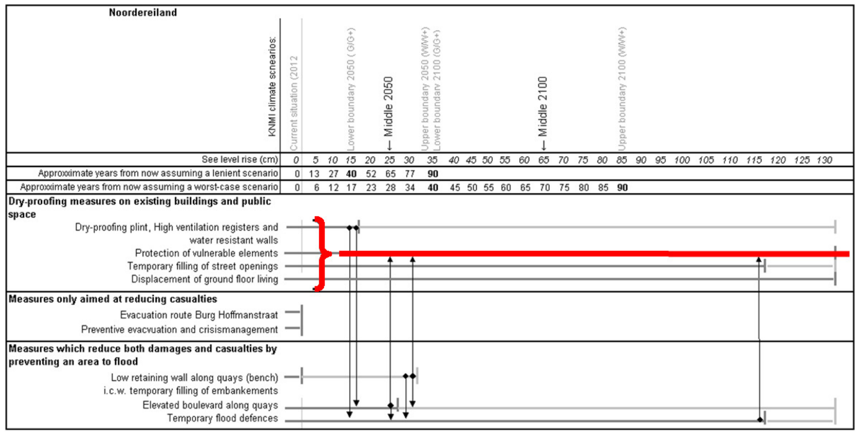

Figure 6.4 **Adaptation pathway Noordereiland PA4**

PA5; Allow partly flooding of area, prevention of flooding in initial stage

PA5 follows the same principal as PA4 where partly flooding is accepted and a shared responsibility policy is implemented. But to provide building owners with time to adjust their buildings, at first the municipality takes full responsibility by taking flood prevention measures up to a certain water level. A low retaining wall or slightly elevated boulevard is constructed. After a number of years an evaluation is done to identify to what extent building owners have managed to dry-proof their buildings. At this point the decision should be made to either proceed as planned or to deviate to an alternative solution by implementing a temporary flood defence.

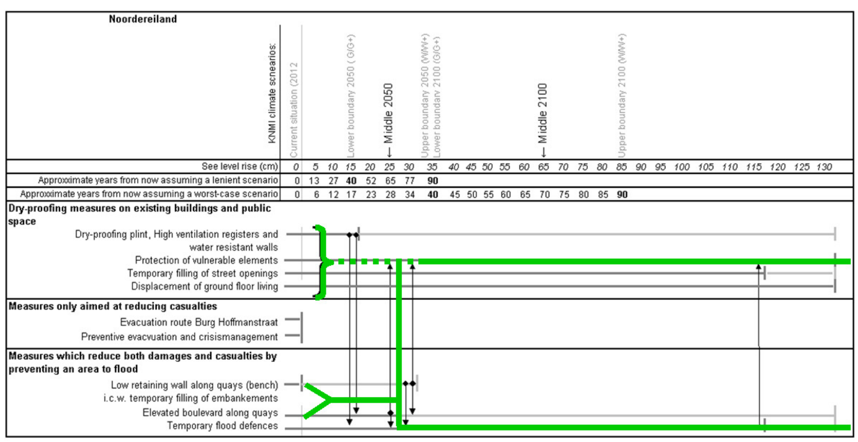

Figure 6.5 **Adaptation pathway Noordereiland PA5**

6.3 Policy approach specific pathways Kop van Feijenoord

PA1; Focus on citizen safety

As for the Noordereiland, in the current situation the municipality is responsible for the crisis management and safety of the citizens. The municipality is not responsible for damages to privately owned buildings, although regulation for ground floor level height is issued by the municipality for new developments. If this policy approach were to be continued, the municipality would need to invest only in measures which aim at reducing casualties (preventive evacuation and crisis management). Optional the municipality could invest in measures which prevent damages to the public space and critical infrastructure. The latter would be in support of crisis management.

This approach remains effective even under extreme climate change conditions and switching to another approach is not necessary, but if required a switch can be made either to a flood defence approach or a dry-proofing approach. This approach focuses on prevention of casualties, but if flooding becomes more frequent and citizens suffer more damages, public support for this policy approach could decrease.

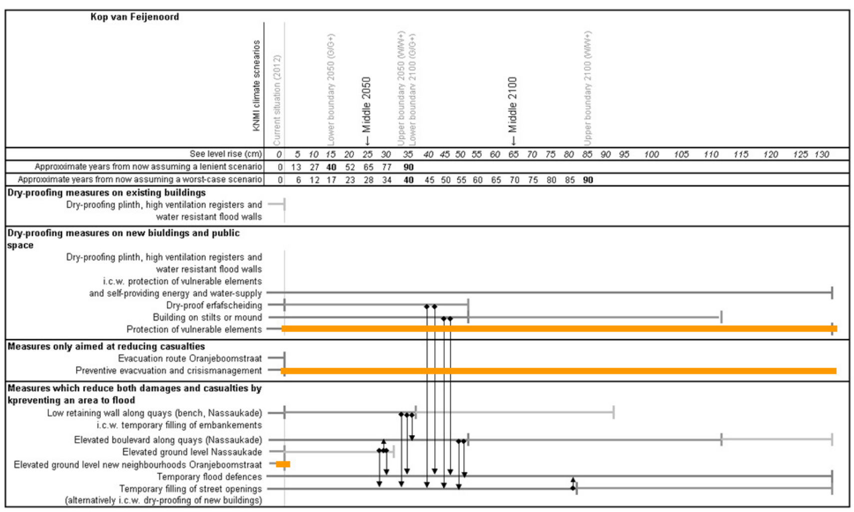

Figure 6.6 Adaptation pathway Kop van Feijenoord PA1

PA2; Damages to buildings, full responsibility building owners

This policy approach assumes that the building owners take full responsibility to prevent damage to teir own property. The municipality will need to take responsibility for prevention of damage to public space and provide sufficient safety measures. The approach is similar to the current policy (PA1) with the difference that the municipality takes measures to prevent damage to the public space and critical infrastructure. This is a challenging approach as substantial water depths can occur in this area. Measures on existing buildings are therefore not effective and not a logical choice, but for new buildings dry-proofing measures as well as (or in combination with) elevated building is effective up to at least 50 years from now.

This approach could be appropriate if the area were to be re-developed on a large scale. This can be accomplished by upgrading the area in phases and focusing on evacuation of citizens and accepting a higher damage level for existing buildings during the upgrading period. This is actually the current policy approach and an already encountered draw back is the resulting diversity in street levels.

The arrows indicate that a switch can be made towards a small-scale flood defense approach. This does imply that initial costs for dry-proofing buildings would be wasted after the dry-proofed buildings are protected by a flood defense, unless the moment of switching would be further in time (e.g. at least 50 years from now) or act as a double layer protection in case smaller amounts of water (seepage, overtopping) would enter the area.

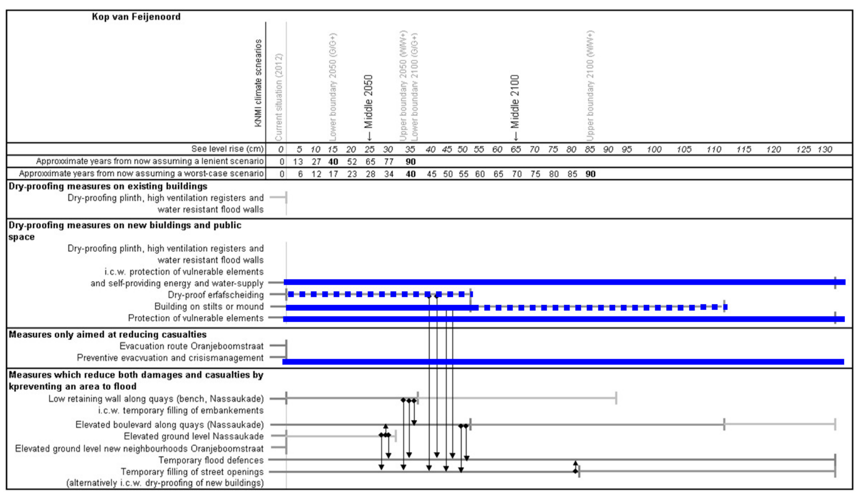

Figure 6.7 **Adaptation pathway Kop van Feijenoord PA2**

PA3; Close the gaps; adapt step by step

As substantial water depths can occur in this area, a flood prevention approach would be an obvious choice. Parts of the borders of the area are already at a sufficient height. Therefore, a flood prevention approach would encompass measures which close these border gaps. This approach can be executed in a robust manner by implementing an elevated boulevard. An alternative is to apply a growth model where an initial lower wall is built and when required due to climate change effects, this wall can be extended into an elevated boulevard. If necessary, a boulevard in turn can also be extended with a temporary flood defence.

Because only parts of the borders of the study area need to be elevated and mainstreaming with current developments is possible, this solution could be quite cost-effective. A large advantage of this approach is that it protects the whole area and not just new buildings. The approach does imply full responsibility by the municipality.

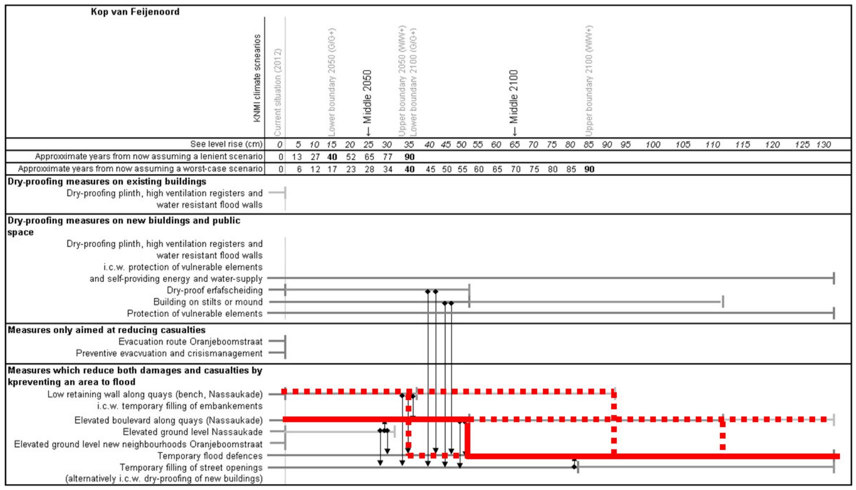

Figure 6.8 **Adaptation pathway Kop van Feijenoord PA3**

PA4; Close the gaps; mainstreaming with planned developments

For the case study area of Kop van Feijenoord an even more robust solution than the elevated boulevard is probably possible which makes optimal use of the developments which are currently taking place along the Nassaukade. Many parts of the Nassaukade are currently not in use and lie fallow. By elevating the ground level and developing dry-proof buildings on these parts, opportunities can be seized for implementation of robust flood measures in combination with a high potential development of the area. The current economic situation probably does not allow for such development, though to be able to apply this adaptation path, the opportunity will need to be seized at present.

The effectiveness of this measure was not evaluated, but was estimated by expert judgment during the workshop to be effective up to a sea level rise of at least 85 cm. From this approach a switch can be made to a temporary flood defense if required.

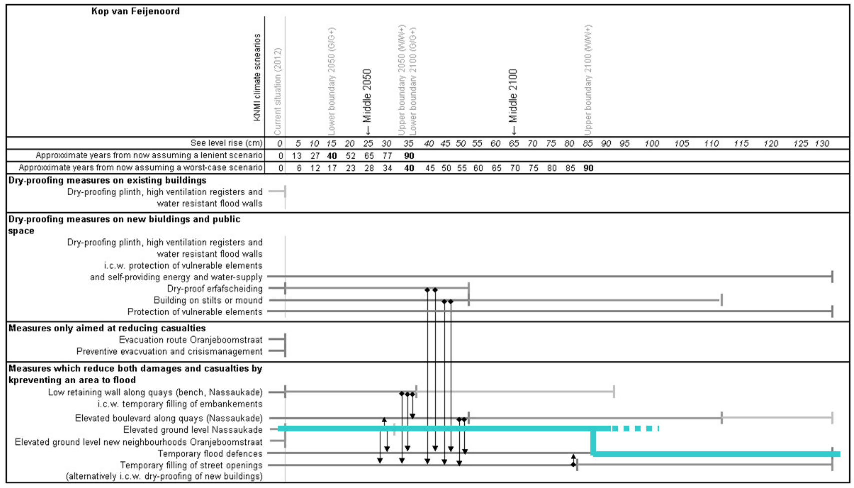

Figure 6.9 **Adaptation pathway Kop van Feijenoord PA4**

6.4 Possible external factors of influence on the choice of flood risk management strategy

Besides a preference for certain policy approaches, other external factors can influence the choice for a flood risk management strategy.

Outcomes of the Delta programme.

The choice for appropriate flood risk reducing measures for the Noordereiland and Kop van Feijenoord can not be made without considering the possible outcome from the Delta Programme, especially the outcomes concerning the Maeslant flood defence. A growth model would be favourable as one can adjust depending on the pace of climate change, as well as to what is decided on the Maeslant flood defence.

The pace of climate change

PA's which assume a partly or full responsibility for damages to buildings by the building owners require enough time for retrofitting the buildings. Dry-proofing measures are preferably applied when a building reaches its end-of life cycle and renovation is required. Choosing this approach is risky as climate change effects could increase more rapidly than foreseen. On the other hand, the choice for a robust measure could turn out to be heavily overdimensioned and thus overspend if the pace of climate change effects is less rapid than foreseen.

Economic developments

The economic developments have already proven to be of great influence on urban development. Limitations in funding as well as stagnation in urban developments reduce the possibilities to take measures.

Flood insurance

In the Netherlands there is no possibility to take out flood insurance. Recent years this has been under discussion and if insurance would come available, this could be added to the list of measures. Such a measure would be in line with policy approaches assuming some or full responsibility for building owners.

6.5 Adaptation pathways for Noordereiland and Kop van Feijenoord, summary of results

6.5.1 Noordereiland

Five policy approaches were identified for the Noordereiland. A summary of the policy approaches is given in Table 6.1. Under work package 2 Packages of Measures (PoM's) were identifies. The PoM's which resemble a policy approach are listed in the final column.

Table 6.1 Overview of policy approaches for the Noordereiland and relation with Packages of Measures developed in WP2

Noordereiland Policy approach	Measure type	Responsibility	Flood Risk objectives	Similar to PoM
PA1	Water in - Reduction of casualty risk	Municipality: safety Building owner: building	Casualties	
PA2	Flood prevention – robust and reactive	Municipality	All	
PA3	Flood prevention -reactive	Municipality	All	N1

PA4	Water partly in	Shared respon-sibility	All	N2
PA5	Flood preven-tion – transi-	Initially mu-nicipality, later	All	N3

For each policy approach a specific pathway was developed in line with the policy. These developed adaptation pathways for the Noordereiland are illustrated in Figure 6.10.

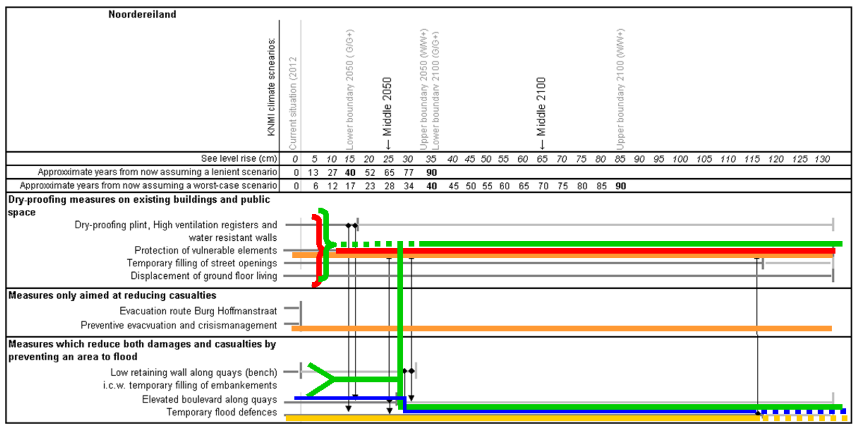

Figure 6.10 **Overview of adaptation pathways Noordereiland**

Five adaptation pathways were identified, each providing a strategy which is able to cope with climate change effects for the long term. The current policy approach (PA1) is a robust strategy and does not require switching to another policy approach, but only addresses the risk for casualties. PA4 assumes a shared responsibility and if feasible will also provide a long term solution. The PA's focussing on prevention of flooding are seen to be effective for a period of 30 - 65 years, depending on the climate change rate. But these measures all require a switch to either a temporary flood defence or the dry-proofing of buildings.

6.5.2 Kop van Feijenoord

Four policy approaches were identified for the Kop van Feijenoord. A summary of the policy approaches is given in Table 3. Under work package 2 Packages of Measures (PoM's) were identifies. The PoM's which resemble a policy approach are listed in the final column.

Table 6.2 Overview of policy approaches for the Kop van Feijenoord and relation with Packages of Measures developed in WP2.

Kop van Feijenoord Policy approach	Measure type	Responsibility	Flood Risk objectives	Similar to PoM
PA1	Water in - Reduction of casualty risk	Municipality: safety Building owner: building	Casualties	
PA2	Water in - Reduction of casualty risk and damages	Municipality: safety and public space Building owner: build-	All	F2
PA3	Flood prevention – grow model	Municipality	All	F1
PA4	Flood prevention - mainstreaming	Municipality	All	F3

For each policy approach a specific pathway was developed in line with the policy. These developed adaptation pathways for the Noordereiland are illustrated in Figure 6.11.

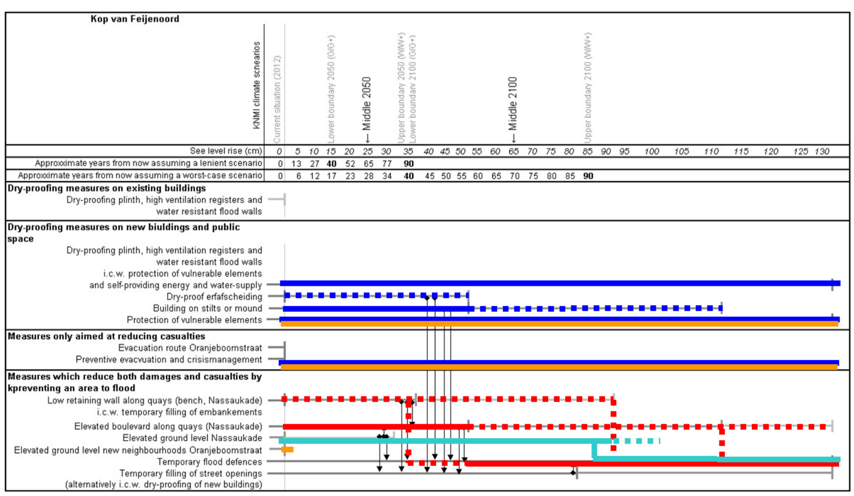

Figure 6.11 Overview of adaptation pathways Kop van Feijenoord

Four adaptation pathways were identified, each providing a strategy which is able to cope with climate change effects for the long term. The current policy approach (PA1) is a robust strategy and does not require switching to another policy approach, but only addresses the risk for casualties. Dry-proofing measures only provide a solution for new developments and do not contribute in reducing damages to existing buildings. The adaptation pathways, which assume a flood defence policy, provide a long term solution that addresses both the casualty risk and the prevention of flood damages. PA3 is an adaptive solution, which evolves in relation to the rate of climate change. PA4 is a more robust solution integrated with the urban developments in the study area. Similar to the adaptation pathways for the Noordereiland, the flood defence solutions at some point all require a switch to a temporary flood defence measure.

7 Conclusions and recommendations

7.1 Overall summary of results

For the unembanked area within the Feijenoord neighbourhood and for the Noordereiland, adaptation pathways have been developed. Information on the effectiveness over time of possible measures gained through a tipping point analysis, acted as building blocks to the development of the pathways. The current urban layout was taken as the reference situation and compared to a situation with implementation of measures. The effectiveness over time of the measures were tested against a set of maximum acceptable limits on flood risk.

The results show that the higher areas within the study area only require immediate attention when it comes to ground floor bound living and the presence of hazardous activities in floodable areas. On the other hand, the urgency to tackle the encountered flood risk for the lower lying areas 'Kop van Feijenoord' and 'Nooredereiland' is very high.

For the Noordereiland it is seen that dry-proofing measures are highly effective in reducing the flood risk. Flood defense measures are slightly less effective but will still provide sufficient flood risk reduction for at least a period of 35 years. For the Kop van Feijenoord dry-proofing measures are not sufficient to reduce flood risks due to the large encountered water depths. For this area the flood defence measures show the highest effectiveness. The actual choice depends on the policy one wants to follow as is illustrated through the adaptation pathways.

The research focused mainly on the areas where the flood risks were highest. For the area where large flood depths are expected, the emphasis is on solutions aimed at flood prevention such as flood walls and temporary barriers. Solutions where water can flow controlled within the urban area are less effective in these areas, but these measures could be interesting in areas which flood with smaller water depths.

The urban scale of the study resulted in very specific and concrete measures. The choice of a policy can not be made though without considering the larger scale level.

7.2 The adaptation pathways method as an aid to urban flood risk strategy development

The adaptation pathway method aids policy makers in making a choice for a certain long term flood risk management approach. The method results in an insight into the urgency to adapt to climate change, insight into the effectiveness over time of the possible measures and visualizes the link between long term policy approaches and the possible measures.

The method proved to be an added value to the design research process as it adds an extra dimension through the insight into the effectiveness of solutions on the longer term. By connecting the technical solutions, different policy approaches and information on the physical boundary conditions such as the flood risk and climate change, a bridge towards developing long term policy was created. In addition it links the urban planning and flood risk management. Like the research design exercise, the method also brings different expertise together and from the experience it was also learned that the *process* of developing the adaptation pathways was as important as the actual end-result.

From the experience it was also learned though that the concept of adaptation pathways is not easily understood. A development of adaptation pathways session therefore requires taking time to introduce the method.

It was also seen that the effectiveness of measures and strategies depends strongly on the choice of the objectives. In this research the objective on social disruption was set quite strict and for the current urban design already none of the assessed areas complies with the set objective. Less strict objective will result in lower flood risk and more robust measures. It is therefore of great importance to choose a set of objectives which is sufficiently supported by the stakeholders. The exercise also showed that some of the objectives could not be assessed thoroughly due to a lack of information. It is therefore recommended to define objectives which can be assessed in accordance to the data availability.

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9 Appendix

9.1 Increasing water levels

Due to the fact that the study area is very close to the sea, the high water levels in the river are mainly caused by the water levels at sea. The influence of the river discharge on the water levels is negligible for this stretch of the river as is illustrated in Figure 9.1.

Figure 9.1 Influence of sea levels and/or river discharges on river water levels (J.P. de Waal, 2007). The water levels in the 'Rivierengebied' (river area) are the result of the river discharges, in the area 'Zeegebied' (sea area) the water levels are determined by the sea levels and in the 'Overgangsgebied' (transition zone) both the river discharge and the sea levels influence the water levels. The study area is located within the circle.

The flood risk can therefore be linked to the sea level rise. An overview of the water levels in relation to sea level rise, is shown in Table 9.1 (Slootjes et al, 2011). The increase in river water levels in relation to the see level rise is illustrated in Figure 9.2.

Table 9.1 Shifting water levels (box) and flood frequencies (arrows) due to sea level rise. Water levels for the current situation (WS huidig) and two climate change scenario's (G+ 2050 and Veerman 2100) for a series of return periods (Herhalingstijd).

Verschuiving waterstanden (cm +NAP)			
Herhalingstijd	WS huidig	WS G+ 2050	WS Veerman 2100
10	284	312	336
25	296	320	345
50	304	326	355
100	311	331	369
250	319	339	389
500	325	347	405
750	328	353	414
1000	330	359	421
1250	332	364	426
2000	336	375	437
2500	338	380	442
4000	344	391	453
5000	346	396	458
7500	353	406	468
10000	359	413	475
20000	377	431	492
50000	402	455	514

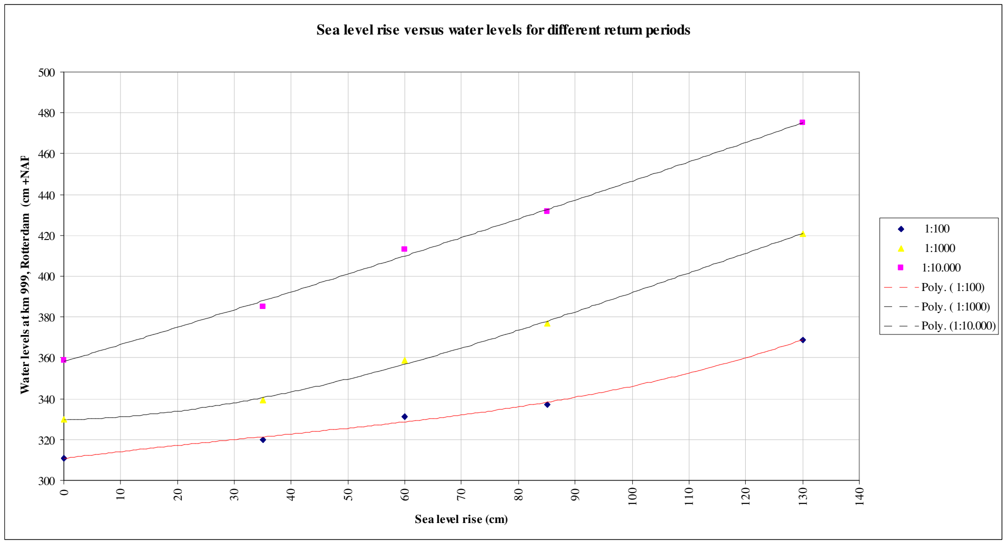

Figure 9.2 Water levels in relation to the sea level rise for a flood with return period 1:100, 1:1000 and 1:10.000 years at river km 999, Rotterdam.

9.2 Flood risk objectives

From the tipping point analysis it is therefore seen that to meet the chosen objectives, measures are required which reduce the risk of social disruption (electricity substation, communication network, ground floor bound living and hazardous activity), reduce the risk of damages to existing and new buildings as well as to public space and reduce the risk of casualties.

For the areas unprotected by flood defences, at present policy is only in effect for newly developed areas. These areas are elevated to a height equal to the current 1:10.000 water level. Presently the Province of South Holland is developing alternative policy for new urban developments based on a maximum tolerated flood risk to people and social disruption. Based on this development, objectives and threshold values have been defined in the context of this project in line with the policy of the Province. In this project this policy has been extended with objectives and threshold values for damage to buildings and infrastructure. These defined objectives and threshold values need to be met throughout the life span of the specific area, building or function. E.g. if a sports centre is planned and the expected life span is 30 years, then the centre ought to be assessed according to the estimated flood risk in 30 years.

Objective 1: Social disruption

1.1 Functions in public area:

Water in the public area is accepted as long as the social disruption does not exceed 10 affected days/year/ha.

The objectives 1.1 and 1.2 are equal, but a distinction is made for functions linked to the public space and to buildings and private space because the responsibility and possible responses are different for these two groups. The threshold value of 10 affected days/year/ha is equal to the value that is prescribed by the Province, and is based on experiences with flooding in other areas (Huizinga et al, 2011).

The function categories linked to the public space are:

- Utilities
- Transport and accessibility (emergency services, public transport and personal traffic)
- Recreation (This has been added to the list defined by the Province)

The function categories linked to buildings and private space are:

- Dwellings (low and high rise)
- Economic activity building (9:00 to 17:00)
- Industry
- Public building

The threshold value would need to be assessed for each function. This would be a time consuming and complex task. Therefore as a guideline for this project, the functions have been grouped into three categories:

- 'accepted flooding; hardly ever' (probability < 1:10.000 years);
- 'often' (probability < once a year).

- ‘sometimes’ (probability < 1:100 years) and

Functions already in place which fall into the category ‘hardly ever’, need to comply as soon as possible. Newly planned function as well as other functions already in place will only need to be adapted when a change of function is planned. These functions will then need to keep functioning in situations that comply with these frequencies. Designs should be assessed to see if the threshold for social disruption is exceeded or not. Paragraph 9.3 gives an overview of the functions and their requirements.

Objective 2: Risk of loss of life

The risk of loss of life expressed as the individual risk (IR) may not exceed 10^{-6} for 95% of the area

The used threshold has been adopted from the policy that is being developed by the Province of South Holland. The threshold is based on the values for safety applied in the field of external safety. The Individual Risk (IR) is defined as ‘the probability that an unprotected person could die as a result of a flood in one specific location within a period of one year, taking into account the possibilities for evacuation’.

For the determination of the risk, use is made of the tool developed by the Province of South Holland.

Objective 3: Direct damages

3.1 Damages to existing buildings:

No damage is tolerated (including the interior) for flood events with a frequency ≥ 1:100 years.

3.2 Damages to newly build and renovation

No damage is tolerated (including the interior) for flood events with a frequency ≥ 1:1000 years.

3.3 Damages to the public space:

No damage is tolerated (including the interior) for flood events with a frequency ≥ 1:100 years.

Currently policy is only in effect for newly developed buildings. The policy states that no water should enter the building up to a flood frequency of 1:10.000 years. This policy already takes into account possible future increases in flooding frequency and water levels.

The defined objectives and threshold values developed for the project need to be met throughout the life span of the building, covering future increases in flood frequency and water levels. E.g. if a building is planned with a life span up to 2100 assuming a sea level rise of 60 cm for the year 2100, then the building should be able to cope with a river water level of 3,59 m +NAP (Table 1.1), The frequency of such a river water level in the current situation is approximately 1:10.000 year. Note that in this context ‘Coping with’ is defined as ‘no damage’ where the current policy states that no water should enter the building. The objective for this project therefore allows water to enter the building, as long as no damage occurs to the building or interior. This leaves more room for alternative measures.

For the existing buildings and public space, the threshold is set at an event with a probability of 1:100 years for the following reasons:

- The threshold can not be too strict because adjustments to existing build are costly and difficult to perform

- No large damages are expected for the public area

- This threshold equals the threshold set for water on the street from smaller watercourses

- Psychologically this feels like a once-in-a -lifetime event.

For the determination of the damages the method developed by Veerbeek was used (Verbeek et al, 2008). This method focuses on damages to buildings (including the interior) and damages to infrastructure. Other damages are not considered within the context of this project.

9.3 Overview of functions and threshold values

In Table A.1 an overview is given of the functions and the required threshold value. The threshold values are based on the severity factor (Ernst factor) defined by the Province of South-Holland (Huizinga et al, 2011). For some functions other values have been chosen. This is indicated in the column 'remarks'.

Table 9.2 Overview of functions and threshold values

	Threshold value (Frequency < 1:X years)	**Remarks**
Function in relation to public space:		
Utilities:		
Gas	Often (1:1)	No outfall expected
Water	Sometimes (1:100)	Little outfall expected. Fast repair possible.
Underground electricity cables	Sometimes (1:100)	
Electricity substation	Hardly ever (1:10.000)	
Communication	Hardly ever (1:10.000)	Not addressed by the Province of South-Holland
Sewer system	Often (1:1)	Only accounts for a closable sewer system
Transport and accessibility		
Evacuation and emergency services routes	Hardly ever (1:10.000)	
Other roads	Often (1:1)	

Metro including the metro stations	Hardly ever (1:10.000)	High damages expected and long recovery time
Train including the train stations	Hardly ever (1:10.000)	High damages expected and long recovery time
Other public transport	Often (1:1)	
Recreation		
Sportsfields	Often (1:1)	
Public parks	Often (1:1)	
Events locations	Often (1:1)	
Function in relation to buildings and privately owned space		
Dwellings		
Groundfloor bound living (single floor)	Hardly ever (1:10.000)	
Non-groundfloor bound living	Sometimes (1:100)	
Economic activity buildings		
Offices (9 – 17)	Sometimes (1:100)	More severe appraisal then the Province due to loss of income
Stores and catering inductry	Sometimes (1:100)	More severe appraisal then the Province due to loss of income
Industry		
Non-hazardous activities	Sometimes (1:100)	More severe appraisal then the Province due to loss of income
Hazardous activities	Hardly ever (1:10.000)	More severe appraisal then the Province due to loss of income and environmental hazard
Public building		
Education and day-care	Sometimes (1:100)	More severe appraisal then the Province. It is undesirable for a school or day-care centre to encounter frequent flooding.
24-hour medical care	Hardly ever (1:10.000)	

*) In red the functions are indicated which should 'hardly ever' flood, in orange the functions labelled as 'sometimes' flooding allowed and in green the 'often' flooding functions.

To develop the scientific and applied knowledge required for Climate-proofing the Netherlands and to create a sustainable Knowledge infrastructure for managing climate change

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