Climate Proof Cities

Knowledge for Climate

Quantifying the sensitivity of our urban systems

Impact functions for urban systems

Revised version

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Content

Summary

The urban area can be seen as a set of *physical elements* such as roads, buildings and the people residing within the cities and the *urban functions* such as living, transport or recreation. These physical elements and urban functions together form the urban system. The expected climate change, including changes in temperature, rainfall, and sea levels, will in many ways have an impact on the urban system, however, consequences for the urban system are not yet adequately understood.

The Climate proof Cities program aims at "strengthening the adaptive capacity and reducing the vulnerability of the urban system against climate change and to develop strategies and policy instruments for adapting our cities and buildings" (Knowledge for Climate, 2012). Within the context of this program, the project 'Sensitivity and vulnerability of urban areas' aimed to quantify the sensitivity of urban areas to climate change (heat, drought and urban flooding) and identify the most sensitive objects to climate change within the Dutch urban area.

To be able to quantify the sensitivity of the urban system, impact functions which describe the relation between the climate hazard and resulting impacts are required. An impact function (or sensitivity or damage function) describes the relation between a climate hazard exposure (e.g. pluvial flooding, drought) and the resulting (negative) impact such as damage or casualties. The project focussed on the development of such impact functions to describe the impacts due to heat and pluvial flooding. In line with the context and target audience for the Climate Proof Cities program, these functions were developed for use on an urban scale and should be applicable by municipalities. The developed functions are a first attempt to describe the relations between the climate hazard exposure and its impact and the presented material provides a basis for others to further develop and/or adapt through improved knowledge.

An impact framework was first developed to be able to compare the impacts from the different climate hazards. This framework groups the impacts into five impact categories. The impact for a category is measured through a standard unit, which provides the possibility to compare the magnitude of the impacts for the different climate hazard. The functions were applied within several case studies to demonstrate and test the use of the functions and to gain a first insight into the sensitivity of Dutch urban systems to climate change.

For the two climate hazards 'heat' and 'pluvial flooding' which were elaborated, it was seen though that the emphasis of impacts lies in very different fields. Heat mainly affects the health of human beings, an impact rarely encountered through pluvial flooding, while pluvial flooding causes material damages which is hardly an impact as a result of heat. A common ground is found though in a loss of business income either due to business interruption or due to productivity loss and lower spending by customers.

Impact categories	**Unit**	**Description**
Material (tangible) damages	Currency	Damage to physical elements
Production losses	Currency	Losses that occur due to the interruption of economic services and urban functions caused by the hazard
Emergency response	Currency	Emergency response costs during and after the event
Casualties	Number of people. Often these are “translated” into monetary damages.	People injured or deceased
Discomfort (intangible damages)	Number of people affected and/or duration of the disruption.	Interruption of daily routines which can not be expressed monetary and immaterial damages (stress, discomfort, emotional value). Damage to eco-system (services), culture, landscape, etc

The results from the cases on pluvial flooding show that flooding of buildings, especially those with basements or lack of doorsteps, can result in high damages. The costs made by the fire brigade contribute considerable to the overall impact as well. Damage to the electricity networks are very rare at present and are not expected to increase rapidly in the short term. It is recommended though to implement flood proof electricity transformer faults and communication elements when these are to be renewed.

The results of the heat impact analysis show that mortality in The Netherlands is higher due to cold than to heat. The urbanization effect has been calculated in more detail for the city of Rotterdam compared to its direct rural surroundings. In this case, the reduction in mortality and morbidity amounts to 0.4 and 7.7 MEuro for the urbanized part and the reduction in productivity in the city amounts to 3.2 MEuro compared to the rural surroundings.

Damage sensitivity of an urban area depends on many factors including typology, industrial and economic activities. It is therefor recommended to include a damage sensitivity analysis when performing an urban flood risk or climate change assessment study.

1 Introduction

1.1 The need for impact functions

The expected climate changes, e.g. changes in temperature, rainfall, and sea levels, will in many ways have an impact on urban functions and on people living in urban areas situated in deltas and coastal regions such as the Netherlands. However, the consequences for these urban functions and the population are not yet adequately understood. A good understanding of how, when and where climate change and its effects will have an impact on urban areas is of vital importance to take adequate measures.

One can argue that it is sufficient to identify if and where an increase in e.g. heat island effects or pluvial flooding is foreseen (exposure). Many analysis on urban vulnerability only identify these aspects, but this exposure only becomes a problem if this results in a significant and felt impact on the urban environment. Gaining insight into the nature and scope of an impact can help identify which aspects contribute most to the impact. Measures can be taken to decrease the exposure, or to decrease the impact. Gaining insight in the mechanisms of exposure and impact will allow for selection of the more cost effective approach. This project focuses on quantifying the impacts of exposure to extreme weather on the urban system in order to improve our capacity to assess the vulnerability of urban areas to climate change at the scale of buildings, streets and neighbourhoods.

1.2 Project context

1.2.1 Knowledge for Climate

Knowledge for Climate is a research programme for the development of knowledge and services aiming at climate proofing The Netherlands. Governmental organisations (central government, provinces, municipalities and water boards) and businesses, participate actively in the research programming. Knowledge for Climate is the scientific research programme that supports the National Programme for Spatial Adaptation to Climate Change (ARK), conducted by the Dutch government, the Association of Provincial Authorities (IPO), the Association of Netherlands Municipalities (VNG) and the Association of Water Boards (Knowledge for Climate, 2012).

1.2.2 Climate Proof Cities – project 2.3

One of the eight scientific themes within the Knowledge for Climate research programme is Climate Proof Cities (theme 4, urban areas). This research programme aims at "strengthening the adaptive capacity and reducing the vulnerability of the urban system against climate change and to develop strategies and policy instruments for adapting our cities and buildings" (Knowledge for Climate, 2012).

The impact functions as reported in this document, were developed as part of the project 'Sensitivity and vulnerability of urban areas' (project 2.3 within theme 4). Project 2.3 aimed to quantify the sensitivity of urban areas to climate change (heat, drought and urban flooding) and identify the most sensitive objects within the Dutch urban area. To be able to quantify the sensitivity of the urban system, impact functions which describe the relation between the climate hazard and resulting impacts are required. To aid in assessing the sensitivity of the urban area, the project focussed on the development of impact functions for heat and pluvial flooding. Functions on river and sea flooding are already available and currently being improved within the context of the Delta program. Impact functions for flooding and drought due to groundwater fluctuations have not been developed due to the lack of sufficient knowledge on this topic.

1.3 Background information

1.3.1 Sensitivity and vulnerability

The focus of the project is on the development of impact functions to aid in quantifying the impact sensitivity of urban areas. **Sensitivity** or susceptibility is the easiness by which a system (the urban area) is disturbed by a hazard (Pasztor and Bosch, 2011) and the number of impact that is the consequence of this disturbance. Quantifying the sensitivity is about quantifying how much a system is disturbed given a certain increase in hazard, thus for this project sensitivity describes the relation between (changes in) meteorological conditions and the damage that could occur to people, buildings, infrastructure networks - such as roads, railroads, subways, utilities, sewerage – vehicles and economical and social disturbance and ecological damage.

The **vulnerability** describes to what extent a system is susceptible to climate change and is derived on the one hand by the exposure of the system to a specific hazard and the sensitivity of the system to the impact of the exposure. On the other hand is the ability of the system to cope with either changing the sensitivity to the exposure or the mitigation of the impact of the hazard. By quantifying the systems sensitivity, insight is gained into one of the four variables which determine the vulnerability of a system. This is illustrated in figure 1.

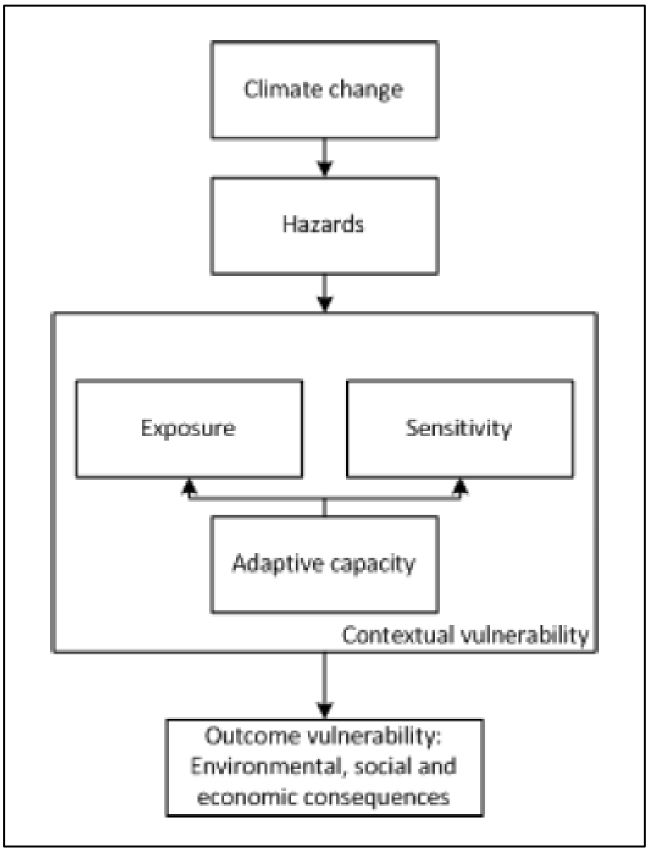
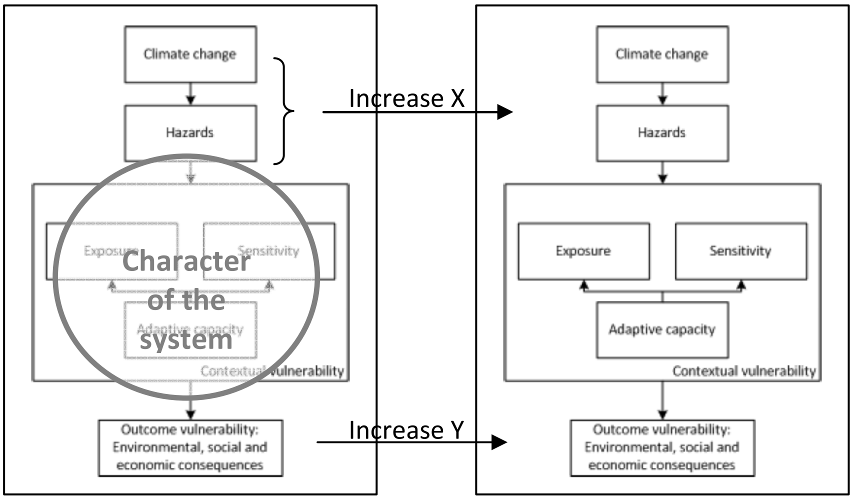


Figure 1: Overview of variables which determine a systems vulnerability to climate change (Fünfgeld & McEvoy, 2011).

Here a distinction is made in a 'contextual' vulnerability and 'outcome' vulnerability. The contextual vulnerability is a measure which describes the vulnerability as a systems property, the character of a system. The character of a system is described by its degree of exposure, the sensitivity and its adaptive capacity. The exposure is a measure describing to what extent a system is actually exposed to a hazard. E.g. an urban system with a large sewer overcapacity is not likely to be exposed to pluvial flooding on a frequent basis. The sensitivity describes to what extend a system actually suffers when exposed to a hazard. The adaptive capacity is a measure to describe to what extent a system is able to recuperate after being hit by a hazard by adapting to the increased exposure or sensitivity e.g. as a result of climate change. These three factors are seen as a constant factor often defined through indicators. They are influenced by implementing adaptation measures, thus this implementation changes the character of a system.

The outcome vulnerability describes to what extent a system reacts due to a climate change or hazard increase given the character of the system. A system in which there is a considerable increase of impact due to a slight increase in hazard, is considered vulnerable.



The exposure, sensitivity and adaptive capacity when used to define the character of an urban system (the contextual vulnerability), often are expressed through indicators. The effect of a hazard increase on the urban system (the outcome vulnerability) is often evaluated through modelling of the system and uses impact functions to describe the sensitivity of the system. These impact functions on the other hand can also aid in defining the sensitivity indicators which are used to determine the contextual vulnerability. The impact functions are thus useful for the assessment of both types of vulnerability.

1.3.2 The urban system

The urban area can be seen as a set of physical elements such as roads, buildings, the people residing within the cities and the urban functions such as living, transport, recreation and economic and industrial activity. The physical elements and urban functions together form the urban system. A hazard can have an impact on these elements and functions, causing damage to the physical elements and disturbing daily life when functions become interrupted.

1.3.3 What is an impact function

An impact function (or sensitivity or damage function) describes the magnitude of an impact (e.g. damage, casualty) as a result of exposure to a (climate) hazard (e.g. pluvial flooding, drought). The exposure to the climate hazard is often expressed in terms of resulting variables from the hazard such as water depth or temperature increase.

These functions are used to quantify the results of climate hazards and can be applied to:

- predict impacts (e.g. damages, casualties) now and for future climate scenario's;
- to calculate damages due to specific events;
- to evaluate the effectiveness of measures.

1.4 Using the report and the sensitivity functions

Within the context of this project the developed functions are a first attempt to describe the relation between the climate hazard and impact for the urban environment and act as a basis for others to further develop and/or adapt through improved knowledge. In line with the context and target audience of the Climate Proof Cities program, these functions were developed for use on an urban scale and should be applicable by municipalities.

This report gives an overview of the developed impact functions for pluvial flooding and heat stress on the urban environment and describes the background and assumptions on which these functions are based (chapter 3 and 4). The functions have been applied on several case studies to demonstrate and test the use of the functions and to gain a first insight into sensitivity of Dutch urban systems to climate change and illustrate a sense of urgency. This is described in chapter 5. An overview of the approach is given in chapter 2.

2 Approach

For the development of the impact functions first insight into the current knowledge state was gathered through a literature study (Stone et al, 2011). This study resulted in an overview of possible impacts due to the different climate hazards; heat, drought and flooding. For the climate hazards heat and pluvial flooding this so-called long list of possible impacts was narrowed down to a shortlist for which impact functions were then developed. These functions were tested through case studies on their applicability and to gain a first impression on quantified impacts due to pluvial flooding and heat. The case study results also act as an example of the application of the functions. A detailed description of the research phases is given in the following paragraphs.

1. *Overview of possible impacts due to climate hazards (long list).*

Through the literature study (Stone et al, 2011) a list of urban elements susceptible to one or more of the hazards was developed. This gives an overview of all the possible impacts per climate hazard on the urban system. The so-called long list is added to appendix 1.

2. *Definition of impact categories*

To be able to compare the impacts from the different climate hazards, an impact framework was developed. This framework groups the impacts into five impact categories (Table 1). The impact for a category is measured through a standard unit, which provides the possibility to compare the magnitude of the impacts for the different climate hazard.

The idea to define impacts through a standard set of categories was taken from the field of fluvial and sea flooding impact research. Flood damages are often expressed in terms of direct and indirect, tangible and intangible damages. The impact functions developed within the context of this study, are to be applicable on a municipality scale and thus developed for urban planners, developers etc. The categories were therefore chosen such that they reflect the perception and experience of the municipalities/local governments and make it possible to identify which urban elements and urban functions are hit by a hazard.

Table 1: Urban climate impact framework

Impact categories	Unit	Description
Material (tangible) damages	Currency	Damage to physical elements
Production losses	Currency	Losses that occur due to the interruption of economic services and urban functions caused by the hazard
Emergency response	Currency	Emergency response costs during and after the event
Casualties	Number of people. Often these are “translated” into monetary damages.	People injured or deceased
Discomfort (intangible damages)	Number of people affected and/or duration of the disruption.	Interruption of daily routines which can not be expressed monetary and immaterial damages (stress, discomfort, emotional value). Damage to eco-system (services), culture, landscape, etc

3. Selection of significant impacts to develop functions for (short list)

From the long list, a selection of impacts was made for which impact functions were developed. This is the so-called short list. The selection was made based on:

- Expected relevance of the impact
    - Expected level of damages
    - Perceived as important or high hindrance (e.g. receives a lot of press attention)
- Availability of data and information

A further explanation on the possible impacts for pluvial flooding and heat is given in the paragraphs 3.1 and 4.1.

4. Development of functions

A preceding research executed within the context of this project (Van Riel, 2011) focused on the gathering and analysis of historical rainfall damage data. It was seen that due to lack of appropriate data the development of damage functions for pluvial flooding through an empirical approach was not possible within the context of this project. In the cases where sufficient data for development of empirically based damage functions was lacking, it was decided to develop the impact functions through a theoretical approach based on the results from literature review, expert judgement and experience. The functions are described in paragraphs 3.2 and 4.2.

5. Application of functions in case studies

The functions were applied on several case studies to demonstrate and test the use of the functions and to gain a first insight into the sensitivity of Dutch urban systems to climate change. The case study results are provided in chapter 5.

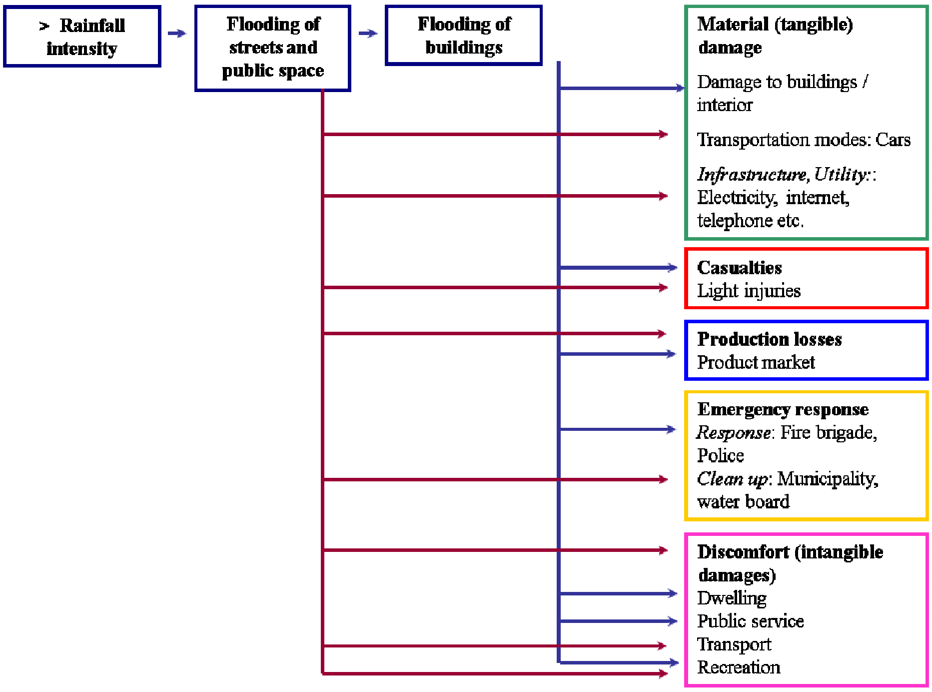
3 Pluvial flooding

3.1 Overview of possible impacts

The impact/damage functions developed within the context of this project are developed for use on a municipality scale. In The Netherlands pluvial flooding is a local problem. The scale and duration of the events result in local problems and it is therefor chosen to develop functions which describe the impacts on a local scale. These functions can be applied by municipalities to identify areas susceptible to damage due to pluvial flooding and can be used to evaluate the effectiveness of measures aimed at reducing the impact of pluvial flooding. These functions are not applicable for assessment of e.g. the yearly damages due to pluvial flooding on a national scale.

The functions focus on the physical processes through cause – effect relations. The KNMI climate scenarios predict on the one hand a decrease of the number of rainy days but on the other hand an increase in the average precipitation volume per rain shower. This is due to an increase in rainfall intensity. The urban system is designed to be able to store a certain volume of water. Heavier rainfall results in overflowing of the storage system (infiltration capacity, sewer system, open water system) which in turn results in flooding of streets and under certain circumstances flooding of basements and even ground floors of buildings. This in turn can result in an impact on the urban functions, e.g. if a shop or an office is flooded, the work activity will be disrupted for a period of time. Figure 2 illustrates this cause – effect relation and the specific impacts it could cause.

Figure 2: Overview of impacts to the urban system due to pluvial flooding.



Material (tangible) damages

The urban assets in the streets which could become damages when flooded, are cars and electrical facilities. Damage to buildings is caused by water reaching the outer wall and flowing into the building. In The Netherlands the flow velocity and water depths due to pluvial flooding are not very large, thus the force of the water is not very high and when a building is flooded the encountered damage is mainly expected to be the damage to the interior.

Casualties

Fatalities due to pluvial flooding in the Netherlands are extremely rare. However, accidents can occur due to e.g. a loosened manhole cover. Furthermore, illness could occur if people come in contacted with polluted water. This can be a problem in neighbourhoods with combined sewer systems or when flood water enters a building through the buildings sewer system. In the longer term people can become ill due to prolonged exposure to dampness of a building. Emergency services (e.g ambulance or fire brigade) can be hindered due to flooding of crucial roads or due to flooding of a hospital basement which in rare occasions could lead to casualties when people do not receive treatment on time.

Production losses

Flooding can cause jammed traffic, flooding of commercial buildings or flooding of electricity or communication substations which can result in an electricity or communication failure. These situations can cause a disruption of economic activities within the location of flooding but also at other sites upstream and downstream of the production chain.

Emergency response

When flooding occurs, four emergency services are involved. The fire brigade is mobilised to empty depressions (e.g. viaducts) and basements, the police is involved in traffic management and public protection, and the municipality and water board are responsible for the cleaning of the streets and sewers.

Discomfort (intangible damages)

Daily life is temporarily disrupted when a flood occurs although it should be noted that pluvial flooding within The Netherlands often is of short duration. Flooding of the streets disrupts the traffic flow. If buildings are flooded, work, living, and if it concerns a building with a social character, public services are interrupted. An electricity or communication failure can cause disruption of a neighbourhood and could last for a longer period of time.

3.2 Impact functions

Functions have been developed for a selection of possible impacts (the short list). The impacts for which functions were developed, were selected based on the expected extent of the impact, the perceived importance and/or the availability of information and data. An overview of the selected impacts (the short list) for which functions have been developed and a motivation of the selection is presented in table 2. The following paragraphs each present and explain a function. For each variable in these functions an overview is given of the available knowledge on the values for the variables. This provides a rough first estimate of numbers to be used when one does not have detailed information at ones disposal. The development of the impact functions provided a first set of functions based on the current state of knowledge. These functions require further improvement though and each paragraph therefor concludes with an overview of the knowledge gaps.

Table 2: Overview of the selected impact for which functions have been developed and motivation for the selection (short list).

Impact category	**Impact**	**Motivation**
Material (tangible) damages	Buildings and contents	It is known that damage to buildings and contents are common as a pluvial flood impact. Functions are already available.
	Electricity supply	No examples of damage to electricity substations and network are known, but these elements could be sensitive to flooding if rainfall intensity increases. Recently information on the sensitivity of the electricity and other utilities has become available through studies on sensitivity of flood prone areas in Rotterdam (De Kort, 2012). This information makes it possible to development a function to describe the possible damage as a result of flooding of an electricity network element.
Production losses	Business interruption	Flooding of commercial buildings could cause business interruption. Currently examples are already available of flooding of shops and even a cinema.
	Traffic interruption	The streets are the first to flood and examples are available of flooding of viaducts and roads causing traffic hindrance.
	Electricity failure	If part of the electricity network is damages, this could result in an electricity failure. Although no examples are known, the impact could be considerable if failure would occur more often as a result of increasing rainfall intensity.
Emergency response	Fire brigade	Almost every actual flooding event required assistance from the fire brigade for the draining of basements and viaducts.
Discomfort (intangible damages)	Flooding of medical service	The continuity of medical services is of vital importance ans should not be interrupted by flooding of buildings or roads.

Impact not taken into account are; damage to vehicles, damage to networks other than electricity networks, injuries to people, production losses other than in table 2 e.g. due to interruption of communication networks, emergency response by police, municipality or water board, discomfort other than interruption of medical services.

Figure 2 illustrates the pathways from rainfall to impact. This figure shows that there is no direct link between the rainfall intensity and the final impacts as the pathways consist of several steps and each step can be described through underlying variables which determine whether the rainfall intensity will actually cause an impact. An example of such variables is given in figure 3. The developed functions are based on these variables. This approach is supported by the research by Spekkers et al (2012) which concludes that variations in damage to property and content can not only be explained by rainfall characteristics and it is therefor recommended to also study other explanatory variables such as the building properties and characteristics of the urban drainage system. All impact functions describe the behaviour of the water through the occurred water depth. Some impacts are also determined by the duration of flooding. In The Netherlands the flow velocity is negligible and is therefor not included in the impact functions. The other variables are specific per functions.

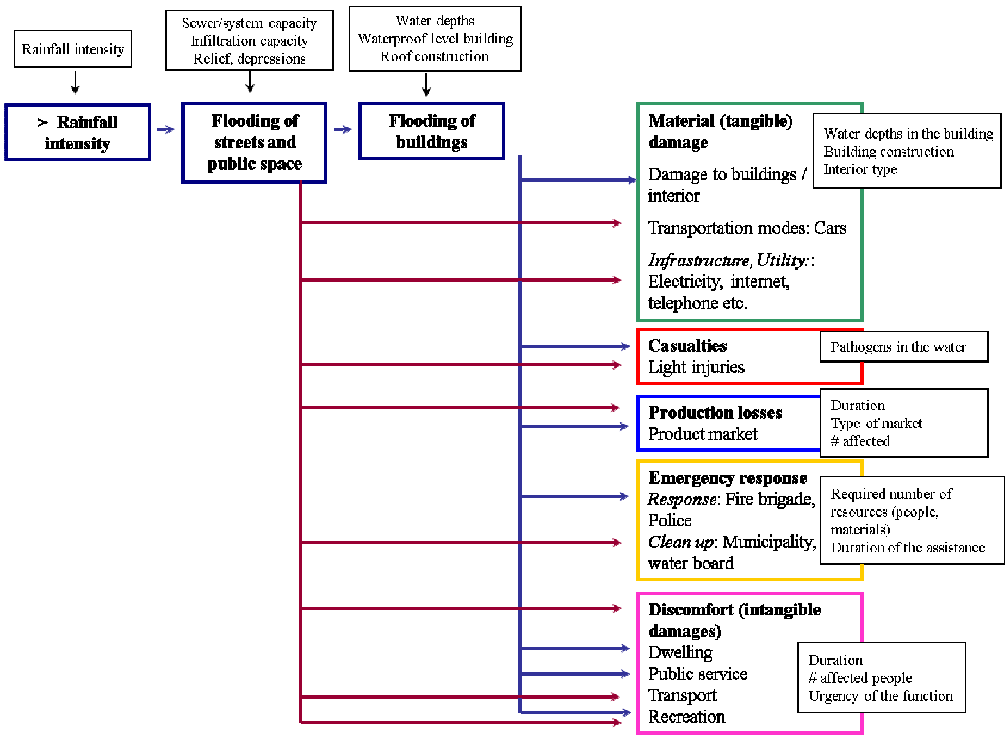


Figure 3 Example of variables which influence the pluvial flood impact.

Water depth

Urban flooding of streets is modelled with use of computer simulations and in some occasions monitoring data is available. These models simulate the flooded area and water depths for a certain rainfall event and although these models are still in a developing stage, outcomes of these models can be used as input for the functions.

Flood duration

Although the more advanced and complex simulation software can give insight into flood duration, most often this information is not available. Stichting RIONED performed an inventory through a survey of 203 responding municipalities (Luijtelaar, 2008). From this survey it was found that approximately 75% of the municipalities encounter flood durations of less than 1 hour.

Flow velocity

The flow velocities of flood water depend on the gradient of the terrain. In sloping areas high flow velocities pose a significant hazard for properties and people. Buildings can be damaged, roads eroded, cars wrecked and people may be flushed away by the power of the flow. For flat lowland areas this exposure however tends to be negligible.

3.3 Material (tangible) damage

3.3.1 Buildings and contents

The amount of damage to buildings is on the one hand determined by the water characteristics such as water depth, flow velocity and flood duration and on the other by the susceptibility of a building to flooding. Pluvial flooding in the Netherlands does not cause large water depths nor flow velocities. This is mainly due to the small differences in relief and the short flood duration. As a result pluvial flooding only causes damage to the structural elements of a building and to the content on basement and ground floor level. The susceptibility of a building depends on the materials used and on the type of building. In a bungalow all the living functions will be located on the ground floor causing more damage to the content than for a two storey house. Damages to a building with a basement will be larger than for a building without a basement.

Different functions describing flood damage in relation to the water depth are already available for the evaluation of large flood events caused by fluvial or sea flooding. E.g. through the casualty and damage module (Groot Zwaaftink and Dijkman, (2007), the Multicoloured manual (Penning-Rowsell at al, 2005 or by Bilal (2007). The available knowledge on the amount of damage in relation to the occurred water depth for pluvial flooding events shows a wide spread range. A simple approach for the damage to buildings and content function was therefor chosen. If improved knowledge becomes available, the function can be further detailed.

3.3.1.1 Equation

$COST_{building;i}$ = *if* $WD \geq TH_i$ *then* $CV_i * NUM_{build,i} + BV_i * NUM_{build,i}$ *else* 0

with:	$COST_{building}$	=	Total damage to building of type i including content damage (€)

	WD	=	Water depth above ground level (m)
	TH_i	=	Threshold for flooding of building type i (m); Level of doorstep or lowest vent hole (basement, crawl space)
	CV_i	=	Average content damage for building type i value (€)
	$NUM_{build,i}$	=	Number of flooded buildings of type i
	BV_j	=	Average building damage for building type i (€)

When for a building of type i the water depth exceeds a threshold, the damage is calculated as the sum of the damage to the building and the content times the number of flooded buildings. The function allows for a differentiation in damages based on the building type, e.g. buildings with basements or crawl spaces, one or multi-floor buildings.

3.3.1.2 Values for the variables in the Netherlands

Flooding threshold for buildings

Damage to buildings will start to occur when water enters a building. The threshold value for water entering a building is determined by the lowest water proof level, e.g. a doorstep, a basement window or ventilation opening. Through history the doorstep height has fluctuated triggered by factors such as building regulations, experiences with flooding, accessibility of a building for wheelchairs or by fashion. Veerbeek and Gersonius (2012) conducted a survey on the height of doorsteps within a neighbourhood in Rotterdam. No other similar research is available on distribution of doorstep height in the Netherlands. The average median for the doorstep height was found to be approximately 10 cm with an average 95% confidence range of 15 cm. It is therefore suggested to assume a 10 cm threshold for buildings without a basement and a 0 cm threshold for buildings with a basement. The ratio of buildings with and without basements will vary across the Netherlands and within cities. It is therefore suggested to assume a ratio based on areas characteristics or by expert judgment.

Average content and building damages

The damage equation for houses makes a distinction between damage to the structure and damage to the content of a house. The average total content value for a Dutch house was estimated to be 70 k€ (Briene et al, 2002). Corrected for inflation and economic growth (an inflation rate of 1.7% per year Is assumed) the average content value for a Dutch house is estimated to be 83 k€ (2012).

The damage amount of the building is determined by the value for reconstruction. (Briene et al, 2002) estimated the total reconstruction costs for two types of houses by correcting the market value with the average value for land (Table 3).

Table 3: Building value (BV) estimation (Briene et al, 2002). For the inflation correction an inflation of 1,7% is per year is assumed.

	Estimate 2002 (€)	Correction for inflation, +18,4 % for 2012 (€)
Apartment	102.000	121.000
Family home	171.000	202.000

Spekkers et al (2012) analysed a database made available by the Dutch Association of Insurers. With use of this database he performed a case study for the province of South Holland for the year 2004 and extracted an average claimed amount of damage per client.

Table 4: Average claimed amount of damage per client (381 content claims and 679 property claims, 2004 and with inflation correction for 2012). For the inflation correction an inflation of 1,7% is per year is assumed.

Insurance claims for the province of South Holland, 2004	**Average claimed amount of damage per client (€, 2004)**	**Standard deviation (€, 2004)**	**Average claimed amount of damage per client (€, 2012)**	**Standard deviation (€, 2012)**
Content	817	416	935	476
Property	1229	553	1406	633

Note that these are only averages for the Province of South Holland and for the year 2004. The average amount was calculated together with the standard deviation. No information is yet available on the distribution skewedness. The damage amount per client are not very high, but the actual amount of damage is determined by the number of household being hit and the frequency at which flooding occurs. Many smaller incidents could amount in a larger damage number.

3.3.1.3 Knowledge gaps

In the field of damage assessment to buildings due to pluvial flooding, several knowledge gaps were identified. Tackling these knowledge gaps will improve the accuracy of the damage equations and therefor the damage predictions.

- More information from actual occurred flood events. Across The Netherlands over the past years many incidents of pluvial flooding have occurred but the damages have not been monitored accurately. Gathering damage information from different incidents will improve the insight into the actual damage amounts and provide data for the validation of damage equations. This accounts not only for information on damages to buildings, but also for damage to other assets which will be discussed in the following paragraphs.

- Differentiation in thresholds per building type including buildings with basements. Veerbeek and Gersonius (2012) assessed the thresholds for buildings. A further differentiation per building types will provide a better damage estimation.

3.3.2 Electricity supply

Electricity is distributed through a power grid. A high tension network distributes the electricity from the central power stations to the regional middle tension networks. Through the middle tension networks the electricity is distributed to the bulk consumers and to the low tension network. The low tension network provides electricity to households and smaller consumers (De Haan, 2012). Pluvial flooding is very unlikely to cause failure in the high tension network. The middle and low tension electricity transformer faults are located in the streets and other public areas and could be damaged by pluvial flooding. Damage to electricity cables due to pluvial flooding is not expected (Huizinga et al, 2011).

The middle tension networks are constructed in rings. If a failure occurs within the ring, electricity can be provided through an alternative route (high redundancy). Most failures within the middle tension network are repaired within hours although it is expected that damage due to flooding will require more time to repair. If an electricity failure occurs through the middle tension network, hundreds to even thousands of customers could be affected (De Haan, 2012). The low tension network is most often constructed as a linear system, thus with low redundancy. Failure in the low tension network often last longer than a failure in the middle tension network. The number of affected customers per failure is much lower though than for the middle tension network (De Haan, 2012).

Pluvial flooding as a cause for failure of the electricity network is rare. In 2011 approximately 0.5% of electricity failure in the middle and low tension network was caused by weather conditions (De Haan, 2012) which includes flooding, but also covers other causes such as storm damage. The consequences of a power failure are substantial though as is further discussed in paragraph 3.4.3. This paragraph discusses the physical damage to the power network system through damage to the transformer faults.

3.3.2.1 Equation

$$COST_{trafo} = \sum_{i=1}^{n} (if\ \ WD \geq TH_{trafo;i}\ then\ UC_{trafo;i}\ else\ 0)$$

with:	$COST_{trafo}$	=	Total replacement cost of transformer vaults in an area (€)
	WD	=	Average water depth above surface in the area (m)
	$TH_{trafo;i}$	=	Threshold water depth of transformation vault *i* (m)
	$UC_{trafo;i}$	=	Unit cost of electricity substation (transformer) (€)

If the water depth remains lower than a certain threshold (THtrafo) no damage will occur. If this threshold is exceeded, it is assumed that the transformer will fail and needs a replacement. The total cost is calculated as the replacement cost (UCtrafo) of that transformer.

3.3.2.2 Values for the variables in the Netherlands

Threshold value for electricity substation

The default threshold values are taken from (De Kort 2012). Through a quick scan De Kort evaluated the threshold value of a electricity substation in the middle and low tension network within the flood prone areas of Rotterdam. De Kort concluded that a water depth of 30 cm will cause damage to the low tension substation, at 35 cm damage can occur to street lamps and at 50 cm a middle tension substation can experience damages. The policy for the flood prone areas (river flooding) is to shut down the electricity if a water depth of 20 cm or more is expected. For pluvial flooding it is not yet possible to make accurate predictions on short notice and it can be assumed that the electricity will not be shut down during a pluvial flooding event. De Kort recommends further research on the thresholds at which different types of substations are expected to fail.

Replacement costs electricity substation

There are many different types of electricity substations and the replacement costs will vary equally. The STEDIN (electricity network provider for the Rotterdam area) approximated the costs for full replacement of a low tension substation at €5.000,- and a middle tension substation at €55.000,-. This is a rough estimate. Costs for repair of a substation are assumed to be lower than the replacement costs.

3.3.2.3 Knowledge gaps

When developing the damage equation and gathering information on the variables, the following knowledge gaps were identified.

- More accurate estimate of replacement and repair costs. Very little is known on the costs for repair and replacement of transformer vaults. The values provided in this report are based on expert knowledge provided by one person.

- Validation of threshold value. The water depth at which transformer faults become damages requires further investigation.

3.4 Production losses functions

3.4.1 Business interruption

Business interruption can be caused by flooding of a commercial building or area, by an electricity failure or as a result of traffic disruption. This paragraph and impact function focusses on the interruption of production as a result of flooding of a commercial building or area. An interruption due to electricity failure or traffic disruption is addressed in the paragraphs 3.4.2 and 3.4.3.

The flooding of a commercial building or area will result in interruption of work activity. Work areas are temporarily not available, appliances or merchandise might be wet or even damaged, personnel will be involved in cleaning and work activity can only resume after completing the cleaning activities. The extent of the interruption depends on factors such as the duration of the flooding and time required for cleaning, the type and size of the business as well as the type of building.

3.4.1.1 Equation

$COST_{business,I,j} = \Sigma_{i,j}$ *if* $WD \geq TH_{Bus}$ *then* $(D_{flooding} + D_{cleanup,I,j} - D_{minBus,I,j}) * DAM_{Bus,I,j}) * AMOUNT_{Bus,I}$ *else* 0

with:	$COST_{business,\ I,j}$	=	Total damage due to business interruption (€)
	WD	=	Water depth above surface (m)
	TH_{bus}	=	Threshold for flooding of building type; the building its doorstep or lowest vent hole (m)
	$D_{flooding}$	=	Duration of the actual flooding (hours)
	$D_{cleanup,\ I,j}$	=	Time required to clean-up, restore and restart for business of type i (Hours)

	$D_{minBus, I,j}$	=	Minimal time at which business of type i starts to encounter damages (Hours)
	$DAM_{Bus, i}$	=	Average damages per hour for business interruption of type i (€/Hour)
	$AMOUNT_{Bus, I,j}$	=	Number of affected businesses of type i

The equation focusses on business interruption as a result of flooding of a building. The threshold therefor depends on the type of building. The duration of the interruption is the result of the duration of the flood and the time required to clean up, restore and start up. In addition the function provides the possibility to define a minimum time at which damage starts to occur as for certain businesses only after a certain time of interruption, an impact will be felt. When applying this equation duplication of damages should be avoided if flooding would also cause an electricity failure resulting in business interruption as well.

3.4.1.2 Values for the variables in the Netherlands

Business types

The equation allows for differentiation of the damages by business type. Several classifications are applies in the Netherlands. The Dutch Central Bureau for Statistics (CBS) uses the classification known as the Standaard Bedrijfsindeling (SBI) (website CBS), which classifies a business according to the economic activity group of the business. This classification consists of 21 main groups of which the majority can be found within the urban area. A classification can also be made according to the size of a business, either by profits or number of employees.

Threshold for flooding of businesses

It is assumed that business interruption starts to occur when a commercial building is flooded. For the equation on damage to houses a distinction was made for buildings with or without a basement where the threshold for a house with a basement was set at a water depth of 0.10 m and with a basement at 0 m. A distinction could be made between types of businesses when it is plausible to assume that a certain type of business will be located within a specific building type.

Duration of the business interruption:

The duration of the interruption is equal to the duration of flooding plus the time required to clean-up and/or restore services and restart operations. It is assumed that clean-up, restore and start-up can only begin after the flood waters have drained away and buildings have had some drying time. There are very little numbers available though on the average flood duration as well as the time required to clean-up and restore. From the survey performed by the

Stichting RIONED (Luijtelaar, 2008) it was concluded that approximately 75% of the municipalities encounter flood hindrance durations of less than 1 hour. No information was found on the time required to clean-up and restore.

Minimal time at which business of type i starts to encounter damages

This variable was taken form the experiences on damages due to an electricity failure where it is assumed that a short interruption does not immediately result in business losses. If the interruption is of a short duration, production can be made up at a later stage (Bijvoet et al, 2003). If required, this delay can be expressed by applying a time threshold. No information for a minimum time delay is available though through literature.

Damages for business interruption per hour

The damages due to a business interruption can be approximated by assuming that damage due to one hour of interruption equals one hour of no profit. This can result though in an overestimation of the damage as pluvial flooding will only have an effect on the ground floor.

The CBS provides the profits per business type on a yearly base as well as the number of businesses of a certain type. From these numbers a rough estimate on profits per hour can be extracted as is illustrated in table 5.

Table 5: National statistics for the year 2010 on businesses; labour and finance per branch (CBS, statline.nl). The first two columns show the information as provided by the CBS. The column 'business result per company' is a division of column 2 by column 1. The remaining columns divide the business result per year by the number of required days or hours. (Note, these numbers have not been corrected for inflation).

Business branches (SBI 2008)	Total number of businesses (2010)	Business results per branch x mln euro per year	Average business result per company per year x mln Euro	Average business result per company per day Euro	Average business result per company per hour (8-hour work day) Euro	Average business result per company per hour (24-hour work day) Euro
C Industry	50745	17186	0,34	1082,02	135,25	45,08
D Energy supply	660	3525	5,34	17063,61	2132,95	710,98
E Drinkwater companies and water treatment	1135	900	0,79	2533,39	316,67	105,56
F Construction industry	127610	6537	0,05	163,66	20,46	6,82
G Trade	193260	22767	0,12	376,37	47,05	15,68
H Transport and storage	29875	4720	0,16	504,77	63,10	21,03
I Hotel and catering industry	44340	1893	0,04	136,40	17,05	5,68
J Information and communication	52915	7819	0,15	472,09	59,01	19,67

One can argue that the economic damages due to business interruption from direct flooding will be in the same order as a business interruption due to an electricity failure. It should be noted though that an electricity failure will cause all production which requires electricity to come to a hold and thus resulting in higher economic damages.

3.4.1.3 Knowledge gaps

Several knowledge gaps were encountered when developing the damage equation and gathering information on the variables.

- Water depth thresholds for different types of businesses. The damage to businesses is determined by the threshold level of the building in which a business houses. Only after a building is flooded, will the damage start occur. Learning more on the thresholds of buildings in which different types of businesses are housed, will provide an improved damage assessment due to business interruption. This knowledge gap links to the knowledge gap identified under paragraph 3.3.1 which discussed the material damages to buildings.

- Duration of flooding and required time for clean-up, restore and startup. Duration of a flood impact is essential information as input for the damage assessment, but very little is known on the impact duration due to flooding.

- Minimal time at which a business starts to encounter damages. Bijvoet et al (2003) assume a minimum business interruption time before damages start to rise. Further research is required first of all assessing the assumption; is it a correct assumption? And secondly for which businesses this would account and what is the length of these time lags.

- More insight into business damages per business branche due to pluvial flooding.

3.4.2 Traffic disruption

The survey undertaken by the Stichting RIONED (Luijtelaar, 2008) showed that more than 50% of the 203 responding municipalities consider a flooded main road, tunnel or shopping street as a flood hindrance. Approximately 20% of the municipalities have encountered flooding of one or more main roads for a period of less then 1 hour and approximately 7% for a period of 1 – 6 hours. Whether the flooding of roads actually leads to damages, depends on factors such as the time of the flooding, the duration of the blockage and the number and capacity of alternative routes.

3.4.2.1 Equation

$COST_{traffic}$ = *if* WD ≥ $TH_{traffic}$ *and if* ROADCap > $TH_{ROADCap}$ *and if* $RoadCap_{alt}$ < ROADInt then $D_{Flooding}$ * ($NUM_{PassTraf}$ * $COST_{PassTraf}$) + ($NUM_{FreightTrans}$ * $COST_{FreightTrans}$) *else* 0

with:	$COST_{traffic}$	=	Costs due to traffic disruption (€)
	WD	=	Water depth above surface (m)
	$TH_{traffic}$	=	Threshold for disruption to traffic (m).
	ROADCap	=	ROADCap of blocked road (No. vehicle equivalents per hour)
	$TH_{ROADCap}$	=	Minimum road capacity set as limit to indicate if the road is a main road (No. vehicle equivalents per hour)
	$RoadCap_{alt}$	=	Available alternative road capacity (No. vehicle equivalents per hour)
	ROADInt	=	Traffic intensity of blocked road (No. vehicle equivalents per hour)
	D_{delay}	=	Average delay time per vehicle (Hours)
	$NUM_{PassTraf}$	=	Number of affected passenger cars per hour (Cars/Hour)
	$COST_{PassTraf}$	=	VoT average for a passenger car (€/Hour).
	$NUM_{FreightTrans}$	=	Number of affected freight traffic (Trucks/Hour)
	$COST_{FreightTrans}$	=	VoT Cargo transport by road ((€/Hour).

The magnitude of the traffic disruption as expressed by the equation is based on the duration of the blockage due to a flood. It is assumed that a blockage only occurs if a certain water depth is reached and that a blockage is only relevant if it applies to a main road. In addition it is assumed that the blockage will only result in traffic disruption if the capacity of the alternative routes is not sufficient to cope with the additional traffic.

This equation assumes that information on road capacities is available or can be provided through expert judgement. If this information can not be made available, one can also choose to only indicate if disruption will take place, thus if the threshold is exceeded yes or no.

3.4.2.2 Values for the variables in the Netherlands

Traffic thresholds

If water enters a car this can damage the engine and car oil can cause contamination. It is therefore undesirable to let water enter the engine or muffler of a car. For an average car this will occur approximately at a water depth of 30 cm in still water. Another factor is the danger of open manholes and obstacles which can not be seen through contaminated and troubled water. The website risicokaart.nl sets a limit for the maximum water depth a car can drive through at 20 cm and (Pieterse et al, 2009) assume a limit at 50 cm. The damage functions applied in the HIS SSM (Groot Zwaaftink and Dijkman, 2007) assumes that car damage will occur from a water depth of 40 cm and USAGE (2007) at a water depth of 30 cm. These values vary between 20 and 50 cm. Based on this information, it is recommended to set a water depth threshold value for traffic at 30 cm.

Road type

The flooding of main roads is considered to cause larger hindrances than the flooding of roads in the residential areas. The equation provides the possibility to define at which road capacity a road is considered to be a main road (Threshold road capacity).

Redundancy and delay time

The delay time is the additional time required per vehicle to reach its destination. If alternative routes are available and the capacity of these routes are sufficient to handle the additional traffic, this equation assumes the delay time to be negligible. If this is not the case, the delay time is defined by the number of delayed vehicles (e.g. average traffic intensity of the blocked road or traffic intensities of the blocked road for certain times of the day) in relation to the total road capacity and traffic intensity of the alternative routes. Road capacity and traffic intensity is specific for each location. The determination of the delay time requires expert judgement or the use of traffic models.

If no alternative routes are available, the delay time can be estimated by multiplying the duration of flooding by the traffic intensity (number of vehicles per hour).

Costs for traffic delays

The Kennisinstituut voor Mobiliteitsbeleid (KIM) provides average numbers for the Netherlands on the costs of traffic delays per vehicle type (table 6).

Table 6: Traffic delay costs (2006) per vehicle type, Euro per hour (KIM, 2006) en corrected for inflation 2012. For the inflation correction an inflation of 1,7% is per year is assumed.

Vehicle type	Euro / hour (2006)	Euro / hour (2012)
Passenger traffic	5,92	6,55
Transportation of goods	42,35	46,86
Business travel	29,46	32,60
Commuting traffic	8,57	9,48

3.4.2.3 Knowledge gaps

- The costs for traffic delay are based on average numbers for the Netherlands. These numbers can be used to provide a rough estimate of traffic delay costs. More insight into actual traffic delay costs due to pluvial flooding is required.

- This equation assumes traffic delay when no sufficient capacity of alternative routes is available. More research is required though on the traffic development during flooding of roads to gain more insight into the process and actual delays.

3.4.3 Electricity failure

Paragraph 3.3.2 discussed the function describing the damages to the electricity network. Damage to the electricity network in turn will result in failure of electricity supply to businesses and households. During an electricity failure production processes are interrupted and when electricity is recovered, often time is required to start up the production process. In addition materials can be lost during the electricity failure e.g. perishable goods. Many activities within a household require electricity or sufficient lighting (Bijvoet et al, 2003). An electricity failure therefor results in material damages (e.g. loss of materials), production losses and causes disruption of household activities and leisure time.

As was explained in paragraph 3.3.2 pluvial flooding is more likely to cause damage to the low tension network and to a lesser extent to the middle tension network due to the smaller water level thresholds of the low tension electricity substation. It is mainly households and smaller businesses which are connected to the low tension network, though failure of the middle tension network will affect a large group of customers including the larger businesses (De Haan, 2012).

From the yearly inventory by the KEMA (De Haan, 2012), it is seen that at present only approximately 0,5% of the causes of an electricity failure in the low and middle tension network can be contributed to weather conditions and this encompasses more than just pluvial flooding. At present damage to the electricity network and resulting impacts due to pluvial flooding therefor are not considered a problem. Though if an electricity failure due to flooding does occur, the costs of an electricity failure are expected to be quite high and in future if rainfall intensities increase, electricity failure may occur more frequent and. Therefor for this research it was chosen to develop an equation on electricity failure to be able to assess future pluvial flooding impacts.

3.4.3.1 Equation

$COST_{ElectFail}$ = *If* WD ≥ TH_{Elect} *then if* $D_{outfall} \geq D_{MinPriv}$ *then* $(D_{outfall} - D_{minPriv}) * DAM_{priv} * AMOUNT_{Priv}$ + *if* $D_{outfall} \geq D_{MinBus}$ *then* $(D_{outfall} - D_{minBust}) * DAM_{Bus}) * AMOUNT_{Bus}$ *Else* 0

with:	$COST_{ElectFail}$	=	Costs due to electricity failure (€)
	WD	=	Water depth above surface at electricity substation (m)
	TH_{Elect}	=	Threshold at which electricity substation fails (m)
	$D_{outfall}$	=	Duration of power failure (Hours)
	$D_{MinPriv}$	=	Minimal power failure at which private households starts to encounter damages (Hours)
	DAM_{priv}	=	Average damages per hour for a private household (€/Hour)
	$AMOUNT_{Priv}$	=	Number of affected private households
	D_{MinBus}	=	Minimal power failure at which businesses starts to encounter damages (Hours)
	DAM_{Bus}	=	Average damages per hour for business interruption (€/Hour)
	$AMOUNT_{Bus}$	=	Number of affected businesses

The costs due to electricity failure depend on two physical variables, the water depth and the duration of the failure. If a certain water depth at an electricity substation is reached (the threshold value), the substation will fail due to material damages. It is assumed that all households and businesses linked to the specific substation will experience an electricity failure when the threshold is exceeded. The total damages are equal to the damages for households and businesses.

No differentiation has been made for the time of failure (daytime versus evening, weekday versus weekend) as well as type of business. The SEO (Bijvoet et al, 2003) estimated that the damage to businesses and public services on a Sunday would encompass 1/10th of the damages encountered on a weekday, thus extending the equation by including variability, is recommended if this information is available .

3.4.3.2 Values for the variables in the Netherlands

Threshold electricity failure

The threshold values for electricity failure are equal to the threshold values for damage to the electricity network (see paragraph 3.3.2).

Duration of the failure

The duration of the failure is equal to the duration of flooding plus the time required to provide an emergency power unit or repair (or replace) the substation. It is assumed that repairs can only begin after the flood waters have drained away. There are very little numbers available though on the average flood duration as well as the time required to repair a substation or provide alternative emergency power unit. The inventory by the RIONED (Luijtelaar, 2008). concluded that approximately 75% of the municipalities encounter flood hindrance durations of less than 1 hour.

The average time a customer was without electricity for 2011 due to failure of the low-tension network was 146 minutes and for the period 2006 – 2010, 192 minutes (De Haan, 2012). For the Middle-tension network these numbers are respectively 77 and 138 minutes. These failures are not just accounted though to pluvial flooding. As approximately 0,5% of the causes of electricity failure in the low tension network are accounted to weather influences (De Haan, 2012), these numbers can be interpreted as an average time to solve an interruption of electricity supply excluding the time required for an area to drain. The equation on damage to an electricity substation does assume though that a flood will cause considerable damage to an electricity substation such that a full replacement is required if a substation were flooded. Replacement of a substation will require more time than the average time to solve a standard electricity interruption but often temporary measures are taken.

Minimal time at which households and businesses starts to encounter damages

The equation provides the possibility to include a time threshold if it is assumed that damages only start to develop after a certain period of time. In the Netherlands, the height of compensation for electricity failure is laid down by law and only kicks in after a minimum duration of electricity interruption. A private household is entitled to compensation if the duration of the failure exceeds four hours. For a smaller business, the compensation is linked to the duration of the failure as well as the type of network failure. These time lags are not necessarily related to the actual damages.

Tension network	**Minimal duration (hours)**
High-tension network	1
Middle-tension network	2
Low-tension network	4

Damages to households

According to Dutch law a household is entitled to 35 euros after four hours without electricity. For every additional four hours without electricity, a household receives 20 euros. The first 35 euros compensate for the damage to content of freezer and refrigerator. The following 20 euros are to compensate the experienced inconvenience.

In 2003 the Stichting voor Economisch Onderzoek (SEO) performed a research into the costs of electricity failure (Bijvoet et al, 2003). They too assumed the damages to be a sum of the damages to households and businesses. The damages for a household were based on an estimate of the value of an hour of free time. For an employed person they assumed the value of one hour of free time to be €9,43 (50% of average gross income per hour in 2001). For an non-working person the value of free time was estimated to be half of the value for an employed person, thus €4,72 per hour (Bijvoet et al, 2003). In 2010 approximately 60% of the Dutch population belonged to the 'employable age group' (20 -65) (based on numbers form the Centraal Bureau voor de Statistiek (CBS), statonline.nl). The results for damages to businesses could not be used for this study as the business damages were calculated on a national scale.

Damages to businesses

According to Dutch law a business receives €195,- for the first duration of failure (1, 2 or 4 hours) and for every additional four hours without electricity they receive €100,-. For larger businesses, individual arrangements are made. It is advised to only apply these numbers if one is interested in estimating the lower limit value for damages due to electricity failure, as it is most likely that the damages encountered by small businesses will be higher than 295 euros if a business is closed down for a period of 6 to 8 hours.

In 2006 the EIM executed a research into the damages of power failures to small businesses (Hoevenagel, 2006). Approximately 2000 small businesses were asked to fill in a survey. The average damage per power failure and per business was approximately €550,-. This confirms the assumption that the compensation as defined by law does not cover the actual damages encountered by small businesses. The costs per power failure per line of business are shown in table . This includes production losses as well as material damages.

Table 7: Costs per event and per business sector for 2005 resulting from the EIM survey (Hoevenagel, 2006). For the inflation correction an inflation of 1,7% is per year is assumed.

Business sector	**Costs per power failure (€) for 2005**	**Costs per power failure (€) for 2012**
Industry	1274	1434
Construction	370	416
Trade	558	628
Lodging	542	610
Transport	213	240
Financial services	665	748
Commercial services	474	533
Other services	86	97

Number of affected businesses and households

According to Haan (De Haan, 2012), on average 18 clients (households and businesses) were affected per failure event in the low-tension network in 2011 and 772 due to failure in the middle-tension network. These failures can be accounted though to damages in an electricity substation or within the network itself. The latter will result in less clients being affected. These numbers can therefore only be used as a lower boundary to the number of clients affected due to damage to an electricity substation.

On the other hand the results from the EIM research (Hoevenagel, 2006) showed that an electricity failure does not always induce damages as only approximately 37% of the respondent businesses which experienced a failure in 2005 encountered actual damages due to the failure.

The number of households and businesses can also be estimated by the Thyssen polygons method, or by assuming an equal number of households and businesses per substation. An example of Thyssen polygons is given in figure 4. In addition an estimate can be made of the percentage of households and businesses which actually encounter damages.

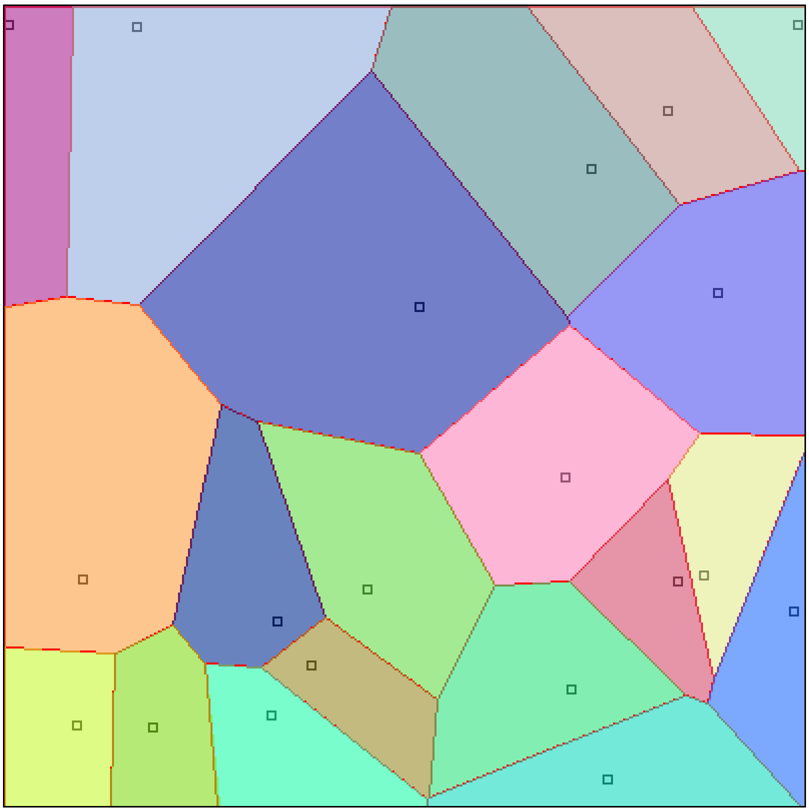


Figure 4 Example of Thyssen polygons. Each side of a polygon is placed in the middle of two electricity substations assuming that the created area around each substation covers the service area.

3.4.3.3 Knowledge gaps

The encountered knowledge gaps with regard to electricity failure are:

- Lack of insight into the duration of electricity failure due to pluvial flooding. The duration of the electricity failure is an important factor in determining the damage and an improved estimate is therefor required.

- Insight into damages to both households and businesses due to electricity failure.

- The number of households and businesses connected to a low and middle tension substation.

3.5 Emergency response

3.5.1 Fire brigade

The fire brigade plays an important role during pluvial flood events. The fire brigade assists when buildings or public space are flooded by pumping water out of basements and other depressions where water accumulates. The CBS annually summarises statistical information of the Fire brigade (CBS, 2011). In 2010 just over half of the turn-outs performed by the fire brigade were for assistance of situations other than a fire. 24% of these turn-outs (approximately 10.000 turn-outs) were to give assistance in a storm or pluvial flooding event. These are considerable numbers and thus assistance by the fire brigade is taken into account for the assessment of impacts due to pluvial flooding.

3.5.1.1 Equation

$COST_{FBAss}$ = (*if* $WD \geq TH_{Build}$ then $AMOUNT_{FloodBuild} * COST_{EmAss,}$ *else* 0) + (*if* $WD \geq TH_{RP}$ then $AMOUNT_{FloodPB} * COST_{EmAss,}$ *else* 0)

with:	$COST_{FBAs}$	=	Total cost of emergency assistance by the fire brigade (€)
	WD	=	Water depth above surface (m)
	TH_{Build}	=	Threshold for building with basement (m)
	$AMOUNT_{FloodBuild}$	=	The number of flooded buildings with basements
	TH_{RP}	=	Threshold for roads and public space (m)
	$COST_{EmAss}$	=	Cost per turn-out emergency assistance by fire brigade (€)

Assistance by the fire brigade is required when a flooded building or depression can not drain naturally and needs to be emptied through pumping. A flooding of a building of a public space becomes a problem when a threshold is exceeded. The total costs are the accumulation of the number of assets being flooded and the cost per turn-out, assuming that each flooded asset requires one turn-out of the fire brigade.

3.5.1.2 Values for the variables in the Netherlands

Number of flooded assets

The number of assets flooded depends on the threshold value for the specific assets. For public space, the threshold value for roads is applied assuming that below this threshold no assistance is required.

Only buildings with a basement are taken into account. The number of buildings with basements within a neighbourhood varies strongly throughout the Netherlands. As an indication to the ratio between flooding of buildings and public space, Veldhuis concluded that 80% of turn-outs were to assist in draining of buildings and 20% other than buildings (Veldhuis, 2010). These numbers are based on statistical data from the CBS between 1994 and 2005. The CBS data for 2010 (CBS, 2011) gives information on the type of object assistance is give. Approximately 55% of the assistance due to storm or pluvial flooding was on buildings. In July and August 2010 heavy thunder storms caused heavy rains and damages to buildings and public space resulting in a high turn-out by the fire brigade.

Costs for turn-out of fire brigade

The total costs of the emergency assistance by fire brigade in 2010 was calculated at 1.1 billion Euro (CBS, 2011). In That year the fire brigade turned out a total of approximately 150.000 times. According to these numbers the average cost per turn-out for 2010 would be approximately €7500,-. The costs are based on the budgeted expenses minus the budgeted income. The expenses encompass all costs such as salaries, accommodation, equipment and maintenance. Income is derived through provision of services (CBS, 2010). A turn-out can be for a range of incident types such as fires, accidents or flooding/ storm damages and thus these costs include a range of small incidents as well as large incidents, the latter having higher costs.

As part of a research carried out by the Nederlands instituut fysieke veiligheid (Nibra, 2010), the costs for turn-out of the fire brigade were estimated to be €245,- per turn-out (3137 turn-outs per year assuming 1 hour per turn-out and 6 persons involved). This is a considerable lower cost as this only includes the costs for an actual turn-out. A news article on the website of the local newspaper of Beuningen estimated the cost for unnecessary turn-out for a fire alarm to be approximately €700,-. They assume 28 persons involved at a personnel cost of €20,- to €30,- gross per hour.

The estimates for the costs for a single turn-out of the fire brigade in the Netherlands are seen to be in the range of a few hundred to a few thousand Euros. It is likely though that the costs for a single turn-out for flooding of a building or road will approximate a few hundred euros as this can be accounted as a smaller incident and as the estimates of the actual cost of a turn-out are also within this range.

3.5.1.3 Knowledge gaps

To improve the estimation of costs made by the fire brigade during a flood incident, the following points require improvement:

- A better estimate for the cost per turn-out for a flooding incident

- The number of turn-outs specifically for pluvial flooding.

3.6 Discomfort (intangible damages)

3.6.1 Health facility; accessibility and disruption

If a health facility can not be reached by vehicle, or if the health facility is (partly) flooded, this will cause unacceptable disruption for such a facility. It was chosen not to express this disruption in monetary units as no information was found on the costs.

3.6.1.1 Equation:

DIS_{AHf} = *if* $WD \geq TH_{transport}$ *or if* $WD \geq TH_{building}$ *then* yes, *else* No

with:	DIS_{AHf}	=	Disruption to public health facilities (yes/no).
	WD	=	Water depth above surface (m).
	TH_{AHf}	=	Threshold at which access roads to health facility are blocked. (M).
	$TH_{building}$	=	Threshold at which water will enter health facility (m).

This equation only indicates if a facility will be disrupted. The material damages due to pluvial flooding can be taken into account through the equation for material damages to buildings. Disruption occurs either if the building is flooded (exceedance of the buildings threshold) or if the roads leading to the facility are blocked (exceedance of the threshold for roads).

3.6.1.2 Values for the variables in the Netherlands

Thresholds

The thresholds for the accessibility of roads and for flooding of buildings can be found in the preceding paragraphs (respectively 3.3.1 and 3.3.2).

3.7 Summary pluvial flooding functions

The functions all have two variables in common; the Threshold value and the cost per unit. The values for the variables have been filled in as much as possible through information available for The Netherlands. This often results in a range of costs indicating the magnitude or class. An overview of the threshold values and range of costs is given in Table 8.

Table 8: Summary of the threshold values and average costs per unit

Impact	**Urban aspect**	**Threshold (m)**	**Average costs per unit (euros 2012) ((min - max)**	**Unit**
Material (tangible) damage	Houses and interior	0 (basement) 0.1 (without basement)	Content : 750- - 1750 House: 400- - 1200	House per event
	Electricity supply	0.3 (low tension) 0,35 (street lights) 0,5 (middle tension)	5000 55.000,	Low-tension and middle-tension electricity fault
Production losses	Business interruption	0 (basement) 0.1 (without basement)	5,- - 2000,- (2010)	Business per hour
	Traffic disruption	0.3	5 – 50	Per vehicle per hour
	Electricity failure	0.3 (low tension) 0,5 (middle tension)	Households: 0 – 80 Businesses: 80 – 2500 (based on legal compensation)	Per event 1 – 8 hour
Emergency response	Fire brigade	0 (house with basement) 0.3 (roads)	250 - 1000	Per turn-out per vehicle
Discomfort (intangible damages)	Accessibility health facilities	0 (basement) 0.1 (without basement) 0.3 (roads)	-	Per health facility

4 Heat

4.1 Overview of possible impacts

Global warming combined with the urban heat island effect will lead to relatively higher temperatures in Dutch cities. This report is a first attempt to quantify the economic impact of increased temperatures due to global warming and due to urban heat islands. The study is limited to the direct effects of heat on humans: mortality (how many people die), morbidity (how many people get ill) and productivity. Other impacts of heat on humans, such as increased aggression, decreased sleep quality (Döpp et al, 2011) are not included in the analysis.

The focus is on ambient temperature as the thermal stressor, although it is realized that not only temperature determines human stress , and that other aspects like relative humidity and solar radiation are also important. In the effect of heat on the human body (also called thermal strain)[1], interaction with air quality and micro-organisms may also play a role. The resulting effects on society can be quantified using economic damage indicators. Economic damage is related to material damage, such as roads that deform due to heat, but also to lost crop harvests and lost livestock. Figure 5 gives an overview of the main impact area's. For heat we will focus on health and economic damage related to health and productivity.

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[1] Heat strain refers to the adjustments made by the individual in response to the heat stress. These adjustments include biochemical, physiological, and psychological processes.

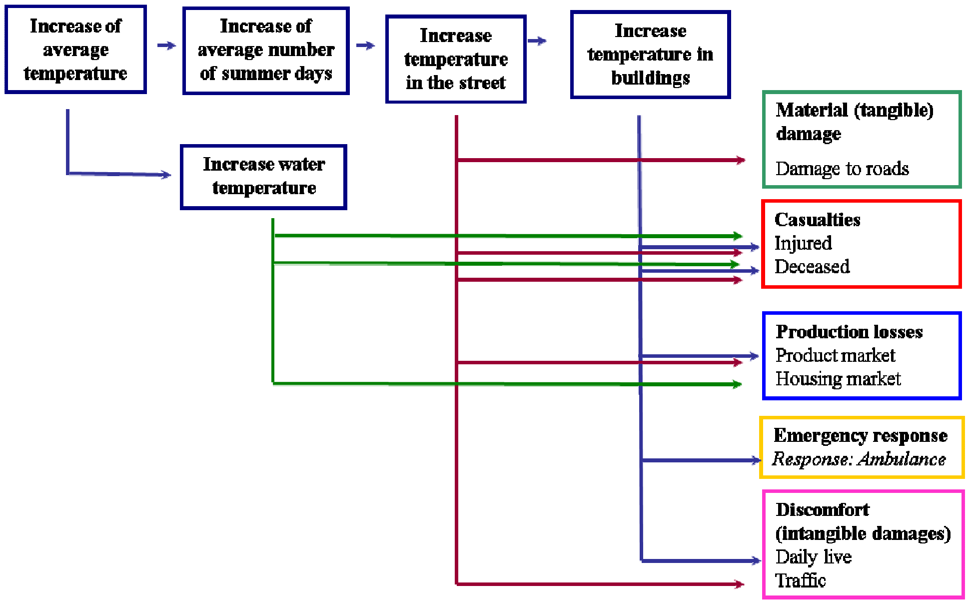


Figure 5: Overview of impacts to the urban system due to heat

Figure 6 gives a more detailed interrelation of effects. Global warming in urban heat islands lead to increased ambient temperatures. High temperatures, combined with solar radiation, absence of wind and high relative humidity determine the amount of heat stress[2]. Even when clothing insulation is minimized and activity is kept to a minimum, heat strain occurs in heat stress conditions. Generally, humans are well equipped to tolerate heat strain, but special groups like the elderly are vulnerable to heat strain, which may lead to cardiovascular and respiratory failure. The discomfort associated with thermal strain leads to behavioural changes, such as more aggression, with potential disruptive effects on social cohesion or traffic control. The economic damage of heat is mainly caused by material damage of road infrastructure and buildings, damage to crops and livestock and extra energy use (air conditioners). It should not be forgotten, however, that urban heat may also contribute to extra income, for instance due to increased sales (ice cream) or even increased tourism in relatively cold countries (Metroeconomica, 2006b).

[2] Heat stress refers to the total heat-related load on the individual from both environmental and metabolic sources.

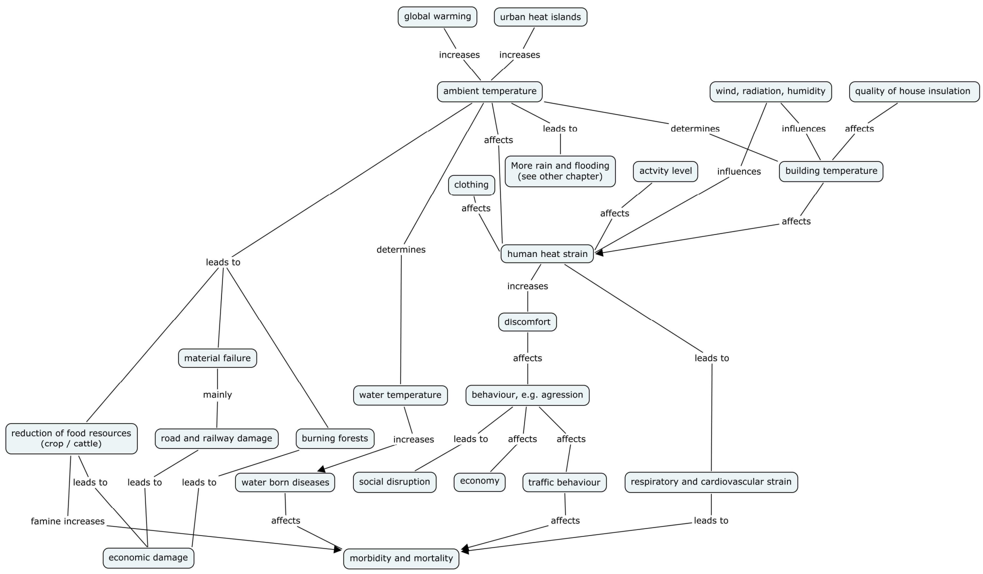


Figure 6: Detailed overview of impacts of global warming and urban heat islands.

4.1.1 Health impacts

Mortality and morbidity are the health impacts that are quantified in this study. The increase in ambient temperatures in cities now and in the near future leads to increased temperatures inside city dwellings, which in turn increases the thermal strain of subjects living there. Thermal strain is linked to human health. It is well documented that climate related excess mortality (which can be seen as an extreme case of being not healthy) is lowest at ambient temperatures of about 17°C in The Netherlands (Huynen et al., 2001). Mortality increases considerably at lower and higher ambient temperatures. Kovats and Hajat (2008) clearly show that the mortality mainly occurs in subjects over 75 years of age (Figure 7).

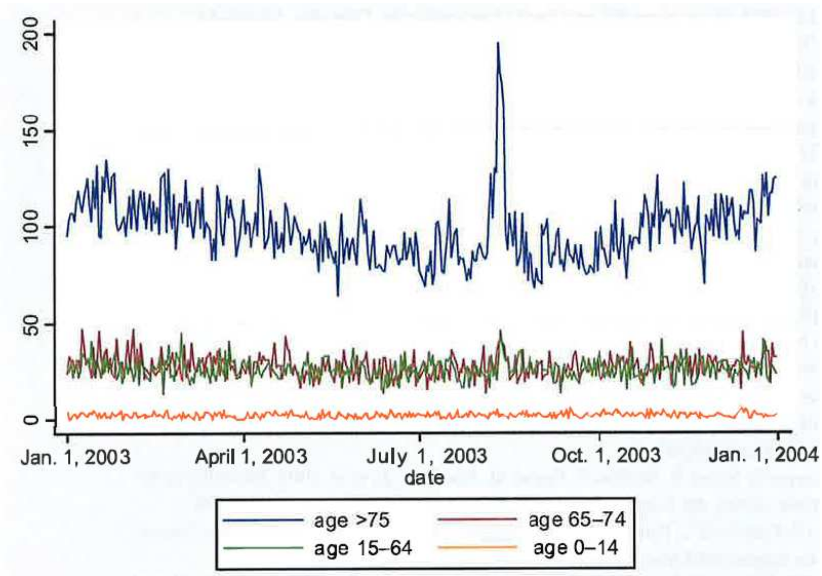


Figure 7: Mortality in greater London in 2003 (Kovats and Hajat, 2008). Note the strong effect of climate on mortality for subjects over 75 years old.

Mackenbach et al. (1997) showed that 10 elderly people die extra every week in Dutch nursery homes when the ambient temperature is 25-30°C compared to 15-20°C. In most epidemiologic studies, a direct link is made between ambient temperature and mortality or sometimes morbidity. Other climatic effects like wind are seldom taken into account, even though they are known to affect mortality (Kunst et al., 1991).

TNO has received data on daily mortality from Statistics Netherlands and combined this with weather data from the Royal Netherlands Meteorological Institute. The period is exactly 15 years: from January 1, 1991 to December 31, 2009. The average number of deaths during a day is 377. If we assume a population of 16,5 million subjects, the daily death rate is about 0.02 pro mille. Above 20°C ambient temperature the number of extra deaths equal about 8 subjects for every 1°C increase in temperature. This means that mortality increases with 2.1% for every 1°C increase in average daily temperature. Hübler et al. report an increase of 0.7% above ambient temperatures of 10°C and 3.6% above 24°C (Hübler et al., 2007). If we include relative humidity in the linear regression equation, mortality increases with 7 subjects per day for every 10 % increase in relative humidity and 10 subjects per day for every degree increase in ambient temperature. For comparison: the increase in mortality (% above average) was 17% for the UK (Hunt et al., 2006) and 9% for Germany (Koppe et al., 2004) during the 2003 heat wave.

As far as we know, the doses-response relations we described for mortality are not available for morbidity. Although hospital admissions are not a perfect indicator of morbidity, data show that an increase is observed during heat waves. For the heat wave in London, an increase of 16% of hospital admissions was observed in the over 75 age group (Metroeconomica, 2006b). The evidence thus far indicates that the morbidity burden in the heat is not as dramatic as seen in mortality.

4.1.2 Economic impact

Several factors related to heat can contribute to economic costs. In their thorough analysis, Metroeconomica (2006b) mentioned the following average costs for the heat wave in 2003 (in million pounds):

Built environment	124
Agriculture	88
Energy	80
Health	41
Transport	27
Water	0
Retail	-3
Tourism	-38

Surprisingly, productivity is not included in this analysis. In our analysis we include health (quantified by mortality and morbidity) and productivity.

Reports in which heat stress and heat strain are quantified in monetary units are scarce. Tol (2002) was probably one of the first that estimated death related to cardiovascular problems for different parts in the world and multiplied these numbers with the value of a lost life (estimated by him as 200 times capita income). Jorgenson et al. (2004) employed a similar macro approach for the US but also included an economic equilibrium model. They concluded that heat related mortality and morbidity significantly contributed to the total economic effect of global climate change (6-9% contribution to the effect in 2100 for a "warm" climate scenario).

Hübler and Klepper (2007) estimated macro-economic damage through heat waves for Germany until the year 2100. Only hospital admissions and reduce work productivity were quantified. The costs of hospital admissions are based on a model of extra heat days, data on extra hospital admissions during the heat wave in 2003 in London and average costs of hospital admissions in Germany. The costs of loss of work productivity are based on a production decrease of 3-12% at temperatures between 26 and 36°C. Bux (2006) estimates that the productivity is 3-12 % less in the temperature zone of 26-36°C as compared to thermoneutrality. This loss is directly applied to the total income from work, without feedback loops. The productivity loss leads to a loss in future heat waves of 0.03 to 2.8% of the current gross income. A comparable study is available for the UK (Metroeconomica, 2006a en 2006b). Work in the heat may lead to kidney related problems and thus to extra costs (Gezondheidsraad, 2008). A 2003 overview study by researchers at the Helsinki University of Technology and the Lawrence Berkeley National Laboratory in the U.S. showed that once the temperature rises above 25 degrees, productivity decreases by 2% per degree (Seppänen et al., 2004). Recently data was published by Zhao et al. (2009), based on a lab study. Although all studies agree that the effect of heat on productivity is considerable, large differences exist in productivity loss estimation.

In the framework of the KvK project Climate Proof Cities several stakeholders in particular policy makers in the big cities expressed a need to have a tool that roughly indicates the economic costs during heat waves. Due to the large uncertainties in the dose-effect relations and the assumptions on life costs, hospital uptake or productivity losses, the cost estimations in model that is constructed have to be considered as tentative. Future insights are necessary to improve the model.

There is a high degree of uncertainty inherent in the estimates, with the greatest uncertainty in health costs. This is among others due to the problem of how to value a human life.

4.2 Impact functions

Based on the considerations above we constructed a first draft of an economic cost model for temperature changes in The Netherlands.

4.2.1 Mortality

Based upon an analysis of meteorological data – daily averaged temperatures from 1995 until 2010 (source: KNMI) – and statistics about deaths – from 1-1-1991 until 31-12-2009 – in the Netherlands (source: Statistics Netherlands) it was concluded that above temperatures of 16ºC (24-hours average) about 5.71 persons per ºC/day decease extra, in addition to the average number of deaths. Below 16 ºC, the number drops to 4.06 persons/ºC/day. At very low temperatures, not as much persons decease (relatively speaking) when compared to very high temperatures. Another way of determining the relation between mortality and ambient temperature was the use of curve fitting. The derived formula was used to estimate the costs of mortality.

4.2.1.1 Equation

$$M = (377 + (0.81 - 0.0511*T - 0.00389*T^2 + 0.00000964*T^4) * 38.73) * (18000))$$

with:	M	=	Mortality cost per day (Euro)
	T	=	The 24-hour averaged temperature (ºC)
	377	=	The average mortality per day (n/day)
	38.73	=	The standard deviation
	18000	=	Value of one year of life lost (Euro)

The extra mortality costs appear when comparing results of a scenario calculation for a future year with the sum of daily costs of the current year. Scenarios used are the KNMI06 scenarios for the Netherlands (Hurk et al., 2006).

This relation as described above is, however, specific for the Netherlands and for the current climate, and it is unknown how the relation will develop under changed climate conditions. For the calculations it is assumed that the evolution of the sensitivity of the Dutch population for heat and cold will proceed slowly, and that the 1991-2009 period relation can also be applied to the period around 2050. This important assumption cannot be substantiated. Equally, like in all damage studies, it is assumed that no (behavioural) adaptation takes place.

The economic costs resulting from extra mortality are calculated using several climate-scenarios. The 24-hour averaged temperature under various climate scenario's was compiled from the KNMI-transformation program [3]; a program used for generation of climate data for impact studies. Average 24-hours temperatures for the period 2036-2065, generated by the program, were used to calculate the extra daily mortality resulting from high and/or low temperatures.

Most of the deaths during heat waves occur in age-cohorts above 75 years (Kovats and Hajat, 2008). Statistics show no decrease in the number of deaths in the first three months after a heat wave, therefore, it can be concluded that the deaths occurring during a heat wave are extra deaths that wouldn't have occurred without the event. The number of years lost before a natural death would occur has to be assumed. Arbitrarily, 1 year was assumed. In the case of 2 years, the monetary damage would be doubled.

The value of one year of life lost in the calculations was estimated to be EUR 18,000.= (in line with Metroeconomica (2006b), a study in which guidelines from the United Kingdom were adhered to). This is lower than usually is assumed in European studies on the costs of air pollution, in which the "value of a life-year" typically is EUR 40,000 – 52,000 for all age groups (Source: EC4MACS and NEEDS study for DG research). Changing the value of life could mean more than a doubling of the monetary damage.

4.2.2 Morbidity

Parsons et al. (2011) have shown that in the United Kingdom, each ºC rise in temperature above 18ºC means an extra 0.36% of hospital admissions. Each ºC lowering in temperature below 18ºC means a drop in hospital admissions of 0.64%. It is assumed that these numbers can be applied to the Netherlands. Several studies show a wide range in extra hospital admissions during heat waves (WHO, 2009).

In the Netherlands, the number of daily hospital admissions is about 11,000 (2838 per 10,000 inhabitants, source: Statistics Netherlands). The average costs associated with a hospital admission in 2010 were EUR 4,975.= per admission (Ernst and Young – from their website, 2011).

These costs were combined with the current average 24-hours temperatures and the average temperatures resulting from the several climate-scenarios to calculate the costs in the current and (possible) future climates. The difference between the current and future costs are the extra costs caused by climate

[3] http://climexp.knmi.nl/Scenarios_monthly/transtoelichting.cgi

change. Also this calculation is based on the assumption that the national pattern of hospital admissions with regard to average temperature will not change if the climate changes.

4.2.2.1 Equation when ambient temperature >18°C

Mb = (11000 * 5000) + (T – 18) * 0.0036 * 11000 * 5000

4.2.2.2 Equation when ambient temperature <=18°C

Mb = (11000 * 5000) + (18 - T) * 0.0064 * 11000 * 5000

with:	Mb	=	Morbidity cost per day (Euro)
	T	=	The 24-hour averaged temperature (ºC)
	11000	=	Average number of hospital intakes/day
	5000	=	Average cost of hospital uptake

4.2.3 Productivity

Not much is known about the effect of temperature on productivity. Recently some work was done on productivity (Zhao et al. 2009). They identified a relation between work time (t), wet bulb globe temperature (WBGT) and productivity. The formula for medium physical labour is:

Productivity (%) = -0.364 * t*t + 0.7476 * t – 0.05301 * WBGT + 2.09. If we assume that WBGT equals ambient temperature – 5.6 (relative humidity of 50%) and if we set t to 8 hours, the productivity changes by 0.5% for every 10°C ambient temperature increase. However, the study is difficult to apply to real work situations, for instance since ambient temperature is not similar to temperature in buildings where most work is performed. Therefore, we decided not to use these data, but the data of Seppänen et al. (2004) who concluded in a review that productivity within buildings drops with 2% per °C temperature rise, when the temperature in the building rises above 25ºC.

4.2.3.1 Equation when ambient temperature <=25°C

P = (469817 *10^3)/1800

4.2.3.2 Equation when ambient temperature > 25 °C

P = (469817 *10^3)/1800 – ((469817 *10^3)/180000) * T * 2 – 50

with:	P	=	Productivity per day (Euro)
	T	=	Corrected daily temperature (ºC) – see below

	469817 $*10^3$	=	National turnover of The Netherlands in Euro
	1800	=	Workable hours in a year

Other literature sources, for example Hübler and Klepper (2007), also assume significant loss in productivity above ambient temperatures of 25 to 26ºC. In order to calculate the costs, it is assumed that high temperatures outdoors lead to indoor temperatures just as high. Loss of productivity does not or hardly occur at low temperatures, because Dutch buildings are generally properly heated. Only the construction and transport sectors (each contributing about 2.8% to the GDP) show losses in productivity during periods with frost.

The gross added value from production in base-prices (GDP) was EUR 525,921 million in the Netherlands in 2010. Not all production sectors suffer from loss of productivity because of heat, however. Therefore, all sectors in which the working pace and added value per unit of time are mostly determined by machinery (agriculture, forestry, fishery, mining, industry (textile, clothing, furniture and repair of machinery excluded), energy production, water companies, waste treatment, traffic (postal services and couriers excluded)) are not incorporated in the calculation. In addition, it is assumed that productivity losses will not occur in workplaces that have artificial cooling. It is assumed that the penetration of cooling in utility buildings is the following[4]:

Care: 19%

Hospitals: 60%

Shops: 53%

Offices; 65%

If both the above factors are taken into account, the remainder of GDP that is influenced by productivity losses by heat is an added value of EUR 215,538 million, or 41% of the total GDP.

The average 24-hour temperature, as calculated from the KNMI scenarios, is not applicable in the calculation of loss in productivity, because productivity losses are connected with the temperature during working hours. In order to calculate productivity losses, the temperature during each hour of the day is needed for each climate scenario. For arriving here we assumed that the daily proceeding of the temperature would not change by climate change and that the daily temperature profile could be applied to future climates as well. This

[4] Source: http://www.gaswarmtepompboek.nl/2-4-2-bestaande-bouw/

hourly temperature profile under the current climate was obtained from the KNMI, averaged over a period from 1995 until 2010. The hourly temperature in the future scenarios then was obtained by the following procedure. First, the hourly temperatures (from the 1995-2010 dataset) were divided by the 24-hours averaged temperatures from the same dataset, resulting in a discrepancy factor for each hourly block. The discrepancy factor was, subsequently, multiplied with the 24-hours averaged temperature from the scenarios) to obtain an estimated hourly temperature in each scenario.

4.2.3.3 Equation

$$Th_{scenario} = \frac{Th_{1995-2010}}{T24h_{1995-2010}} \times T24h_{scenario}$$

with:	$Th_{scenario}$	=	the hourly temperature in a scenario (ºC)
	$Th_{1995\text{-}2010}$	=	the averaged hourly temperature in the 1995-2010 dataset (ºC)
	$T24h_{1995\text{-}2010}$	=	the 24-hour average temperature from the 1995-2010 dataset (ºC)
	$T24h_{scenario}$	=	the 24-hour average temperature from a scenario (ºC)

In this calculation, it was further assumed that all labour occurs between 08:00 (am) and 18:00 (pm).

Using the assumption that the GDP mentioned above is earned in 1800 hours per year, the value added during each hour in the time period 08:00 – 18:00 was calculated for the current situation and for the climate scenarios. The difference between these two values is an estimation for the productivity losses caused by climate change (at least, the part that corresponds with a drop in human activity because of heat).

Because averaged 24-hour temperatures were used in the calculation, the result is actually an underestimation. In some years temperatures can reach much higher values than the average, leading to a higher loss in productivity.

4.3 Results

4.3.1 Global warming scenarios

The calculations explained in the sections above provide a first estimation of the yearly damage by temperature increases caused by climate change as it is expected to occur in 2050, under the assumption that the economic and demographic structure of the Netherlands in 2050 is similar to the structure in 2010, and that the temperature related mortality and morbidity functions remain constant up to 2050. The numbers thus represent an order of magnitude and cannot be used in absolute terms.

For both extra mortality and hospital admissions it seems that, under the assumptions used, global warming leads to a greater reduction of cases in wintertime, than it leads to a rise in mortality and hospital admissions during warmer summers. Therefore, the damage is ‘negative’ or, in other words, climate change will lead to a benefit in mortality and hospital admissions. The monetary gain is highest for hospital admissions. During the two warmest summer months, the extra costs in hospital admissions turn out to be relatively low (see Table 1), though the extra mortality is relatively higher. A warmer scenario also leads to a higher “benefit” in cold-related mortality, however.

Losses in occupational productivity occur, according to the applied calculation method, mostly in the W scenario (the W scenario assumes a 2ºC rise in temperature in 2050, worldwide, compared to 1990). In the W-scenario the losses occur in a few days. The drier and warmer W+ scenario assumes a longer period in July and August with 24-hour averaged temperatures above 21ºC (with peak-values of 22.5ºC); these lead to hourly temperatures during the daytime several degrees Centigrade above 25ºC. The (monetary) damage as a result of productivity losses increases rapidly in this scenario. Each 0.1ºC above 25ºC results in a loss of EUR 0.24 million per hour [5].

The calculations were carried out using measured temperatures in the Dutch meteorological station De Bilt, located in a rural area. Therefore, the urban heat-island effect (higher peak-temperatures in urban areas compared to rural areas) is not taken into account. For this reason the extra mortality, hospital admissions and losses in occupational productivity in cities are probably underestimated. The “gains” in mortality and morbidity (see table 9) could be lower because of this effect.

Table 9: Monetary damage by heat stress in MEuro / year.

KNMI06 scenario	G	G+	W	W+
Mortality	-12	-16	-23	-25
of which in July and August	1.3	2.7	3.7	8.7
morbidity (hospital admissions)	-103	-137	-193	-249
of which in July and August	-5	-1	2	14

[5] The loss of labour productivity can be calculated, using the equation mentioned above, as 0.2% of the GDP that can be considered as influenced by extreme temperatures per 0,1°C temperature increase. Or: 0,2% [decrease of labour productivity per 0,1°C temperature increase] * 1/1800 [working hours per year] * 215538 mln Euro [part of the GDP that is influenced by heat stress in 2010].

losses in occupational productivity	0	0	3	180

4.3.2 Urban heat island effect

For estimating the extra impact due to the urban heat island effect, data were used of a meteorological station in Rotterdam provided by a weather amateur station in Capelle, a part of urban Rotterdam and compared to (rather) non-urbanised data provided by KNMI for Rotterdam Airport. We follow roughly the approach advanced by Roodenburg (1983). Minimum (Tmin) and maximum (Tmax) ambient temperature values were available per day. The average day temperature can be calculated by the following formula (derived from the KNMI data over 15 years):

Average daily Temp = -0.201697 + 0.42740 * Tmin + 0.55183 * Tmax

The average daily temperature was inserted in the spread sheet with the impact formulae described in paragraph 1.4. The time period was January 1, 2009 to December 31,2009.

The results are shown in Table 10. The presumption is that the entire Netherlands is either an urban heat island or a rural area.

Table 10 Additional costs if The Netherlands would have been an urban heat island, compared to The Netherlands as a rural area (in MEuro/year). NB: calculated with 2009 temperature data only.

	Urban Island compared to rural area
Mortality	-4
of which in July and August	3
Morbidity (hospital admissions)	-62
of which in July and August	-5
Productivity losses	392

Similar to the effect of the climate scenarios, the mortality and morbidity costs decrease due to the relative larger contribution of cold than heat. The productivity loss is considerable due to the increase in temperature occurrences above 25°C in urban heat islands.

5 Case studies

5.1 Pluvial flooding

5.1.1 Introduction

The damage functions developed for pluvial flooding have been applied to two case study areas; Nijmegen and Rotterdam-Noord. For each area flood model results were combined with information on urban land use. This information acted as input for the damage equations. More information on the overland flow modelling is given in Appendix 2.

5.1.2 The case study areas

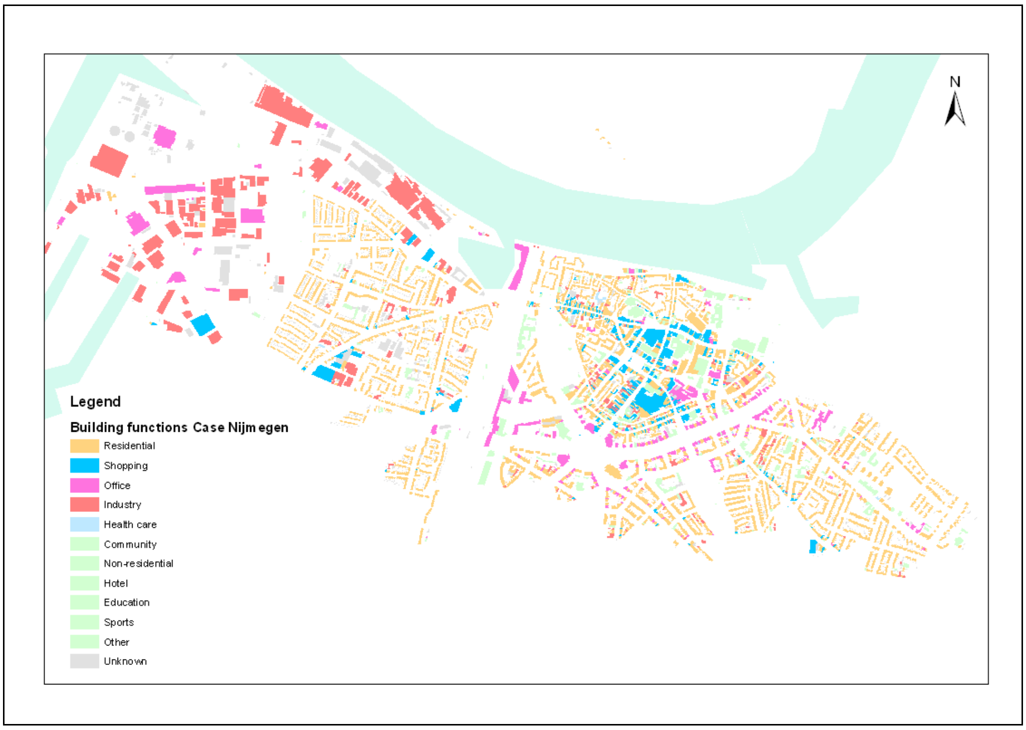
Two case study locations were chosen. The Rotterdam-Noord case study area lies in the West of the country in an area with very little relief. The Nijmegen area which lies in the East of the Netherlands shows more relief. The Rotterdam-Noord area is an end of the 19th century to beginning of the 20th century urban area mostly with residential use. Smaller shops are found in the area and on the edges recreational areas. The Nijmegen case study area encloses the city centre and some of the surrounding neighbourhoods. This also incudes part of an industrial area. Table 11, fiigure 8 and figure 9 provide a summary of the two case study areas.

Table 11: Summary of the case study areas Rotterdam-Noord and Nijmegen.

	Rotterdam-Noord	Nijmegen
Neighbourhood age	End 19th– beginning 20th century	1920 - 2000
Neighbourhood functions	Mainly residential, some recreation and shops	Mainly residential
Sewer system	Traditional combined	*No information*
Total number of buildings considered	8159	9864
Residential buildings	7276	5343
Shops	587	352
Offices	17	209
Industry	unknown	298
Other or unknown	279	3662

Figure 8: Case study area Rotterdam-Noord, building use..

Figure 9 Case study area Nijmegen, building use..



5.1.3 Application of the impact functions

Material damages to buildings

For the estimation of material damage to residential houses and content, use was made of the values by Spekkers et al (2012). For each flooded house a content damage value of €817,- was applied and a property damage value of €1229,-.

For both the Rotterdam and Nijmegen area a map was used with information per building on the use of the building. Only the buildings with a residential use were considered for the damage estimation on buildings, as the material damage values are based on insurance benefits for households. The buildings map was overlaid with the flood maps. For each building which intersects with the flooded area, the minimum water depth at the building was taken as the flood level. This choice was made to prevent an overestimation of the number of flooded buildings. A building will only be flooded through gaps such as ventilation holes, doorways and basement windows and it is not realistic to assume that the maximum flood depth will always occur at these gaps.

Within the case study areas an estimation of the percentage of buildings with basements was made with use of Google streetview. Although the number of houses with basements vary across the case study areas, an approximated average of 10% was assumed and applied for both area. For 10% of buildings which lie within the flooded area it is assumed that they have a basement which will flood. In addition the number of buildings which encounter a minimum flood depth of 10 cm are also assumed to suffer damages due to flooding. From these houses, 10% is distracted as these are assumed to have a basement and were already accounted for.

Material damages to electricity supply network

The threshold for damage to electricity substations is set at 30 cm. As no information was available on the locations of electricity substations. Only the number of locations where the flood depth is larger than 30 cm are listed. It depends on the presence of a substation if damage to electricity substation and electricity failure will occur.

Business interruption

Within the case study area Rotterdam-Noord mainly the business type ‘Trade’ is present. In the case study area Nijmegen also Offices, Industry and Hotel and Catering are found. Based on the values in Table 3.4 (column Average business result per company per hour (8-hour work day)) a damage of €50,- per hour of interruption was applied for Rotterdam-Noord and €65,- for Nijmegen (an average number for Industry, Trade and Information, Hotel and Catering and Information and Communication, where the latter is assumed to represent an average damage for offices). No information on the duration of the interruption was available. Damages were therefor calculated for an interruption of 1 hour and 8 hours.

Traffic disruption

Traffic is interrupted when a road is blocked by a flood with a water depth of at least 30 cm. No information was available of traffic movement in the case study areas. Therefor only the number of blocked roads is given.

Turn-out fire brigade

It is assumed that the fire brigade will turn out for every house and commercial building with a flooded basement and for blocked roads. A cost of €1000,- is assumed for every turn out.

Health services

In both case study areas no hospitals are located. Other types of health services were not evaluated.

5.1.4 Summary of results of the case study impact analysis

A summary of the results from the impact evaluation is given in Table 12 (Rotterdam-Noord) and Table 13 (Nijmegen). A full overview is provided in Appendix 3.

Table 12: Overview of impact analysis results for case Rotterdam-Noord.

Rainfall events and increase of rainfall intensity	Bui8 +15 %	Bui 50 + 50%
Damage to houses		
Property damage	94202	98420
Content damage	62645	65450
Total damage (x 1000)	157	164
Traffic disruption (# locations)	0	0
Emergency services; turn out fire brigade (x 1000)	133	133
Damage to electricity substation and Electricity failure (# location)	0	0
Business interruption		
1 hour interruption	3300	3300
8 hour interruption	26400	26400

Table 13: Overview of impact analysis results for case Nijmegen.

Rainfall events and increase of rainfall intensity	Bui8	Bui50 + 75%
Damage to houses		
Property damage	9842	821104
Content damage	6545	546040
Total damage(x 1000)	16	1367
Traffic disruption (# locations)	0	1
Emergency services; turn out fire brigade (x 1000)	7	554
Damage to electricity substation and Electricity failure (# location)	1	>1
Business interruption		
1 hour interruption	130	6045
8 hour interruption	1040	48360

In the Rotterdam case it is seen that large parts of the study area become flooded already at a Bui 8 + 15% (figure 12). A further increase of the rainfall intensity only adds a little to the water depth throughout the area. The flood extent (the total flood area) does not increase. As a result, many houses are assumed to become flooded with a Bui 8 +15%. There is very little damage increases seen when the rainfall intensity increases further. For this exercise it was chosen to apply a fixed damage amount for every flooded house. No differentiation of damage is applied in relation to the water depth. Therefor the total damage to houses does not increase when the rainfall intensity increases. This also applies to the other impacts.

The Nijmegen flood results do show an increase of flood extent when rainfall intensity increases. As a result the number of flooded objects also increases and so do the damage estimations.

In these case studies it is seen that mainly houses with basements become flooded. The damage for residential buildings are the highest, followed by the costs the fire brigade makes. The damage to businesses is relatively small compared to the damages to the residential buildings and fire brigade.

These case study results show an urgency to address pluvial flooding for both case study areas. In the Rotterdam area it is a general problem across the area where in Nijmegen it is a location specific problem with larger water depths but in future situations a larger area is foreseen to become flooded. Damages are mainly caused by flooding of buildings with basements. This results in damages to these buildings and content as well as large costs made by the fire brigade. A large reduction in damages can thus be accomplished by preventing basements from flooding. At present other types of damages are not as high and thus not as urgent, but could increase due to climate change.

These case study results are based on many assumptions made for the flood modelling as well as for the impact analysis. To be able to make more accurate estimations, this case study shows that it is essential to improve the following information:

- Realistic urban flood modelling results.

- Percentage of buildings with basements and an Improved insight into average numbers (or percentages) of buildings with basements which actually flood. This information can be gathered from pluvial flooding experiences or through detailed database information combined with detailed modelling.

- The economic activities in an area and improved estimates of the impacts due to business interruption. The case studies show small numbers, but depending on the type of businesses, this cost estimate could be too low.

- The locations of electricity transformer faults.

- Information on traffic movement.

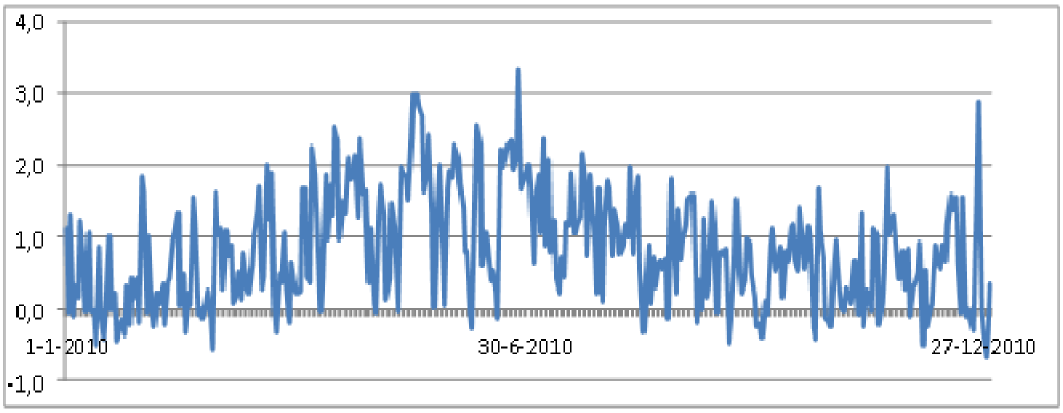
5.2 Heat

5.2.1 Case description Rotterdam

Despite its highly urbanized structure, the Netherlands features very different degrees of urbanization. For example, if one were to draw a straight line crossing the towns of Alkmaar and Arnhem thereby dividing the Netherlands in two equal parts, the south-western part would count 75 percent of the Dutch citizens and the north-eastern part only 25 percent.

To relax the assumption on total (non)urbanization in the Netherlands somewhat, we describe temperature difference and their projected effects in and around Rotterdam respectively. For this exercise we used the temperature data from Rotterdam-Capelle and Rotterdam Airport for the year 2010. The average temperatures were derived from minimum and maximum temperatures using the formula above. The average difference between urban and rural temperature in the resulting data amounts to 0.7°C (Figure 10).

Figure 10: Difference in average temperature urban/rural Rotterdam weather stations, 2010. Source: TNO based on KNMI/PB2RDF.



5.2.2 Case results

5.2.2.1 Mortality

In the greater Rotterdam region (population 1,395,640) the number of all-cause deaths in 2010 was 11.796[6]. The comprehensive formula developed by

[6] *Greater Rotterdam was defined here as the corresponding NUTS3-region (COROP) Groot-Rijnmond. Data source: Statistics Netherlands.*

Daanen and Bode takes temperature related deaths as an estimated share of the standard deviation in deaths. Applying this formula to local temperature data covering the period between March 1, 2008 and March 1, 2012, an average number of daily deaths of 32 results, with a standard deviation of 3,8. Adding up daily deaths differences as shares of the standard deviation for the urban temperature series results in 208 deaths explained by temperature for 2010. In the rural case this number is 232, 24 higher than the urban case. This figure illustrates the dominance of cold related deaths in the Netherlands. With rising temperature the aggregate number of temperature related deaths will probably decrease (PBL, 2012).

5.2.2.2 Morbidity

The number of hospital admissions per 10,000 inhabitants in the Greater Rotterdam region was 2,241 in 2009. Since data for 2010 hospital admissions were not available at the time of research, we applied an average annual growth rate based on the 1996-2009 period to arrive at a figure for 2010. This estimation amounts to 2,313. This is considerably lower than the national average, probably due to the comparatively young population in Greater Rotterdam. Applying the morbidity function by Parsons (0.36 percent more hospital admissions per centigrade temperature above the threshold of 18 ºC, 0.64 decrease below the threshold) provides a projection of regional hospital admissions attributable to cold and heat for 2010. The colder weather in the rural case leads to an expected difference in the number of hospital admissions of 1,557. Assuming hospital admission costing € 4,975 per case, the estimated cost difference for 2010 amounts to 7.7 million Euro.

5.2.2.3 Productivity

Productivity loss may result in serious economic impact on affected regions. Two issues are of central importance: how does the work pace react on temperature, and to what degree is ambient temperature reflected in the workplace? In other words, assumptions have to be made on the effect of temperature on the working body, and the extent to which ambient temperature impacts on temperature in buildings. Considering the first issue, we follow the analysis by Seppänen et al (2004), assuming that no temperature impact is felt under 25 ºC and two percent production loss per centigrade above that threshold. For the second issue we make here a (strong) sectoral assumption, namely that only agriculture and industry (manufacturing/building and construction (NACE Rev. 1.1 sectors A-F)) will be affected since most of the human work in these sectors takes place either outside or indoors but highly vulnerable to ambient temperature. Of course, considering these two assumptions results can only function as rough estimates of the real impact of temperature on economic production[7]. Taking average day temperature as our starting point it turns out 2010 had 3 days with temperature above 25 ºC urban and 2 rural (airport). Only assessing daily production impact for those days for agriculture and industry results in 4.1 million Euro production loss in the urban case, and 0.9 million Euro in the rural case; a difference of 3.2 million Euro.

It should be noted that the time of day was not taken into consideration. Neither the circumstance of holidays or other non-workdays was taken into account. Moreover, sectoral impact should be assessed based on more empirical evidence at disaggregated sector level to arrive at reliable estimations of current and future production loss.

[7] Literature shows that productivity is influenced by extreme high temperatures. However, we do not know how the impact is distributed over various economic sectors. Factors such as the degree of process automation in industry and the share of air conditioned buildings in workplaces are important. In this chapter (partly due to differences in detail of GDP data) two different assumptions regarding sectors that are influenced by GDP are used. More empirical evidence is needed to substantiate these.

6 Conclusions and recommendations

6.1 Overall conclusions

The Climate Proof Cities project which focused on the 'sensitivity and vulnerability of urban systems', aimed at quantifying the sensitivity of urban areas to climate change (heat, drought and urban flooding) and identifying the most sensitive objects within the Dutch urban area. To aid in assessing the sensitivity of the urban area, the project therefor focussed on the development of impact functions for heat and pluvial flooding. The impacts due to flooding and drought as a result of groundwater fluctuations were not further investigated due to a lack of available knowledge on this topic and already on going research by other parties.

The impact functions were based on an impact framework which categorises the different impacts into five categories. The framework was developed to be able to compare the impacts from the different climate hazards. For the two climate hazards 'heat' and 'pluvial flooding' which were elaborated, it was seen though that the emphasis of impacts lies in very different fields. Heat mainly affects the health of human beings, an impact rarely encountered through pluvial flooding, while pluvial flooding causes material damages which is hardly an impact as a result of heat. A common ground is found though in a loss of business income either due to business interruption or due to productivity loss and lower spending by customers.

Comparing impacts due to pluvial flooding or heat also encounters problems as a result of scale differences both geographically as in time. Where pluvial flooding has a local impact, heat will cover a large region and will last over a longer period of time. For this study it was chosen to focus on a local scale and provide insight and tools for use by municipalities. Other studies have looked into the impacts due to pluvial flooding on a national scale or are still on going. These studies are tackling research questions such as 'what does pluvial flooding cost us on a national and yearly base?'. Results from these studies can be compared with the results from the heat case study.

6.2 Conclusions pluvial flooding

Impact functions which quantify the impacts of pluvial flooding, aid municipalities in identifying which elements are most sensitive to flooding. This information is then used to select appropriate measures to either reduce the flood exposure (e.g. by increasing water storage of the system) or reduce the sensitivity of the urban elements by reducing damages as a result of flooding.

Pluvial flooding damage can not be just explained by the rainfall intensity. A variety of variables contribute and influence the damage to households and content such as occurred water depth or the height of doorsteps. The impact function developed within the context of the CPC project encompass these variables based on the cause-effect relation.

A common variable in all the functions is the threshold variable, which describes at what water depth an urban element starts to encounter damages. Up to this water depth no damage will occur. The threshold value is a first indicator for the sensitivity of urban element to pluvial flooding as an element with a low threshold value will encounter damages quite soon after water reaches the element making it very sensitive to urban flooding. The location of the elements within the urban system adds to the sensitivity as lower areas will fill up first. On a street scale often the streets are the first to fill up, after which the sidewalks start to flood after which the outer walls of the buildings are reached. These buildings on average have a doorstep height of approximately 10 cm, but buildings with no doorstep (garage, shop) or with a basement or crawl space are more prone to flooding. Electricity transformer faults and communication substations are mostly located on the sidewalk or against building walls. With a threshold of 30 cm these elements are in general not very sensitive. On specific locations where these are situated in a lower lying area the sensitivity will be high though. Traffic though is the first to be hindered by flooding either by roads or tunnels and other depressions flooded. Every time high intensity rains occur to such an extent that houses become flooded and/or traffic hindered, the fire brigade turns out to undo the depressions, basements or crawl spaces of the surplus of water. The efforts made by the fire brigade should not be overseen and underestimated.

The results from the cases show that flooding of buildings, especially those with basements or lack of doorsteps, can result in high damages. The costs made by the fire brigade contribute considerable to the overall impact as well. The sensitivity of urban elements can be reduced by increasing the threshold value. (Veerbeek and Husson, 2012) showed that a small increase in threshold increases the climate proofness of buildings considerably. This can be accomplished by implementing and heightening door steps and by water proofing the lower 25 cm of buildings through closing any openings and applying water proof basement windows. When reducing the sensitivity of buildings by preventing them from flooding, automatically this will reduce the costs made by the fire brigade. If also measures are taken to prevent tunnels and other depressions to flood, this will further reduce costs made by the fire brigade.

Damage to the electricity networks are very rare at present and are not expected to increase rapidly in the short term. It is recommended though to implement flood proof electricity transformer faults and communication elements when these are to be renewed. Lowering the water depths will also contribute in lowering the impacts of the urban system to pluvial flooding. This is accomplished by increasing the storage capacity of the sewer system or providing storage in the street through adjusted street profiles or measures such as water squares.

The effect of climate change on the sensitivity of urban systems was very briefly evaluated through the case studies. The flood modelling results were not of a sufficient enough level to be able to make preliminary conclusions on potential effect of climate change. The case studies do show though that (1) the functions are applicable to evaluate climate change effects as well and (2) that damage sensitivity levels in the existing situation would allow for investments in adaptation.

This report delivers a first set of impact functions for quantifying pluvial flooding impacts. The case shows that with these functions first estimates can be made on the approximate height of impact. Paragraph 3.2 explains the functions and gives guidelines on the use of the functions and an overview of available information on values for the function variables such as replacement costs for an electricity substation or the costs of a turn out by the fire brigade. The functions have been developed based on available knowledge and offer a basis to further develop upon. Within the text explaining the use of the functions (paragraph 3.2) overviews of knowledge gaps are listed which need to be addressed to be able to improve the functions. For example, If more accurate values are available, these can be applied within the function.

6.3 Conclusions heat

Mortality in The Netherlands is higher due to cold than to heat. The W+ scenario for global warming in The Netherlands (the worst case) would lead to a considerable reduction in mortality equivalent to about 25 MEuro due to less people that die. Also, the cost related to hospital uptake would be about 250 MEuro less for scenario W+. The increase in summer temperature, however, would lead to a decreased productivity equivalent to about 180 MEur. The net economic effect of scenario W+ for global warming in The Netherlands would therefore be a benefit of about 95 MEuro.

If The Netherlands would be one big city, the temperature profiles during the day are different than when The Netherlands would have been one rural area. Mortality and morbidity would cost 4 and 62 MEuro less respectively. In an urban environment, the productivity would decrease enormously because temperatures would be much higher during the day. The net additional costs would be 326 MEuro.

The urbanization effect has been calculated in more detail for the city of Rotterdam compared to its direct rural surroundings. In this case, the reduction in mortality and morbidity amounts to 0.4 and 7.7 MEuro for the urbanized part and the reduction in productivity in the city amounts to 3.2 MEuro compared to the rural surroundings.

6.4 Recommendations

This report offers the results on impact functions which were developed to aid in quantifying the effects of climate change. For both the functions for heat and pluvial flooding, there is room for improvement. The following points are recommended for further research:

- Damage sensitivity of an urban area depends on many factors including typology, industrial and economic activities. It is therefore recommended to include a damage sensitivity analysis in an urban flood risk assessment as an essential part of the urban water management plan.

- Utility networks such as electricity, telephone, mobile phone and internet seem to have a lower probability of failure but with “unacceptable” impacts. It is therefore recommended to pay extra attention to flood and heat robustness of these vital networks and objects.

- The case study results represent the result of a preliminary analysis using simplified functions based on available data. Future research is required to validate the functions and perform sensitivity analyses in order to substantiate the initial conclusions.

- The functions focus only on the negative effects. To be able to do a sound cost-benefit analysis, insight into positive impacts should also be looked into. It is therefore recommended to also incorporate positive impacts into the functions.

- To be able to validate case study results, information on impacts for occurred situations is required. It is recommended to improve the monitoring and gathering of impact data for occurred events.

- Impact analysis is a socio-economic assessment. The results could be further improved by treating the problem from both a social and economic point of view. This accounts especially for the impacts on business, for the up scaling of the pluvial flooding impacts to a national level and for the down scaling of the heat impacts to a city scale.

- To be able to perform a reliable flood impact assessment, it is required to improve the flood modelling of the urban area by coupling sewer and overland flow models and by increasing the resolution of the flood models.

Detailed recommendation and research gaps have also been identified in the previous chapters.

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7.1 Introduction

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8 Appendix 1; Overview of urban elements – longlist

Physical elements			**Impact by hazards:**					
Buildings	*By function:*	*By …*	**Pluvial flooding**	**Fluvial and coastal flooding**	**Ground water flooding**	**drought**	**heat**	**air quality**
	Residential - low-rise	Age, value	•	•	•	•		
	Residential high-rise	Age, value	•	•	•	•		
	Industry	Chemical, nuclear	•	•	•	•		
	Public buildings		•	•	•	•		
	Offices		•	•	•	•		
	Shops		•	•	•	•		
Property	Vehicles		•	•				
	Interior		•	•				
	Private ground					•		
Water	Open water					•	•	
	Ground water				•	•		
Public space (green)	Park				•	•		
	Sport fields				•	•		
Infrastructure	Roads	Roads, Bridges and viaducts		•		•	•	
	Railway system	Railroads and stations, metro tram		•			•	
	Drinking water	pump station and distribution network		•			•	

	Electricity	Central and local power stations, distribution network	●	●		●		
	Gas			●				
	Communication	Radio and television stations, telephone system	●	●				
	Sewer system	Sewage plants and system		●				
	ICT	Hubs and network		●				
	Money transfer centre			●				
Urban functions								
	Dwelling		●	●	●	●	●	
	Work and economic activities		●	●			●	
	Recreation		●	●	●	●		
	Transport		●	●		●	●	
	Public services	Hospital, emergency services, education, zoo, nursing home, Penitentiair facility, museum and library, church, sporting facility etc.	●	●				
Living creatures								
	Human beings	Age		●			●	●
	Animals			●	●	●	●	
	Ecology, nature			●	●	●		

9 Appendix 2; Overland flood modelling

Use was made of the flood simulation results from the case executed by (Veerbeek and Husson, 2012). Modelling of overland flow of storm water was executed with use of TUFLOW (2011) and AQUAVEO (2012) (Veerbeek and Husson, 2012). These modelling results are not fully representative for the actual situation as only the overland flow is being modelled. The process within the drainage system is not taken into account and thus the model does not reflect real conditions (Veerbeek and Husson, 2012). The model is merely used to indicate where water accumulates when the capacity of the drainage system is exceeded. It is assumed that the capacity of the drainage system is sufficient to drain the design rainfall event 'BUI8', which corresponds to a 2-year return period. At heavier rainfall event flooding of the streets will start to occur.

The cases consider two rainfall event, Bui8 which is the design rainfall event for which the Dutch sewer systems are developed to cope with and has a return period of two years, and Bui50 which has a return period of 50 years. Figure 11 shows the development of the rainfall intensity in time for the two rainfall events. It is seen that Bui8 has a smooth development in time while the Bui50 suddenly increases considerably over a short period of time.

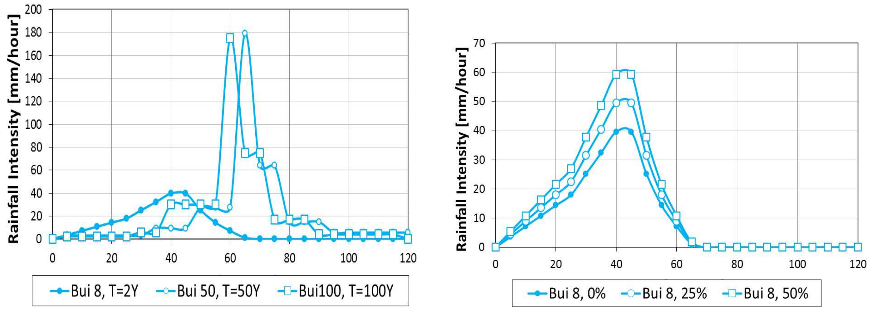


Figure 11; Bui8, Bui50 and Bui100 (left). Percentual increase of flood intensities for Bui8 (right) (Veerbeek and Husson, 2012).

For both rainfall events, climate change factors have been incorporated by increasing the rainfall intensity with a certain percentage as is illustrated in Figure 11. The total resulting rainfall volume is described in Table .

Table 14; Increase of rainfall intensity for Bui8 and Bui50.

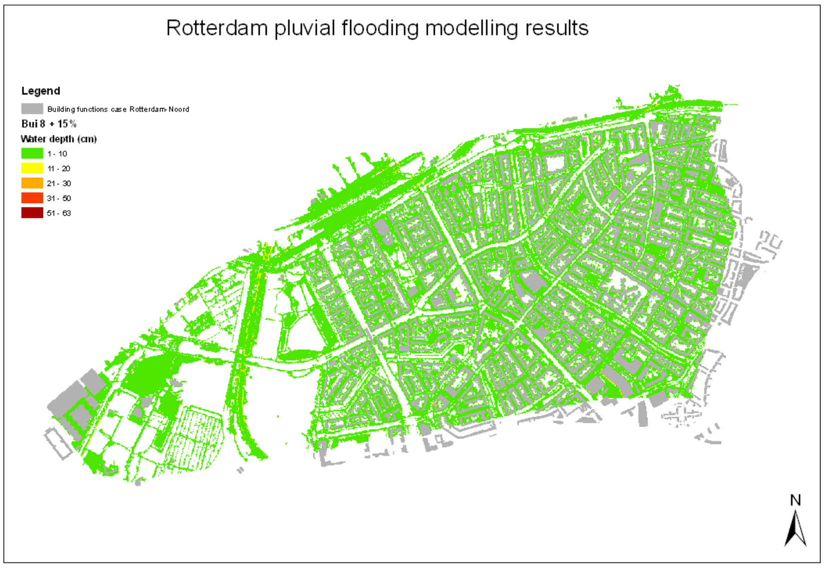
	Bui8	Bui50
Return period (years)	2	50
Total rainfall volume (mm)	19,90	42,95
+5%	20,90	45,10
+10%	21,89	47,25
+25%	24,88	53,69
+50%	29,85	64,43
+75%	34,83	75,16

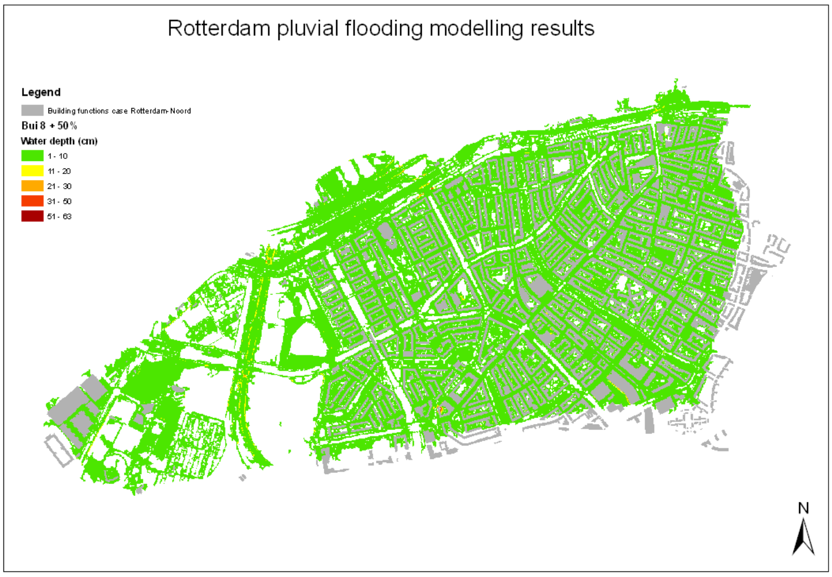
For Rotterdam the rainfall events were increased with a percentage of 25, 50 and 75. For the Nijmegen case an increase of 5, 10 and 50 percent was evaluated.

The water depths as calculated by the model are shown in figure 12 (Rotterdam) and figure 13 (Nijmegen).

Figure 12; water depth as calculated by the overland flood model for Rotterdam.

Rotterdam





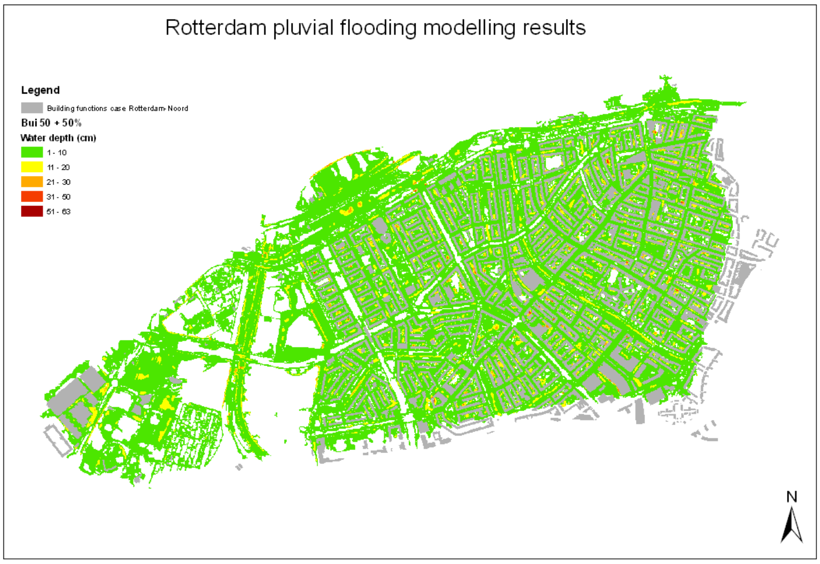
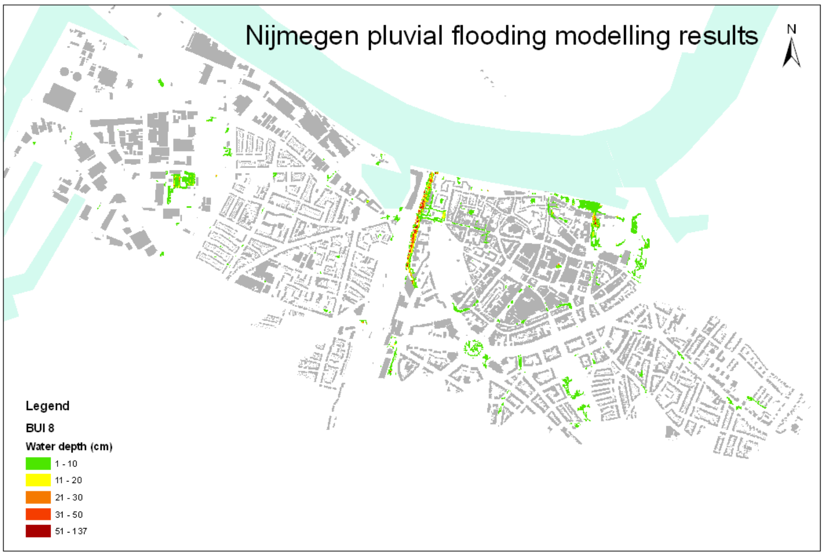
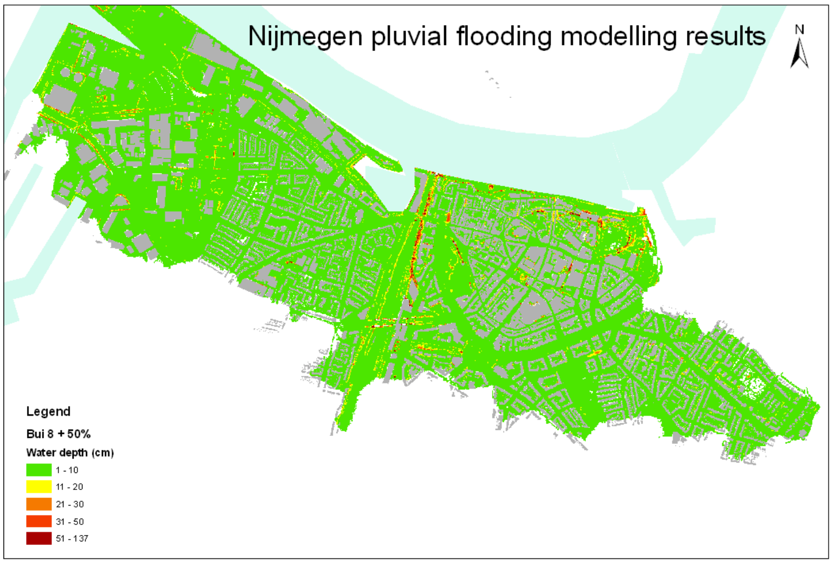


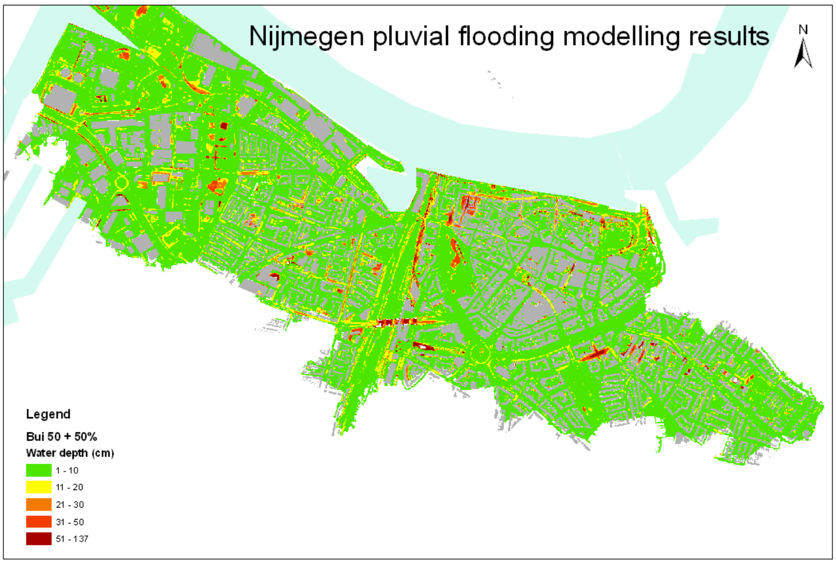
Figure 13; water depth as calculated by the overland flood model for Nijmegen.

Nijmegen





Nijmegen pluvial flooding modelling results
N
Legend
Bui 8 + 50%
Water depth (cm)
1 - 10
11 - 20
21 - 30
31 - 50
51 - 137



Nijmegen pluvial flooding modelling results
N
Legend
Bui 50 + 50%
Water depth (cm)
1 - 10
11 - 20
21 - 30
31 - 50
51 - 137

10 Appendix 3; Case study results pluvial flooding

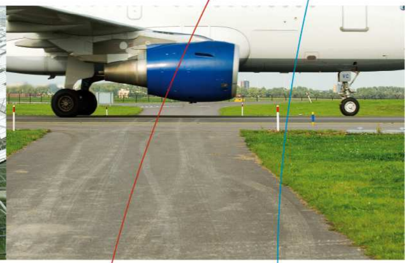
Table 15: Overview of impact analysis results for case Rotterdam-Noord.

Rainfall events and increase of rainfall intensity	Bui8 +15 %	+ 25%	+ 50%	Bui50	+ 25%	+ 50%
Damage to houses						
# houses ≥ 1 cm water depth	6722	6725	6725	6731	6732	6738
# houses with flooded basement	67	67	67	67	67	67
# houses ≥ 10 cm water depth	0	2	0	1	3	3
# flooded houses without basements	0	2	0	1	3	3
Total number of flooded houses	67	69	67	68	70	70
Property damage	94202	97014	94202	95608	98420	98420
Content damage	62645	64515	62645	63580	65450	65450
Total damage (x 1000)	157	162	157	160	164	164
Traffic disruption (# locations)	0	0	0	0	0	0
Emergency services; turn out fire brigade (x 1000)	133	133	133	133	133	133
Damage to electricity substation and Electricity failure (# location)	0	0	0	0	0	0
Business interruption						
# commercial buildings ≥ 1 cm water depth	661	661	661	661	661	661
# commercial buildings with flooded basement	66	66	66	66	66	66
# commercial buildings ≥ 10 cm water depth	0	0	0	0	0	0
# flooded commercial buildings without basements	0	0	0	0	0	0
Total number of flooded commercial buildings	66	66	66	66	66	66
1 hour interruption	3300	3300	3300	3300	3300	3300
8 hour interruption	26400	26400	26400	26400	26400	26400

Table 16: Overview of impact analysis results for case Nijmegen.

Rainfall events and increase of rainfall intensity	Bui8	+ 25%	+ 50%	+ 75%	Bui50	+ 25%	+ 50%	+ 75%
Damage to houses								
# houses ≥ 1 cm water depth	53	55	51	4525	4650	4651	4668	4720
# houses with flooded basement	5	6	5	453	465	465	467	472
# houses ≥ 10 cm water depth	2	2	1	4	37	47	56	124
# flooded houses without basements	2	2	1	4	33	43	50	112
Total number of flooded houses	7	8	6	457	498	508	517	584
Property damage	9842	11248	8436	642542	700188	714248	726902	821104
Content damage	6545	7480	5610	427295	465630	474980	483395	546040
Total damage(x 1000)	16	19	14	1070	1166	1189	1210	1367
Traffic disruption (# locations)	0	0	0	0	0	0	1	1
Emergency services; turn out fire brigade (x 1000)	7	8	7	532	545	545	549	554
Damage to electricity substation and Electricity failure (# location)	1	1	1	>1	>1	>1	>1	>1
Business interruption								
# commercial buildings ≥ 1 cm water depth	21	23	20	792	801	802	805	807
# commercial buildings with flooded basement	2	2	2	79	80	80	81	81
# commercial buildings ≥ 10 cm water depth	0	0	0	1	3	4	4	13
# flooded commercial buildings without basements	0	0	0	1	3	4	4	12
Total number of flooded commercial buildings	2	2	2	80	83	84	85	93
1 hour interruption	130	130	130	5200	5395	5460	5525	6045
8 hour interruption	1040	1040	1040	41600	43160	43680	44200	48360



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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