Knowledge for Climate

Flood Impact Assessment for the Rotterdam Unembanked Areas

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Flood Impact Assessment for the Rotterdam Unembanked Areas

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1 Summary

Extending the flood damage assessment for the unembanked areas (HSSR02), this study attempts to provide a comprehensive flood impact assessment for the unembanked areas in the Rotterdam-Rijnmond area. Projected inundation depths are adjusted by incorporating the doorstep heights of individual buildings. This results in a reduction of estimated damages by about 35%. Nevertheless, the estimated annual damages might triple for a moderate climate change scenario and could increase 8-fold for an extreme scenario. Apart from a damage assessment, flood prone critical functions have been identified. Significant flood impact on traffic is only expected during extreme events. This also holds for telecommunication and utilities. Electricity supply could be interrupted due to limited inundation of local transmission stations. Yet, this affects only a small set of households. Flood sensitive functions like schools or elderly homes are mainly located outside flood prone areas. On neighbourhood level, the single most vulnerable area is Feijenoord. The expected damages in Feijenoord exceed those from all other neighbourhoods combined. Other flood vulnerable neighbourhoods include the Noordereiland and Heijplaat. Together with the Kop van Zuid-Entrepot area, Heijplaat is expected to be most sensitive to the effects of climate change.

2 Samenvatting

De uitkomsten uit deze studie vormen een uitbreiding op het project HSRR02 waarin de potentiele overstromingsschade wordt geschat voor de buitendijkse gebieden voor de regio Rijnmond-Drechtsteden. Dit project richt zich op zowel een verdieping als een verbreding van het inschatten van de gevolgen van overstromingen in het buitendijks gebied in de regio Rotterdam-Rijnmond. De schademodellering is verbeterd door het incorporeren van de drempelhoogtes van individuele gebouwen waardoor de inundatiediepte in veel gevallen wordt verkleind. De geschatte schadereductie bedraagt hierdoor ongeveer 35%. Desondanks verdrievoudigt de geschatte jaarlijkse overstromingsschade bij een gemiddeld klimaatscenario en verachtvoudigt deze bij een extreem scenario. Naast de schadebepaling richt het project zich tevens op het identificeren van de blootstelling van kritieke functies in het gebied. De uitkomsten tonen aan dat substantiële vervoersproblemen enkel te verwachten zijn bij extreme overstromingen. Dit geldt tevens voor mogelijke verstoring van de communicatie en nutsnetwerken. Een uitzondering wordt gevormd door een aantal schakelkasten. Uitval van deze kasten heeft echter enkel gevolgen voor een klein aantal huishoudens. Op buurniveau is vooral Feijenoord kwetsbaar voor overstromingen. De geschatte overstromingsschade is groter dan die van alle andere buurten gecombineerd. Andere kwetsbare buurten zijn het Noordereiland en Heijplaat, waarbij de laatste samen met de Kop van Zuid-Entrepot tevens zeer gevoelig is voor de effecten van klimaatverandering.

3 Extended summary

While the majority of cities in The Netherlands are protected by a system of dikes with a relatively high safety standard, a significant amount of urban areas is located in flood prone unembanked areas. Although recently, significant progress has been made in estimating the potential impacts of (climate change induced) floods on these areas, much remains unknown. Yet, in order to upgrade or adapt these areas to a possibly increased flood risk, a detailed assessment is needed of the expected impacts.

This project aims at extending the initial flood damage estimations made in the previous Knowledge for Climate HSRR02 project (Veerbeek et al, 2010a) both in depth and in breadth focussing on the Rotterdam-Rijnmond area. This includes the implementation of the doorstep heights of individual buildings in the inundation depth calculations. Although this seems a trivial aspect, the outcomes might be significant since the expected inundation depths in the area are limited. Furthermore, the flood impact assessment is extended by a comprehensive analysis of the affected critical infrastructure and functions (e.g. schools, elderly homes).

The outcomes show that especially for lower return periods, the estimated inundation depths for the unembanked Rotterdam area are limited. The adjusted elevation levels therefore cause significant damage reductions, which add up to an average of about 35%. For higher return periods associated to larger inundation levels, the reduction significantly drops.

While no significant trend in doorstep heights can be observed over the age of the building stock, some differentiation can be found between the different neighbourhoods. Especially for the flood prone and populated Heijplaat-area a conservative estimation rates the damage reduction at 37% in the current conditions. On the lower end, an average damage reduction of about 19% the Feijenoord-area is expected after implementation of the doorstep heights.

Due to the often high elevation levels combined with the location of the housing blocks and infrastructure, the exposed number of assets to flood inundation is relatively limited. The expected aggregate mean annual damage for housing and infrastructure though is considerable, and estimated at €77k. Application of the G+ and Veerman CC-scenarios increases this level to €222k and €615k respectively. To put this number in perspective, this currently amounts to only €4.07 per housing unit per year (including the infrastructure damage). When breaking down these costs per neighbourhood, the Feijenoord area is expected to be the biggest contributor, accounting for more than 25% of the estimated annual damage. Damages to infrastructure are a significant contributor to the aggregate damages; these account for almost half of the expected flood damages. Due to their proximity to the perimeter of the areas, they damage contribution is largest during frequent flooding (RP = 10Y). Application of the CC-scenarios doesn't reduce this relative contribution; also here about half of the expected flood damages stem from the road network.

The area hosts a significant amount of critical infrastructure and functions that host social groups that are especially sensitive to flooding. The most flood prone critical piece of infrastructure in the area seems to be the train tunnel for which the entrance on the southern side of Rotterdam is located within the floodplains. Currently this entrance is expected to be flooded only during extreme events. Application of the CC-scenarios might shift this event to more frequent occurrences with RPs of 100Y and 10Y for the G+ and Veerman scenario respectively. While the 3 bridges and their access points are located outside the floodplains, the connecting main road structure is not. Especially the Willemsbrug-Koninginnenbrug trajectory crosses the flood prone Feijenoord area to connect to the hinterland. Apart from the road and train network, the area also hosts various telecommunications, energy and water related infrastructure including 1 power station. The actual flood hazard for these installations differs since they are distributed over the complete area at different elevation levels. Local transmission installations serving individual housing blocks are found throughout the region but only result in local power failure in 10s of building units. The unembanked area hosts 37 schools of which 4 are located in frequently flooded areas (RP = 50Y or less). From these 4 schools, 3 are located in low rise buildings.

When breaking down the assessment to the individual neighbourhoods, the expected flood damage distributions show significant differences. In absolute terms, the expected annual flood damage in Feijenoord exceeds the damage for all other investigated neighbourhoods combined. Application of the CC-scenarios changes this ranking; the Heijplaat and Kop van Zuid-Entrepot areas are especially sensitive to increasing water stages and their consequent damages. When comparing the average expected annual damage per ha, the neighbourhoods can be divided into two groups: The Feijenoord, Heijplaat and Noordereiland areas all show significant damage levels, while for Katendrecht, Kop van Zuid, Kop van Zuid-Entrepot (and to a lesser extent the Afrikaanderwijk) the relative expected annual damages are minimal. Especially for the lower ranked neighbourhoods, the flood damages for infrastructure often exceed those for housing; due to the location of the residential areas, the expected damages to housing occur only during extreme events.

The overall conclusion of these outcomes is that the vulnerability of the unembanked urbanized areas in the Rotterdam-Rijnmond region is limited. Only during extreme flood events infrastructure and critical functions are affected. Also the estimated damages during such events are significant. Especially the neighbourhood of Feijenoord and to a lesser extent the Noordereilandd and Heijplaat are the most vulnerable areas to flooding. Significant changes in impacts caused by climate change and associated flood events are most likely to occur in Heijplaat and the Kop van Zuid-Entrepot neighbourhoods.

4 Introduction

Within the Knowledge for Climate programme (Knowledge for climate 2011), the Rotterdam-Rijnmond area acts as the main urban case-study to gain insight in the potential effects of climate change driven flood risk. A particular sub domain within this area is constituted by the highly urbanised unembanked region along the Meuse River. Previous studies (Veerbeek et al, 2010a) comprised of a detailed flood risk assessment that gave insight in the actual risk differentiation stemming from the high level of differentiation in morphology, occupancy and specific characteristics associated to the current flood defence systems. Particularly in the study “Flood risk in the unembanked areas” (Veerbeek et al, 2010b) a detailed appraisal has been delivered of the potential damage distribution resulting from the flooding of the Meuse River using the current exceedance probabilities as well as those associated to a moderate and extreme climate change scenario. Although methodological progress has been made in flood damage assessment, there are many open issues and uncertainties that provide room for improvement.

The project “HSRR3.1: Adaptive Strategies” aims at developing urban adaptation strategies for the urbanised unembanked areas in the Rotterdam-Rijnmond, that can cope with climate change and the associated increased flood risk stemming from the river Meuse. A basic requirement for an informed adaptation strategy is a comprehensive vulnerability assessment that covers both tangible and intangible flood impacts. The main aim of the project is therefore:

- Identify and quantify the vulnerability of the Rotterdam-Rijnmond unembanked area for the current conditions and two climate change scenarios;

To achieve this, a three main research steps have been identified:

- Further develop the damage assessment by evaluating the flood sensitivity of individual assets and extending the damage assessment methodology;
- Identify flood prone critical functions in the area (e.g. utility lifelines, kindergartens, etc.);

The outcomes should provide a deep insight into the flood vulnerability of the Rotterdam-Rijnmond unembanked area on a high level of detail using state-of-the-art assessment methodologies. An important requirement of the outcomes is that they provide a basis for the identification and application of responses for the current conditions as well as for those under the applied climate change scenarios.

This sub-report covers the methodological aspects of the assessment, the model output, the associated observations and resulting conclusions of the assessment. The initial part covers a recapitulation of the outcomes of the HSRR02-project which set the baseline for this research. Then, the adjusted damage assessment methodology is presented including the outcomes, observations and interpretation. This is followed by the assessment of critical functions in the area and the applied adaptation tipping point method. Finally, the outcomes are combined into a framework which should provide an initial guideline for the responses.

5 Assessment of previous results hsrr02

The Knowledge for Climate-project HSRR02, Flood risk in unembanked areas, focussed on assessing the flood hazard as well as the potential flood damages for the complete Rijnmond-Drechtsteden area which covers the unembanked area between the North Sea and the city of Dordrecht (241,12 km^2). Flood hazard has been derived from extrapolating a set of water stages in the Meuse River under specific scenarios and for a range of return periods (Huizinga et al). These water stages were interpolated and projected over the adjacent unembanked areas where in combination with a 5 meter resolution digital elevation map (DTM) the maximum inundation depths have been calculated. Apart from the current probability distribution, the project also incorporates 2 climate change (CC) scenarios with different horizons: a moderate CC-scenario for 2050 (G+) and a severe CC-scenario for 2100 (Veerman). For the Rotterdam-Rijnmond area, these scenarios are mainly driven by sea level rise (SLR). The moderate G+ scenario for 2050 was based on a SLR of 30cm, while the extreme Veerman scenario for 2100 was based on an SLR of 130cm. Note that the SLR for the G+ scenario for 2050 was derived from the G+ scenario for 2100 which assumes a SLR of 60cm. The value for 2050 was created by linear interpolation to the current conditions. Apart from the CC-scenarios, the consequences of 2 regional adaptation measures (‘closable but open’) have been assessed. The flood hazard component has been complimented by a study on the potential flood velocities in the area, since these might invoke structural damages to the exposed infrastructure and building stock. The potential consequences of flooding have been studied by applying a detailed flood damage model that incorporates individual assets (Veerbeek et al, 2010b), thus addressing the large level of differentiation within this highly urbanized area. This component focussed on assessing flood damages to housing and infrastructure for 7 return periods (10, 50, 100, 1000, 2000, 4000 and 10,000Y) to gain insight in damage distribution and progression. Furthermore, the damage assessment involved an extensive analysis of spatial (damage clustering) and temporal damage distribution (damage distribution over the age of the building stock) to identify urgencies and provide data for potential mitigation measures. The applied depth-damage curves consisted of several damage components (e.g. cleaning costs) which resulted in a more detailed insight in the potential flood damage composition in the area. Since the Rijnmond-Drechtsteden area covers a substantial industrial area (i.e. the port of Rotterdam) an additional assessment has been made that focuses on the potential vulnerabilities of industrial objects (Lanting et al, 2010) in which additional flood risk is compared to the inherent risks associated to the hosted industrial functions. While the main outcomes of the HSRR02 project are summarized by Veerbeek et al (2010a), the outcomes of the vulnerability assessment (Veerbeek et al, 2010b) are most relevant for this study.

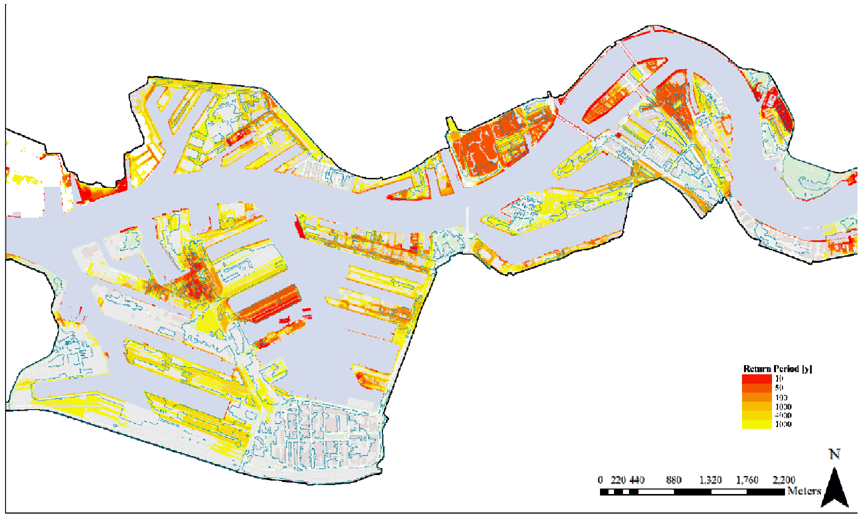


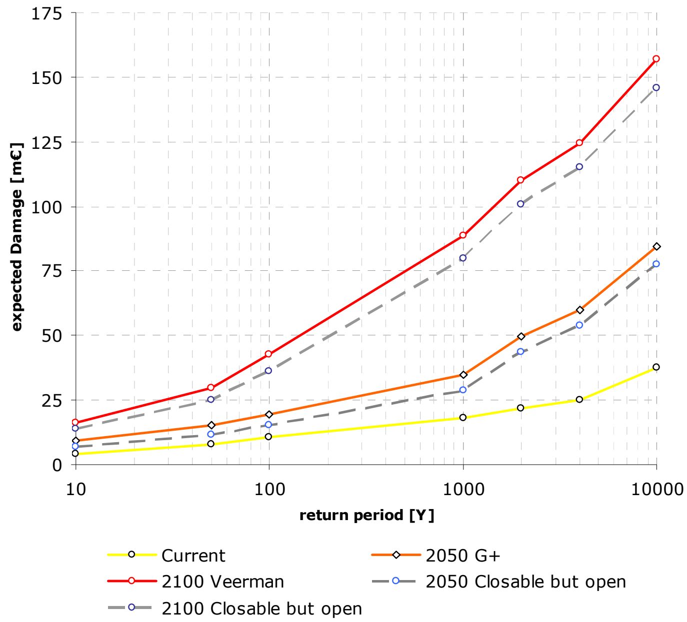
Figure 1: flood extent associated with the predicted return periods for the cur-rent conditions in the Rotterdam unembanked area.

The main conclusions from the report were subdivided into a set of topics. From these topics, the main conclusions are summarized are:

Climate Change Scenarios:

- *Increase of expected mean annual damage.* These levels increase by 75% for the G+ 2050 scenario and additionally by 147% for the Veerman 2100 scenario;
- *Proportional damage increase.* The applied climate scenarios result in a proportional increase of expected damages for the range of return period;
- *Shifting return periods.* When compared to the current probability distribution, the G+ 2050 scenario increases flood damages by about a factor 100, while the Veerman 2100 further amplifies this increase to a factor 1000;

Figure 2: Expected aggregate damage levels in HSRR02. From Veerbeek et al, 2010



Damage composition and distribution:

- *Damages to infrastructure.* The expected damages for infrastructure range between 18% and 40% compared to those for housing;
- *Damages to housing.* The expected damages for housing comprise for 48% of damages to the interior (furnishings). Expected damages for cleaning and drying (11%), floors and interior walls (11%), doors and windows (4%), kitchen (9%) and installations (18%) account for the remaining 52%;
- *Temporal distribution*. Within the current probability distribution, 60% of the frequently flooded houses (RP = 10) are built within the period 1980-2000. This percentage drops to 35% for a 100 year flood event. For the Veerman 2100 scenario, the majority of flooded buildings is almost uniformly distributed in age classes for a 10 year flood event, but consists during a 100 year flood event for 30% of historic buildings.
- *Damage clusters.* For lower return periods, 50% of the flood damages are located in about 15% of the identified damage clusters. For longer return periods and the applied climate scenarios this ratio decreases further to about 7%.
- *Relative damage*. The relative mean damage levels spread over the complete housing stock show substantial differences. For the current probability distribution, these drop to less than € 6 per housing unit for Rotterdam and Dordrecht. Because of the small housing stock, in Bergambacht this accounts for more than € 600 per housing unit. Application of the climate change scenarios result in about a 10-fold increase for Rotterdam and Dordrecht, while being almost stable for Bergambacht and Nederlek.

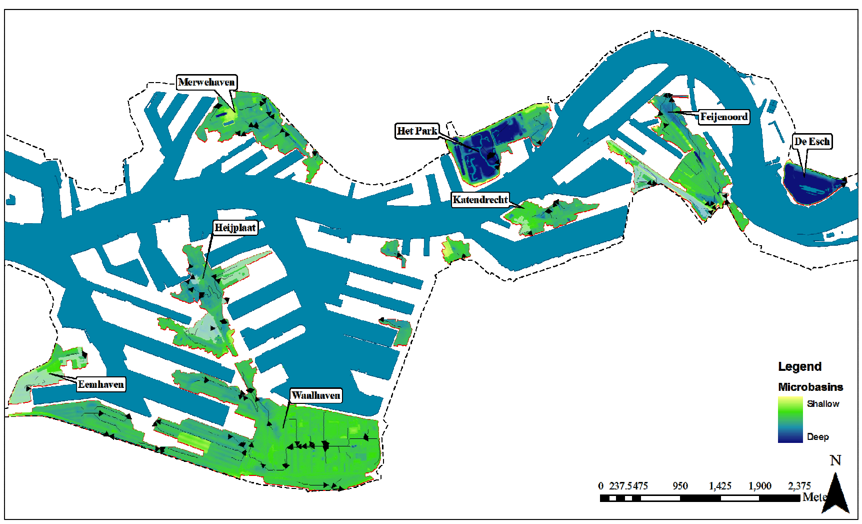
While these conclusions provide a deeper insight in the flood vulnerability of the area, the outcomes still lack breadth and depth to provide a solid framework for choosing possible responses. This is first of all related to the scope of the study, which focuses on a relatively large area covering 46 different municipalities that host a mix of residential, service and industrial areas. To establish a perspective on local adaptation measures, potential flood impacts have to be assessed on the level of neighbourhoods, blocks and individual assets. Furthermore, the sensitivity of especially houses (the majority of occupation in the area) to flood damages needs further attention; within HSRR02, flood damage estimations hardly articulate the large level of differentiation between individual houses. These could significantly change the predicted damage levels. Additional questions have to be asked when focussing on flood impact assessments as a whole. Within the HSRR02 project flood impacts are almost exclusively covering flood damages, while omitting other issues (e.g. casualties, critical infrastructure). While this might make the assessment fit for a benefit-cost appraisal, various safety aspects are underexposed. Finally, the outcomes do not provide a clear direction in relation to potential responses. While this was not the aim of the study, a clear set of recommendations regarding the scale, time and urgency of measures is lacking. This makes the connection to other projects focussing on adaptation measures rather difficult.

6 Vulnerability assessment hsrr31

6.1 Extending the flood duration by assessing micro-watersheds

Huizinga et al (2010) indicate that the expected flood duration is less than 35 hours since these are is estimation for the duration of the storm surge coming from the North Sea which dictates the water stage in the Rotterdam unembanked area. Within the HSRR02 study and the preceding Urban Flood Management Dordrecht (Veerbeek et al, 2009; Van Herk et al, 2011) project, the assumption therefore is made that the flood duration in the unembanked area is never longer than 35 hours. Yet, both studies fail to investigate if the area hosts micro-watersheds in which the floodwater will reside even after the critical water stages have receded. Although all of the area drains into the Meuse River, the storm water network might be saturated well beyond the 35 hour limit. Furthermore, surface water bodies that are used as local outlets might not be able to absorb the floodwater. To identify areas that might be experiencing longer flood durations, delineation of watersheds > 1ha has been performed. The outcomes are shown in figure 3, in which all micro-watersheds are identified, the stream direction to the outlet points and if the flow network drains back into the river.

Figure 3: Micro-watersheds within the unembanked area including stream direction and isolation.



Delineation shows that within the populated area of Rotterdam (i.e. excluding the port area) 15 combined micro-watersheds of over 1ha exist, covering a total of 10km2. With the exception of the micro-watersheds are located in ‘Het Park’, ‘De Esch’, which are green zones, most micro-watersheds are relatively shallow. Furthermore, the largest micro-watershed is located in the Waalhaven, an industrial area hosting port related functions. Within these watersheds 5244 building units are located of which 3087 are housing units. Depending of the flood extent these numbers indicate the upper bound for the number of buildings that might suffer from floods beyond the actual high water period. Yet, after the storm water drainage network and surface water bodies reach their operational levels, it is expected that the excess water can be drained out without the need for additional pumping.

6.2 Improving existing assessment by evaluating heterogeneity of the building stock

6.2.1 Improving Background

The Rotterdam housing stock shows a large variety in housing types (e.g. detached, apartment buildings), construction period and materialization. Within the municipal GIS-records, most of these characteristics are not expressed which results in a uniform processing within the flood damage estimation model.

An important property of the individual housing units is the location of the openings in relation to ground level. Since practically none of the buildings in Rotterdam is flood-proofed, the location of the front defines the main threshold level for which floodwater can enter a building. This location is a function of the local elevation of the housing unit which is defined by a predefined norm. Yet, the location is also determined by building typology and architectural style which, especially for pre-war built housing, often differs between individual units. The differences between front doorstep heights might range from centimetres to several decimetres. Especially for low inundation values associated to frequent floods these characteristics might significantly change the expected number of inundated housing units, the expected inundation levels and the expected subsequent flood damages. To address this issue, an on-sight inventory of the individual housing has been performed. Apart from measuring the height of doorsteps, other characteristics that might influence flood sensitivities have been identified. These include the occurrence of alternate ground floor bounded functions (e.g. parking garages), ventilation slots and basements.

A typical example of the differentiation ground floor and door step elevation is depicted in figure 4, which shows a characteristic street profile in the Noordereiland area. Since the street is composed of individual row houses built at different stages, every house has a distinctive entrance. The entrance levels are therefore mixed.

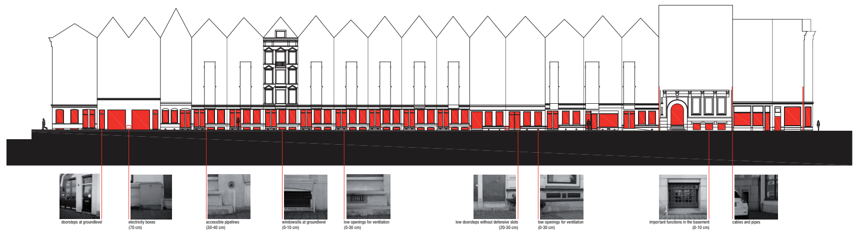


Figure 4: typical street profile in the Noordereiland area. unembanked area.

6.2.2 Methodology

The housing stock in the populated part of the Rotterdam unembanked area consists of about 19000 units of which 8000 are located on ground floor level[1]. These are distributed over an area of 3685 ha. Within the constrained resources of this study, it was not feasible to include all these units in the survey. Therefore, the survey was limited to the flood prone areas identified in the HSRR02 study (Veerbeek et al, 2010b) associated to a 10,000y flood event for the extreme Veerman CC-scenario for the year 2100. In total, Y housing units have been surveyed which are depicted in figure 5. About 40 surveyors (students) divided over 10 groups covered the area in a period of several days. Identification of the housing units was performed using Mobile Phone GPS in combination with a pre-manufactured digital map that indicated the survey objects. As a backup, printed maps were handed out.

The surveyors estimated doorsteps heights using a rulers and noted down additional building characterises, exemplified in table 1. Verification was performed by comparison results in Google Streetview™ as well as performing a cross-check on a representative sample of the surveyed houses.

Table 1: Example of GIS attribute entry from the survey

FID	Basement	Ground Level Function	Est. doorstep height [cm]	Type building
17	*No*	*Parking*	*70*	*Appartement Flat*

[1] This region includes the unembanked areas of the neighbourhoods: Afrikaanderwijk, Bospolder, De Esch, Delfshaven, Dijkzigt, Drievliet, Eemhaven, Feijenoord, Heijplaat, Hillesluis, Katendrecht, Kop van Zuid, Kop van Zuid-Entrepot, Kralingseveer, Nieuw-Mathenesse, Nieuwe Werk, Noordereiland, Oud-Charlois, Oud-IJsselmonde, Oud-Mathenesse, Pernis, Schiemond, Spangen, Stadsdriehoek, Struisenburg, Tarwewijk, Vondelingenplaat, Waalhaven, Waalhaven-Zuid and Zuiderpark.

The outcomes of the survey were added to the GIS-database as additional attributes indicating the minimal flood entry level, a binary attribute indicating the occurrence of basements and an attribute indicating alternate ground floor functions. Subsequently, the flood damage estimation model was adapted to accommodate these attributes by introducing a feature-dependent threshold level as well as functions to adjust flood depths and filter out alternate ground floor functions.

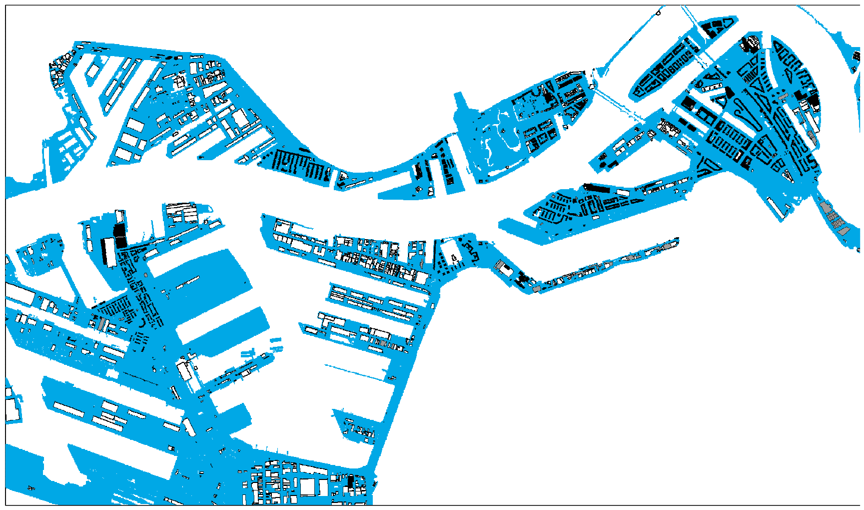


Figure 5: Flood extent of a 10,000Y flood (Veerman 2100) and housing units covered in the on-sight inventory (marked in black) unembanked area.

6.2.3 Operational Issues and Implementation

The assignment of doorstep values as the minimal flood entry point might neglect the permeability of walls, through which flood water might enter the building below the identified threshold level. Especially brick buildings might be susceptible to these artefacts since some bricks are porous. Furthermore, depending on mortar types, additional pore networks might occur that depending on the flood duration and water pressure might facilitate floodwater entry. Since most brick houses are constructed using cavity walls which consist of two brick layers, water penetration might only occur during longer periods of flooding. Nevertheless, additional research needs to be performed to fully assess the range of this effect.

A second, more important issue results from the fact that the survey only covered the exterior of the buildings. This raises issues about the actual height of the floor level beyond the doorstep, which might vary and be located well below the identified flood entry level. In combination with a baseline condition, this uncertainty is handled by introducing two distinct ways of handling this issue:

- *Base*. The elevation of the doorstep is not taken into account;
- *Threshold*. The ground floor level of the housing unit is assumed to be the same as the adjacent terrain level. The doorstep elevation level acts therefore as a threshold value; if the expected flood level exceeds the threshold, inundation levels are assumed to equal to those adjacent to the entry point;
- *Elevation*. The ground floor level of the housing unit is assumed to be equal to the doorstep elevation. Inundation levels are acquired by subtracting the doorstep level from the inundation levels adjacent to the entry point.

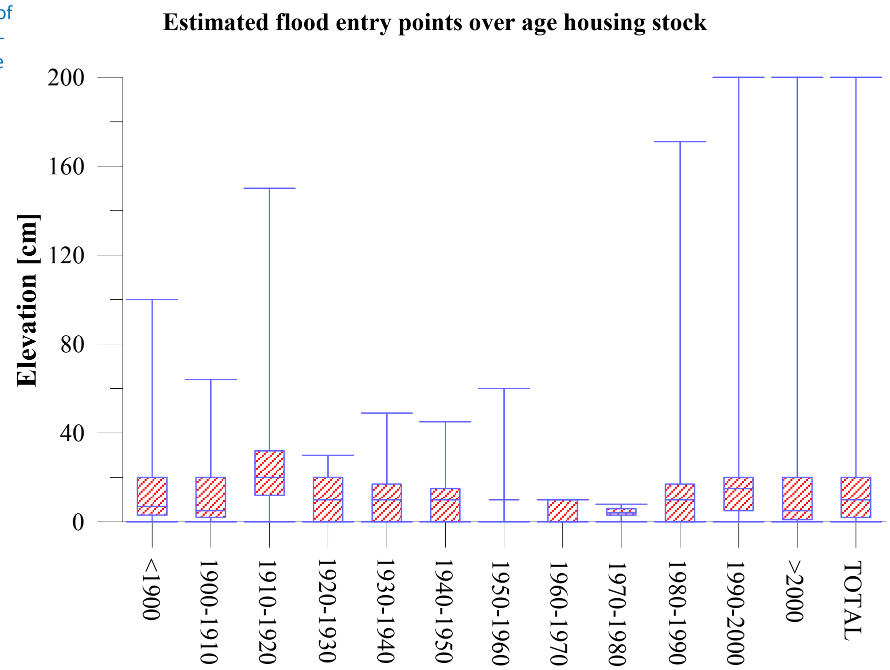
Together, these two approaches define a range in which the actual values are located. For individual housing units, both approaches should result in lower damage estimations for the lower range of flood depths. For the higher range of flood depths, the damage levels associated to the threshold-method should converge to the baseline methodology, while those for the elevation-method are estimated to be somewhat lower. Note that this behaviour should not necessarily be observed on district or case study level since here a wide range of flood depths can be observed.

Note that the calculated damages are strongly dependent on the building's function on ground floor level. Since no accurate estimates exist for the variety of functions found on ground floor, non-housing functions have been omitted from this study. Furthermore, the survey regrettably did not include an inventory of the building content nor did it investigate non-reported functional transitions (e.g. homeowners that converted their basement to office spaces or bedrooms).

6.2.4 Outcomes

Before assessing the effect of integrating the flood entry elevation into the flood damage assessment model, some insights might be gained by inspecting the relationship between the observed elevations and the construction age of the surveyed buildings. In figure 6, the 95% confidence intervals and ranges of the observed values are depicted.

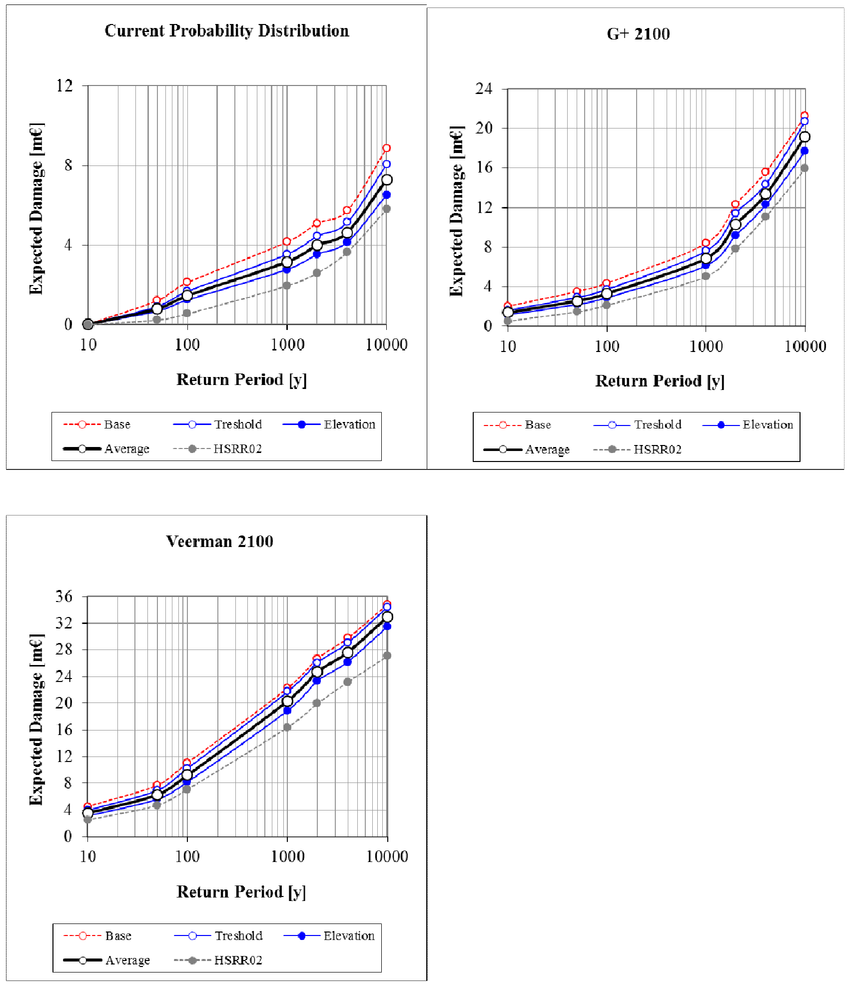
Figure 6: Distribution of the observed flood entry points over the age of the building stock



What first of all can be observed is that there is relatively little differentiation between the observed values; the 95% confidence level bounds are all within a 15cm margin. Although this range might seem relatively small, it might prove to be significant since the observed flood depths are often limited to several centimetres of water. A small set of individual buildings are accessed through elevated entrances, hence the relatively large ranges for the 1910-1920, 1960-1970, 1980-1990, 1990-2000 and the >2000 bins. With the exception of the 1910-1920 and 1990-2000 bins, the median value remains relatively stable over the years, which suggest no major changes occurred that changed access requirements of houses. The average median for these bins is about 9cm.

The effect of the adjusted flood entry elevations differs between assets and locations. The aggregate results for the Rotterdam-Rijnmond area are presented in Figure 7. The graphs cover the cumulative expected flood damages for return periods ranging between 10 and 10,000 years. Additionally, the cumulative flood damages from the HSRR02 project are depicted.

Figure 7: Distribution of expected flood damages over a range of return periods for housing units in the Rotterdam-Rijnmond region.



The first observation that can be made from figure 7 is that the expected damages of the current study are all above those presented in the previous HSRR02 project. The main reason for this is that the GIS-dataset that covers the housing stock offers a higher level detail than the set used in HSRR02. The current dataset includes all individual housing units, while the previous dataset narrowed down buildings only to block level. While previously, the amount of inundated houses had to be approximated by subdividing the blocks into smaller units, the current dataset allows a direct assessment of the number of inundated housing units. Apparently, this number is higher than the approximations in HSSR02. Consequently, the estimated damages are higher.

While Figure 7 indicates diverging cumulative damages for low and medium return periods, this does not necessarily imply that the effect of the increased flood entry levels are only significant for moderate to extreme events. To gain more insight in the contribution of the adjusted flood entry levels, the relative damage reduction (compared to the baseline level) has been calculated. The outcomes are presented in table 2.

Table 2: Expected damage reduction resulting from integration of elevated flood level entry paths resulting from on-site inventory

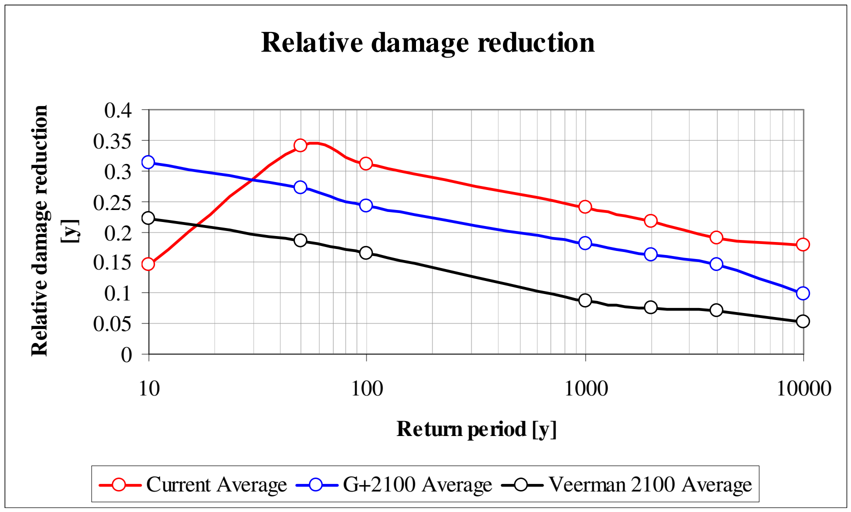
Return Period		10	50	100	1000	2000	4000	10000
Current	Threshold	-4.6%	-24.5%	-20.9%	-14.8%	-12.7%	-10.4%	-9.1%
	Elevation	-24.8%	-43.5%	-41.2%	-33.2%	-30.6%	-27.7%	-26.4%
G+ 2100	Threshold	-20.9%	-17.1%	-14.7%	-9.3%	-7.1%	-7.9%	-2.7%
	Elevation	-41.8%	-37.2%	-33.9%	-26.8%	-25.3%	-21.2%	-16.8%
Veerman 2100	Threshold	-13.0%	-9.9%	-7.4%	-2.4%	-2.3%	-2.3%	-1.2%
	Elevation	-31.3%	-27.2%	-25.7%	-15.1%	-12.6%	-11.9%	-9.5%

Except for the current probability distribution, table X shows a declining trend indicating a decline in the relative damage reduction resulting from the elevated flood level entry points. The sharpest drop is noticeable for the Elevation method, for which a 25% (from 41.8 - 16.8%) decrease is estimated during the G+ 2100 scenario. Nevertheless, the effect does not vanish for higher return periods, which suggests that within the increasing flood extent there is a significant amount of housing units with limited inundation. For the current probability distribution, the trend is different: until medium return periods (RP=50) the reduction increases after which it gradually drops. This suggests that a subset of housing units gets flooded frequently (RP < 50) and only beyond the 50Y return period, the flood extant expands significantly.

For the lower return periods, especially the effect of the elevation method is substantial (e.g. 41.8% for a 10y RP in G+ 2100). This suggests that the incorporation of doorstep heights, elevated ground floors and other factors that decrease the exposure to flooding has a significant effect on the estimated damages.

The question now becomes if these results can be generalized using a weight factor or some regression function that applies the damage reduction to different datasets. Therefore the progression of relative damage reduction is shown in figure 8, using the average reduction values of the threshold and elevation method.

Figure 8: Average relative damage reduction for a range of return periods



The first observation from figure 8 is the anomaly for the graph representing the current probability distribution; the damage reduction for a 10Y period drops far below the trend. This is due to the fact that currently a handful of housing units are located in the direct vicinity of the Meuse River. These houses flood frequently and experience medium inundation depths that are hardly influenced by adjusted flood entry levels. The observed reduction is therefore significantly lower. A further observation is that the reduction beyond the 1000Y return period progresses almost linearly. Using a first degree polynomial, the reduction D_r as a function of the return period Y, for the current, G+ 2100 and Veerman scenario then becomes:

$$D_r(Y) = -(5.464\mathrm{E}-06)Y - 0.141 \quad (1)$$

$$D_r(Y) = -(8.745\mathrm{E}-06)Y + 0.184 \quad (2)$$

$$D_r(Y) = -(3.29\mathrm{E}-06)Y + 0.086 \quad (3)$$

where $Y \geq 1000$.

For lower return periods, regression might still be possible but requires more complex regression functions.

Finally, the question is if the adjusted estimated damages for the different scenarios also result in a trend change when compared to the outcomes from HSRR02. The outcomes for the accumulated damages have therefore been compared and are depicted in figure 9, which covers the total range of return periods as well as the lower range.

Figure 9a: Comparison of the damage distribution over a range of return periods in ordinal scale for the expected return periods for the current conditions, the G+ 2100 CC-scenario and the Veerman 2100 CC-scenario.

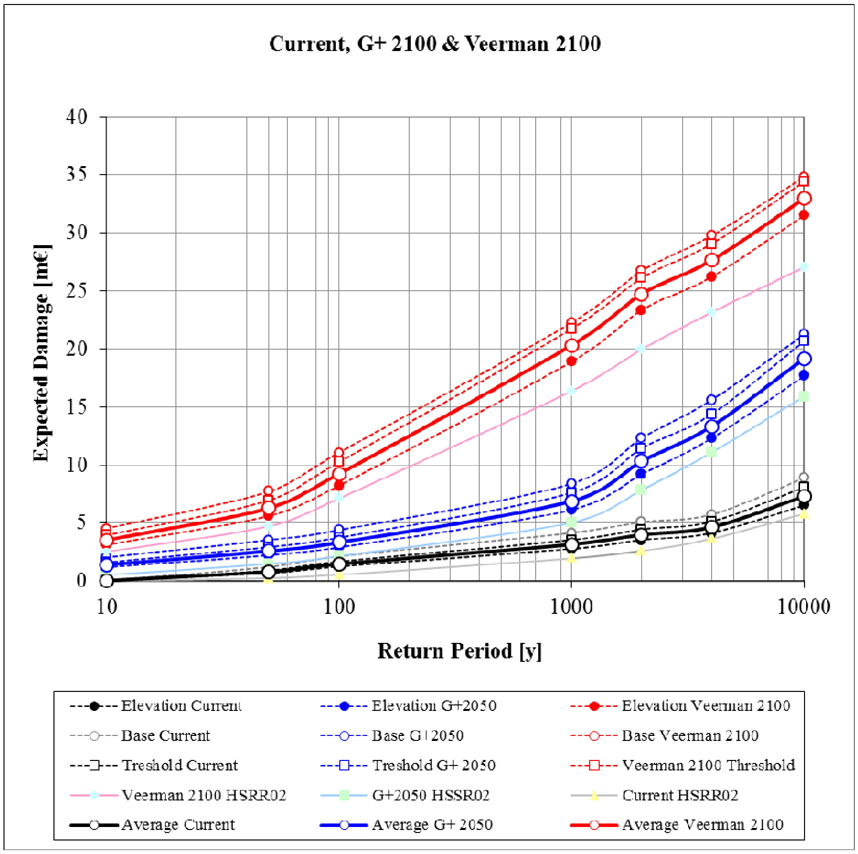
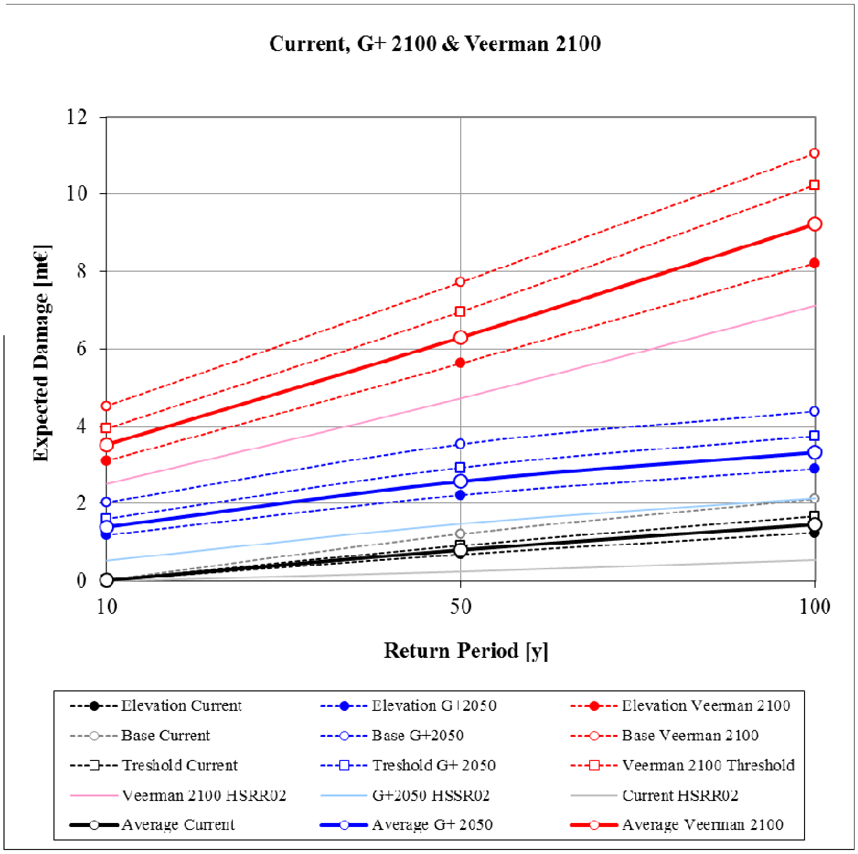


Figure 9b: Comparison of the damage distribution over a limited range of return periods for the expected return periods for the current conditions, the G+ 2100 CC-scenario and the Veerman 2100 CC-scenario.



The depicted outcomes from figure 9 show that no actual trend changes can be observed. The accumulated damages depicted in Base, Threshold, Elevation and Average follow the trends observed for the outcomes from HSRR02. This holds even for lower return periods (figure 9, right). A reason for this is that the amount of inundated houses is simply to large to notice the effects of areas safeguarded from flood damages due to high doorstep elevations. This effect might become noticeable on neighbourhood level when only a limited set of housing units are processed in the calculations.

Table 3. Expected Annual Damage for the unembanked Rotterdam area

Scenario		**EAD [k€ 2011]**	**Decrease**
Current	*Baseline* *Adjusted*	*102.0* *77.6*	*24.2%*
G+ 2100	*Baseline* *Adjusted*	*280.8* *222.1*	*20.9%*
Veerman 2100	*Baseline* *Adjusted*	*812.7* *615.4*	*24.3%*

6.2.5 Interpretation

From the observations in the previous paragraphs, the conclusion is justified that incorporation of individual doorstep elevations and the subsequent adaptation of flood entry points, leads to a significant reduction in flood damage estimation. Especially since the flood depths in the Rotterdam-Rijnmond unembanked area are relatively small, the damage reduction can reach levels of about 42%. The question remains if the reduction values are general for unembanked areas outside the Rotterdam-Rijnmond area. Further surveys need to be performed to sustain this claim. Nevertheless, within the Rotterdam-Rijnmond area, the majority of doorstep heights are within a relatively small range of elevation and the reduction rates for especially higher return periods show a strong linear correlation. The effect of the reduction becomes significantly smaller though for larger return periods and subsequent larger inundation depths, which makes general application of weight factors in for flood damage assessment using higher return periods less effective.

Unfortunately, current doorstep heights are not integrated in the municipal datasets for individual buildings. Since the survey work for large areas is relatively labour intensive, registration and integration these heights into the datasets for new buildings makes application less recourse intensive.

6.3 Completing the assessment by identifying critical functions

6.3.1 Background

While the assessment of flood damages is a vital part of any flood vulnerability assessment, the assessment is incomplete without an inventory of flood prone critical functions. These include on the one hand functions that host communities especially vulnerable to flooding (e.g. elderly, children) and on the other hand functions that play a crucial role in the functioning of the neighbourhood, city or region (e.g. utility lifeline, infrastructure, etc.). The latter can be identified as drivers for indirect damages although actual quantification is intricate (e.g. Veerbeek, 2007) and beyond the scope of this research project. The overall categories and actual inventory of vulnerable functions are based on Veerbeek (2011) and on the available data.

Vulnerable communities can be classified as those who need assistance or guidance during an actual flood event. This relates to behavioural aspects (e.g. the ability to execute an evacuation procedure) as well as self-sufficiency. In practice though, avoiding exposure to flooding of these communities is part of a social norm.

The classification of critical functions potentially causing indirect damages is somewhat more complex. In the strictest sense of the concept these include all functions that are vital during and after an emergency or provide functionality for the emergency response system. For this research project an assessment of all organizations, equipment and processes involved in emergency response have been omitted; the research focuses on:

- *Power supply*. Functions related to the electricity supply: power plants, transmission stations;
- *Communication*. Phone distribution and internet hubs;
- *Infrastructure*. Regional roads passing through the case-study area.

An important aspect in relation to flood prone power plants, transmission stations and internet hubs is the actual area these functions serve and their relative position in the distribution network (i.e. their importance in relation to connected nodes). Up till this point, this information unfortunately has not been provided and due to their strategic importance, might not become available in the future. Furthermore, since no detailed plans are available for individual features, their actual sensitivity is unknown. Nevertheless, a safe assumption is that especially functions related to the power grid are relatively sensitive to flooding.

6.3.2 Methodology

The identification of functions hosting vulnerable communities as well as critical functions is performed by a combination of GIS-based analysis and verification using Google Streetview™. As an upper bound, all functions intersecting a 10,000-year flood associated to the extreme CC-scenario (Veerman 2100) have been included. In the appendix, results for lower return periods and more moderate CC-scenarios are included.

Note that the identification of functions hosting vulnerable communities is merely indicative. Since the occupation of these functions is time-dependent, these might not be functioning during an actual flood. Furthermore, the lead-time of the flood and the subsequent evacuation policy might prevent actual exposure of these communities. Nevertheless, the flood prone identified functions can be regarded as ‘critical’ in a worst-case scenario.

6.3.3 Outcomes

Within the Rotterdam area a number of 73 critical functions have been identified, distributed over their subsequent categories as shown in table 4.

Table 4: Amount of flood prone critical functions for a 10,000Y return period in the Veerman CC-scenario

Functions	# exposed
Telecommunications	*1*
Transmission stations	*37*
Power stations	*1*
Education	*37*
Child Care	*3*

The distribution of these functions is shown in figure 10.

Figure 10: Identified flood prone critical functions and functions hosting vulnerable communities

Schools and Child Care

Under current conditions, out of 37 educational facilities (mainly schools) 9 are located in flood prone areas. From these 6, 4 are within the 4000Y flood extent while 2 are located in frequently flooded zones (50Y or less). Application of the G+ CC-scenario moves the majority of educational facilities to the 4000Y flood extent while the Veerman CC-scenario further shifts them to the 1000Y flood extent. From the schools located in flood prone areas, one is a high rise building in the “Kop van Zuid”-area (college) while the others are located in small low rise buildings in the “Noordereiland”-area. The latter might need additional attention since it is within the current 50Y flood extent. All 3 kindergarten are located in areas only exposed to extreme events (> 10,000Y).

Electricity related functions

The identified transmission stations typically look like those presented in figure 11; small brick-based utility sheds often accessed by entrance doors. Within these sheds, equipment converts the strong power current to household current after which it is distributed to individual households. Contact with water renders the equipment unusable. The majority of transmission stations is located outside the major flood hazard zones; from the 37 identified transmission stations, 33 are located in 10,000Y or less flood extents. Yet, all of them are exposed to floods with associated return periods of a 1000Y or more. The applied G+ CC-scenario shifts this to the 1,000Y flood extent. Only under the extreme Veerman CC-scenario, the transmission stations suffer from frequent flooding with return periods of 50Y or less. Currently though, no major flood impacts is expected that would lead to disruption of electricity supply on local or regional level.

Figure 11: Typical examples of transmission stations found in the Rotterdam area

Transmission Stations

Electrical transmission stations are located throughout the Rotterdam-Rijnmond unbanked area and are used to transform high voltage electrical current is into consumer voltage. This process takes place in several steps in which the current is downgraded from high to medium to low voltage current. The service area of the transmission stations differs; the prime input transmission stations used for high to medium voltage transformation serve entire districts while on the local transmission stations that output consumer voltages serve several blocks. While data on this hierarchy was not available, the locations of all transmission stations have been acquired. Through an onsite survey, in which several transmission stations were opened, the critical inundation depth was set at 30cm above ground level (see figure 12) for consumer voltage current and 50cm for medium voltage current. At this depth short circuiting can be expected since the copper wires are not sealed against infiltration of water. This would result in an interruption of the electricity supply of the service area. Repair is cumbersome since not only the connection needs to be replaces but also the input cable.

Figure 12: Local transmission stations and their critical failure depth

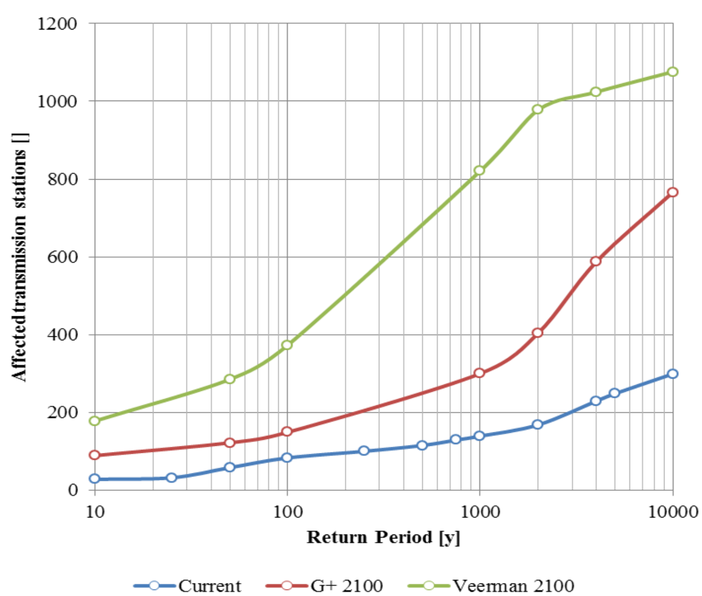
Note that the policy for safeguarding power interruption against flooding is inconsistent. While the Dutch building code requires electricity meters and in-house distribution to be located at a minimal height of 150cm above ground floor level, the electricity supply system (i.e. the transmission stations) are set at a much lower standard. For older housing units, the meters are often located below current regulations although this mostly concerns the water and gas meters and distribution units.

To obtain information about the exposure of the transmission stations and the subsequent susceptibility to electrical power failure in the Rotterdam urban agglomeration, the locations of the individual stations have been intersected with the flood extent associated to the different return periods. For this analysis a threshold of 30cm of inundation has been applied. The outcomes are shown in figure 13, where red dots mark exposure to frequent floods and green dots mark exposure to infrequent floods. Furthermore, an approximation is shown of the service area of the transmission stations by tessellating the area based on the closest proximity to the individual locations. Although this method ignores potential hierarchies in the electricity distribution network, it provides some indication about the differentiation in building number within the individual service areas.

Figure 13: Exposed local transmission stations for the current flood probability distribution.

Of the 1244 transmission stations, 299 are exposed to potential inundation above 30cm during an extreme event (i.e. RP=10,000Y). For frequent floods, this number decreases substantially to only 28 for events with return periods of 10 years. To obtain insight in the consequences of the applied CC-scenarios, the method is applied for the G+ and Veerman scenarios for 2100. The outcomes are shown in figure 14. For return periods below 50Y, the G+ scenario results in about a 200% increase in exposed transmission stations. The Veerman scenario increases this rise to about 500%. On the high end of the return periods, the increase drops to about 150% and 300% respectively.

Figure 12: Number of inundated local transmission station (>30cm) for the range of return periods and CC-scenarios in the Rotterdam urbanized area.



Gas distribution

Although less sensitive to the effects of flooding than the electricity supply network, various components in the gas supply are susceptible to failure as a consequence of flooding. These susceptibilities mostly concern aging assets, i.e. casted iron gas pipes used until the 1970 which break easily under mechanical pressure (Onderzoeksraad voor de Veiligheid, 2009). Generally, these pipes are situated 120cm below ground level and taken that they can withstand a pressure of about 0.15 bar, the critical inundation depth is about 30cm. This would result in infiltration of water into the pipes, subsequent blockage and potential gas explosions.

Figure 14: Exposed gas lines for the current flood probability distribution.

From the approximately 173km of gas lines, currently about 41km is exposed to floods with critical inundation depths (i.e. RP=10,000) which corresponds to about 24%. For frequent events (RP < 100Y) this ratio drops to less than 1%. Application of the G+ and Veerman CC-scenarios increases the exposed ratio of gas pipes to critical inundation depths significantly (see figure 15) ultimately resulting in 98% for an extreme event (RP=10,000Y) under the Veerman scenario. An important observation from figure 15 is the substantial increase of exposed gas pipes for frequent events. While for the G+ scenario a 100Y flood results in an exposure to critical inundation of about 7.5% of total length of the gas pipe network, the Veerman scenario boosts this ratio to about 23%. For the expected 1000Y event, these ratios rise to about 25% and 83%.

Note that the figures above reflect the worst case scenario in which all pipes are assumed to be constructed before 1970. This results in an overestimation since during various urban renewal cycles, the pipe network has been retrofitted locally over time. Unfortunately this data was not available for this research project.

Several gas distribution stations are located within the unembanked area. These are vulnerable for floods with inundations above 100cm resulting in potentially critical gas pressure.

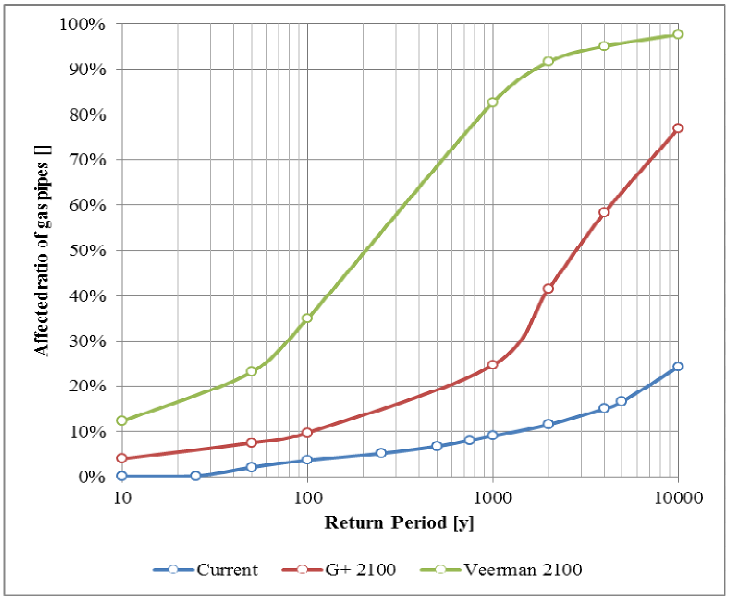


Figure 15: Ratio of exposed gas lines for the range of events under current conditions and the CC-scenarios.

Apart from the gas network, the gas connections within especially older residential areas are potentially sensitive to inundation. Often the gas meter and distribution installation are located only 40cm above ground floor level.

Telecommunications related functions

The Waalhaven area, Rotterdam hosts one of the 4 main telecommunication hubs in The Netherlands: The AURA, which is planned to be reconstructed in the near future. Within the current probability distribution the hub is not located in a flood prone area. Application of the G+ and Veerman CC-scenario's for 2100 moves the hub into the floodplains with return periods of 4000 and 1000 years respectively. The main power supply of the hub is routed through a series of transmission stations located on ground flood level. Failure of these stations is non-critical since diesel generators on the first floor are allocated for non interruptible power supply (IPS). The IPSs can operate for 48 hours without refuelling. In combination with the expected flood extent, the conclusion is justified that the AURA's flood vulnerability is neglect marginal; the possibility of flood driven major regional telecommunication disruptions is therefore negligible.

Local telecom hubs are located throughout the area and typically serve up to about a hundred local customers. Actual location data of these hubs was not available for this research. Currently, KPN (the main telecommunications provider in The Netherlands) uses a standard in which all equipment is placed 30cm above ground level. Yet, the equipment is sensitive to flooding, which could result in local disconnection of households and businesses during events in which flood levels exceed those 30cm.

UMTS/GSM antennas are located throughout the area to provide mobile connectivity. Generally, these antennas are placed on rooftops which suggest they can withstand severe flooding. It is unclear if any part related to the power supply is located on ground floor.

Apart from telephone lines, major communication facilities to especially consumers are provided by the cable network. Formerly only used for transmitting the radio and television signal, the cable currently provides a range of Internet Protocol IP-related services (including telephony). The main signal is distributed to households and companies by local distribution installations (see figure 16). These installations are located in large numbers throughout the area since they service often no more than a single housing block. Local survey showed that these installations are sensitive to inundation above 30cm which results in short circuiting and signal loss. Especially since television/internet is a major source of information, failure compromises the coping capacity of the area during floods.

Figure 16: Cable distribution installation.

Road network

In relation to potential evacuation and disaster management, a good functioning road infrastructure is of vital importance. Roads provide accessibility of emergency response teams (e.g. police, fire department) but also ensure connectivity to safe havens, i.e. local evacuation points or embanked areas within the adjacent urban agglomeration. In order to identify the sensitivity of the infrastructural network, dislocated areas have been identified during a 4000Y-flood. This return period marks the exceedance norm for the adjacent dike ring protecting the urbanized polder on the southern side (the northern side has a standard of 10,000Y). The outcomes are shown in figure 12.

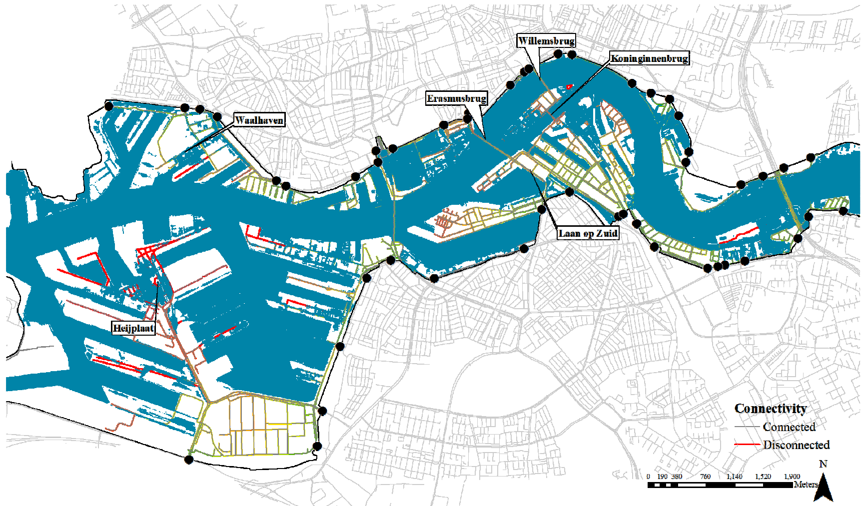


Figure 12: Isolated areas during extreme flooding (RP= 4000Y)

What can be clearly perceived from figure 12 is that only small portions of the infrastructure network get isolated. The majority of these ‘islands’ are located in port areas, e.g. the northern part of the “Heijplaat”-area and “Waalhaven”. This means that apart from the housing units actually flooded, no housing units will be isolated. Obviously, this is only the case for floods with return periods below the 4000Y and 1000Y safety standards of the adjacent dike. Beyond these, the area might be disconnected altogether.

An additional indicator related to the infrastructure network is the actual distance of the different locations to a ‘safe haven’. In this case, the distances to the embanked area are a critical parameter during evacuation. To compute these distances, a series of ‘inlet-points’ have been defined that mark access to roads leading into the hinterland behind the dikes. Using a shortest-path method, the actual distance from every point on the ‘inlet-points’ in the unembanked area has been calculated. The results are depicted in figure 13.

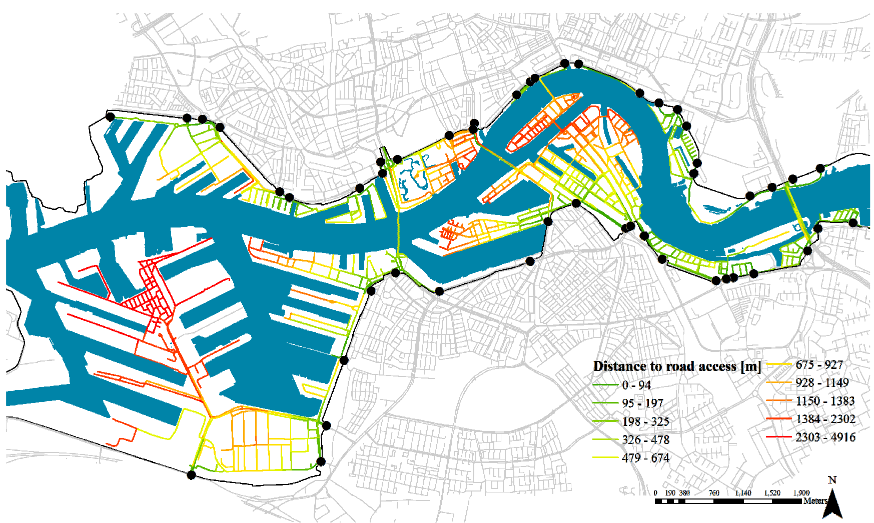


Figure 13: Estimated distances to the nearest ‘inlet-point’ on the embanked area

Since the area is in close proximity to the unembanked area and 'inlet-point's are located at fairly even intervals, the distances are relatively short; the furthest points are about 5 5km away. Note that those are located in the port zones of the "Heijplaat" area. The populated areas are connected by several roads to 'inlet-points', thus reducing the chance of traffic congestion during possible evacuation.

Special attention is required to the access roads to bridges and tunnels since they provide local connectivity to the Rotterdam centre as well as regional connectivity. On the northern side, all bridge connections are on or above the elevation associated to the 10,0000Y design standard of the dike ring. On the southern side, the road system connecting to the "Erasmusbrug" is under current conditions safeguarded against flooding. Under the G+ and Veerman CC-scenarios, the main connection ("Laan op Zuid") is located within the 10,000 and 1000Y flood extents respectively. The "Willemsbrug-Koninginenbrug" trajectory crosses the flood prone Feijenoord area. Disconnection proceeds for return periods of 50Y or more.

Metro and Railroad network

Within the Feijenoord area, the so called "Erasmus"-line connecting the Rotterdam centre to the southern part transforms from an underground to an elevated track. The tunnel entrance is under current conditions located outside the floodplains. Only under the extreme Veerman CC-scenario, the tunnel might be flooded for evens with return period of 1000Y or more. Note that this return periods is beyond the standard of the current dike projecting the adjacent urbanized polders; this case would therefore represent a major catastrophe characterized by major socio-economic disruption.

The Feijenoord area is also crossed by a major railroad line connecting the provinces of Zuid-Holland and Brabant. Furthermore, this track also connects The Netherlands to Belgium by regular and high speed train lines. Disruption of this line for longer periods could therefore severely disrupt national and international train traffic. Alternative connections require substantial rerouting and are of limited capacity to compensate this disruption. Although the majority of the track is elevated well above ground level, the Meuse River is crossed by tunnel. Within Feijenoord, the tunnel entries are located within the flood planes and are not protected by flood proof walls that extent outside the floodplain. Currently the tunnel entry is located in the 1000Y flood extent. The G+ and Veerman CC-scenarios shift this extent to 100 and 10Y respectively.

Additional Functions

For Dutch street lanterns, the critical inundation depth is about 35cm. Inundation above this level will result in short circuiting since electricity cables are not shielded against water infiltration.

6.4 Conclusions

The overall exposure of critical and sensitive functions in the unembanked area of the Rotterdam area is limited. Currently, traffic interruptions due to flooding are only expected during extreme events. This conclusion extends to the identified tunnels that facilitate the connection to the Rotterdam centre and the hinterland. Yet, the applied CC-scenarios do cause some concern since the frequency of these extreme events shifts into more regular events. For the electricity supply and distribution, a similar conclusion can be drawn. All transmission stations are located within the 1000Y floodplain and only during the extreme Veerman CC-scenario, they move within the extent of regular flood events. With the exception two, sensitive functions (e.g. education facilities) are also only affected by extreme flood events.

7 Adaptive refinement: zooming in on neighbourhood level

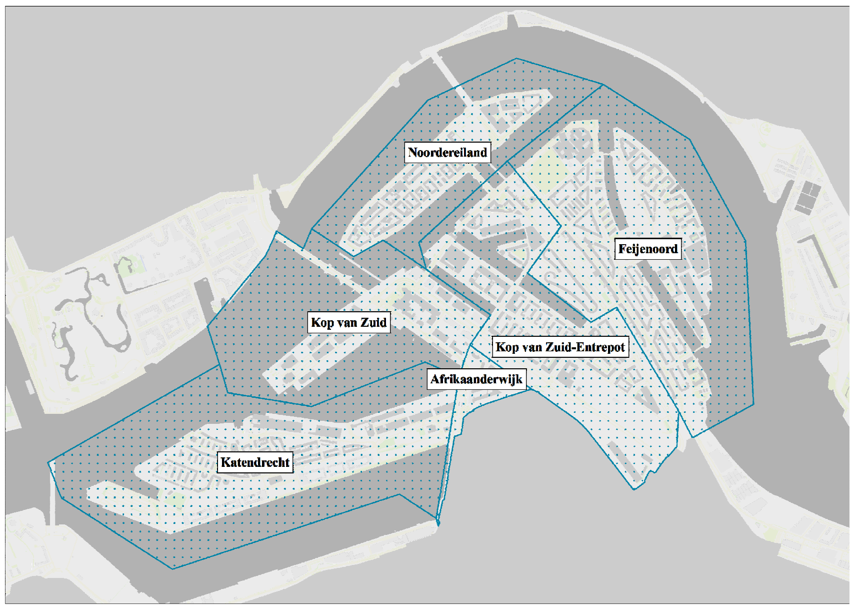
7.1 Historical context

7.1.1 Historical development of the case study area

In 1850, “Feijenoord” and part of “Kop van Zuid” area are still an island separated from the mainland by a narrow river called “Het Zwanengat”. The area mainly consists of farmland and small port related industry. This industry expands between 1860 and 1880 especially on the northeastern areas. During this period the “Westerbinnenhaven”, “Entrepothaven” and “Koningshaven” are excavated. The latter separates the northern part of Feijenoord referred to as the “Noordereiland”. During this period the area is connected by railway to the Rotterdam centre by constructing a bridge connection to the north. During the early part of the 20st century, the port of Rotterdam expands to the southwestern part of Feijenoord. Around 1900 the “Rijnhaven” and some years later the “Maashaven” were excavated, creating the “Wilhelminakade”, developed to support the increasing activity of the Holland-America Line and a peninsula around the old village “Katendrecht”. This period marks the definition of the final geography of the area; no major excavation or reclamation activities have been performed after this period in time. After World War II, the area undergoes gradual reconstruction, transforming the area from a mainly industrial zone to a residential area. At the same time, the departure of port related activities also marks an economic downfall of the area which results in substantial decay during the 1960s. During the 1970s the first urban renewal projects are executed focusing mainly on social housing. Apart from the existing tunnel, a second connection to the Rotterdam centre is created by construction of the “Willemsbrug” which connects the “Noordereiland” to the centre. Further connectivity is provided by the newly constructed train station “Rotterdam Zuid”. The 1980s mark a turning point for the area. During those years a revaluation of the area takes place which leads to the development of a new masterplan “Kop van Zuid”. The masterplan aims at upgrading the area by the introduction of high quality housing and services. The plan also accommodates a new bridge connection, directly connecting the “Kop van Zuid”-area to the Rotterdam centre. Because of the massive scale of the urban renewal, the construction of this new vision covers more than two decades. The success of this urban revitalization results in the development of a smaller extension, as defined in the “Plankaart 2010 – Kop van Zuid 2” blueprints. This plan involves further densification of the area (mainly through housing) and an extension of the “Willemsbrug” straight into the “Feijenoord” area.

In short, in a little over a century the area witnessed a transformation from agriculture to brownfield area after which it was redeveloped into a diverse residential district which is still witnessing further expansion and upgrading.

Figure 13: Different neighbourhoods based on administrative boundaries



7.1.2 Flooding in the area

The unembanked area in the Rotterdam region has always been vulnerable to storm surge driven river flooding of the river Meuse. Reported floods that affected the area are the floods of 1906, 1916 and the catastrophically large flood of 1953 that inundated most of the South-Western part of The Netherlands. Although unembanked Rotterdam area suffered significant damages due to this flood event, no casualties were reported. With the completion of the Maeslant and Hartel storm surge barriers in 1996, the threat of storm surges is practically eliminated.

7.2 Comparison between neighborhoods

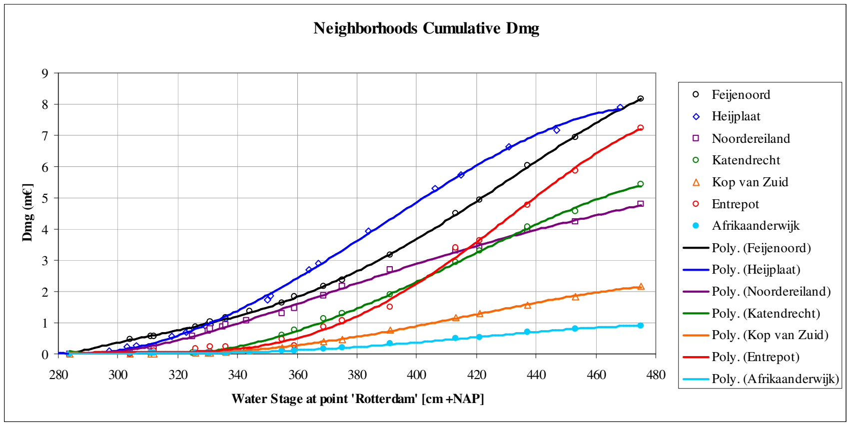


Figure 14: Comparison of the damage distribution associated to the observed water stages in the Meuse River

Figure 14 illustrates a clear division between neighbourhoods suffering damages from the lower bound of water stages and those from medium to higher water stages. Damage progression Feijenoord, Noordereiland and Heijplaat areas proceeds from a Meuse water stage below 300cm +NAP, while for all other start suffering from flood damages at 325cm +NAP or higher. The rate of the damage progression between neighbourhoods also shows different behaviour. While the rate for the Noordeiland area is almost constant (i.e. linear progression), the Kop van Zuid-Entrepot area shows a strong S-shaped progression. While the expected flood damages are largely depended on the interplay between flood extent, location and density of assets, the graphs presented in figure 45 clearly show the changing relative contributions of the neighbourhoods to the accumulated flood damage of the total area. While the Feijenoord area dominates the expected damages on the lower and higher end of the graph, the Heijplaat area is expected to exceed those damages between a range of 330cm and 465cm +NAP. The area which shows the steepest curvature is the Kop van Zuid-Entrepot area, which suffers only minor damages below the 360cm +NAP water stage, but climbs to a 3rd rank above the 420cm +NAP mark; for the lower end of the water stages (associated to low return periods) the area is well protected (see figures X left) while the growing flood extent for higher water stages inundates a disproportionally large amount of housing units.

When associating these water stages to their estimated return periods as well as comparing the effects of the applied CC-scenarios, the outcomes change. Figure 46, shows the average damage progression (per HA) for the different neighbourhoods: the damage density.

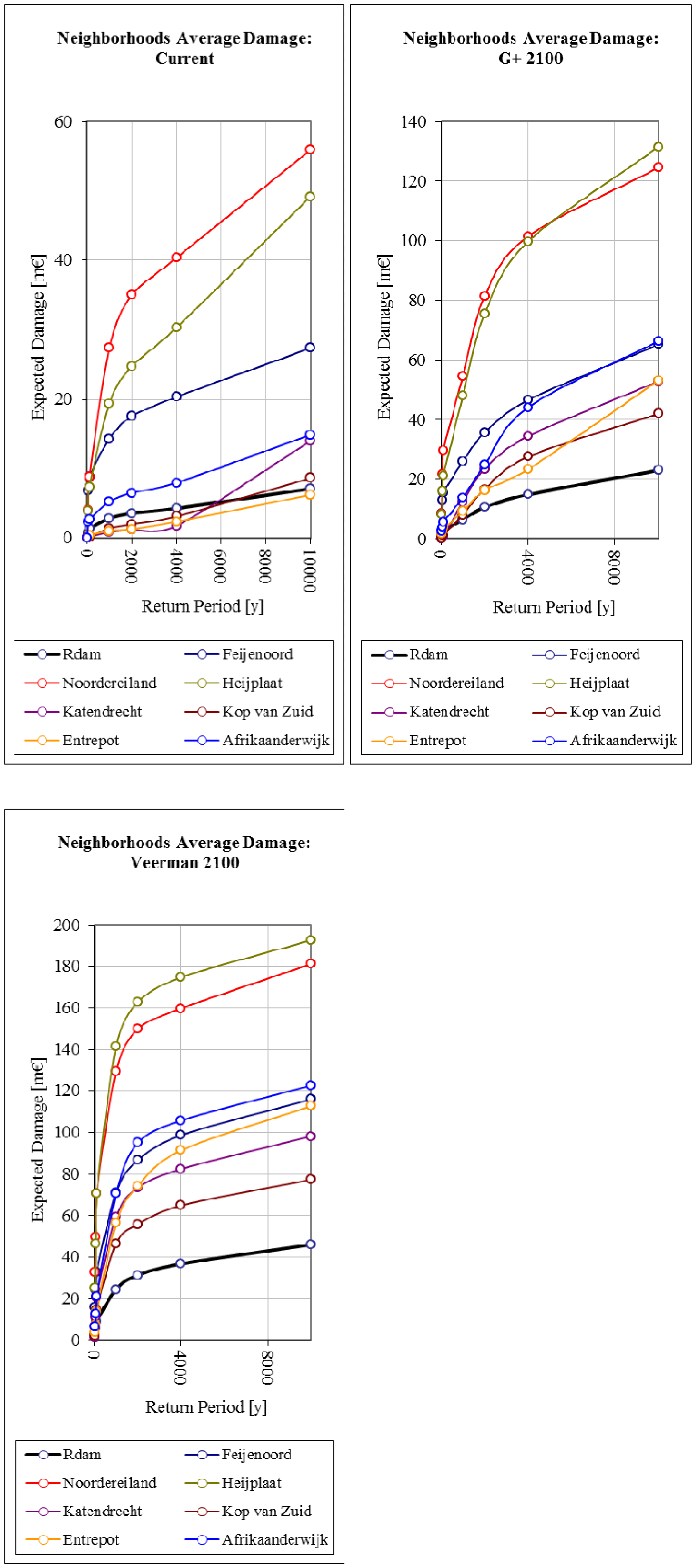


Figure 46: Expected average flood damages per HA for a range of return periods for the current, G+ and Veerman CC-scenarios.

For the current conditions, figure 46 clearly indicates dominance in damage density for the Noordereiland area, followed by the Heijplaat and Feijenoord areas. While all graphs shapes show exponential decay, the damage density fro the Katendrecht area shows a clear threshold between the 2000Y and 4000Y return periods, where the curve bends from concave to convex. Application of the CC-scenarios shows a similar behaviour under the G+ CC-scenario for the Kop van Zuid-Entrepot area. The CC-scenarios also move the Heijplaat area from rank 2 to rank 1 (Veerman CC-scenario) in estimated damage density.

An important observation from figure 46 is that with the exception of the Kop van Zuid-Entrepot and Katendrecht areas under current conditions, all neighbourhoods show a larger estimated damage density than for the complete Rotterdam area. This confirms the vulnerability but also questions to what extent these areas are representative in relation to other neighbourhoods in the unembanked area. The discrepancy between the case study neighbourhoods and the overall Rotterdam area only increases under the G+ and Veerman CC-scenario.

To provide an overall indication of the relative ranking between neighbourhoods, the relation between damage components and the potential impact of CC, a qualitative assessment has been produced. The outcomes are shown in table 12. The rank for frequent flooding and extreme events has been based on a division of the EADs, in 2 bins: 10Y-1000Y events and 1000Y-10,000Y events. Although this division is arbitrary, it provides a good indication of the contribution of these events and their relative importance between neighbourhoods. The colouring of the table is based on the relative contribution of each item, e.g. the differences between damage contributions of frequent or extreme events or the relative increase resulting from CC.

Table 5: qualitative assessment of flood vulnerability indicators per neighbourhood

Neighbourhood	**Susceptibility**			**Damage Distribution**	
	Frequent Flooding (rank)	**Extreme Events (rank)**	**Climate Change**	**Infrastructure**	**Housing**
Arikaanderwijk	*4*	*7*	*7*		
Feijenoord	*1*	*1*	*2*		
Noordereiland	*3*	*3*	*3*		
Katendrecht	*6*	*5*	*5*		
Kop van Zuid	*7*	*6*	*6*		

Kop van Zuid-Entrepot	*5*	*4*	*4*		
Heijplaat	**2**	**2**	**1**		

8 Conclusions

The outcomes of this research don't so much change the conclusions made in the HSRR02 project, but extent and differentiate these outcomes.

The first methodological extension concerned the implementation of the doorstep heights that provide accessibility to the housing units but also largely determine the flood entry elevation. While often omitted in flood damage assessment, the outcomes show a major reduction of the expected flood damages when actual doorstep heights are taken into account. Especially for lower return periods, the estimated inundation depths for the unembanked Rotterdam area are limited. The adjusted elevation levels therefore cause significant damage reductions, which add up to 35% of the baseline levels. For higher return periods associated to larger inundation levels, the reduction significantly drops.

While no significant trend in doorstep heights can be observed over the age of the building stock, some differentiation can be found between the different neighbourhoods. Especially for the flood prone and populated Heijplaat-area a conservative estimation rates the damage reduction at 37% in the current conditions. On the lower end, an average damage reduction of about 19% the Feijenoord-area is expected after implementation of the doorstep heights.

This leads to the following conclusion:

- ***For the unembanked Rotterdam area, the implementation of adjusted doorstep heights in the flood damage model leads to a significant reduction in expected flood damages to housing units of about 35%.***

Due to the often high elevation levels combined with the location of the housing blocks and infrastructure, the exposed number of assets to flood inundation is relatively limited. The expected aggregate mean annual damage for housing and infrastructure though is considerable, and estimated at €77k. Application of the G+ and Veerman CC-scenarios increases this level to €222k and €615k respectively. To put this number in perspective, this currently amounts to only €4.07 per housing unit per year (including the infrastructure damage). When breaking down these costs per neighbourhood, the Feijenoord area is expected to be the biggest contributor, accounting for more than 25% of the estimated annual damage. Damages to infrastructure are a significant contributor to the aggregate damages; these account for almost half of the expected flood damages. Due to their proximity to the perimeter of the areas, they damage contribution is largest during frequent flooding (RP = 10Y). Application of the CC-scenarios doesn't reduce this relative contribution; also here about half of the expected flood damages stem from the road network.

- ***The estimated annual flood damage for the area is close to €77k but might triple for a moderate and increase 8-fold for an extreme CC-scenario;***

- ***The expected damages to infrastructure comprise of almost 50% of the aggregate flood damages;***

- ***The average annual damage per housing unit is as low as €4 including infrastructural damages.***

The area hosts a significant amount of critical infrastructure and functions that host social groups that are especially sensitive to flooding. The most flood prone critical piece of infrastructure in the area seems to be the train tunnel for which the entrance on the southern side of Rotterdam is located within the floodplains. Currently this entrance is expected to be flooded only during extreme events. Application of the CC-scenarios might shift this event to more frequent occurrences with RPs of 100Y and 10Y for the G+ and Veerman scenario respectively. While the 3 bridges and their access points are located outside the floodplains, the connecting main road structure is not. Especially the Willemsbrug-Koninginnenbrug trajectory crosses the flood prone Feijenoord area to connect to the hinterland. Apart from the road and train network, the area also hosts various telecommunications, energy and water related infrastructure including 1 power station. The actual flood hazard for these installations differs since they are distributed over the complete area at different elevation levels. Local transmission installations serving individual housing blocks are found throughout the region but only result in local power failure in 10s of building units.

- ***Significant traffic interruption due to flooding occurs only during extreme events. Application of CC-scenarios might shift these events to higher frequencies.***

The unembanked area hosts 37 schools of which 4 are located in frequently flooded areas (RP = 50Y or less). From these 4 schools, 3 are located in low rise buildings.

- ***Out 37 schools located in the unembanked area, 3 schools are vulnerable to flood risk.***

When breaking down the assessment to the individual neighbourhoods, the expected flood damage distributions show significant differences. In absolute terms, the expected annual flood damage in Feijenoord exceeds the damage for all other investigated neighbourhoods combined. Application of the CC-scenarios changes this ranking; the Heijplaat and Kop van Zuid-Entrepot areas are especially sensitive to increasing water stages and their consequent damages. When comparing the average expected annual damage per ha, the neighbourhoods can be divided into two groups: The Feijenoord, Heijplaat and Noordereiland areas all show significant damage levels, while for Katendrecht, Kop van Zuid, Kop van Zuid-Entrepot (and too a lesser extent the Afrikaanderwijk) the relative expected annual damages are minimal. Especially for the lower ranked neighbourhoods, the flood damages for infrastructure often exceed those for housing; due to the location of the residential areas, the expected damages to housing occur only during extreme events.

- ***Of all the investigated neighbourhoods, the expected annual flood damage for Feijenoord exceeds the combined damage of all other neighbourhoods together;***

- ***Per ha, the Noordereiland, Feijenoord and Heijplaat neighbourhoods show significantly higher damage levels than the other neighbourhoods;***

- ***The Heijplaat and Kop van Zuid-Entrepot neighbourhoods are especially susceptible to CC and the associated higher water stages.***

All in all, the vulnerability of the Rotterdam unembanked area to flooding is limited. In terms of vulnerable functions, only during extreme events with high return periods the infrastructural capacity as well as sensitive social functions (e.g. education) are exposed to floods. The expected flood damages in the area are significant, but moderate. Especially the Feijenoord area is expected to suffer from flood damages to buildings and infrastructure. The Heijplaat and Kop van Zuid-Entrepot areas are especially susceptible to the potential impacts of CC.

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10 Supplement

10.1.1 Feijenoord

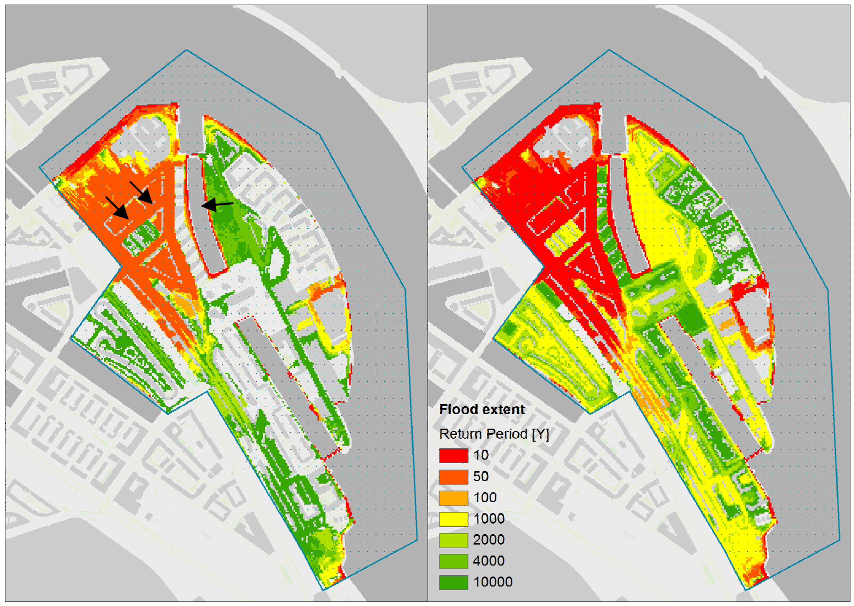


Figure 1: Estimated flood extent for the Feijenoord area for the current (left) and G+ (right) CC-scenario. The arrows mark the pathways through with the flood initially proceeds towards the centre area.

Extensive flooding in the Feijenoord area currently progresses initially over a few critical pathways; First the Northern part of the embankment floods after which the flood extent quickly expands to the central area using only limited conveyance route. This results in major flooding with return periods of 50Y or more, with inundation depths ranging from a few centimetres to several decimetres. Beyond the 100Y return period, the pathway expands after which the floodwater enters throughout the Northern area. During extreme events (> 1000Y) the flood spreads further South as well as towards the Eastern peninsula. Application of the G+ CC-scenario has significant consequences for the area. The conveyance paths disappear, and the central area is flooded frequently from the North. The total flood extent expands, covering almost the entire Feijenoord area for events with return periods exceeding 1000Y. Application of the Veerman CC-scenario results in frequent major flooding of the area since return periods shift with a factor of about 200.

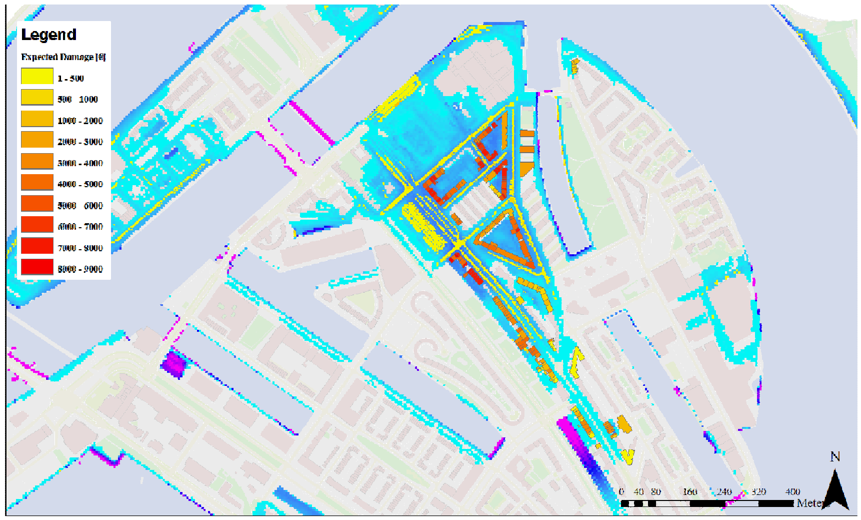


Figure 2: Spatial distribution of flood damages to infrastructure and housing units on the Feijenoord location (RP = 2000Y)

For the current probability distribution, the Feijenoord area is sufficiently flood prone to suffer from damages during frequent flooding. Beyond the 10Y return period the expected damages rise substantially. Application of the adjusted flood entry points resulting from elevated doorsteps and other adjustments on building level, reduce damages by an average of 19.1, 19.6 and 12.3% for the current, G+ 2100 and Veerman 2100 scenarios respectively. For the applied two CC-scenarios, the damages increase substantially. While the expected damage for the G+ 2100 scenario evolves relatively gradual, an threshold effect can be perceived for the 100Y return period for the Veerman 2100 CC-scenario, showing a disproportional damage increase.

With the exception of the Veerman 2100 CC-scenario, these results indicate a rather gradual progression of expected flood damages over the range of return periods as the flood extent expands over the area. To further investigate this hypothesis, the damage assessment needs to include the expected damages suffered by the local road system. The outcomes are presented in figure 3.

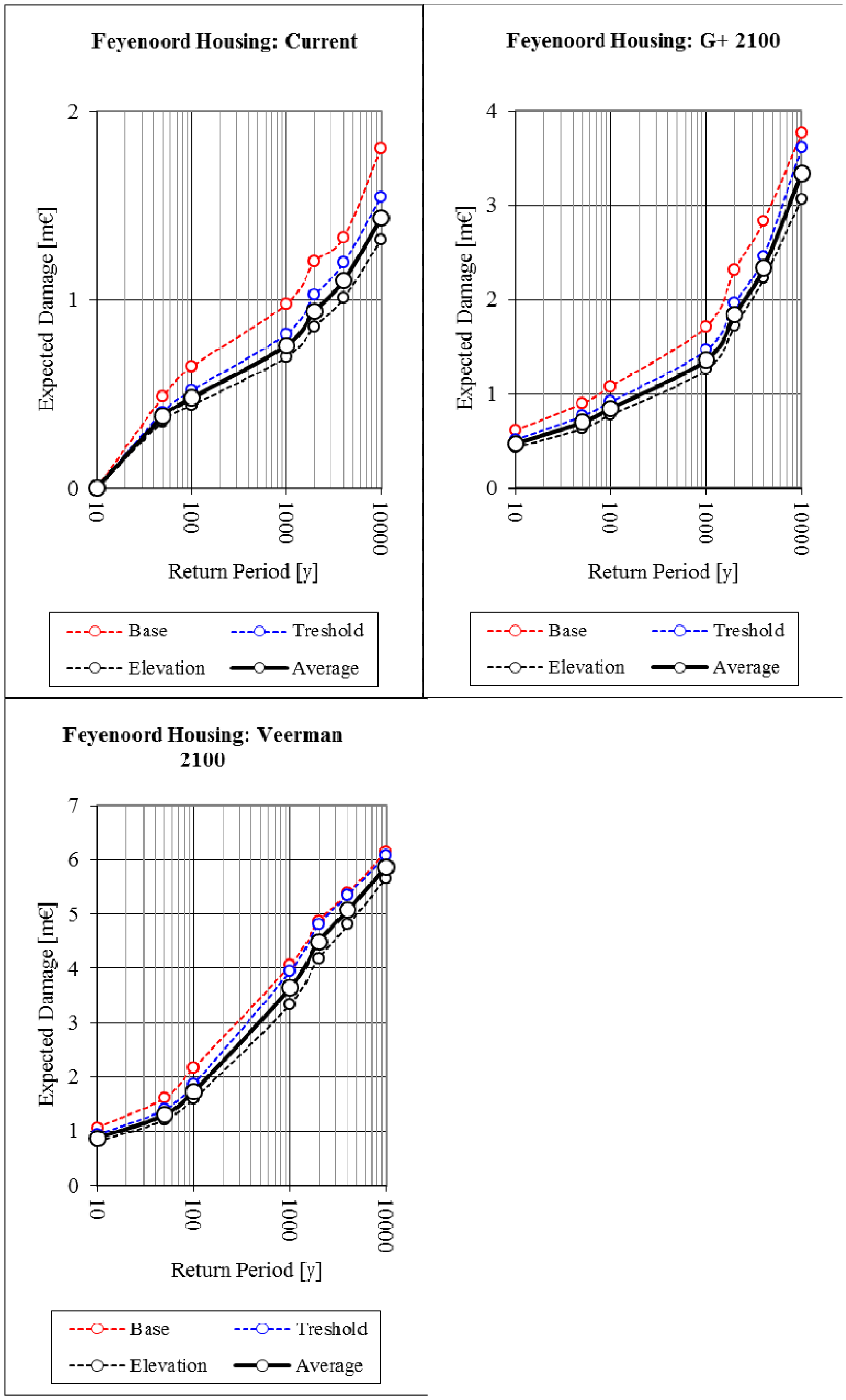


Figure 3: Expected damages for housing for a range of return periods and CC-scenarios, with and without application of the adjusted flood entry points

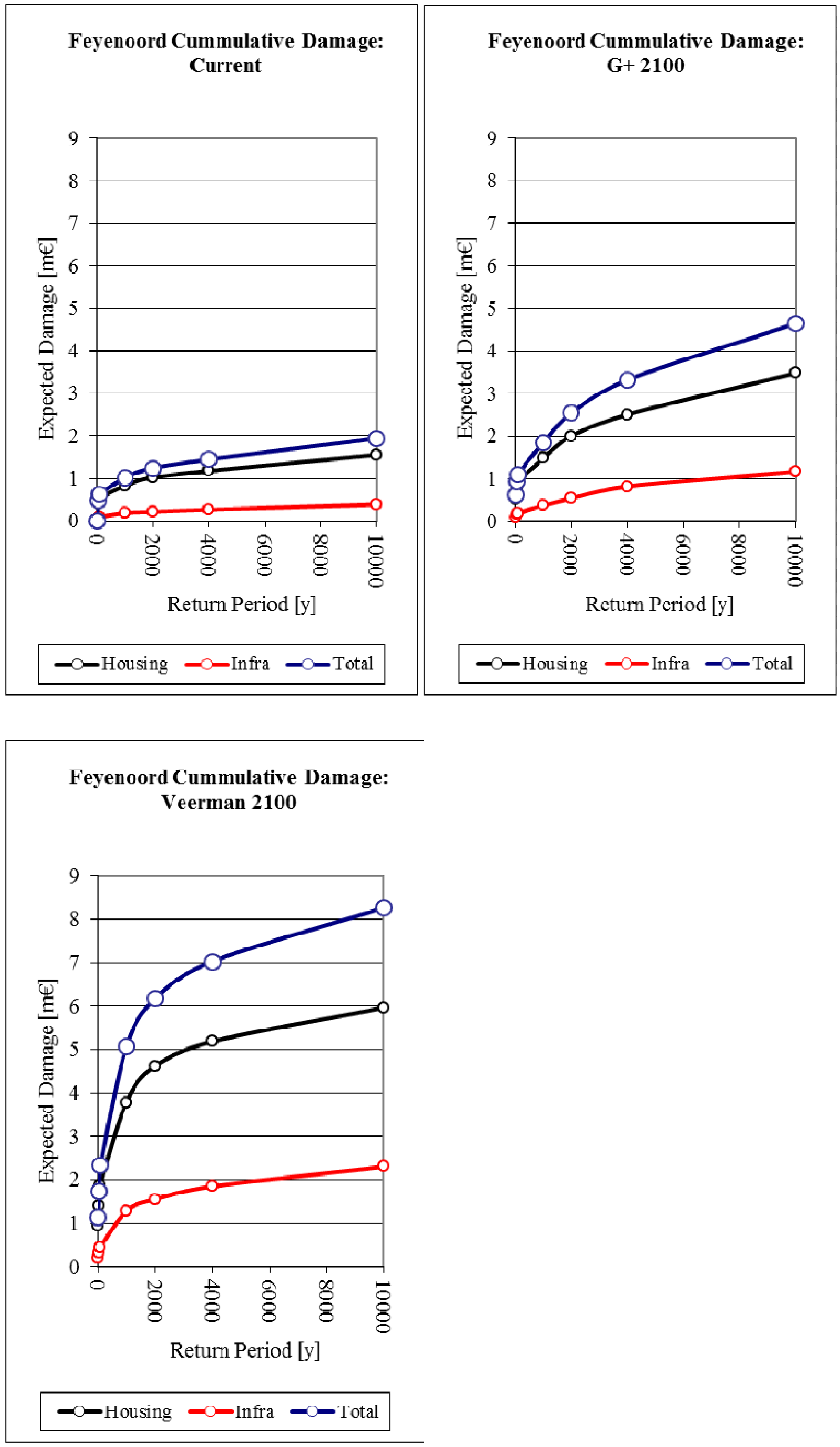


Figure 4: Expected damages for housing and infrastructure for a range of return periods and CC-scenarios

The damage progression depicted in figure 4 shows an almost 'classic' progression with rapidly increasing damages over lower return periods (< 100Y) and a more modest progression for rare events (> 100Y). Application of the CC-scenarios somewhat alters this behaviour. For the G+ CC-scenario, the curve's bend (between the 2000 and 4000Y return periods) is less strong which indicates a more linear proportional progression of damages. Application of the Veerman CC-scenario shifts the curve back to the current behaviour; i.e. a strong bend around the 200Y return period.

The damage composition clearly shows the dominance of flood damages suffered by housing which contribute to about ¾ of the total damage. This can be explained by Feijenoord's high urbanisation level in which the housing-infrastructure ratio shifts towards a higher occupancy by housing units.

To assess the relative impact of the CC-scenarios, the EAD has been calculated which is shown in table 1.

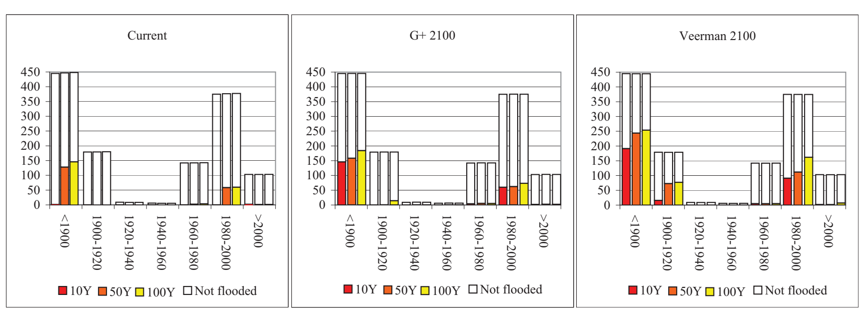
Table 1. Expected Annual Damage for the Feijenoord area

Scenario	**EAD [€ 2011]**	**EAD [€ 2011/HA]**	**Increase**
Current	*20462*	*287*	
G+ 2100	*45473*	*639*	*122.2%*
Veerman 2100	*90308*	*1268*	*341.3%*

Although substantial, the impact of the applied climate change scenarios on the EAD is relatively modest when compared to some of the other areas (e.g. Noordereiland).

For frequent flooding, the damage distribution over the age of the housing stock shows relative peaks (figure 18) around the prior to 1900 and the 1980-2000 bins. This is can easily be explained since the complete housing stock consists for 65% of houses from these periods.

Figure 5: Expected number of flooded houses over the age of the housing stock for the Feijenoord area



10.1.2 Noordereiland

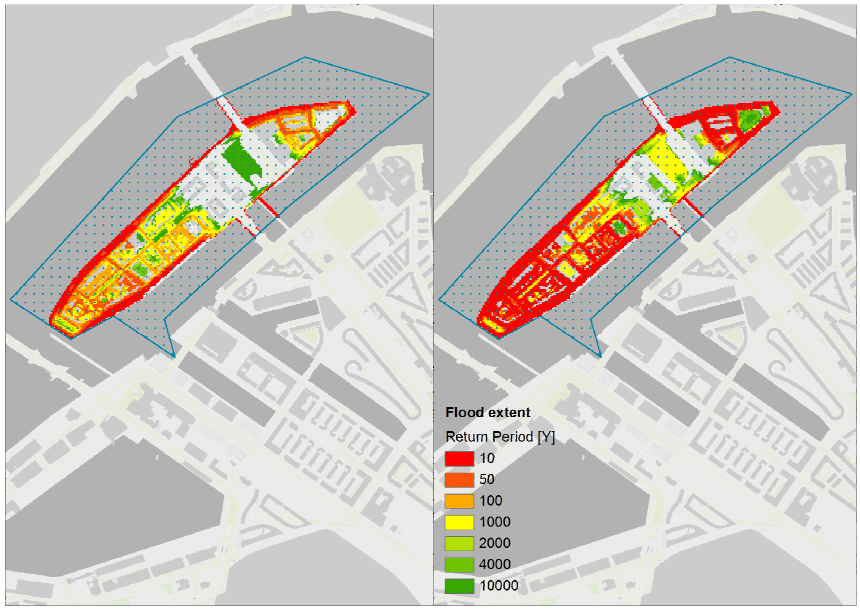


Figure 6: Expected flood progression of the Noordereiland area for the current conditions (left) and the G+ 2100 CC-scenario (right)

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 10Y or less. The flood extent expands along the streets that provide flood conveyance between the densely packed building blocks. Especially on the Southern part of the island, floods occur relatively regularly with return periods of 100Y or less. Application of the G+ CC-scenario causes frequent flooding of almost the complete island, with inundation depths ranging between several centimetres and about 2 decimetres. The centre part of the island is located on a much higher elevation and provides the connection to the Rotterdam city centre and the Feijenoord area. This part is safeguarded against flooding in the current conditions and floods only during extreme events under the G+ CC-scenario.

Figure 7: Spatial distribution of flood damages to infrastructure and housing units on the Noordereiland location (RP = 2000Y)

The entrances of many of the houses of the Noordereiland are elevated, which should have a substantial effect on the expected flood damages. The outcomes are presented in figure 8.

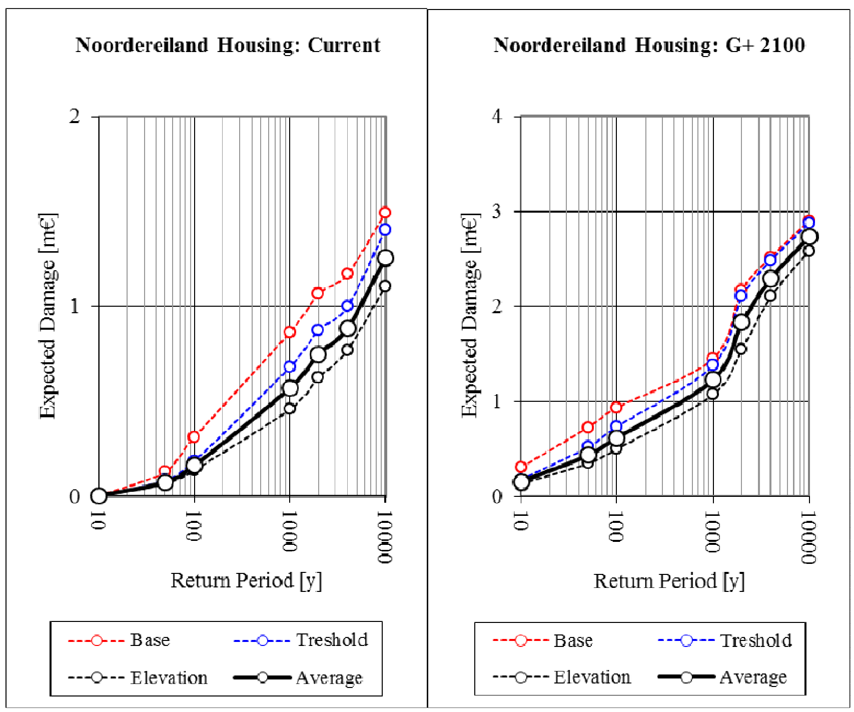
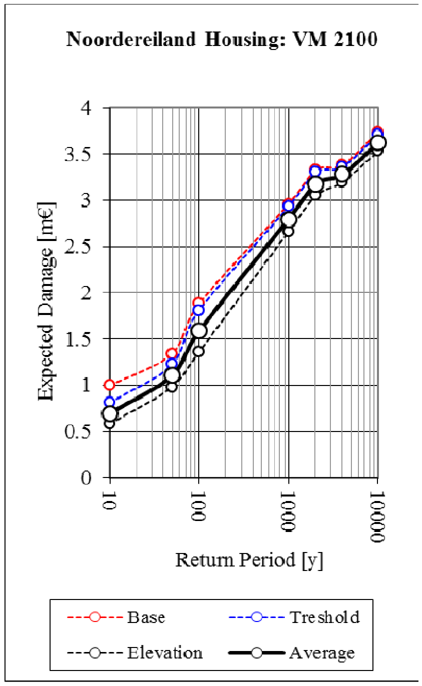


Figure 8: Expected damages for housing for a range of return periods and CC-scenarios, with and without application of the adjusted flood entry points



For the current conditions, implementing adjusted flood entry points reduces damages on average with about 33%. Especially when ground floors are assumed to be on the same level as the doorstep level (elevation), for floods with return periods below 1000Y, this reduction cuts expected damages by more than half. Application of the G+ and Veerman CC-scenarios limits the average effect to about 24% and 11% respectively.

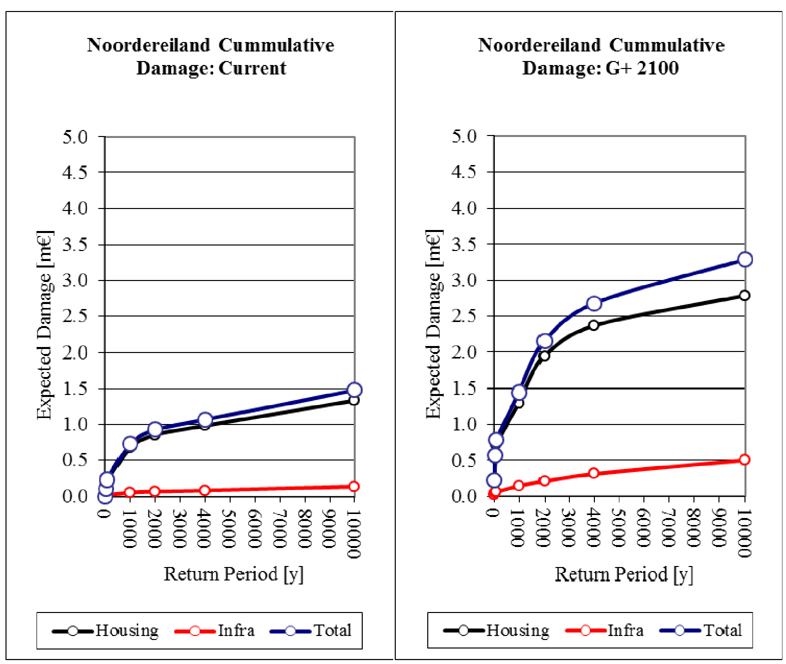
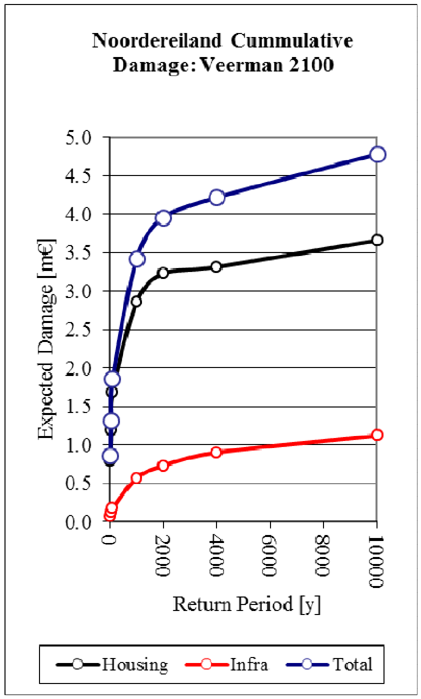


Figure 9: Expected damages for housing for a range of return periods and CC-scenarios, with and without application of the adjusted flood entry points



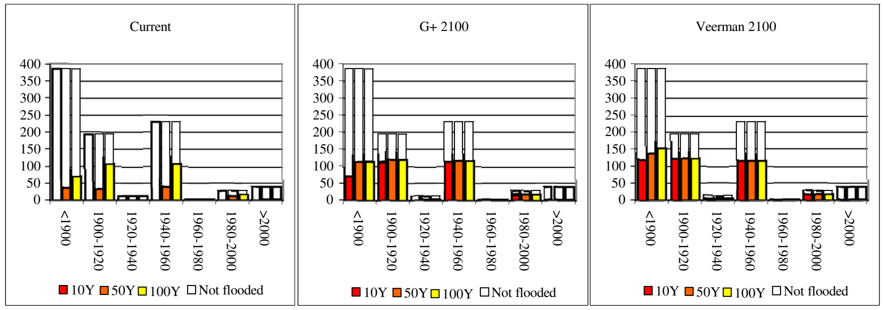
What can be observed from figure 9 for all scenarios is the 'classic' progression of damages over increasing return periods. Application of the G+ scenario creates a small dent in the curve's progression between the 50Y and 100Y return period interval. The contribution of infrastructural damages is relatively low (around 15%) which can be explained by the housing density; houses cover the majority of the island and are predominantly accessed by a single access road along the perimeter of the island.

The EAD is expected to grow 3 to almost 10-fold after application of the CC-scenarios. This is partly due to the relative dominance of damages related to frequent flooding that contribute substantially to the EAD. Since the expected damages for a current 10Y flood are relatively low, a significant increase (e.g. from currently €1106 to €224,141 for the G+ CC-scenario) will increase the EAD much more than a similar difference for higher return periods.

Table 2. Expected Annual Damage for the Noordereiland area

Scenario	EAD [€ 2011]	EAD [€ 2011/HA]	Increase
Current	*6791*	*257*	
G+ 2100	*28272*	*1071*	*316.3%*
Veerman 2100	*68221*	*2585*	*904.6%*

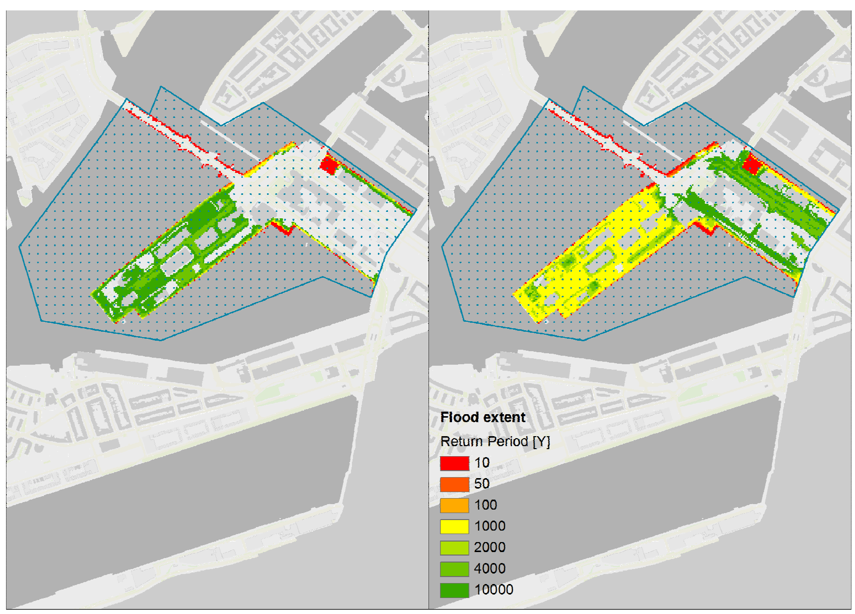
Figure 10: Expected damages distribution over the age of the housing stock for the Noordereiland area



The distribution of frequently flooded houses skews towards houses built beyond 1900 and before 2000. Depending on the flood frequency, peaks can be identified at the 1940-1960 and the 1980-2000 bins for a flood with a 100Y return period, 57.1% of the housing stock built between 1980 and 2000 is exposed to flooding. The applied climate change scenarios flatten out this distribution. Note that the amount of flooded houses under the extreme Veerman CC-scenario is practically stable for the different return periods which implies that the flood extent does not further expand. To some degree this conclusion also applies to the G+ CC-scenario.

10.1.3 Kop van Zuid

Figure 11: Expected flood progression of the Kop van Zuid area, for the current conditions (left) and the G+ 2100 CC-scenario (right)



Compared to the Feijenoord or Noordereiland areas, the Kop van Zuid area is relatively safeguarded against flooding. As can be clearly perceived in figure 11, no major flooding occurs below the 2000Y return period. Yet, the associated elevation marks a threshold; due to the flatness of the peninsula, it floods almost completely for return periods beyond 2000Y. Under the current probability distribution, no flooding occurs in the Northern part of the area for return periods of 10,000Y or less. This area is of vital importance since it hosts an important bridge connection between the Rotterdam centre and the Southern part of Rotterdam. Application of the G+ CC-scenario shifts return periods by about a factor 2 to 4; significant flooding of the peninsula occurs for a 1000Y event while the main street connection on the Northern part suffers from flooding during a 4000Y event or more.

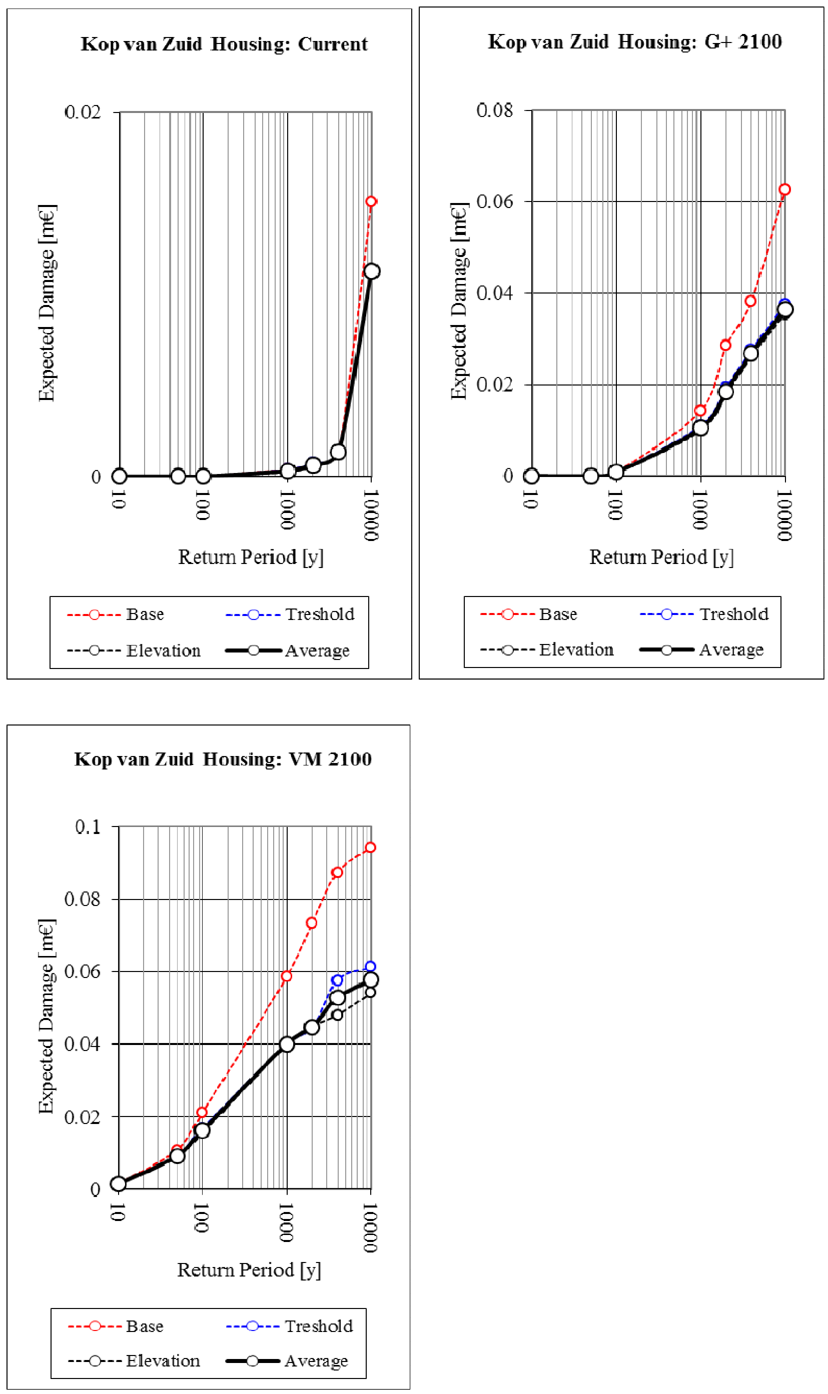


Figure 12: Expected damages for housing for a range of return periods and CC-scenarios, with and without application of the adjusted flood entry points

Since the housing stock in the Kop van Zuid area does not suffer from flooding for events with return periods below 1000Y, the adjusted flood entry points do not add additional flood protection. Beyond the 1000Y event, the relative damage reduction shows large levels of variation which is due to the limited set of houses exposed to flooding. While the average reduction is about 11%, the limited inundation depths cause maximum reductions of about 35%. This causes the already limited expected flood damage to drop to marginal levels during even extreme events. Application of the G+ and Veerman CC-scenarios shifts the return periods and the relative effect of the adjusted flood entry points. For the G+ scenario, the average reduction is about 33% while the average drops to 21%. These values can be clearly perceived in figure 25, where the baseline trend and adjusted trends (i.e. Threshold, Elevation and Average) clearly diverge from return periods of 1000Y and 50Y respectively. These outcomes are significant and show that adjusting the damage estimations for elevated flood entry levels causes a sharp drop in expected flood damages to housing.

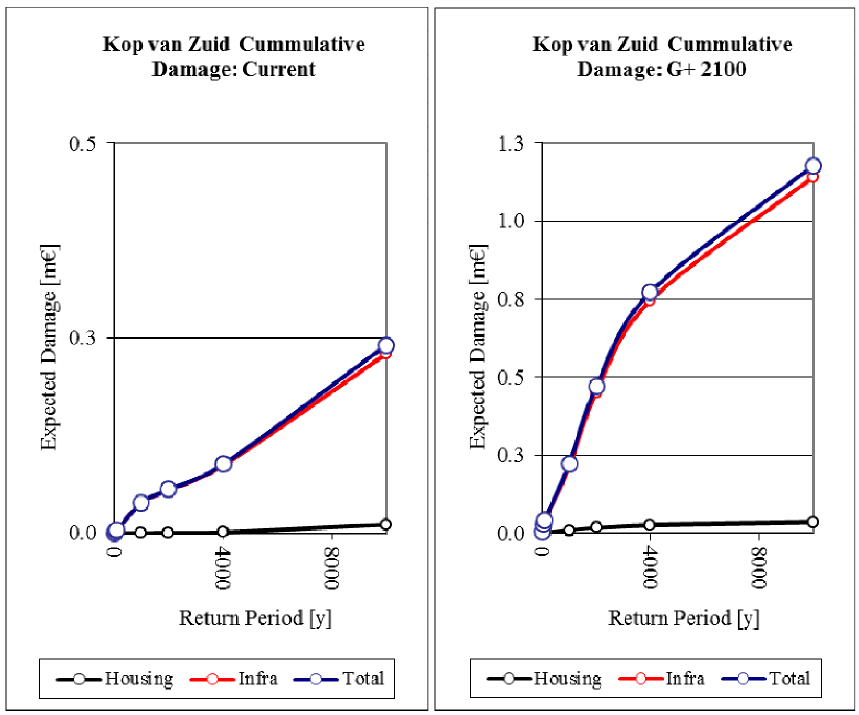
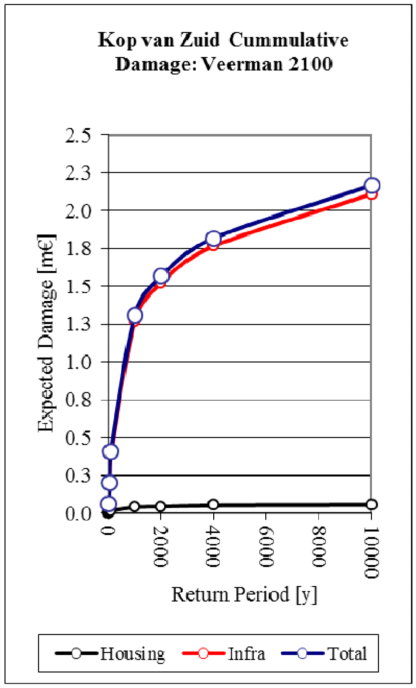


Figure 13: Expected damages for housing for a range of return periods and CC-scenarios, with and without application of the adjusted flood entry points



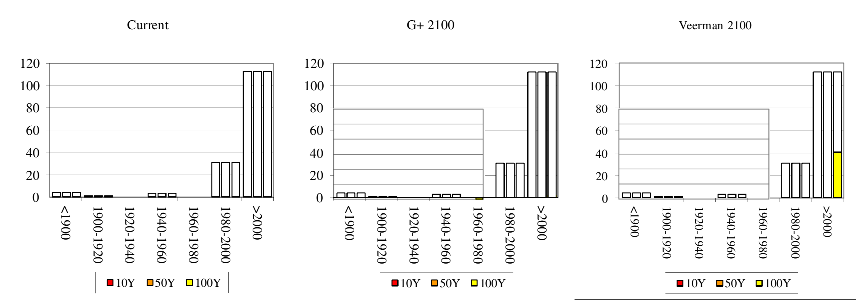
What sets this neighbourhood apart from most other neighbourhoods in the Rotterdam unembanked area is that the cumulative flood damages are almost entirely composed of damages to the infrastructural network. Application of the G+ and Veerman CC-scenarios only make this discrepancy larger. The dominance of flood damages to infrastructure also creates an alternative damage progression which alternates from other neighbourhoods; for the current conditions, the damages almost progress linearly beyond the 1000Y return period, while for the two CC-scenarios, the graphs transform into a more 'classic' shape. The already limited flood damages become almost marginal when translated to EADs (see table 7). Since the current EAD is negligible, the relative increase resulting from the applied CC-scenarios seems significant. Yet, the conclusion is justified that the area is safeguarded against almost all conceivable flood events and subsequent damages.

Table 3. Expected Annual Damage for the Kop van Zuid area

Scenario	**EAD [€ 2011]**	**EAD [€ 2011/HA]**	**Increase**
Current	*225*	*8*	
G+ 2100	*2075*	*74*	*823.5%*
Veerman 2100	*12905*	*460*	*5643.2%*

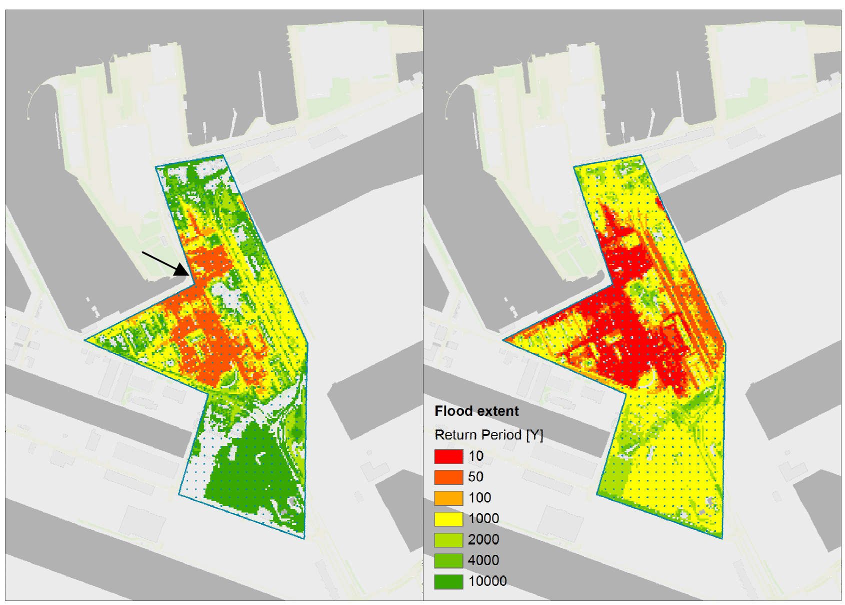
Since the housing stock in the Kop van Zuid area is all dating from 2005 and beyond, an analysis of the exposed houses to flooding over the age of the building stock is not relevant. Currently, the Kop van Zuid hosts 74 housing units on ground floor level which are all elevated by 100cm. From these houses, currently 28 suffer from flood damages during a 10,000Y event. This amount remains the same after application of the G+ CC-scenario for return periods of 4000Y or less. Above the 4000Y mark, all 74 units suffer from flood damages. For the Veerman CC-scenario, this threshold moves towards the 1000Y mark. Although elevated, most of the newly built residential buildings are equipped with parking garages which apart from damages to vehicles, also suffer from flood damages to the installations.

Figure 14: Expected damages distribution over the age of the housing stock for the Kop van Zuid area



10.1.4 Heijplaat

Figure 15: Expected flood progression of the Heijplaat area, for the current conditions (left) and the G+ 2100 CC-scenario (right)



The Heijplaat area is currently expected to experience substantial flooding for floods with return periods of 50Y or more. These flood progress from a pathway from the quay on the Center-north side (as indicated on figure 15). With higher return periods, the floods progress gradually to cover almost the complete area for 10,000Y events. Application of the CC-scenarios worsens frequent flooding significantly; the major populated area is flooded frequently (<

10Y) although the rest of the neighbourhood is generally safeguarded against floods with return periods of 1000Y or more (G+ CC-scenario).

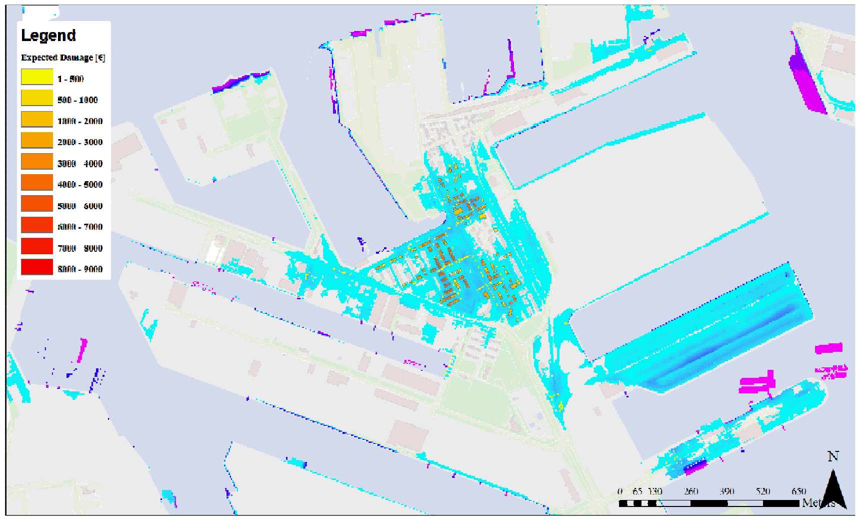


Figure 16: Spatial distribution of flood damages to infrastructure and housing units on the Heijplaat location (RP = 2000Y)

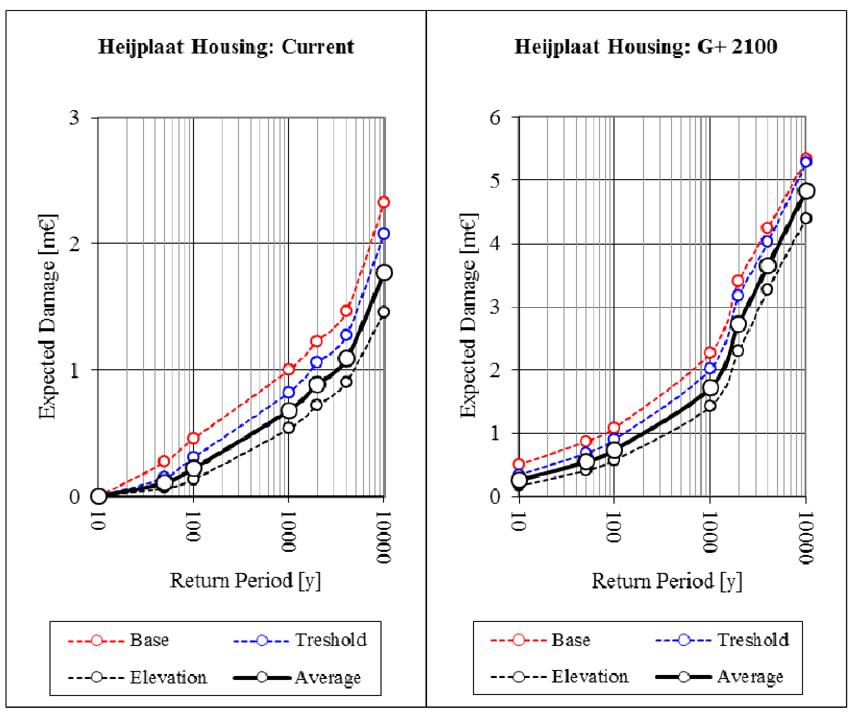
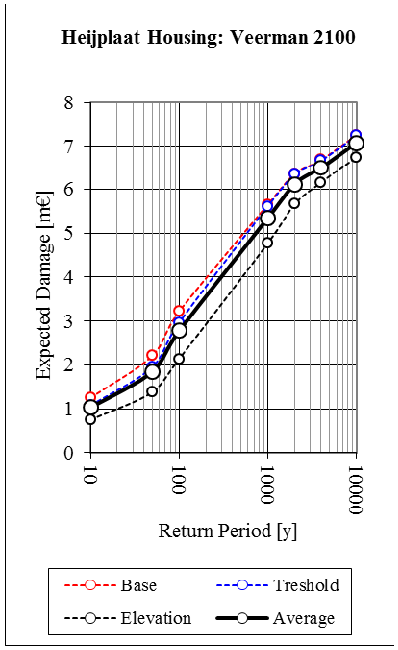
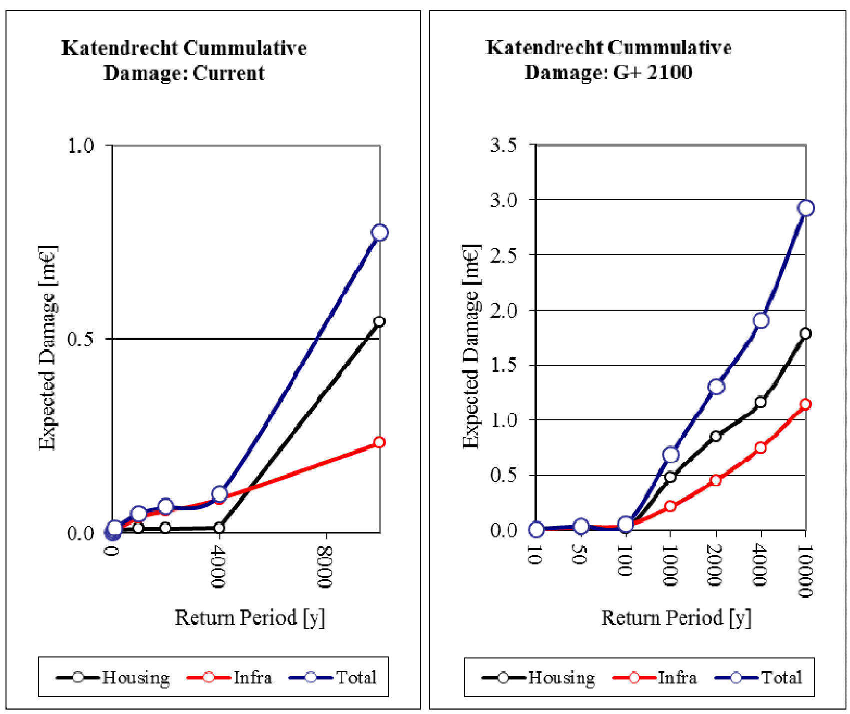


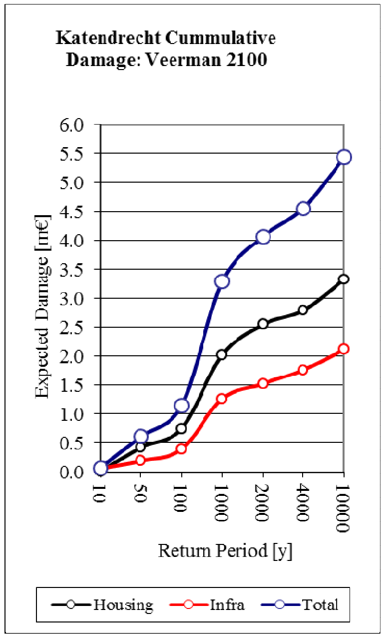
Figure 17: Expected damages for housing for a range of return periods and CC-scenarios, with and without application of the adjusted flood entry points



Application of adjusted floor level entry points only has a limited effect for the Katendrecht area. This is to some extent due to the fact that under current conditions flood damages are negligible for floods with return periods of 4000Y or less. For the current, G+ and Veerman scenarios, the average reduction is about 6%, 9% and 8% respectively.

Figure 18: Expected damages for housing and infrastructure for a range of return periods and CC-scenarios





Under the current conditions, the accumulated flood damages clearly show the effect of the protection standard applied in the Katendrecht area. For floods with 4000Y return periods or less, the limited damage levels are mainly composed by those for infrastructure. Application of climate change scenarios changes the damage composition although compared to other areas (e.g. Feijenoord), the expected damages to infrastructure are relatively high (often more than 50%). Threshold effects are clearly observable around the 4000Y return period (current).

Table 4. Expected Annual Damage for the Heijplaat area

Scenario	EAD [€ 2011]	EAD [€ 2011/HA]	Increase
Current	*429*	*8*	
G+ 2100	*4058*	*73*	*844.9%*
Veerman 2100	*35141*	*635*	*8082.8%*

The EADs, increase substantially after application of the CC-scenarios. While currently negligible (€429), they increase by a factor of about 8.5 to 80 after application of the G+ and Veerman scenario respectively. This is mainly due to the fact that currently, almost no damages are suffered from frequent flooding (the main contributor to the EAD). Increasing damages for frequent events make the EAD rise rapidly.

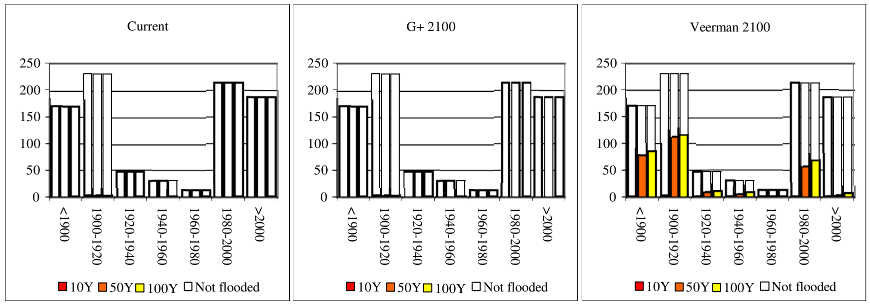


Figure 19: Expected damages distribution over the age of the housing stock for the Katendrecht area

The distribution of houses exposed to frequent flooding clearly shows that most of Katendrecht is safeguarded against flooding. Both for the current and G+ CC-scenario practically no houses are exposed to floods. Only under the extreme Veerman CC-scenario, significant exposure can be observed for floods with return periods of 50Y or above; About 50% of the older segment of the housing stock (built before 1920) is expected to be flooded.

10.1.5 Kop van Zuid-Entrepot

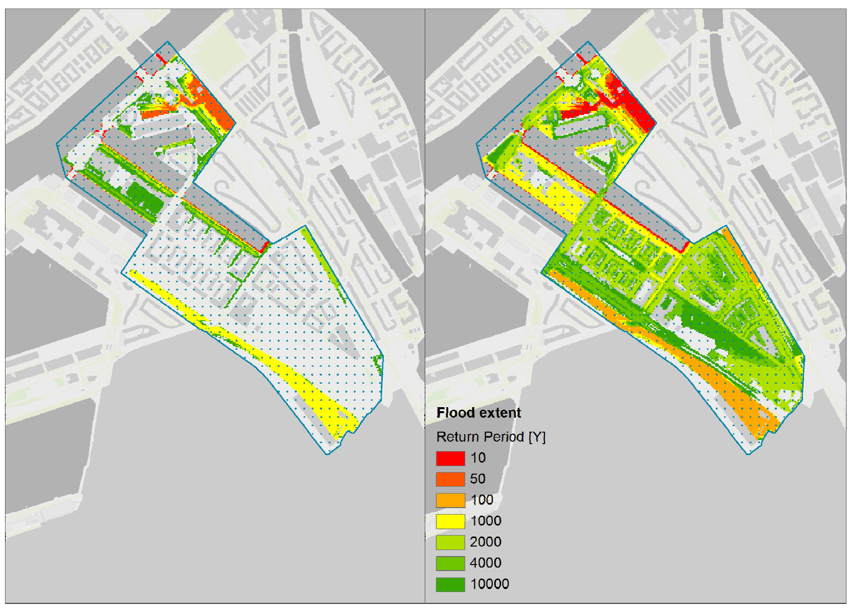


Figure 20: Expected flood progression of the Kop van Zuid-Entrepot area, for the current conditions (left) and the G+ 2100 CC-scenario (right)

Under the current probability distribution, a clear distancing can be made between the North-eastern part of the Kop van Zuid-Entrepot neighbourhood and the rest of the area; the North-eastern part (which is connected to the Feijenoord area) suffers from frequent flooding with return periods of 50Y or more. The rest of the Kop van Zuid-Entrepot is practically safeguarded from flooding. Application of the G+ CC-scenario shifts the return period for the North-eastern part to 10Y or less, while the remaining area floods only during 1000Y events or more.

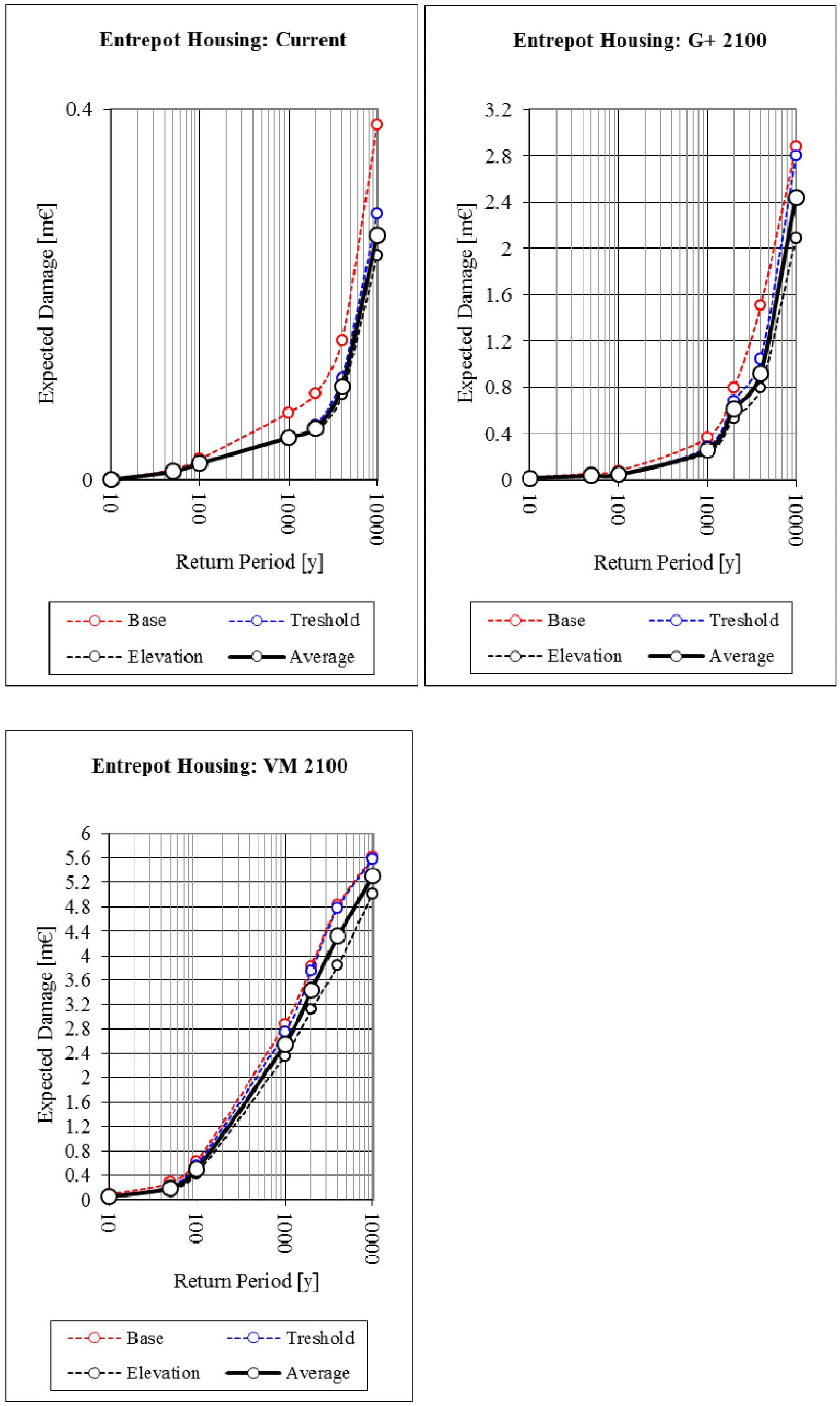


Figure 21: Expected damages for housing for a range of return periods and CC-scenarios, with and without application of the adjusted flood entry points

The implementation of the adjusted flood entry points for the Kop van Zuid-Entrepot area alters the estimated flood damages to the housing units significantly. For the current conditions, damages drop on average with about 31%. For the range of return periods, this relative decrease remains relatively stable (+/- 10%). This separates the area from most other (e.g. Feijenoord area). Under the applied CC-scenarios, the reduction remains almost similar for the G+ CC-scenario (avg. 29%) but drops to about 19% for the Veerman CC-scenario.

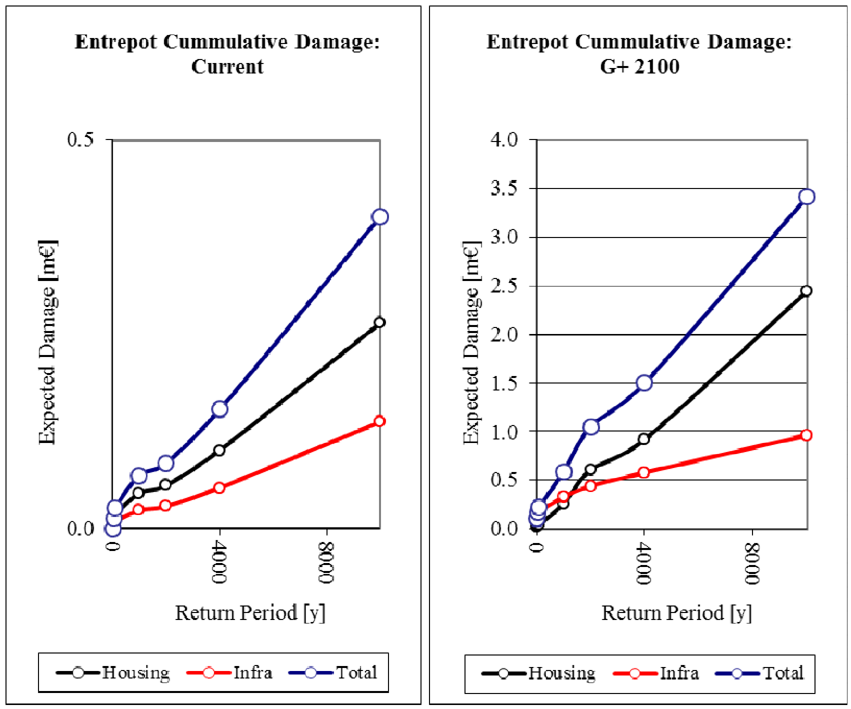
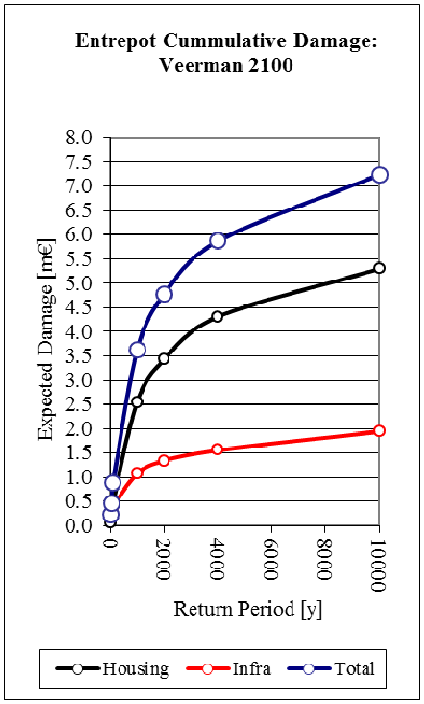


Figure 22: Expected damages for housing and infrastructure for a range of return periods and CC-scenarios



What can be clearly perceived from figure 39, is that the damage ratio between infrastructure and housing remains almost equal; for the current conditions the flood damages to infrastructure are for all return periods about 50%. This behaviour changes after application of the CC-scenarios, where for the G+ CC-scenario infrastructural flood damage initially exceed those to housing but diminish in importance for higher return periods. For the Veerman CC-scenario, similar behaviour is witnessed: for a 10Y event the damages to infrastructure triple those to housing but gradually decrease to about 37% for a 10,000Y event. What also sets the flood damage progression for this area apart from most others, is the almost linear progression of estimated flood damages for return periods above 2000Y (current) and 100y (G+ CC-scenario). Only under the Veerman CC-scenario, the graph shows a more classic behaviour in which the estimated damages diminish exponentially with increasing return periods.

Because limited exposure of the Kop van Zuid-Entrepot area, the EAD for the current conditions is negligible. This does imply that the relative change resulting from the applied CC-scenarios is large (i.e. more than a 10-fold increase for the G+ CC-scenario and a 40-fold increase for the Veerman CC-scenario).

Table 5. Expected Annual Damage for the Heijplaat area

Scenario	**EAD [€ 2011]**	**EAD [€ 2011/HA]**	**Increase**
Current	*786*	*12*	
G+ 2100	*9947*	*155*	*1165.1%*

Veerman 2100	*32764*	*510*	*4067.1%*

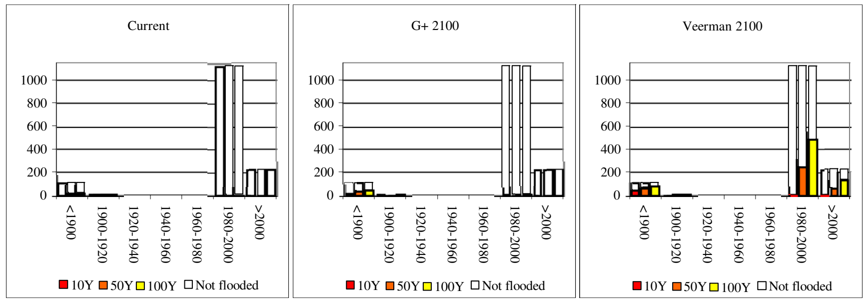


Figure 23: Expected damages distribution over the age of the housing stock for the Kop van Zuid-Entrepot area

When assessing flood damages over the age of the building stock for frequent floods, the amount of housing units suffering from flood damages is currently negligible. The applied G+ CC-scenario changes this exposure especially for the older buildings located in the North-eastern part of the area. Only after application of the Veerman CC-scenario, the recently built housing units suffer from flood damages.

10.1.6 Afrikaanderwijk

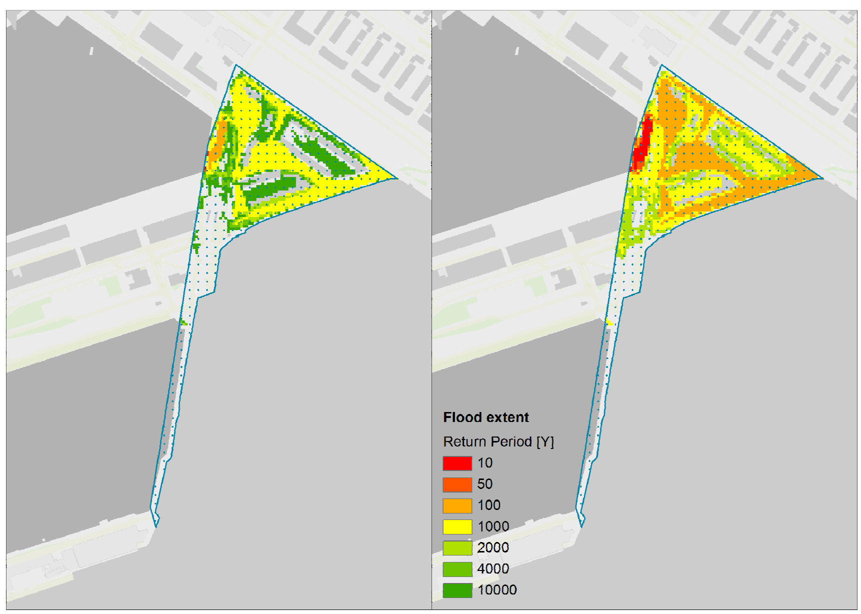
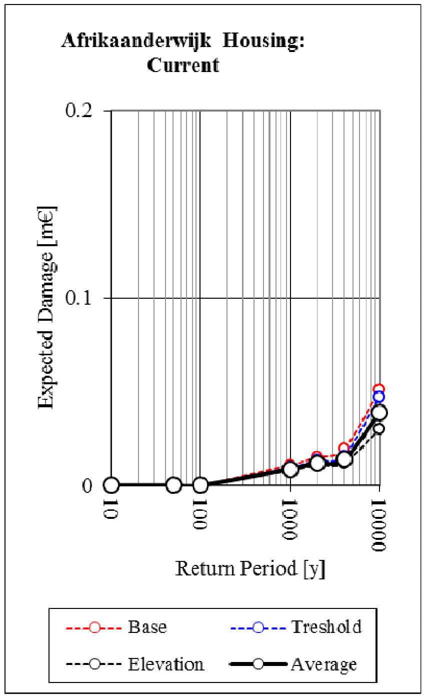
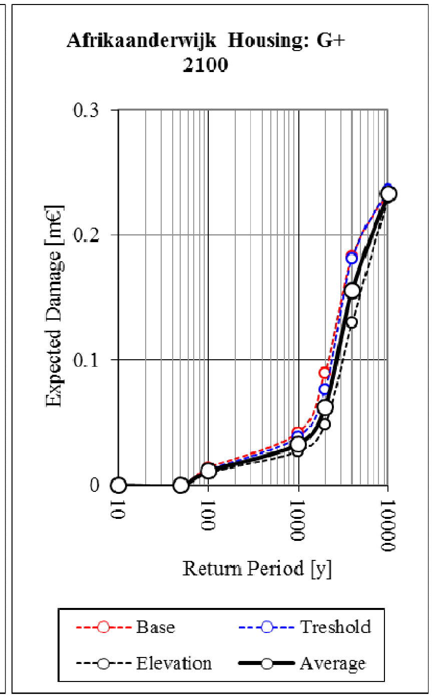


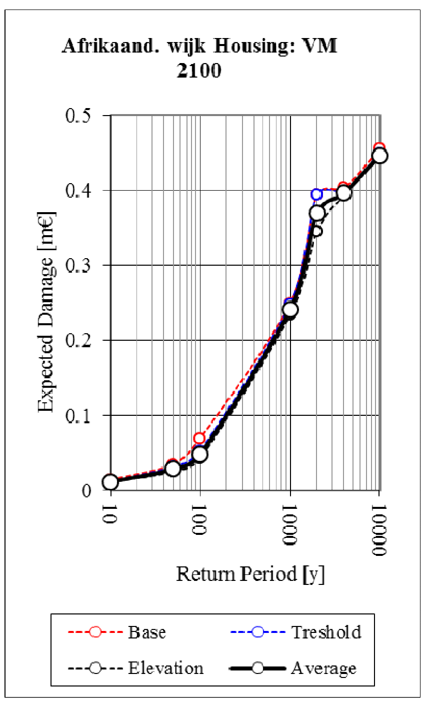
Figure 24: Expected flood progression of the Afrikaanderwijk area, for the current conditions (left) and the G+ 2100 CC-scenario (right)

Flooding of the Afrikaanderwijk area proceeds from the western quay (see figure 41). Overall though, the area is elevated and withstands floods with return periods lower than 1000Y. The area shows a large level of differentiation in elevation, which separates it from many other areas that are generally flat. More populated areas are located in areas that flood only during extreme events with return periods > 4000Y. Application of the G+ and Veerman CC-scenarios shifts return periods significantly although the differentiation in elevation clearly separates the contours of the estimated flood extents.

Figure 25: Expected damages for housing for a range of return periods and CC-scenarios, with and without application of the adjusted flood entry points







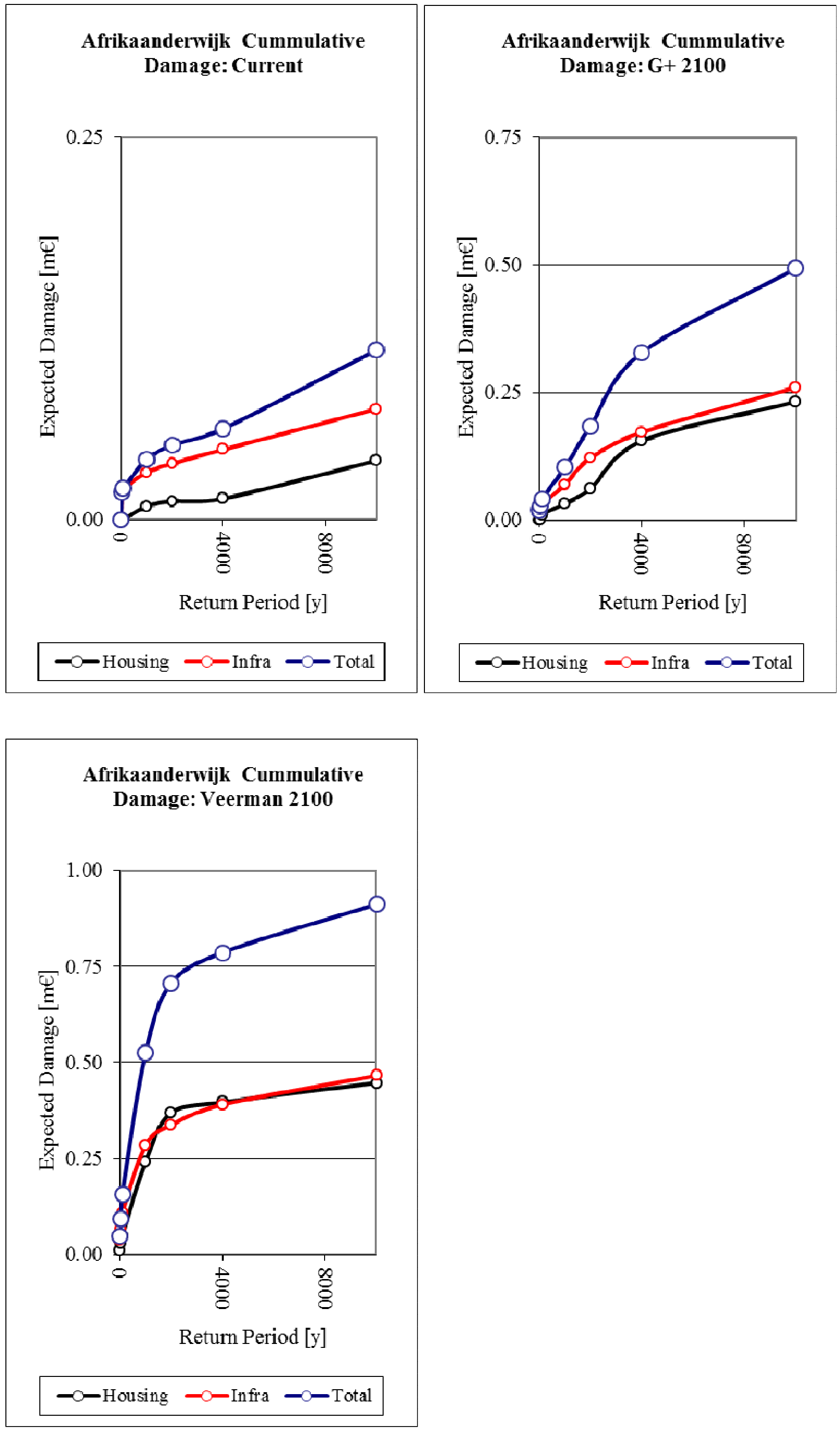


Figure 26: Expected damages for housing and infrastructure for a range of return periods and CC-scenarios

The majority of expected flood damages in the Afrikaanderwijk area are suffered by infrastructure; these are generally twice the damages suffered by housing for larger return periods. Frequent flooding currently does not result in flood damages to the housing stock. Due to the strategic position (i.e. high elevation) of the housing stock, the expected flood damages generally stay below those for infrastructure under the two applied CC-scenarios. Only for a 10,000Y event under the extreme Veerman CC-scenario, the expected damages to housing exceed those for infrastructure. This causes the damage progression to differ significantly from the generally observed behaviour; only under the Veerman CC-scenario the graph shows an exponential decay in expected damages for higher return periods.

The EADs are currently relatively low and only increase by about 50% for the G+ CC-scenario. Only for the extreme Veerman CC-scenario, a significant increase is expected.

Table 6. Expected Annual Damage for the Afrikaanderwijk area

Scenario	EAD [€ 2011]	EAD [€ 2011/HA]	Increase
Current	*717*	*96*	
G+ 2100	*1748*	*235*	*143.8%*
Veerman 2100	*5770*	*776*	*704.7%*

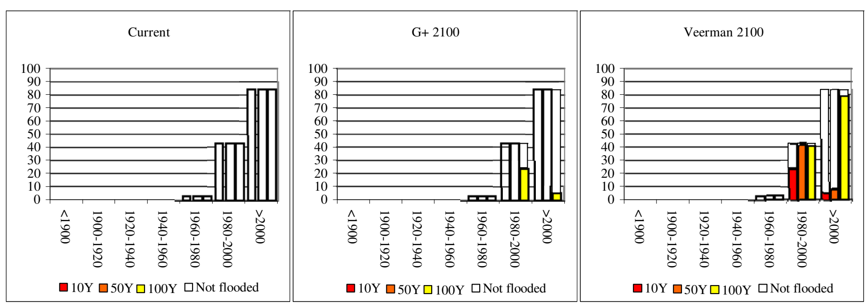


Figure 28: Expected damages distribution over the age of the housing stock for the Afrikaanderwijk area

Although the area is relatively small (7.44 HA), it hosts a significant amount of housing units (130). The housing stock consists exclusively of recently built units. These are located in areas that are currently outside the flood extent of frequent events. Under the G+ scenario, only for 100Y events, a significant portion of the housing units built between 1980 and 2000 suffer from flood damages. Under the Veerman scenario this portion further saturates to almost 100% for 100Y events.

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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