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Flood Risk Assessment

for urban areas in North America

TU Delft

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By

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in partial fulfilment of the requirements for the degree of

Bachelor of Science
in Civil Engineering

at the Delft University of Technology,

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ABSTRACT

Floods are an increasing problem all over the world. Due to climate changes and socio-economic developments multiple areas are at risk. Flood risk is nowadays expressed as the global economic losses due to floods and these losses are raising. HKV and Deltares recognized this problem and started to develop a method to calculate flood risks. A Flood Risk Assessment Tool (FIAT) is used to calculate monetary values of flood risk. This is done by the apparent simple multiplication of exposure, vulnerability and hazard. This risk assessment is one of the steps of gaining knowledge about global flood risk and contributes to prevention of major disasters.

In this Bachelor Thesis an extensive explanation about the procedure of a flood risk assessment for North America is included. The assessment can be performed in multiple ways. One can perform it by using the single land use method, but a multiple land use method as well. The explanation is mainly about the multiple land use method. Problems and difficulties are highlighted for future studies.

Secondly a literature study is performed on elements that are also of importance in flood risk assessment. This study is performed for five cities: New Orleans, Los Angeles, Miami, New York City and Philadelphia. These studies have been investigated on multiple aspects to figure out which of those elements is most sensitive for the monetary value of the flood risk. Aspect taken in to account are: Risk, Population Density, Socio-Economic Development, Flash Flood Fatalities, Urban Planning, Flood Experience, Protection Standards by Scussolini et al. (2016) and “Real” Protection Standards.

Protection levels seemed to be the most important input data for the Flood Impact Assessment Tool used in this flood risk assessment. It decreases the yearly expected damage with a factor ten. Data used by previous studies looked doubtful because of the equal character of all protection levels in the states of America and the source was vague. Some digging however showed that the protection standards aren’t equal at all. A further investigation on this element is suggested. Flood experience shouldn’t be underestimated, because governments in different cities show a trend. Most of the time governments go in to action when something happens. New Orleans and New York for example developed a plan after a hurricane came by. This wait-and-see attitude is a common habit in North America.

Preface

Hereby I present my Bachelor Thesis that I wrote in partially fulfilment of the requirements of the degree of Bachelor of Science in Civil Engineering. During this project I used my knowledge gained in the education on the Technical University of Delft. I liked the challenges that I had to face and despite multiple problems I liked how it all worked out.

I want to thank my supervisors Saskia van Vuren and Bas Koolen for their feedback and support during the last eight weeks. They were available at any moment and always were willing to make time for my questions or my uncertainties. I would also like to thanks Jan Huizinga for his help with the software of QGIS and ArcGIS, with which I was struggling in the beginning. I really appreciate the time that he took out for me, a fantastic gesture!

I have learned a lot that I can apply in further projects. I liked the challenge of this project and the experience gained will be of big help the future!

D.J. Bader
Delft, June 2016

Contents

1

INTRODUCTION

Floods have always played a role during the existence of the human race. People have been fighting against the water for a long time and this fight isn't over yet. It will continue for a long time, because the Earth' surface consists for approximately 70 percent out of water and water doesn't act as we would like it to act. Due to, among other things, the climate changes over the last decades the world has changed and is changing. For example the sea level rose by a world average of 19 centimetres over the period 1901 to 2010 (Stocker et al., 2013), and it's very likely that these climate changes will continue during the 21st century. Different studies also showed that climate change alters the discharge of the Rhine. The winter discharge at Lobith can increase by 0 – 30% by 2050 and the probability of extreme flood events will increase (Ward et al., 2014). A more recent study confirms this, by applying a more complex and detailed model named Generator of Rainfall and Discharge Extremes (GRADE). Also from this model follows that the discharge will increase at Lobith, this will also be the case for other rivers and delta regions. For a more detailed description of the GRADE model, one is referred to the KNMI publication of Rijkswaterstaat (2007).

Another factor is the socio-economic development. Socio-economic development results in a growth of wealth and population. According to the United Nations the population of the world increases every year and will continue to do so for the upcoming years. This will result into more people living in urbanized areas that are vulnerable for flooding and this will lead to more economic losses. In 2003, 30% of the population was living within a 100km range of the coastline, but in 2030 this percentage will have grown to 50% (De Graaf, 2008). This can lead to more fatalities due to floods.

There has also been a development in acceptance of disasters. People are less likely to accept the consequences of a disaster like an earthquake or a flood. For example the earthquakes in Groningen, the Netherlands. People know of the cause of those and are not accepting that they have to deal with damage to their houses and other consequences. This can be translated to the flood risk issue. Most of the countries have a certain policy against floods. In the Netherlands for example, there is a focus on preventing floods. But in other countries there is more of a 'wait-and-see' attitude. They don't want to invest in prevention, but they are ready to pay for all the damages when it happens. It's interesting to see how different countries and even states within a country want to react on dangers and how they are prepared for disasters in terms of, for example, evacuation plans.

The factors that are mentioned above play a very big role in our look on global flood risks. It's easy to see that gaining knowledge about flood risks can be of very good help in the future. So with the right methods we will be able to make right decisions about flood protection issues and management. And those right decisions include the policy that a certain country or city have against such disasters.

1.1 PROBLEM STATEMENT

Deltares and HKV have been developing methods to investigate the global flood risks based on rapid assessments tools and open data. These methods consist on the definition that flood risk is the product of vulnerability, flood hazards and exposure.

Up until recently only a global method was defined. This method is called the 'GLObal Flood Risk with IMAGE Scenarios' (GLOFRIS) (Winsemius et al, 2013). This method uses only two land use categories, urban and peri-urban, and one damage function. The GLOFRIS method is applicable all over the world. But compared to the developed method by Huizinga in 2007 this is a very simplified model, because of the limited number of land use categories. The Huizinga Model (Huizinga, 2007), called 'Bottom-Up Climate Adaption Strategies for a Sustainable Europe' (BASE), uses five land use categories and five damage functions. These five land use categories are Residential, Commercial, Industrial, Infrastructure and Agriculture. This method gives a more specific result, when detailed land use maps can be derived, however it's only applicable in Europe. In 2015 Nootenboom compared those two methods, the global and the European method. He found out that the results of the methods did not differ that much as you would expect, only that the global method overestimated the flood risk compared to the European method (Nootenboom, 2015). But professionals are always interested in the most precise result and thereby the European method is potentially the most valuable method for flood risk assessments. Potentially, because this in only the case when the input data is defined properly. This method is very dependent of the land use maps and damage functions used. When those are not correct, this method isn't more valuable than the method of Winsemius.

For that purpose Huizinga recently developed damage functions for all other continents. He performed a literature study to scale the BASE method up to all over the world. This gives the possibility to get more precise estimations of global flood risks. However, land use maps were still missing for the other continents. Recently several Bachelor Civil Engineering students derived land use maps for Asia, Australia and South-America. After that they applied the multiple land use damage functions from Huizinga. The land use maps of North America are still missing and therefore the damage functions of Huizinga haven't been applied on this continent yet. This will be part of this Bachelor Thesis. The cities that are taken into account for this study can be found in Appendix B. These cities are selected on number of inhabitants. Only the cities with more than 200.000 inhabitants are taken in to account. Nootenboom (2015) also used this set of cities.

In addition to that I would like to broaden the general scope of this subject ('identifying delta regions most vulnerable for flooding'). I would like to dug into the policy of North America against flood risks and see what the differences are with respect to for example the Netherlands or other states and what the influence is of these differences. There are several attitudes against disasters like floods, shortly mentioned in the Introduction, and those will most likely influence the risk for a certain city. When you take for example the existence of emergency plans, the protections levels and the spatial development in to account, how does the city prevents itself against flood disasters and what will be the consequences of those parameters?
All this, together with the damage functions, can be wrapped up in a radar chart. This can provide a quick overview of the flood risks components and the overall flood risk per city. This provides additional information for the ranking of the cities vulnerable for flooding. The result of this literature study could provide as a new focal point in flood risk assessment. Which element should be mapped very accurate to provide a more precise flood risk assessment?

1.2 Objective

The objective of this Bachelor thesis is to identify which American cities are most vulnerable for flooding and experience the highest flood risks. This list will be created out of the up scaled European method of Huizinga and will be compared to the global method of Winsemius. Moreover, to determine a handling perspective we aim to put this in a wider perspective, making an overview of components/aspects that are important with respect to flood risk assessment and management, such as existence of emergency plans, public awareness and protection levels. This will be summarised in radar charts. The ranking list for North America will contain these radar charts and maybe a different ranking will follow out of it. In the end the problem can be subdivided in several research questions:

- How to derive land use maps for the five land use categories, Residential, Commercial, Industry, Agriculture and Infrastructure, in order to quantify flood risk for North America?

- What is the most important aspect / input-parameter with respect to the expected annual damage?
    - What are the differences between the Global Method, with two land use categories, and the model with five land use categories in the calculated flood risk in North America?
    - What is the influence of implementing climate change scenarios on the calculated flood risk in North America?
    - What is the influence of implementing socio economic scenarios on the calculated flood risk in North America?
    - What is the influence of implementing both scenarios, climate change and socio economic scenarios, on the calculated flood risk in North America?
    - What is the influence of sub-aspects, like emergency plans or existence of flood protection, on the calculated flood risk in North America?

1.3 Structure of the report

An overview is given for the general outline of this Thesis report. In chapter two the basic background theory for flood risk assessment is explained. Chapter three explains the procedure that is followed during this study, also so methods are explained and this chapter will be more North America specific. The fourth section consists of the single land use results of the Flood Impact Assessment Tool. Chapter five contains the literature study for the other parameters that could have an influence in flood risk assessment in North America, this will result in several radar charts. Subsequently a discussion on this thesis is given in chapter six. Finally in the chapters seven and eight the conclusions and some recommendations regarding this study are given.

2

THEORETICAL BACKGROUND

In this chapter the theory behind flood risk assessment is explained. There are several components which together form the basis of the assessment. First the types of floods are explained and which ones are taken into account in this Bachelor Thesis. Second a definition of flood risk is given, next up are the different damage categories. Last are the latest developments, especially the socio-economic development and the climate changes.

2.1 TYPES OF FLOODS

Floods are the overflowing of the normal confines of a stream or other body of water or the accumulation of water over areas that are not normally submerged (Field et al, 2012). Floods can appear in various forms, and each of those forms has its own characteristics and also affect different populations. There are multiple sorts of floods, but not all of them are relevant for large scale assessments. Nootenboom (2015) stated that the river and coastal floodings are the floods with the most impact on economic flood damages. The river floods occur most of the time due to extreme precipitation events and effect large areas, where coastal floods occur due to hurricanes or storms. Less important floods are for example the flash and sewer floods. Those floods are very hard to predict, this is due to the local character of the floods, and happen very quickly (Messner et al, 2007). Therefore these types of floods are not taken in to account for the flood risk assessment.

2.2 DEFINITION OF FLOOD RISK

In this Bachelor Thesis the flood risk definition of Kron (2002) is used. This definition is carried out by multiple studies (Jongman et al., 2014; Winsemius et al, 2013). Kron describes flood risk as follows:

RISK = HAZARD * EXPOSURE * VULNERABILITY

This definition consists of four elements. Hazard is defined as the probability of the event and the size of the flood (de Bruijn, 2009). Exposure is the part that represents the elements that could be affected by the flood, because they are located in a flood vulnerable location. (Winsemius et al. 2013). Vulnerability represents the potential damage that the exposed assets can catch when there an actual flood. And finally risk can be defined as the probability that the usual state is disturbed by an event. In terms of flood risk assessment this event will be a flood event (Holz, 2014).

Figure 1: *Flood Risk Framework (Nootenboom, 2015)*

This all can be summarized in the Figure 1 presented above. All three aspects play a role in the definition of flood risk. The side note is, that this is a time dependent dynamic process. The sensitivity of this dynamic process is hard to construe, because of the high uncertainty of all input parameters, but it can be said that all aspects change in time. So an assessment that's produced now can give other conclusions when it's repeated in twenty years. Hazard can change due socio-economic and climate development, the probability will raise. The exposure factor can change due to socio-economic development as well. There will be more people living and working in urban areas and therefore more buildings that can be exposed to a flood. So basically, you can split this assessment in four parts which are explained below.

2.2.1 Hazards
Flood hazard is the probability and the magnitude of a certain flood event. This probability is most often described in terms of a return period. A flood is less likely to occur when the return period has a higher value. The magnitude can be expressed in multiple unites, such as duration, inundation depth, extent and flow velocity. In a large scale assessment like carried out in this study the inundation depth is most often used to quantify the flood risk. This is because inundation depth can be recorded very precise during a flood and the other unites are mostly not measured at all.

2.2.2 Exposure
Exposure contains the elements that could be affected in the event of a flood. In a small scale flood risk assessment you could describe the entire city in land use maps. Every building and road can be appointed to a land use category and you would get a reasonable precise flood risk estimation. In a large scale assessment as carried out in this study it is often a very time consuming job to describe entire cities in this precise level. Therefore in a large assessment a limited amount of land use categories is used. There are only five of them because using more land use categories will take a lot of time to derive the land use maps and also a lot of computer power to calculate the total flood risk. The negative side of using only five land use categories is that the estimation is less accurate.

2.2.3 Vulnerability
Vulnerability represents to which extend the exposed elements are damages or affected by the floods. The standard approach is using depth-damage functions, which relate the inundation depth to a certain damage value. These depth damage functions are derived by Huizinga (2015) and those are land use category – specific. Damage values are usually expressed in monetary values, but there is a difficulty in this. This is because every country uses different currency, those have to be generalized to a certain currency, in this study euros. And those values have to be adjusted to for example inflation.

2.2.4 Risk
For every return period the damage can be calculated and plotted. This plot is called the damage-probability curve. 'Flood risk is the integral of these damages as a function of the probability of exceedance' (Nootenboom, T., 2015; Messner et al., 2007). Risk is most of the time quantified in monetary values, in other words expected annual damage (EAD). It can also be expressed in formula form:

$$\text{EAD} = \int_0^1 D(P)dP$$

Where P is the annual exceedance chance of a flood, in other terms 1/T, where T is in years. And $D(P)$ is the damage calculated for that same flood event (Nootenboom, 2015).

2.3 Damage categories

Damage can be divided in different categories, namely direct and indirect damage. The direct damages are those who cause harm by contact of flood water with property, humans or other objects. Indirect damages are those who occur outside the flood event itself. Think of the costs of traffic disruption or the loss of trust in authorities. Both damage categories can be splitted in tangible and intangible damages, depending on whether or not they can be expressed in monetary values. Tangible damages can easily be expressed in capital or resource flows which can be specified as monetary values. Intangible damage means damage to assets which are not on the market (Merz et al., 2010). A brief overview of the damages is given below in Table 1.

Sort of damage	Examples
Direct, tangible	Damage to buildings, destruction of infrastructure, clean-up costs
Direct, intangible	Loss of life, injuries, negative effect on ecosystems
Indirect, tangible	Cost of traffic disruption, disruption of public services outside of flooded area
Indirect, intangible	Trauma, loss of trust in authorities

***Table 1:** Types of damage due floods (Merz et al., 2010)*

The costs of direct damage is much easier to quantify then the indirect damage costs. This is because the indirect damage costs can be spread over years, while the direct damage can be quantified very quickly. Therefore in this study only the direct tangible damages are considered.

2.4 Latest developments

Like mentioned in paragraph 2.2 the flood risk assessment is a dynamic process in time and in place. Every assessment can be different in ten years. This is due to the changes of the world, but also due to the changes of the input parameters. For example the models used will, most likely, be improved in ten years. But also the data of Open Street Map, that is used to derive the land use maps, will be more valid. The last decades more flood events have taken place over the world, and this development is high likely to continue (Stocker et al., 2013). The two factors that can assigned to this development are socio-economic development and climate changes.

2.4.1 Socio-economic development

Socio-economic development is defined as the increase of wealth and of the population in the world. According to the United Nations the population of the world is growing and will keep growing for the coming decades. This has as a result that the amount of people exposed to floods will be bigger than it will be now. Also can be said that the risk for floods will increase. Beside the growth of the population the growth in wealth will also has its influence. This increase in wealth will has as effect that the assets that are exposed to floods will be more valuable. The costs of the direct tangible damage will therefore increase.

The most used way is to express the increase of exposed assets by using the Gross Domain Product (GDP) or the Gross Domain Product per capita to scale the numbers to a global usable value (Jongman et al., 2014). What should be taken into account as well is the change in land use. When more assets are exposed, there will be more buildings in the area, but these changes are not taken account (yet). The data for these types of developments is very limited. And when it is available the scale is mostly of very low resolution. (Winsemius et al., 2013).

The input data used for these scenarios is derived from the International Institute for Applied System Analysis (IIASA, 2015). The scenarios are called Shared Socio-economic Pathways (SSP), and for this study the scenarios SSP 2 and SSP 5 are taken into account. SSP 2 stands for a medium scenario, where the trend existing nowadays is extrapolated. The slowly decreasing existence of fossil fuels is taken into account, so there will be less greenhouse gas emissions. The SSP 5 however focuses on the economic growth and herein fossil fuels will be the leading energy source. This will lead to a more extreme scenario.

2.4.2 Climate changes

The climate changes will also continue to develop over the coming years. Climate changes mean more precipitation, but also shifts in moments of precipitation. As mentioned in the first paragraph of this chapter floods are more likely to occur after extreme precipitation events. The floods will therefore occur more often, but also on more unexpected moments. This increases the risk. A side note is that the influence of the models for climate change applied in this study is minimal. This follows from the work carried out by former Bachelor students (Schilder, 2016; Nootenboom, 2015). Nevertheless, those are taken in to account for this study to validate this conclusion for the continent North America as well.

There are different models, so called Global Climate Models (GCMs), which can describe climate change estimation up to 2030. The five GCMs taken in to account are: (Warszawski et al., 2014).

- Hadley Centre Global Environment Model
- Geophysical Fluid Dynamics Laboratory Earth System Model
- Institut Pierre Simon Laplace Climate Model
- Model for Interdisciplinary Research on Climate
- Norwegian Earth System Model

In these models different future climate scenarios can be implemented. For this Bachelor Thesis the data from the Representative Concentration Pathways (RCP) is used and specifically the RCP 4.5 and the RCP 8.5. Both describe a climate scenario, RCP 4.5 describes a medium scenario, where RCP 8.5 describes a more extreme scenario.

3

PROCEDURE FLOOD RISK ASSESSMENT FOR NORTH AMERICA

As is shown in the previous chapter flood risk calculation consists of three elements: hazard, exposure and vulnerability. Part of this study is the comparison between two methods. The method with two land use categories and the method with five land use categories. This chapter is constructed out of the following elements. First the hazard assessment is explained, next up is the exposure assessment, and this is split up in the single land use method and the multiple land use method. In paragraph 3.3 the vulnerability assessment is explained, again this is split up for the two methods. Section 4 of this chapter is about the risk assessment, and finally in the last two paragraphs the procedure for deriving the land use maps and implementing those in FIAT is given.

3.1 HAZARD ASSESSMENT

Flood hazard data can be extracted from the global hydrological model named PCRaster GLOBal Water Balance model (PCR-GLOBWB), which has been developed at the Report Department of Physical Geography at Utrecht University, The Netherlands by Van Beek & Bierkens (2008). This model uses explicit routing of the surface water flow by utilization of the kinematic wave approximation, the dynamic inundation of floodplains and a reservoir scheme. As a result this model should produce more exact and realistic travel times of water in ground layers. Those more exact results follow from comparisons made with the real runoff data from rivers. The model is still under construction and for an overview of the activities that are to happen, one is referred to the technological report of Van Beek & Biekens (2008).

The model is based on the leaky bucket model presented by Bergström (1978), therefore PCR-GLOWWB generates for each grid cell (0.5 degrees * 0.5 degrees ~ 50 km^2) and for each time step (daily) an output. This output consists of the water storage in two vertically stacked soil layers and the underlying ground layer, together with the water exchange between the layers and between the layer closest to the atmosphere and the atmosphere in terms of precipitation. The model can also calculate snow storage and canopy intersection.

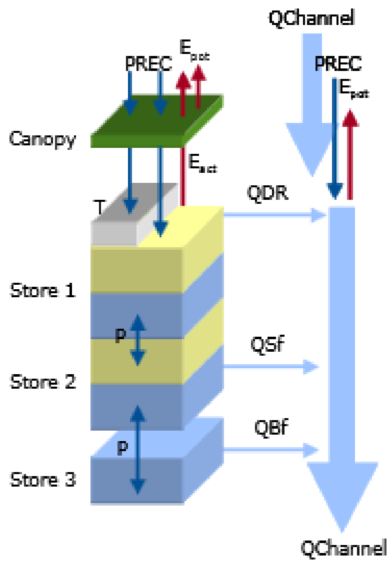

Figure 2: *Modelconcept of PCR-GLOBWB (Van Beek & Bierkens, 2008)*

The Modelconcept of PCR-GLOBWB can be explained with Figure 2 as guidance. On the left, the soil compartment, divided in the two upper soil stores and the third groundwater store and their corresponding drainage components of direct runoff (QDR), inflow (QSf) and base flow (QBf). On the right the resulting discharge along the channel (QChannel) with lateral in- and outflow and local gains and losses are depicted (Van Beek & Bierkens, 2008).

The scale used by this model (~50km^2) is way too big for a large scale flood risk assessment, because all cities would be scaled down to one cell. Therefore a downscale is needed. One cell per city would decrease the assessment drastically, because you can't identify multiple land use categories within one cell. PCR-GLOBWB is downscaled to 1 km^2 to serve as a more detailed model for the flood risk assessment (Winsemius et al., 2013).

3.2 Exposure assessment

In this paragraph the main differences between the single and the multiple land use method will be explained.

The single land use method is a method studied by Winsemius et al. (2013). This method is based on Moderate Resolution Image Spectroradiometer (MODIS) data together with Global Rural-Urban Mapping Project (GRUMP) data. There are two types of urban land cover distinguished. Those are densely populated urban areas and less densely populated areas, also called peri-urban areas. In the high density urban area a part of 75% is considered urban area and for the peri-urban a fraction of 25% is assumed to be classified as urban area (Nootenboom, 2015). For this method only one depth damage function is derived.

The multiple land use method was developed by Huizinga (2007, 2015) and in first instance this method was only applicable in Europe. Since the precise estimation has been proven (Nootenboom, 2015) the method has been up scaled to world level. The method is based on an extensive literature study, wherein data was collected for maximum damage values and depth-damage functions for all countries over the world. An objective of Huizinga was to obtain values and functions for the damage categories that together contribute to over 80% of the overall EU average flood damage (Holz, 2014). These damage categories are the following: residential, commercial, industrial, infrastructure and agriculture. All these categories have their own depth-damage functions and those differ for each country as well. To identify all those land use categories land use maps has to be made. This can be done with different methods, this will be explained later on.

3.3 Vulnerability assessment

The vulnerability assessment can also be divided in the assessment for the single land use method and the assessment for the multiple land use method. These are both explained in the upcoming paragraph.

For the single land use method the vulnerability assessment is rather simple. The land use categories, urban and peri-urban, are assigned a maximum damage value. This damage value is obtained from HAZUS (Scawthorn et al., 2006) for the continent North America. The source is different for every continent, for example for the European values the DamageScanner (Klijn et al., 2007) is used. The maximum damage value can be expressed in a value per unit area or per object. For this study the damage per unit area is used, hereby it is compatible with other data. These values are different for every country, but they have to be scaled to a universal value. This is done by comparing the country specific Gross Domain Product (GPD) to the world average GPD. Both these values are obtained from the World Bank. The values obtained from this comparison need to be adjusted for the inflation and the rate of exchange. After that, the values needs to be combined with flood hazard. For that a relative depth damage function is derived for the urban area. This function is also derived with help of HAZUS (Scawthorn et al., 2006).

The multiple land use method uses a quite similar vulnerability assessment compared to the single land use method. Huizinga derived maximum damage values for all the five land use categories based on a literature study. This information was mostly found in papers by researchers and international institutes that are specified in flood risk assessment studies. The values he found had to be harmonized again, because the values of the countries were scattered. To scale the maximum damage values he used the Gross Domain Product again, only this time compared it to the average value of the continent. For further information about this harmonization one is referred to the report of Nootenboom (2015). From these average maximum damage values the depth damage functions are derived. The maximum damage value is most often reached at a water depth of six metres. In the Figure 3 below the depth damage functions for North America are given. Added is the table with the values as well, this can be found in Table 2. Note has to be made, for the infrastructure function the values of Europe has been used, because Huizinga (2015) did not derive a depth-damage function for the infrastructure in North America. The welfare of North America and Europe can be seen as equal, therefore the assumption is that the Infrastructure is developed equally on both continents.

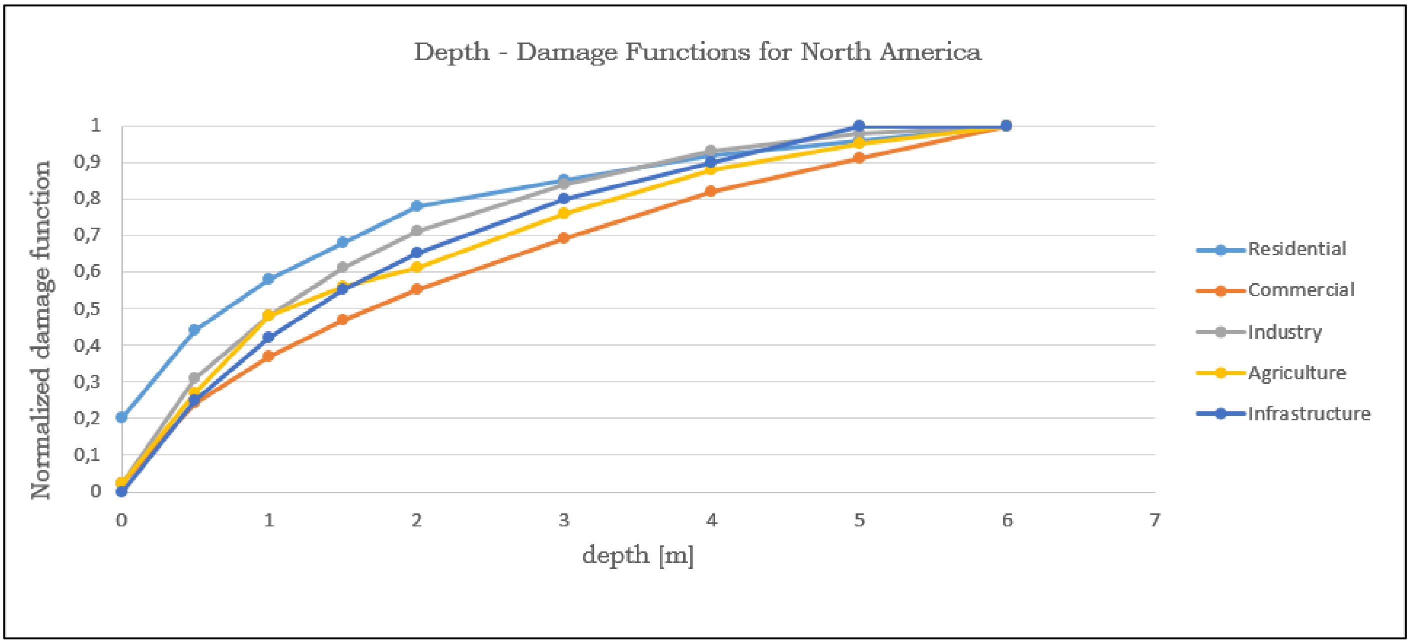

Figure 3: *Depth - Damage Functions for North America based on Huizinga (2015)*

Depth [m]	Residential	Commercial	Industry	Agriculture	Infrastructure
0	0,2	0,02	0,02	0,02	0
0,5	0,44	0,24	0,31	0,27	0,25
1	0,58	0,37	0,48	0,48	0,42
1,5	0,68	0,47	0,61	0,56	0,55
2	0,78	0,55	0,71	0,61	0,65
3	0,85	0,69	0,84	0,76	0,8
4	0,92	0,82	0,93	0,88	0,9
5	0,96	0,91	0,98	0,95	1
6	1	1	1	1	1

Table 2*: Normalized values of depth-damage functions for North America based on Huizinga (2015)*

In Table 3 the maximum damage values are given. These values are expressed in €/m^2. The link with those values to table 2 and figure 3 is that when you multiply these values with the normalized values of table 2 you get the damage done by a flood of a certain depth expressed in a monetary value. The most notable value, in comparison with the European value, is the Agriculture value. The European maximum damage for Agriculture is €0.77 and the North American value is €1324. The difference can be declared by the source that these functions follow from. De HAZUS database from which the American value follows also takes the buildings, like farms, into account, where the European damage only follows from the flooded lands (Huizinga, 2015).

Land use	Average maximum damage [€/m^2]
Residential	788
Commercial	1889
Industrial	1830
Agriculture	1324
Infrastructure	24

Table 3: *Maximum damage values for North America based on Huizinga (2015)*

For the multiple land use method the regional differences are also taken in to account. The average maximum damage values can be scaled to regional levels with the GDP per capita. This is done for the Nomenclature of Territorial Units for Statistics (NUTS) levels (Nootenboom, 2015). These NUTS levels are of different scale. In the EU the NUTS system is dividing Europe in four levels (NUTS-0, NUTS-1, NUTS-2, and NUTS-3). The national boundaries are given by NUTS-0, the major socio-economic regions are represented by NUTS-1, NUTS-2 can be defined as the basic regions for application of regional policies and last NUTS-3 represents the small regions for diagnoses. These NUTS levels are defined by the maximum and minimum number of residents (Holz, 2014). Something similar is being used for North America, the GDP is given per state. This input data for North America is of the NUTS-0 level and thereby still very generalized. Further investigation on this specific subject could be of importance, the smaller the areas that can be appointed to a GDP, the more precise result you get. Region specific damage values, for Europe, can be derived with the following formula:

$$D_{max,NUTS} = D_{max,EU} * \frac{GDP_{pcNUTS}}{GDP_{pcEU}}$$

After this conversion the values are ready to use. The GDP values have been adjusted for inflation, rate of exchange and region. All these steps making the assessment more valuable is the prediction. When the Flood Impact Assessment Tool is scripted right, it should give a better assessment.

3.4 RISK ASSESSMENT

For the single land use method and the multiple land use method the flood risks will be calculated with use of the Flood Impact Assessment Tool (FIAT). This is a tool that combines all elements and calculates the total flood risks for the specific situation. In the FIAT can also be dealt with different climate and socio-economic scenarios. FIAT makes use of the definition of Kron given in paragraph 2.2. For a detailed description of the Flood Impact Assessment Tool, one is referred to the report of Nootenboom (2015).

3.5 Deriving land use maps

An important step in the process for flood risk assessment is deriving land use maps. These maps determine the exposure and the vulnerability of a specific region. For the most exact flood risk assessment a whole area needs to be categorized in several land use categories. In this paragraph the derivation of a land use map is shown.

The base element used is a ShapeFile provided by Nootenboom (2015). This ShapeFile contains the borders of the cities in the world with more than 200.000 inhabitants. An assessment can be done for all cities in the world, but for this study that is not relevant because it is a global assessment. The borders of the city are created with the data from MODIS. This file can be opened with the Geographic Information System QGIS. Here we can see that the city borders are not very well defined. With help of a Google Satellite image this can be adjusted by hand very precisely, but in this study it's performed rougher, because an assessment is our goal, not the exact answer. An example for Coatzacoalcos, Mexico is given in Figure 4. On the left side you can see the city boundaries from the MODIS data and on the right side you can see the adjusted file.

Figure 4: *On the left side the MODIS file and on the right side the adjusted file of the city Coatzacoalcos, Mexico*

Next step is to assign information to the area that is going to be invested. In the Global Information System program QGIS several option are available to retrieve this information. For example Google Maps, Open Street Maps, Google Earth and Bing Maps can be used. These maps contain underlying data stored in attributes. These attributes give the user information about, for example, the type of building, the name of the building etc. This information is useful for assigning the land use categories to the area. Unfortunately this information from Google Maps is not freely accessible. However for OpenStreetMap it is. It's freely accessible and edible by the users. This ensures for a lot of data, but it also raises questions. Every person can edit the data, so mistakes are made quickly. Lately the reliability of OSM improved, due to a control measure. All major changes in maps are reviewed by other long term users. This decreases the amount of mistakes, and therefore we can assume that for this study the data is trustworthy.

So it's clear that the data is going to be extracted from OpenStreetMap. Next step is to categorize this data to form the land classes. This data can be downloaded at planet.osm.org, this websites provides the latest updated Open Street Map of the whole world. This can be downloaded in a reduced file format (.osm.pbf) and subsequently be converted in a, for QGIS and ArcGIS, manageable format. The exact procedure can be found in Appendix C. There is a lot of unnecessary data in OpenStreetMap and for computer calculation time purposes all this data has to be filtered. These filters can be found in Appendix D (Suijkens, 2015; Kosters, 2015).

The last step to complete the land use maps is to delete the overlap between the different layers and the overlap within a layer. The overlap between certain layers can be described as follows; one area is assigned as commercial and agriculture. To evade this all layers have to be subtracted of each other. In this process some details will be lost due to subtracting precise defined layers from coarse defined layers. This step can be performed with the function difference in QGIS. Overlap within a layer means that an area is marked as an industrial area, but the buildings itself are also marked as industrial. Thus this area is counted twice and thereby the assessment is not precise. The function in QGIS that can prevent this is the function dissolve. Now there is no overlap, not between nor within layers. The precise procedure is given in Appendix E (Suijkens, 2015; Kosters, 2015).

Last step for completing the land use maps is to deal with the infrastructure data and the data that is unknown. All data from OpenStreetMap that is mentioned earlier is made out of polygons, infrastructure data isn't. This data is stored as lines and thereby have to deal with in another way. These lines can be buffered into an area. The lines are given thickness. This thickness is estimated on 6 meters per road to take an average value. When this happened, with the function buffer in QGIS, the infrastructure layer is complete and for the sake of completeness this layer is subtracted of the other layers to give a more precise map. A big problem in mapping is the lack of data. Around 75% of the area is not appointed to a land use value. To give a more exact answer this no data layer is given a function as well. This function is going to be derived with the ratio of the other land use classes. This gives an estimation of how the unknown area is divided.

An example of the land use maps is shown below in Figure 5. In the legend the tag '_South' comes from the parts in which North America is divided to make the data more manageable. The continent was divided in South, West, Middle, East and North East.

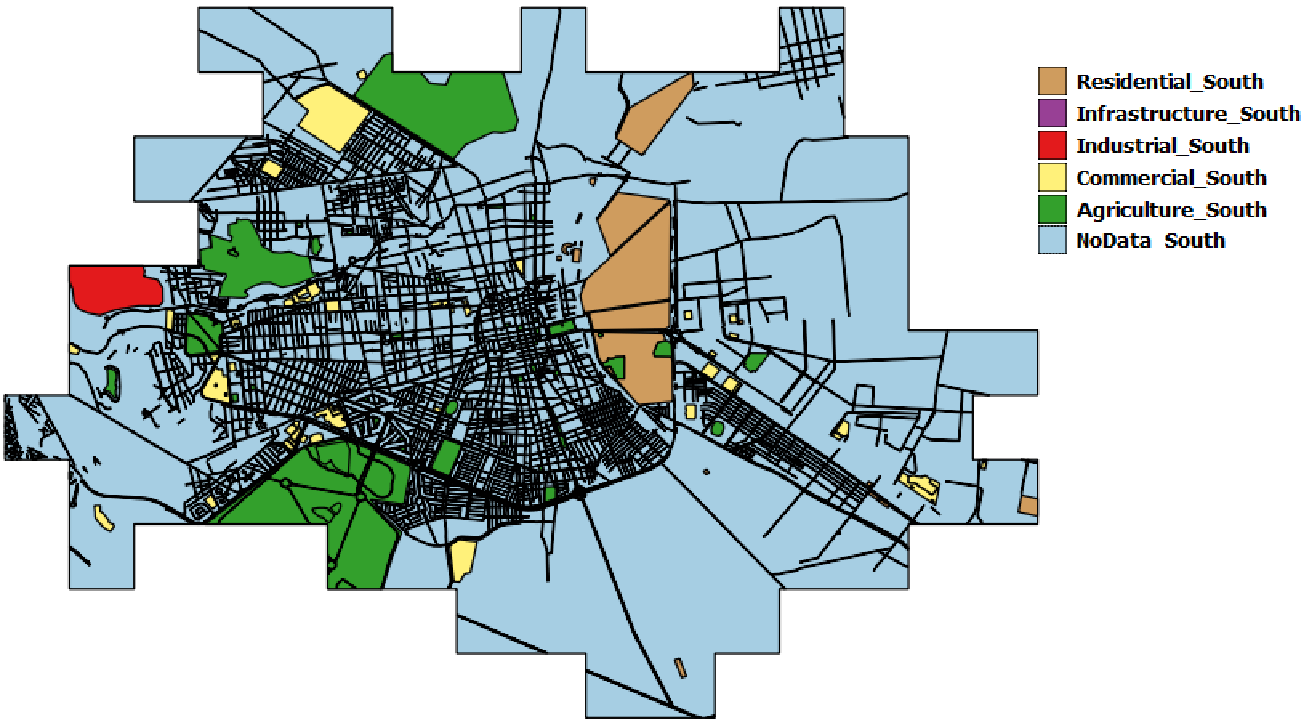

Figure 5: *Example of a derived land use map of San Luis Potosi, Mexico*

3.6 Implementation in FIAT

After the derivation of the land use maps like described above the following step has to be taken. This includes the preparation for the Flood Impact Assessment Tool (FIAT). The tool only works with files in raster format. The created land use maps are of the vector format. A conversion has to be done. QGIS can rasterize a file to a raster with cells of 1 km^2, with the standard rasterize function. The raster cell will be filled with a land use category entirely when a land use category is present for more than 50% in that squared kilometre. This means that a lot of details will be lost within this process. A method with a more accurate scale has the preference.

Therefore the files will be rasterized to a resolution of 100 metres by 100 metres. Every land use category layer will be rasterized to this resolution. If a land use category is present, the cell will be given a value of 1, if it isn't the cell will be given a value of 0. The resolution of the hydrological model PCR-GLOBWB is 1 km^2 and for FIAT this is the standard, so the created rasters has to be up scaled to the 1km by 1km raster. The exact procedure of this is been given in Appendix F (Suijkens, 2015). Less details are lost in the second option given in this paragraph, because the data is subdivided in more little parts and thereby not all info of an area of 1 km^2 is generalized. An example of a rasterizing process is given in Figure 6.

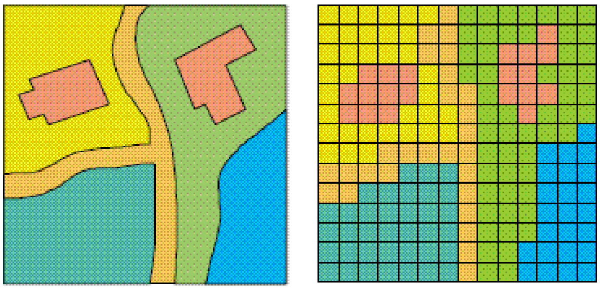

Figure 6: *The rasterizing process. On the left the vector file, on the right the raster file*

With the land use maps in the right format, all necessary information is collected and can be stored in to the Flood Impact Assessment Tool. This tool can, with help of a python script, link the data following from the land use maps, the depth-damage functions and the maximum damage values, and calculate the risk for each city taken into account from these elements. There are several options for running the tool, for example implementing the socio-economic and climate scenarios. Running the tool takes a lot of computer power and can take a lot of time, speaking from own experience. For people carrying out a flood risk assessment in the future it is advised to use a powerful computer.

4

Results flood risk assessment North America

In this section of this Thesis the results of the Flood Impact Assessment Tool are given. Due to multiple issues I was not able to derive the multiple land use results. Therefore in this chapter these issues are explained and the single land use results of Schilder (2016) are produced.

Due to severe performance issues of my computer the derivation of the land use maps took enormous amounts of time. This in combination with the huge amount of data available for North America led to a disappointing result. The Geographic Information System programs QGIS and ArcGIS are not able to handle big chunks of data. As Suijkens (2015) already noticed, these programs get performance issues when they have to work with around 2GB of data. The total amount of data available for all the North American cities mentioned in Appendix B is 36.8GB.

After lot of troubleshooting and struggling with the software, finally there was an action plan. This troubleshooting included for example the lack of knowledge about deriving maps. The input file thought that was needed for deriving the land use maps was wrong *(.db is needed, .osm is not)*, this costed a lot of time already. You also need to connect the programming software Python to the Flood Impact Assessment Tool. But this only works when Python is installed in proper way. Suggested is to do a clean installation of Python, but this isn't always the solution. Python is deeply integrated in Windows and therefore it isn't always possible to uninstall Python completely. As a result, FIAT is searching and using a Python.exe file in a location that isn't even available. Previous students (Kosters, 2015; Suijkens, 2015) eventually did a clean Windows installation and let FIAT run on that one device, for four students. This wasn't an option, because a clean Windows installation would mean loss of all files, and a second laptop wasn't available. But for future studies it could be useful to start off with a clean Windows installation. It should run FIAT properly immediately.

The first approach, processing all data at once, wasn't successful at all. Loads of loading time were a result of that. Second and final approach was dividing the data in different parts. The data of North America has been divided in five near equal parts and so the data is more manageable. Although the data has been chopped in smaller pieces the processing of the data still was a time consuming process, because the chopped parts still were bigger than the 2GB mentioned by Suijkens (2015). Some steps in the process took hours, others took days.

At the time of writing the land use maps are being derived, but I ran out of time to run these results in the Flood Impact Assessment Tool. For that purpose the results produces in this chapter are the single land use results of Schilder (2016) for the continent North America. This is to give an overview of how the results would have been shown and to withdraw a top five of cities for the radar charts.

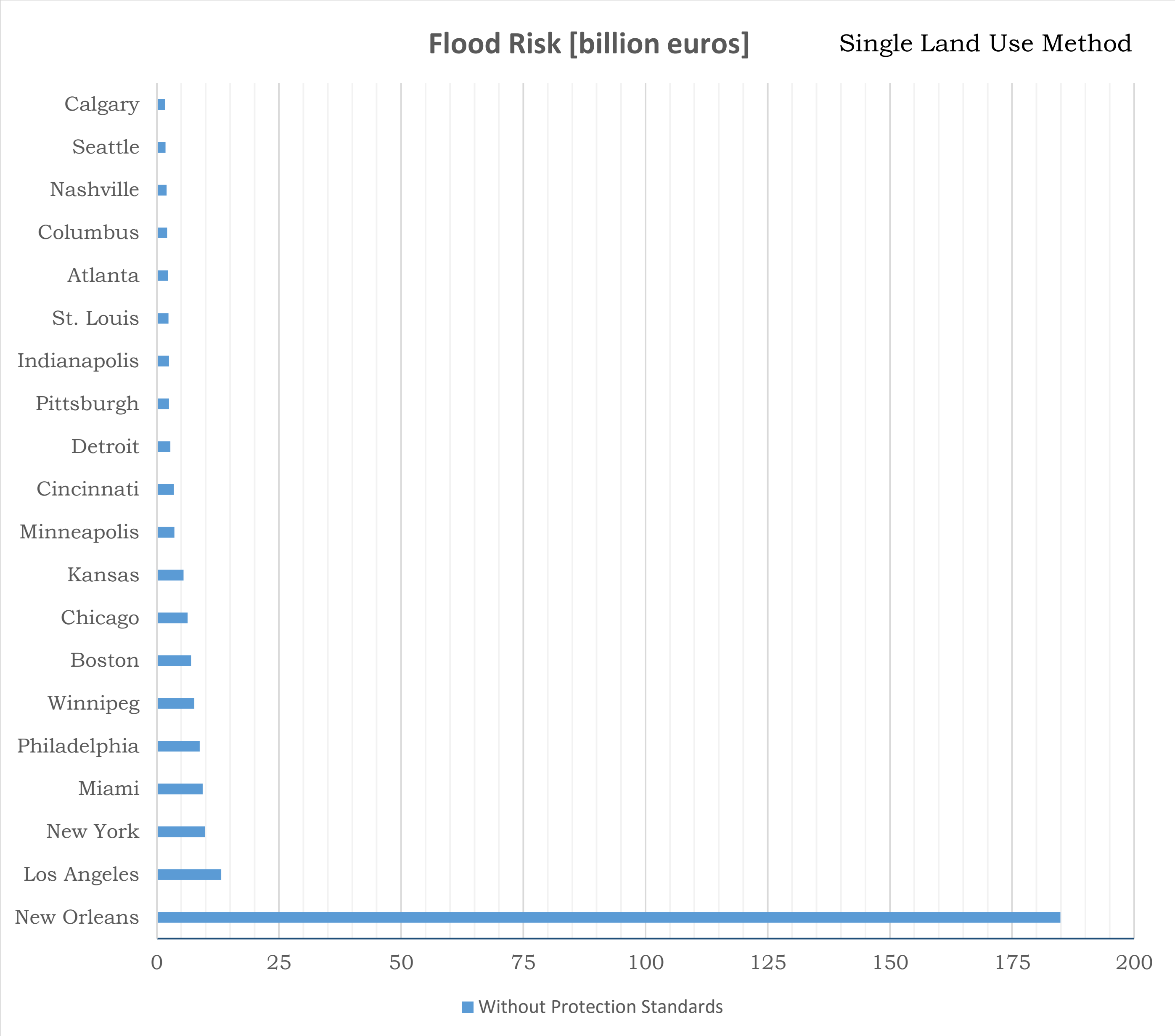

Figure 7*: Ranking of the first 20 North American cities based on flood risk without the implementation of flood protection standards and based on the single land use method (Schilder, 2016)*

In Figure 7 the single land use method results are shown for North American cities. Immediately the risk of New Orleans pops out. The shapefile that is used to cover New Orleans will be completely covered by the flood hazard extent. New Orleans geographic location is at the Mississippi and numerous lakes, this will lead to floodings that cover a greater area and thereby this will lead to more expected damage.

The top five of the list represented above are going to be presented in the radar charts. So the following cities are taken in to account: New Orleans, Los Angeles, New York, Miami and Philadelphia. This study will be explained in chapter five. The influence of implementing the protection standards of Scussolini et al. (2016) is presented in Figure 8. Immediately can be seen that the influence of this data is huge. For all cities, New Orleans excluded, this data will reduce the risk with a factor 10.

The exact values of these graphs are shown in Appendix G.

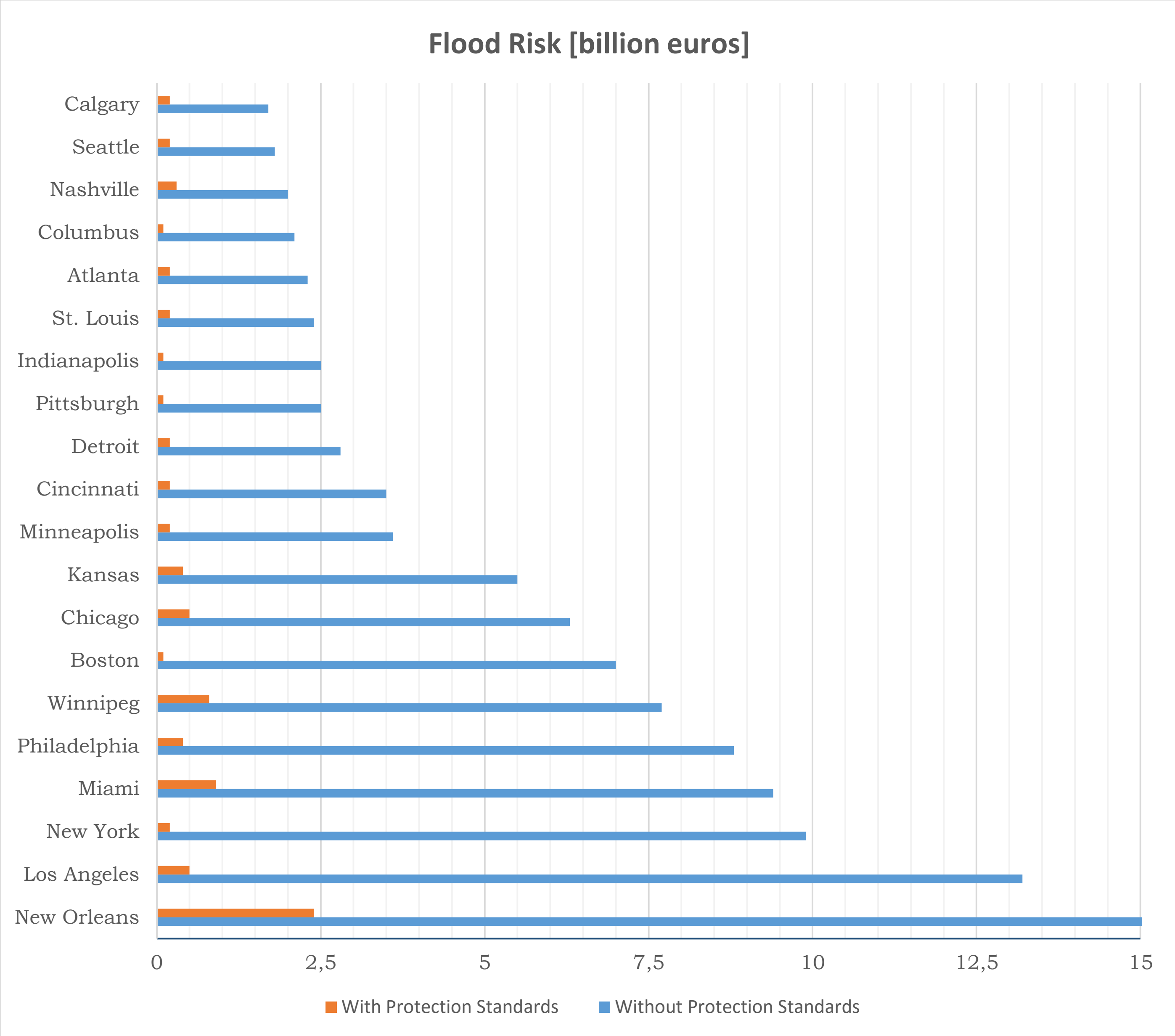

Figure 8: *Ranking of the first 20 North American cities based on the flood risk with implementation of flood protection data of Scussolini et al. (2016) and based on the single land use method, (Schilder, 2016)*

5

FLOOD POLICY RESEARCH

This part of this Bachelor Thesis consists of a literature study. There is a lot of uncertainties in the flood risk assessments and chapters above show the influence of socio-economic and climate changes developments. In this chapter other sub-aspects are discussed. These sub-aspects are also input parameters in the Flood Impact Assessment Tool.

5.1 VULNERABILITY FRAMEWORK

The definition of vulnerability is most often defined as the sensitivity of a certain system to exposure to disturbances or in other words as mentioned earlier to which extend elements are effected by a flood. De Graaf (2008) did a literature study to develop a vulnerability framework which consists of the following elements, shown in Table 4.

Component	Type	Time orientation	Uncertainty of hazard magnitude	Responsibility Netherlands	Responsibility United States
Threshold Capacity	Damage prevention	Past	Low	Clear	Not Clear
Coping Capacity	Damage reduction	Instantaneous	Low	Not clear	Clear
Recovery Capacity	Damage reaction	Instantaneous / future	Low	Not clear	Semi - Clear
Adaptive Capacity	Damage anticipation	Future	High	Undefined	Clear

***Table 4**: Components of vulnerability framework (De Graaf, 2008)*

The threshold capacity is the opportunity or ability of a society to build objects to prevent damage. In flood risk assessment this means, for example, the building of dikes. This should have been done in the past to prevent upcoming floods. In the Netherlands the dikes are constructed to retain the highest experienced flood, but in the United States this is different. There the return periods used to design the flood retention are much lower than in the Netherlands. Threshold capacity is not only for building but also for maintaining those structures and the 'people' in charge of those structures. In the Netherlands this is quite clear, but in the United States there are several governments deciding over the land use planning and the water control structures in these areas. Most of the times the US Army Corps of Engineers is the top institute in this pyramid. The County and City Department are mostly down the line and responsible for the less radical changes. Still, most decisions have to be made in collaboration.

Coping capacity is the ability to react on a flood that exceeds the highest experienced floods. This ability is mostly based upon the existence of emergency plans or evacuation plans. Coping capacity is equal to the damage reduction. With those safety measures the society hopes to evacuate as much people as they can out of the affected area. It is important to have a clear organisational structure and react quickly. The effectiveness of the evacuation is based upon the technical, economic, social and institutional abilities. In the Netherlands the organisational structure is not very clear, because floods do not occur very frequently. That is one of the reasons why the Delta Commission advised to revise the plans developed earlier on, because the focus has always been on collective flood prevention systems. The institutional arrangements are not classified yet, and there is little experience with a disaster scenario (Kind, 2012). The coming years there will be an investigation for the National Delta Programme and flood policy will be included. And thereby the three layer program will be applied. This program is already carried out by the United States.

This ‘multiple layer safety’ followed from intensive collaboration between the Netherlands and the United States. This network is called the ‘Netherlands US Water Crisis Research Network’ (NUWCReN). The goal of this network is to share experience and knowledge about floods. The “multiple layer safety” is spread over the following layers: prevention, land use planning and flood response planning. In the Netherlands most money is spend on the first layer, while the United States of America focussed on all three layers (Kolen et al., 2011). This behaviour in the Netherlands has, however, changed over the last few years, the focus has been partly switched to the other aspects of flood risk reduction. Partly on recommendation of the Delta Commission.

The third component, recovery capacity, relates to the ability of a society to recover to an equal state as it was before the flooding. This will start directly after the event. The recovery determines on the economical capacity of the country, but also on the magnitude of the event. In the Netherlands the consequences of a flood will be catastrophic, also explained by the Delta Commission. The exceedance of the safety levels will not occur much, but when it does the damage will be enormous. This is because of the development of the country and thereby the vulnerability and exposure of the country. That’s one of the reasons why the Delta Commission want to see the plan revised. Recovery time can have a big range, it can be weeks, but years as well. Recovering from the hurricane Katrina, occurred in New Orleans, will take years. A lot also depends on the insurance, how much funding is the government willing to give. It has to be clear who is willing to pay for the damages that occurred.

Last is the adaptive capacity, this is the capacity of a society to adapt itself after a flood happened. The society has to learn from earlier events, just like the Netherlands reacted to Watersnoodramp with the Delta Program. The system may be functioning well at present, but the developments earlier mentioned, like climate change and socio economic developments, make the system dynamic. In America this is the case with New Orleans, there is much more attention for water since Katrina happened.

The options of decreasing vulnerability are shown in Table 5 below. This is a guideline how to develop as a society to prevent further major disasters:

Component	Measures to reduce vulnerability
Threshold capacity	Higher and stronger dikes Increasing capacity of river(s) Increasing drainage capacity of urban areas
Coping capacity	Flood warnings Emergency plans Improved communication to public Elevated major infrastructures Infrastructure resistance against floods
Recovery capacity	Insurance Funds for disasters Organisation in ‘who is responsible’
Adaptive capacity	Integrate flood management with spatial planning Experiments with other modes of urbanisation

Table 5: *Overview of possibilities to decrease vulnerability (De Graaf, 2008)*

5.2 Protection level

Flood protection levels play a big role in a flood risk assessment. The amount of floods occurring is affected by the presence of flood protection measures, think of dikes, dams and reservoirs. These protection levels are mostly expressed in return times. The flood with a return period of 100 years is the flood that is exceeded on average once in every 100 years. So that basically means that there is a one percent chance of occurring in any given year. It is a common misconception that a flood with a 100 year return period will occur with a probability of 1% in a 100 year period. This is in case of dikes, but for the floodplains other standards are used.

The 100-year return period mentioned above is an example. Most countries can 'decide' for themselves which standard of flood protection they would like to maintain. For example in the Netherlands standards for flood protection are ranging from once in 1250 years up to once in 10000 years (Rijkswaterstaat, 2015). But unfortunately the documentation on flood protection levels is mostly not complete or not present at all (Jongman et al., 2014). A way to fill in gaps in the flood protection data is by using the Gross Domestic Product to give an indication. When this is examined on capita basis you can give a prediction for the protection level in a certain area. Regions with a high living standard will most likely be protected with a higher damage reduction measurement. (Feyen et al., 2012). An interesting note is made by Matthijs Kok (2007). He marks that the defences in the city of New Orleans are rebuild and that they are in better state then before. Thereby he says that it is remarkable that a big disaster is necessary to take the right protection measures. Another question mark is stated by the protection level standards that they are applying in the United States. They improved the flooding probability from 1/30 yr^{-1} to 1/100 yr^{-1}, but for example in the Netherlands we maintain a protection level of 1/10000 yr^{-1}. How safe is safe enough? Protection levels of 1/1000 yr^{-1} can be easily supported on economic grounds. An economic optimization can be used for political decision-making. But loss of life issues will push the standards even higher. This is an interesting political dilemma and it's easily to conclude what the American policymakers have chosen for.

Flood protection data for countries outside of Europe are under development at the moment, for Europe a study has already be done by Jongman et al. (2014). Nootenboom (2015) reported that during his study some average values were an assumption, but later on he also stated that already an implementation of small protection measures can reduce the flood risk by a lot. For example implementing a protection level with a return period of five years already gives a reduction of about 60%. This indicates that the input parameter 'protection level' has a big influence on the outcome.

Another side note on the flood protection standards is that the known protection levels mostly are assumed to be homogeneous throughout the whole country. For small countries this is a reasonable assumption, but for a large country like the United States of America this is questionable.

As already mentioned the protection standards for countries outside of Europa are under construction. One of the latest developments is the global database FLOod PROtection Standards (FLOPROS) (Scussolini et al., 2016). This database comprises information in the form of the flood return period associated with protection measures in different spatial scales. This is another method of filling in 'datagap' than the methods used by Jongman et al. (2014) and Mokrech et al. (2015). The database makes use of various sources like literature, policy documents and modelling techniques. The goal of this database is to combine these sources to a more precise estimate of the protection levels in a certain area.

Like mentioned above this database uses different sources and thereby it uses various layers namely

- The design layer, containing information defined by engineers in the design and realisation of the existing flood protection at the coast or river.
- The policy layer, contains the regulative and required standard for protection against floods
- The model layer is on the same basis as Jongman et al. (2014) described. It is based on a flood modelling approach and connects the wealth and protection to each other.

These layers have a hierarchy, because the base of the composition of the database depends on the best information available. This best information means the most trustworthy, reliable or closest to real protection standards. The design layer is consider most reliable because it contains the information closest to reality, the policy and model layer are just indications of the standards. The policy layer is considered to have intermediate reliability because it does not state if a certain prescription is respected. The model layer is the least reliable layer because it is determined indirectly and unless the approximations are validated it consists of a lot of assumptions. To apply all these layers basically when there is no information available in the most reliable layer one can take information from a layer less reliable. For a more detailed explanation of the procedure one is referred to the report of Scussolini et al. (2016). A result of the FLOPROS database for North and South America is shown in Figure 9 on the next page.

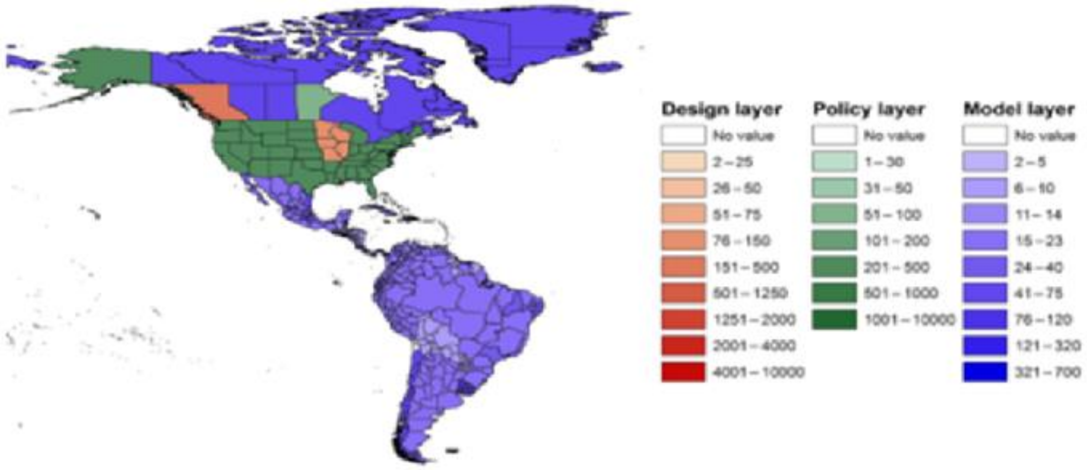

***Figure 9**: North/South America maps of flood protection standards contained in the FLOPROS database. Standards of the design, policy and model layers are indicated in the red, green and blue color scales. White indicates no data available (Scussolini et al., 2016)*

Unless it looks promising, this database is far from complete. There are a lot of uncertainties and a lot of investigation has to be done to validate this database as a perfect source. And thereby it is interesting to see that in North America mainly the policy layer is used for the flood protection standards. The policy layer consists of different entries, but it is less complete than the design layer. Opposite to the design layer the policy layer provides more information for country scale than for city scale (Scussolini et al., 2016). For the United States of America this gives immediately a big difference, because the information is generalized over the whole country. Compared to a smaller country this will have a greater impact.

It is recognized that adaptation strategies for risk management encompass several policy options, which differ from long term options till immediate responses (Hanson et al., 2010). Included in these options are the building regulations. As mentioned earlier Hanson (2010) also states that the risk will rise, due to socio-economic factors, if defence standards are maintained. It is of great importance that the standards also have to be raised. Rich countries have more possibilities to improve their protection standards, but are not always willing to do so. Despite having larger financial capacity, rich countries may or may not choose to do so, because of risk aversion nature of exposed populations or their governments. This can be clearly shown by the difference between the Netherlands and the United States. New York has a higher national GDP per capita, but it is less protected than for example Amsterdam and Rotterdam in terms of return periods.

Although numerous studies (Kosters, 2015; Nootenboom, 2015; Schilder, 2016) has shown that flood risks with protection standards taken into account are significantly lower than the case without protection standards taken into account, the question is how detailed and correct the information on protection measurements is. These studies used the FLOPROS database to calculate the risk, but if the data isn’t correct, the assessments will also be not as precise as we want. Scussolini et al. (2016) calls the information obtained for the policy layer for USA doubtful, because the source used is not clear in where the information comes from. This raises questions, because the policy layer is the key layer for this country. Further investigation for those flood protection standards is suggested.

5.3 Flood insurance

How to deal with floods in combination with respect to money spending can been seen from different angles. As a country / state you can decide to choose for high protection standards, but another option is to pay for the damages that occurred. In the United States of America they have a special flood insurance program. This program is called National Flood Insurance Program (NFIP).

The government has assumed, by creation of NFIP, responsibility for mitigating the societal and economic impacts of flooding. This is guaranteed by establishing this policy that can provide flood insurance (Ntelekos et al., 2010). The program was developed because floods kept occurring over the years and the costs per year kept rising as well. The NFIP not only provided insurance, but also had other activities like mapping and identifying flood-prone areas (Federal Emergency Management Agency, n.d.). Such a program hints to a 'wait-and-see' policy, despite only around 15% of households is participating (Smith & Matthews, 2015). This has different causes. 'Homeowners are for example not aware of the fact that a flood insurance isn't included in the standard insurance', says Loretta Worters, vice president of Insurance Information Institute. Thereby is there a lack of competitors that offer flood insurance and this drives the premiums relatively high. According to the National Flood Insurance Program the average costs of a flood insurance is around $700 a year, but the Federal Emergency Management Agency (FEMA) says otherwise. They talk about a $10000 a year for full risk insurance (FEMA, 2016). The aim of this study is not to explain the flood insurance system in North America. Therefore is from now on assumed that an insurance is present, but simultaneously one have to keep in mind that a limited amount of households are insured against flood due to particular reasons. For more detailed information about the NFIP, one is referred to website of FEMA.

In the Netherlands there is not a compulsory insurance for floods despite the fact that a lot of items are obligatory covered in the basic insurance. It is a risk most people are willing to take, people like to think 'that will not happen in my neighbourhood' and probably the expenses do not weigh up against the profits. In this situation this is a reasonable argument, because the Netherlands are known for their water defences. But it's doubtful to say that providing an insurance for floods has a correlation with the expected annual flood damages.

5.4 Public awareness

To develop an effective communication strategy for flood risk, there is need for a better awareness and understanding of this phenomena. Not only the phenomena itself but also the factors that influence floods.. When people understand a flood better, they will be able to react on a more efficient way and the evacuation plan has a bigger chance on success.

It is devastating to see what the results of a survey about flood risk awareness were in the United Kingdom. Burningham et al. (2007) did a field work investigation and found out that a major part of the inhabitants were not informed at all. This consisted out of different elements. Namely experience, time of living, age, amount of information, difficulty of information and last flood event. This follows from different statements of people living in Woking and Bewdley (Burningham et al., 2007).

Some people are aware that their property is at risk, but they had the attitude of 'it will not happen to me'. The respondents also claim that they did not have any information about the risk status. The institution providing this information should be sure that it is easily accessible and understandable. The terms used by professionals are most of the time not understandable for the 'common' people.

A misconception of many people is that floods will only occur when close to a river. It is also called the invisibility of flood risk. Local experience of flood events is a common reason why people don't consider their property at risk. For example the last major flood event in the Netherlands was in 1953 and thereby people think that it will not happen again soon. This goes hand in hand with the experience with floods. When a flood occurred a year ago, people will be more aware that it will happen again.

This could be translated in a radar chart parameter. People are more likely to act better and quicker when they've already experienced a situation. So when a flood occurred not very long ago the reaction should be better and thereby the number of fatalities should be lower. This is confirmed by Whitmarsh (2008). She states that a direct experience is more effective to result in stronger, focused, more confident, persistent attitudes and attitude behaviour consistency. This is also carried out in psychological literature. This direct experience of the most recent flood may motivate people to seek information to improve their future response on floods and their knowledge about flood events.

The result of this denial is that people do not know how to react on a flood. They are more likely to ignore the emergency plans and go their own way. This will lead to more fatalities and thereby the risk will be greater when people are not aware of the 'at-risk' status.

Also, from a NUWCReN meeting, followed that during an emergency situation people underestimate the consequences of certain events. People like to react closely related to their daily work, despite the fact that in those situation an unlikely reaction can work very effective (Kolen et al., 2011). People react very primitive on an unexpected situation that this will result in more casualties.

So maybe one can say that public awareness is an underexposed aspect of flood risk management. This can be explained by the fact that this part of risk management is hard to control, because it can be influenced by a lot of factors, namely experience, geographic location, attitude and knowledge of floods and rivers (Botzen et al., 2009). These aspects cover a wide range of the subject and thereby there can't be a generalized policy or law. The case is different for every location or person. Getting to know the public and their knowledge about flood risks can be done by for example a survey. This is a time consuming process and one can't predict the effect of it.

A comprehensive research to public awareness in a certain area can deliver results which can be used for flood risk management, but it is not a priority. This is because of the unpredictability of the human mind. The government can anticipate on the results of the survey, but humans act different in an emergency situation. This factor in flood risk management is so shaky, that it is doubtful whether measurements will reach their goals. One can better focus on an aspect that has a less uncertain result.

5.5 Flood fatalities

The damage during and after floods can be expressed in various forms. Economical damage and loss of life are two of them. In this paragraph the focus lays on the loss of life. It is interesting to say what types of floods make the most victims and compare this to the assumption we made in the second chapter: 'river and coastal floodings are the floods with the most impact on economic flood damages. Therefore only these floods are considered in this assessment.'

Primarily the high number of fatalities and damage occurred in developing countries (Wisner et al., 2004). Recently this trend changed, because more damaging and costly floods took place in wealthy countries like the United States and Canada. (Ashley & Ashley, 2008). The thought of immunity quickly adapted to a thought of vulnerability. Wisner et al. (2004) stated that numerous factors contribute to unsafe conditions and worst case scenario fatalities. Factors like physical environment, local economy, performance of public actions and institutions all contribute to the unsafe conditions wherein people live. Also social characteristics, like age, class and gender, have their contribution.

Data for the study (Ashley & Ashley, 2008) has been taken from the National Climatic Data Center (NCDC). Herein all data of occurrence of weather phenomena is stored, like loss of life, damage and sort of flood. Like briefly mentioned in chapter two the floods can be divided in three species: flash floods, river floods and coastal floods. From these three categories the flash flood deaths exceed those of other categories. This can be explained by the time interval wherein flash floods can occur. The short time range of heavy rainfall to a flood is the main problem, there is no time for a big scale evacuation plan. And especially in countries like the Netherlands where a big flood hasn't happened in a long time, people don't know how to react. In Figure 10 is shown how the fatalities are divided over the flood categories.

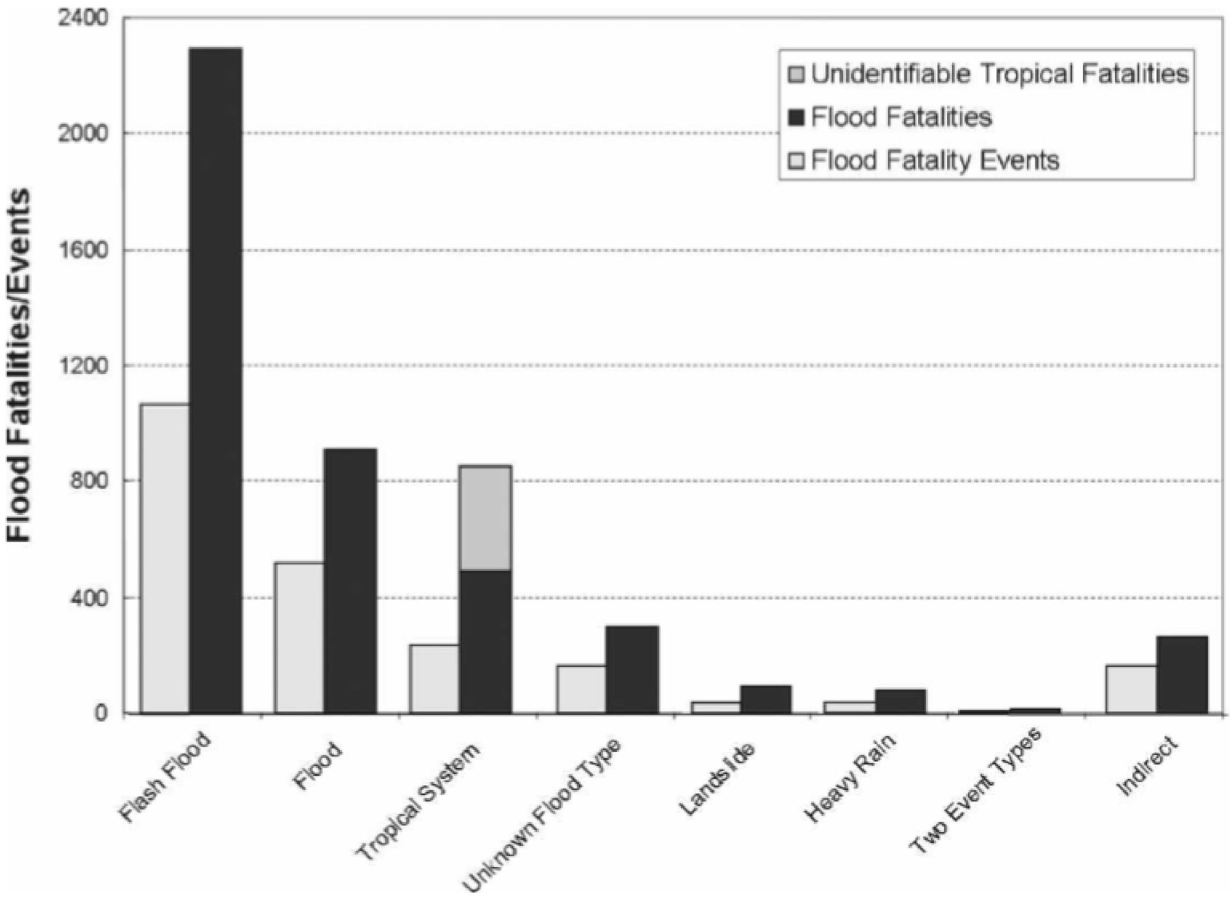

***Figure 10**: The frequency of fatalities and fatal events by flood event type in the United States of America. Black bars represent deaths only due flooding, grey bars represents the deaths followed from tropical systems, but not only due to flooding. Light grey bars are the events of flood fatalities (Ashley & Ashley, 2008).*

So one can say that it could be interesting to see what types of floods happen in what frequency. When a certain area is exposed to flash floods (fatalities) multiple times a year, then the flood risk assessment made in this study could give a divergent result compared to reality.

In Figures 11 & 12 the flood fatalities for river floods and flash floods are depicted. The numbers represent the raw number of total fatalities from 1959 to 2005. Directly can be concluded that in 80% of the states the number of flash flood fatalities is higher. This trend can be seen all over North America and this would suggest that further studies concerning this subject could be of help. How to implement these flash floods in the assessment as well? On the moment they are left out, because of the complexity of predicting and measuring these floods, but there should be enough knowledge to develop a method.

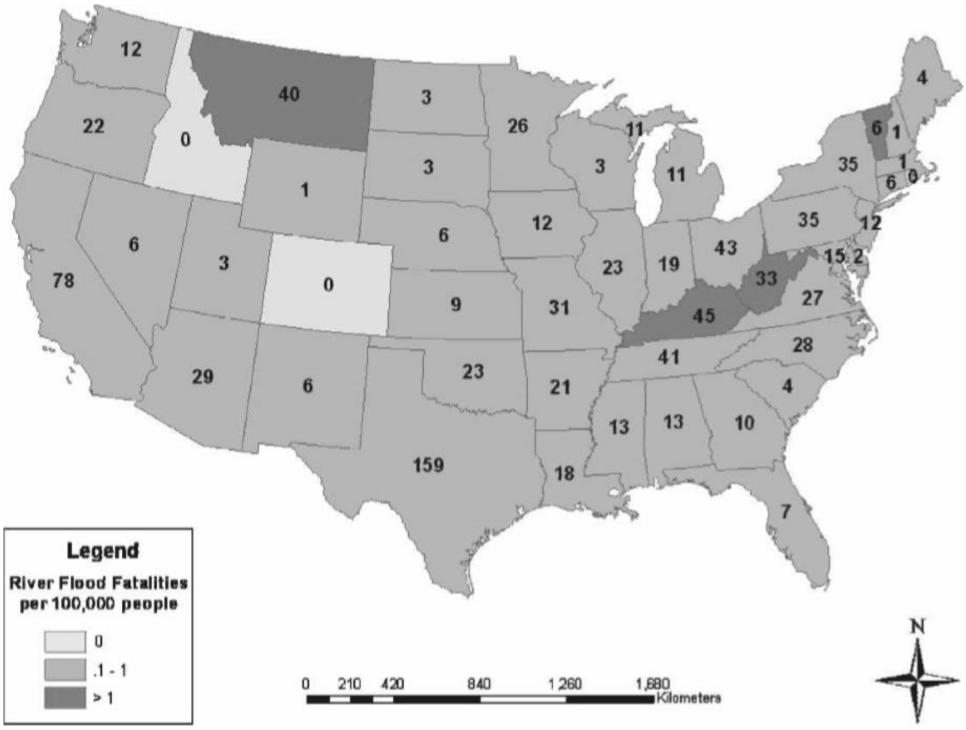

Figure 11: *All river flood fatalities by state standardized by population (per 100.000 people). The number in each state represents the raw number of total fatalities from 1959 to 2005. (Ashley, 2008)*

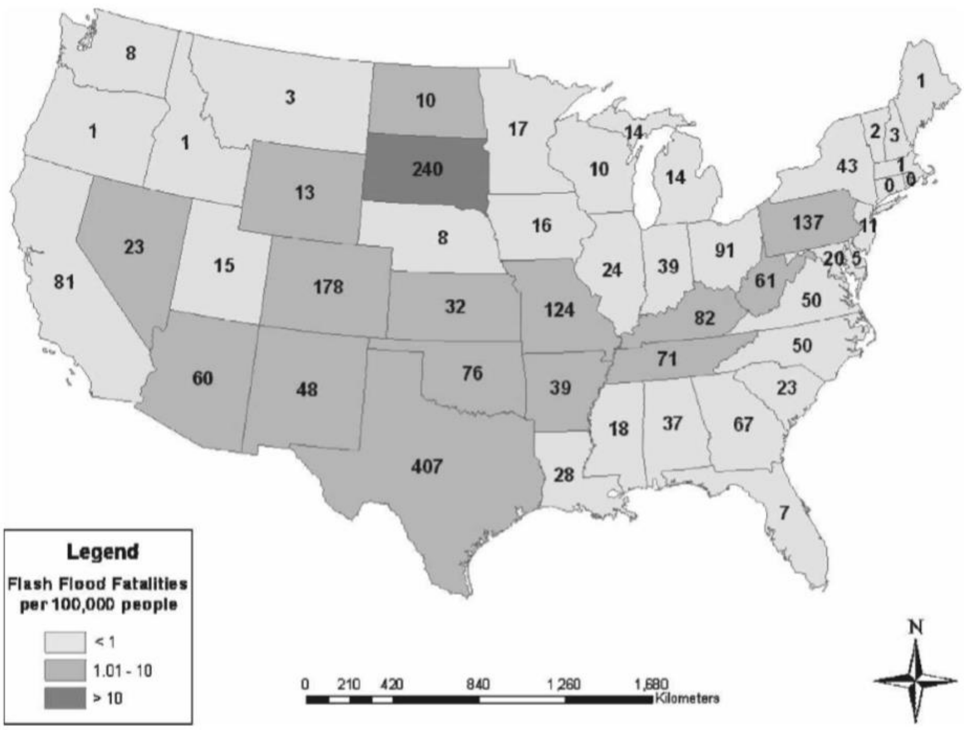

Figure 12: *same as figure 8, but then the case of flash floods (Ashley, 2008)*

5.6 Socio-economic development

Socio-economic development has had a minor introduction earlier on. Socio-economic development is the rate of the growth of welfare and population. The link with flood risk assessments is the number of assets that are exposed due to floods. With an increasing population, more buildings and services has to be build and thereby more land has to be used. When a residential building is built on this, until then, un-used ground, the vulnerability rises. The depth damage functions prove that a residential building is worth more than un-used land. In Figure 13 below the grow rate of cities in North and South America is given.

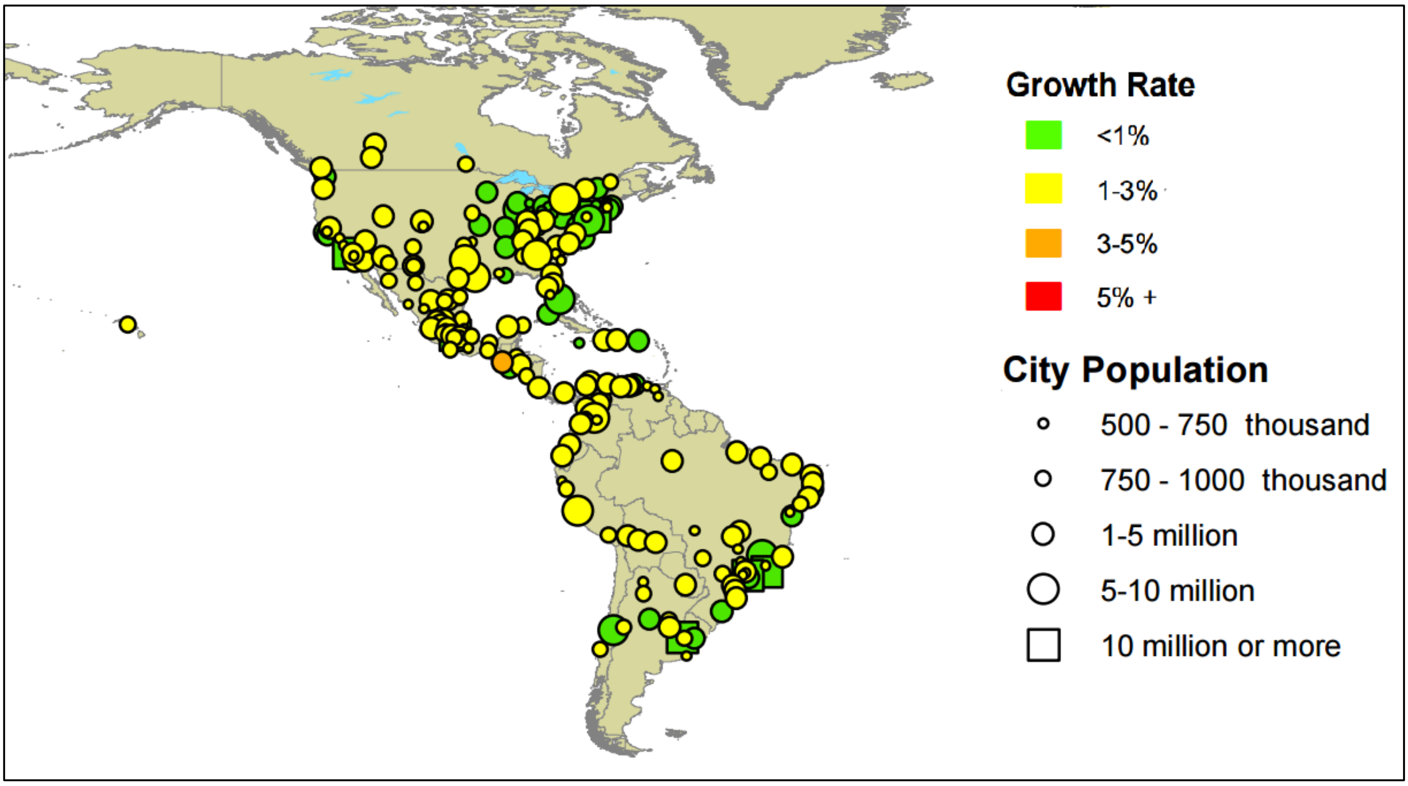

Figure 13: *Rates of growth of urban agglomeration per city for period 2014 - 2030. Obtained from United Nations, 2014*

As can be seen the most cities in North America will grow around 2% the upcoming years. And so the number of assets in the city areas will grow. This is where land use management comes in.

Land use management implementation differs per country, but also per state. This depends on the economic situation, the population density, geographic location, but also on the overall flood policy. Measures that can be taken for protection against flooding differ from small measurements, like making houses more flood-proof, till bigger actions like prohibit institutions to build in a hazard prone area. Measurements apart from urban planning can also be taken, like implementing a flood-risk depending insurance policy. This is one of the elements the United States of America uses.

The influence of the economic situation is expressed in the possibility to develop an urban planning policy and simultaneously execute them. This is possible for more developed countries, but for developing countries this is, most of the time, not possible. At the same time is the city population in developing countries rising faster than in the first world countries (United Nations, 2014).

Di Baldassarre et al. (2010) explained the link between growth of urban population and the increase of fatalities due to floods in Africa. So, intensive and unplanned urbanization on the continent Africa and thereby the increase of inhabitant in floodplains has led to an increase of the consequences of floods. As a solution he brings up to introduce flood forecasting system, building of public awareness and preparedness, but most highlighted is the discouragement to live in flood-prone areas. This is focused on the African continent, but translated to North America this can be seen as the basic management. The building of public awareness and preparedness is equally important in this continent and the discouragement is already be done with the insurance policy.

For the radar chart that will follow from this chapter this means that land use management is definitely something to take in to account. This land use management will not have a direct impact, this is more future-based. Urban planning is for preventing the risk getting higher in the future. Therefore it will not be very decisive for the risk at the moment, but it is something to keep in mind. The presence of land use management policy in a certain area will create a bit of comfort, it shows that there is a plan for the upcoming growth of the population and this plan will, most likely, be there to prevent assets being built in hazard-prone areas.

5.7 Traffic Management

Another aspect that can be grouped under land use management is the infrastructure. This is, opposite to urban planning, especially important for during and after a flood event. When water is rising there are several options to save yourself. One of them is to 'escape' or better said to be evacuated. People are going to higher ground or move itself more landward. In most of the cases this is done by getting to the highways as fast as possible, but as a result there will be traffic jams.

Kolen et al. (2010) distinct four types of traffic management, used in the Netherlands, but applicable in other countries:

- Reference: lets inhabitants free in their choice regarding the method of evacuation. In traffic management terms this can be seen as a bad scenario because of the unpredictability.
- Nearest exit: inhabitants are assumed to be evacuated preventively by going to the nearest exit, without taking the capacity into account. This can also be seen as a bad scenario, because traffic jams are guaranteed.
- Advanced traffic management: evacuees are equally distributed over available exit points, with taking the capacity in to account. This can be seen as a good scenario, because there is an overview of the locations of all inhabitants.
- National Concept Traffic Management: this is a Dutch specific type of traffic management. The entire Dutch highway system is used to regulate the flow of evacuees. The focus is not only on the affected area, but also on the surroundings. The evacuees are familiar with the routes, because under normal circumstances these roads are also used to reach their destinations. More info on the National Concept Traffic Management can be found in the study of Kolen et al. (2010) or Holterman et al. (2009). Note has to be made that this report is in Dutch.

The time available for the evacuation of river areas is 72 hours, for coastal areas this is 24 hours. This window, especially for coastal areas, is not long at all. As is shown in the figure below after 24 hours there are still a lot of cars on the road in the area of the Netherlands that is below sea level. Even though this is the situation with an advanced form of traffic management. These bottlenecks, for example the one marked in Figure 14 with a red circle, can cause a lot of fatalities. So concluded can be that traffic management and infrastructure is an essential subject in flood emergency management and land use management respectively.

For the North America study performed in this thesis it is a reasonable aspect to take in to account. However to compare different traffic management types is not the aim of this thesis. The aspect traffic management will be taken in to account by seeing if there are enough escape roads available, thereafter it will be stored under land use management. When another header is added to the radar charts it will become messy and unclear. In the future a study on this subject could be investigated to get a better overview of which type of management is effective and which is not.

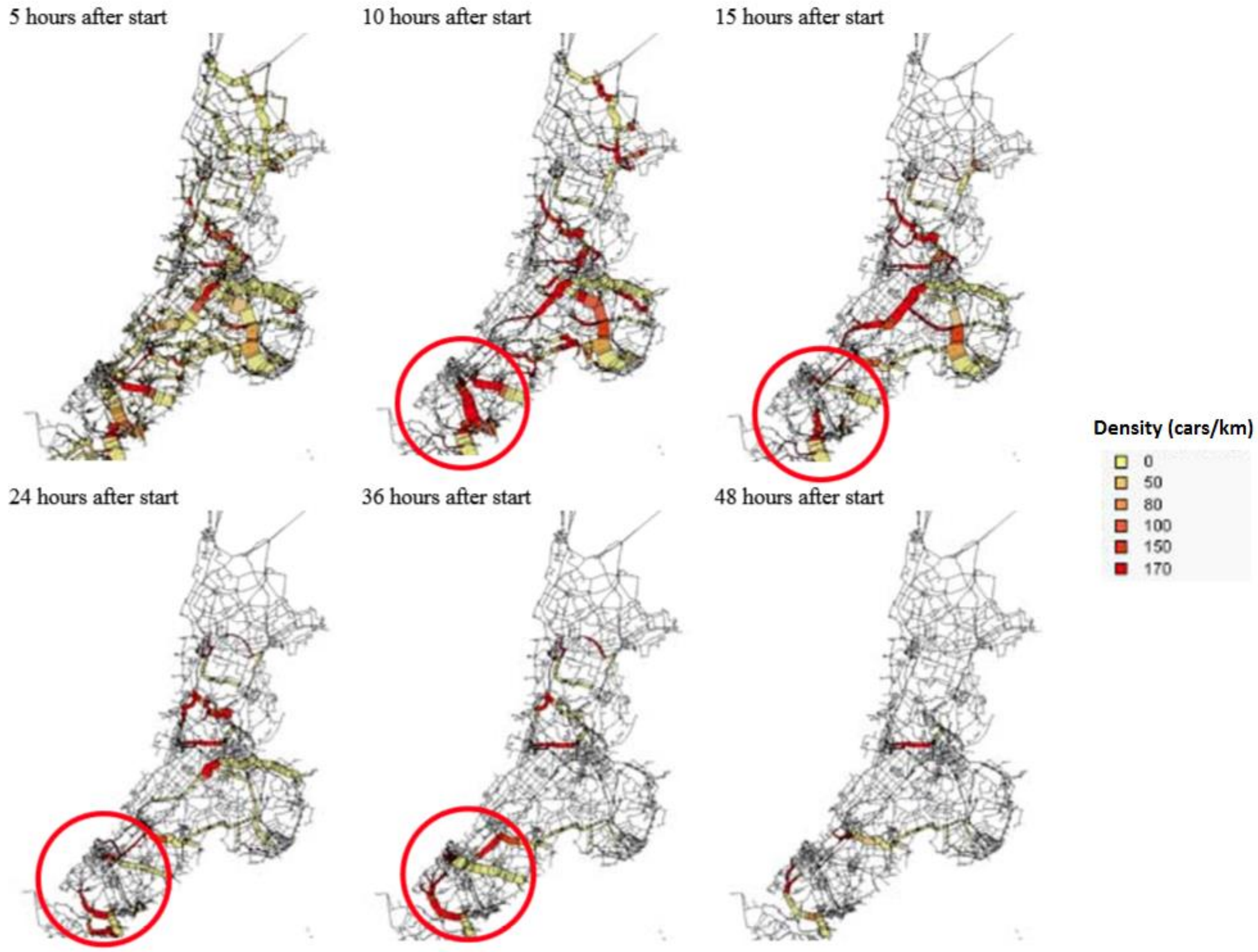

Figure 14: *Progress of evacuation in the Western part of the Netherlands with advanced traffic management. (Kolen, 2010)*

5.8 Climate changes

As mentioned in section 2 is climate change also one of the parameters that influence flood risk. Climate change can be taken in to account in the calculation of the Flood Impact Assessment Tool. There are several models that can 'predict' the climate change in the upcoming years and what kind of influence they have on flood risk assessments. However earlier studies (Schilder, 2016; Nootenboom, 2015) have shown that the influence of these scenarios is not as big as was expected. Only in countries with no or a very low reported protection measurement maintained show that the influence of the climate scenarios is notable. Nootenboom (2015) states that the effect in Europa and North America is much smaller than in, for example, India, China and Russia.

The input parameters for the climate forcing are based on different Global Climate Models (GCMs). These model come from different institutes and countries, because of that there can be said, with high confidence, that the input parameters are valid. Simultaneously can be said that the results of Nootenboom (2015) will be trustworthy and therefore can be concluded that the impact of climate change is minimum.

Yet, it can be taken in to account for flood risk assessments. The models are predicting a future scenario by extrapolating the current trend in climate developments. Maybe it can get worse than we would have expected. City specific results however will not be influenced by a, for example, car free zone. To decrease the already small influence of climate change it has to be done by everyone. All over the world. So for the overall view it can be important, but for city-specific flood risk assessments it is not necessary to map all climate policy actions.

5.9 EMERGENCY MANAGEMENT

After the Watersnoodramp the Dutch government composed a commission that should develop a plan for water retention in the Netherlands. This commission, the Delta Commission, came up with a plan that would protect the Netherlands against most of the storms. This plan was purely focused on the highest protection standards in return times. This has been executed and up to the present day these flood protection measurements did their job. The latest years however, there have been a shift of the focus of flood protection. Reality is that flood protection consists of multiple elements. In the Netherlands the protection standards are very high and the change that something will happen is small. However, if a flood occurred that breaks the Dutch structural measures the results will be disastrous. The Netherlands is not prepared for a flooding. And that is why the 'multiple layer safety' is introduced. This method is a result of the NUWCReN. This organisation is a coalition between Dutch and American experts. They share experiences and information about floods. Multiple layer safety consists of the following elements: prevention, land use planning and flood response planning. In the United States the focus of the flood protection is on all three of these elements where the Netherlands only focused on the first layer (Kolen et al., 2011).

The shift of focus in the Netherlands occurred because you can't develop an absolute protection for flooding. That is the reason that there is an increasing amount of effort and interest for the emergency management. Emergency management consist of multiple elements like early warning systems, disaster planning and evacuation management. The transition from normal life to evacuation mode is basically the definition of emergency management. This is shown in Figure 15. At first the early warning systems give a signal (Td), this warning has to be evaluated. Is the treat dangerous enough to start an evacuation plan or not? This decision (Tc) is made and from that moment on the evacuation should start. This can be started with informing the public, relocating rescuers and aid workers and give traffic information (Kolen, 2013). This all is part of the transition (Tt), the effectiveness of this stage is determined by the existence of evacuation plans and a clear structure for who is responsible for which aspect. From that moment on the evacuation is put in motion and thereby the effectiveness of governments' choices is decreasing. One can say that the first steps are the most important steps in saving human life.

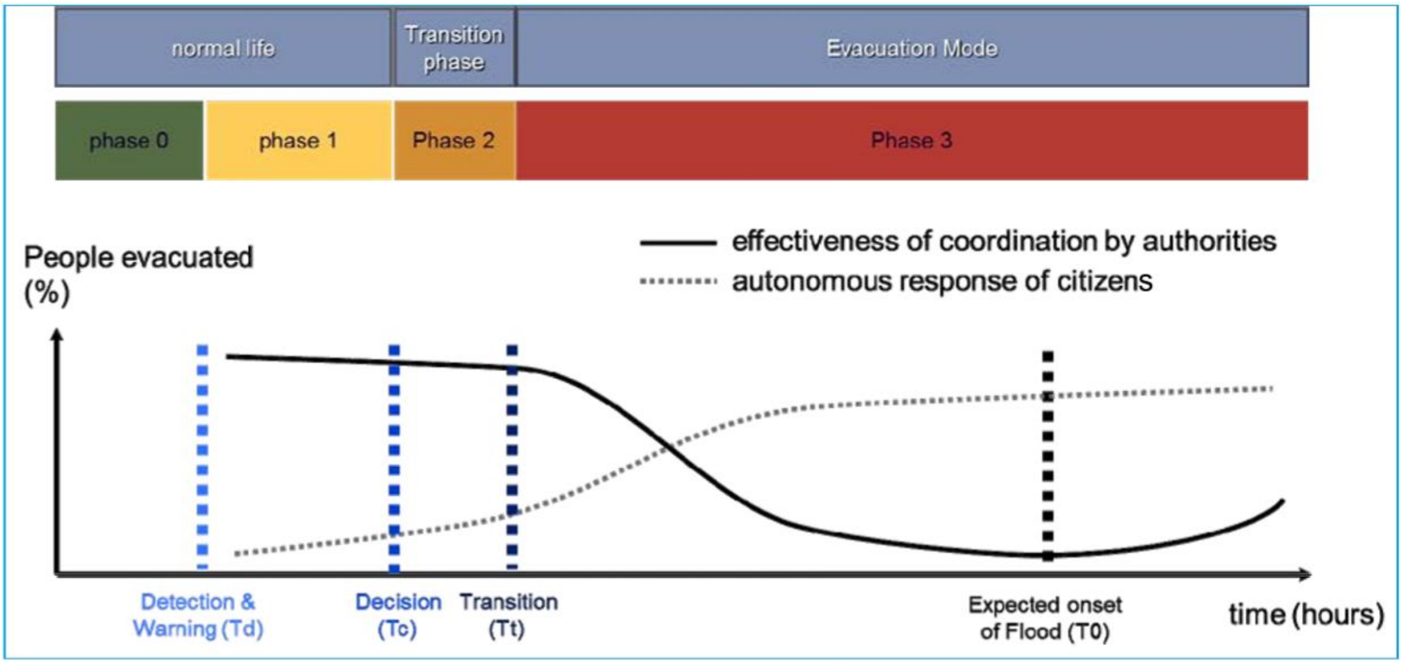

***Figure 15**; Effectiveness of strategic decision making by the government related to the response of citizens over time (Kolen, 2013)*

So these first steps can be seen as phase 2 in the figure above. This so-called transition phase looks like the most important step in emergency management. Here the most process can be made in terms of number of people evacuated. One of the aspects that can influence the response of citizens is the existence of early warning systems. Those systems give a warning when a potential treat can occur. In this stage of emergency management these warnings can form a guideline for the following procedure and thereby have a positive result on the number of people that can be evacuated.

Early warning systems can link the weather prediction to several structural and technical aspects in a certain area, and from that detect a possible threat. But early warning systems can also calculate the dike quality (Krzhizhanovskaya et al., 2011). Breaches in dikes can be predicted and thereby possible threats can be prevented by improving the dike stability. However these type of systems are for support only. As is the case for structural protection measurements these early warning systems can fail as well and with that fail to predict a possible disaster. Early warning system should be present for guidance during the decision making, but not decisive. Common sense has to have the upper hand.

5.10 Other aspects

Note has to be made that the aspects discussed in the previous sections are not the only input parameters that could be of influence for a flood risk assessments. There are numerous other aspects that could be examined. For example the influence of the PCRaster GLOBal Water Balance (PCR-GLOBWB) model. This model is basically the aspect that determines the characteristics of the floods. Van Beek & Bierkens (2008) have shown that the results are more exact than previous models, but the PCR-GLOBWB model is still under construction. The travel times of ground water could be described more precisely and simultaneously the floods could be described more accurate.

Also the types of floods that are occurring over the years can be an interesting factor. Is an area mostly effected by coastal floods or by flash floods? This changes the approach of the flood risk assessment. As mentioned the flash floods result in more fatalities and coastal floods result in more direct, tangible damage. Should flood risk be expressed in monetary values or in fatalities?

So this paragraph emphasizes the fact that this report is not an exact guideline for following flood risk assessments. Main function of this report is to highlight several aspects that could be of influence, and simultaneously could possibly be investigated or studied in future researches.

5.11 Flood Assessment Elements Fiche

This all results in a radar chart that should give an overview for the flood risk per city. In this chart can be seen what is important and what is less important for flood risk assessments. If these radar charts show a clear similarity then can with high confidence be said that the focus of future flood risk assessments could be on that specific element. The proposed elements of the chart are shown in Table 6 below and follow partly from the paragraphs above.

Element	Maximum Score [10]	Minimum Score [1]
Flood Fatalities due to Flash Floods	Number of fatalities is 240	Number of fatalities is 0
Flood Experience	Lot of flood events / Recent floods	No flood events / Long time ago
Population Density	High density compared to rest of North America	Low density compared to rest of North America
Population Development	High grow rate (>5%)	Low grow rate (<1%)
Protection Level according to Scussolini et al. (2016)	High protection standard (1/10000 yr^{-1})	Low/No protection standard (1/1 yr^{-1})
Risk	High risk value following from FIAT	Low risk value following from FIAT
Urban Planning	Active land use management including traffic management	Non active land use management including traffic management
"Real" Protection Level	High protection standard (1/10000 yr^{-1})	Low/No protection standard (1/1 yr^{-1})

Table 6: *Flood Assessment Elements*

All these elements will be scaled from 1 to 10 and from this follows a radar chart like the example in Figure 16 below.

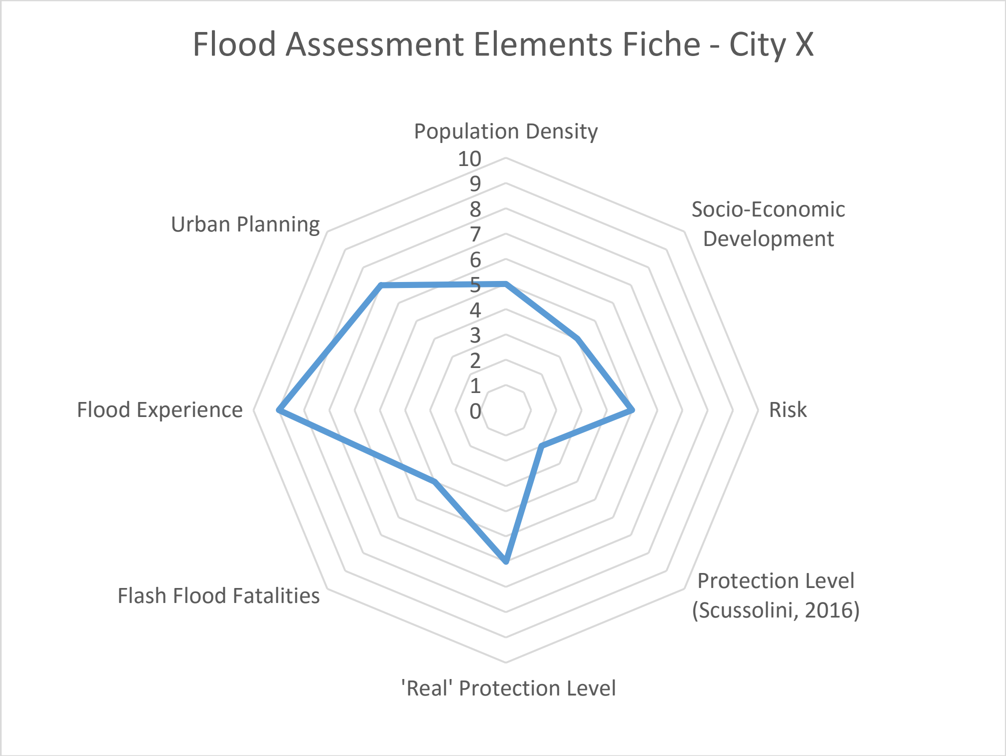

Figure 16: *Flood Assessment Elements Fiche of City X.*

It has to be said that the values attached per category look a bit arbitrary, that is because it is a bit own opinion based. So it is hard to reproduce for further studies, with the next section 'reading guide' is tried to explain the rating system. The fiche is going to be developed for a number of cities. The cities chosen are the top five cities of the flood risk ranking presented in chapter four in Figure 7. The cities are also marked with red dots in Figure 17. Immediately can be seen that all cities are located at the sea.

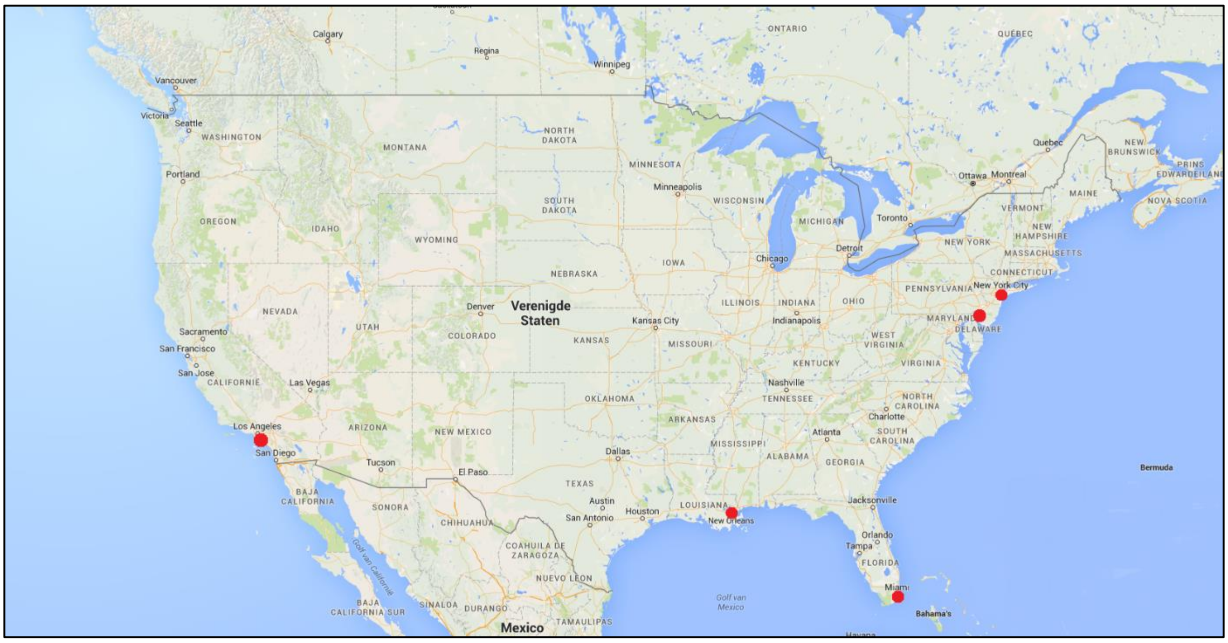

Figure 17: *Geographic Location of the cities taken in to account. Left to right: Los Angeles, New Orleans, Miami, Philadelphia, New York City. (Google Maps, 2016)*

5.11.1 Reading guide

The Flood Assessment Elements Fiche (FAEF) is meant to be a tool, from which information can be taken quickly. This paragraph will contain some explanations about how to read the tool showed above.

Risk is the main element of this fiche, all other components on the fiche can be seen as a part of risk, or better said part of the flood risk assessment. As already demonstrated the Protection Level of Scussolini et al. (2016) is taken in to account for the FIAT tool and this is very decisive for the final value of the yearly expected damage, i.e. risk. The protection data is rated as follows:

Return Period [yr^{-1}]	1/5	1/10	1/25	1/50	1/100	1/250	1/500	1/1000	1/5000	1/10000
Value	1	2	3	4	5	6	7	8	9	10

Table 7: *Rating of the element: Protection Level*

The source for this Protection Level does seem doubtful, mentioned in paragraph 5.2, that's why the 'Real' Protection Level is also taken in to account. This value will present the value that municipalities attach to their own area. The basis for this value is the value of the Protection Level of Scussolini et al. (2016) and the value in the FAEF is based on a consideration if the real values equals, exceeds or doesn't exceed the Scussolini' value.

The value of the element flash flood fatalities is scaled to the maximum amount of fatalities following from (Ashley & Ashley, 2008). The states that has the highest amount of fatalities is South Dakota with a number of 240 fatalities. So the Flash Flood Fatalities element is rated as follows:

Flash Flood Fatalities	0-24	25-48	49-72	73-96	97-120	121-144	145-168	169-192	193-216	217-240
Value	1	2	3	4	5	6	7	8	9	10

Table 8*: Rating of the element: Protection Level*

The value for Flood Experience is own-opinion based. When a lot of flood events happened recently this will most likely end up in a high score, while a lot of flood events in the 19th century doesn't really matter, because there are no persons a life that have experienced those floods. So it is the consideration between time span and quantity. A high score on flood experience could mean that people and government know how to handle in case of an upcoming flood. This will most likely have a decreasing effect on the risk and fatalities in the future.

Element Urban Planning consist of multiple features. There should be a plan regarding the urban area with respect to floods. Floods can be taken in to account when for example houses are made more flood-proof. Also preventing building residential areas in flood prone areas is an element that can contribute to a right urban planning. At last the traffic management is taken in to consideration. This element will be reviewed on the basis of the amount of escape roads landward. A good urban planning will most likely result in a quick escape route and less escape time needed, this will have a decreasing result in flood fatalities.

At last are the elements Population Density and Socio-Economic Development. A high population density means that a lot of people and assets are affected by a flood at this time and a high socio-economic development rate will most likely result in more people and assets that are affected by a flood in the future. The Population Density value is scaled to the densities in North America and the socio-economic development is scaled to the grow rates in the whole world.

Socio-Economic Development	<1%	1 – 3%	3 – 5%	>5%
Value	2.5	5	7.5	10

Table 9*: Rating of the element: Socio-Economic Development*

5.11.2 New Orleans, Louisiana

The city that is leading the way in the flood risk assessment in North America is New Orleans. When the protection data is not implemented the yearly annual expected damage is 184.9 billion euros. This is partly because of the geographic location of New Orleans. The city is located on the banks of the Mississippi and is surrounded by several lakes. Both these elements are very sensitive for heavy rainfall for example. As a result the whole shapefile, used in the Flood Impact Assessment Tool, is covered by the flood hazard extent (Nootenboom, 2015). This will lead to damage for every category in each location.

At first the amount of flash flood fatalities for the state Louisiana is checked in Figure 12. The number of fatalities per 100.000 inhabitants is 28. In comparison to the maximum fatalities in the United States of 240 fatalities, in South Dakota, the amount of fatalities in New Orleans is minimal.

The population density is a measurement for the amount of people that could be effected by a flood, also the number of assets will be high when the population density is high. The number of people living in an area are a measurement for the number of buildings and facilities in that area. The population-weighted density by distance from city hall, based on the population of 2010, for New Orleans is not as high as the other cities taken in to account (Census, 2015). This number has been dropping since hurricane Katrina. Compared to other cities in North America, this number is not outstanding. The decrease of the population density has as consequence that there is more room for socio – economic development. Socio-economic development prospect of the United Nations (2015) is a 1 – 3% range. New Orleans is currently being rebuild, so there will be a possibility to develop a bigger city. This socio-economic development will result in more assets being built in a flood hazard prone area, which will subsequently increase the risk.

Protection level maintained in New Orleans is to protect the city against a 100-year storm (Scussolini et al., 2016). These standards are being implemented at the moment. The situation before hurricane Katrina was worse, the protection levels at that moment were to protect New Orleans against a 30-year storm (Kok, 2007).

Because of the activities at the moment, the 'real' protection level at the moment will not be able to protect New Orleans against a 100-year storm. Billions of dollars are spend on facilitating the higher protection level (Kates et al., 2006). The new protection system should be the best flood control system of all coastal cities in the United States of America. The US Army Corps of Engineers states that the improved levees offer a near-complete protection against the 100-years flood and reduce the damage significantly from a 500-year flood event.

In Figure 18 the floodings during and after hurricane Katrina are shown. As can been seen several areas are left with more than ten feet of water during that time. At the right are the breached levees shown with the colour yellow. This was the main cause of the flooding.

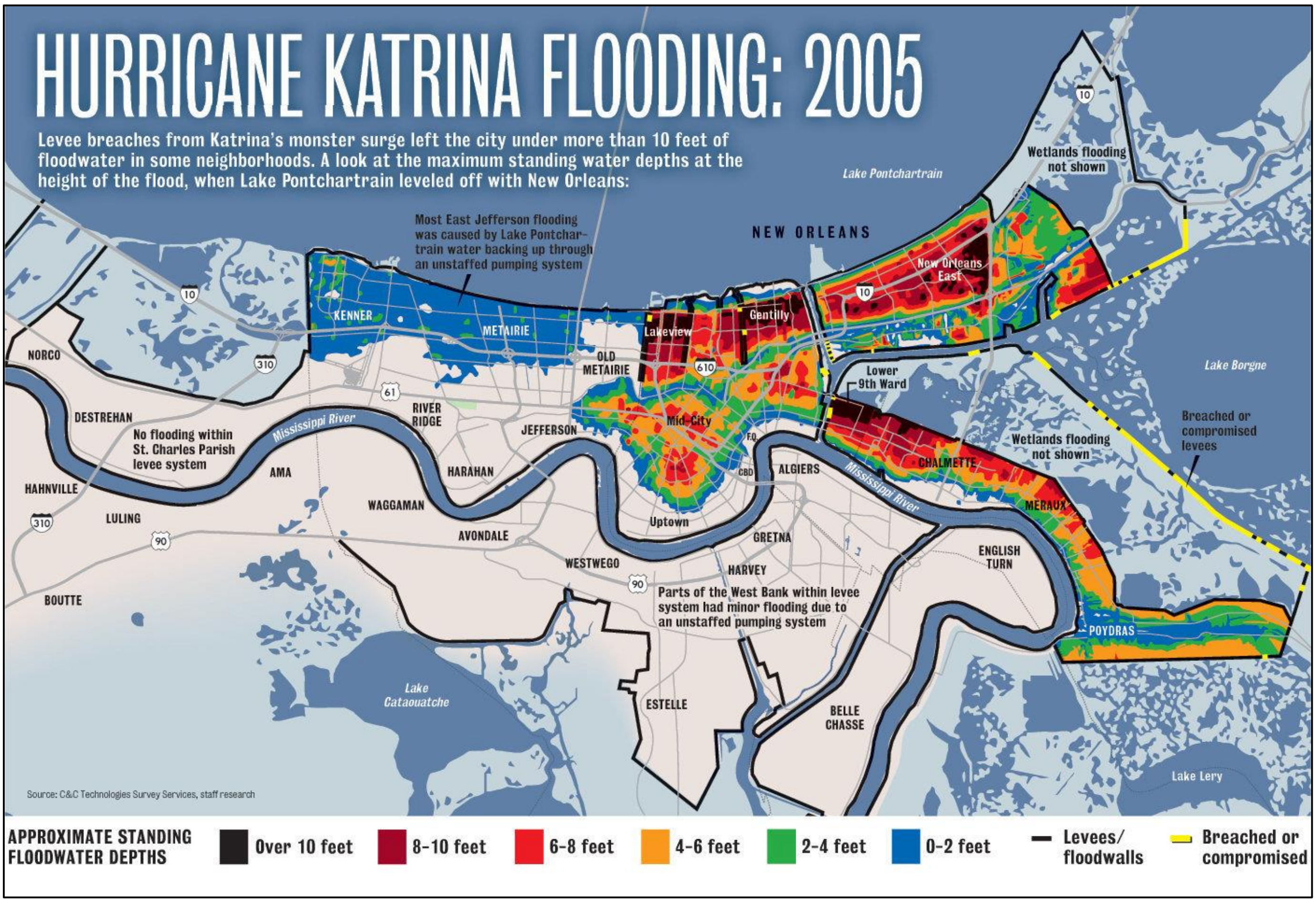

Figure 18: *Approximate standing of floodwater depths during the Katrina flooding in 2005 in New Orleans. (C&C Technologies Survey Services)*

The US Army Corps of Engineers designed a completely new system of flood protection that should be the best of whole United States of America. This system is not only about building dikes and storm surge barriers, but contains also ridge restoration, barrier island restorations, marsh creation and sediment diversion (State of Louisiana, 2012). In Figure 19 is shown how a 500-years storm will cause floodings. All white areas show new barriers or pumps that are built or planned. Immediately can been seen that the inundation depth of this flood is significantly lower. Note has to be made that these flood depths are assumed when 100% of area pump stations are in operation. After producing this data, quickly was announced that these protection measurements are aiming to protect property and not inhabitants. People don't have to fall back in a mind-set of 'this will not happen to me'.

So on first sight it looks like the whole of New Orleans is protected against a 500-years flood, but this isn't the case. The people living in the city will be safer, at least for a limited time span. This limited time span is because of the changing character of the floods. More floods with a destructive character could come up in the future. But people living outside of the city walls are under constant threat of a new storm (Fischetti, 2015). This is because of the wetlands, which are part of the first defending line. The area of this element is reducing yearly due to the oil and gas industry which take all this to make more money. With this first defence line disappearing the protection level lowers as well.

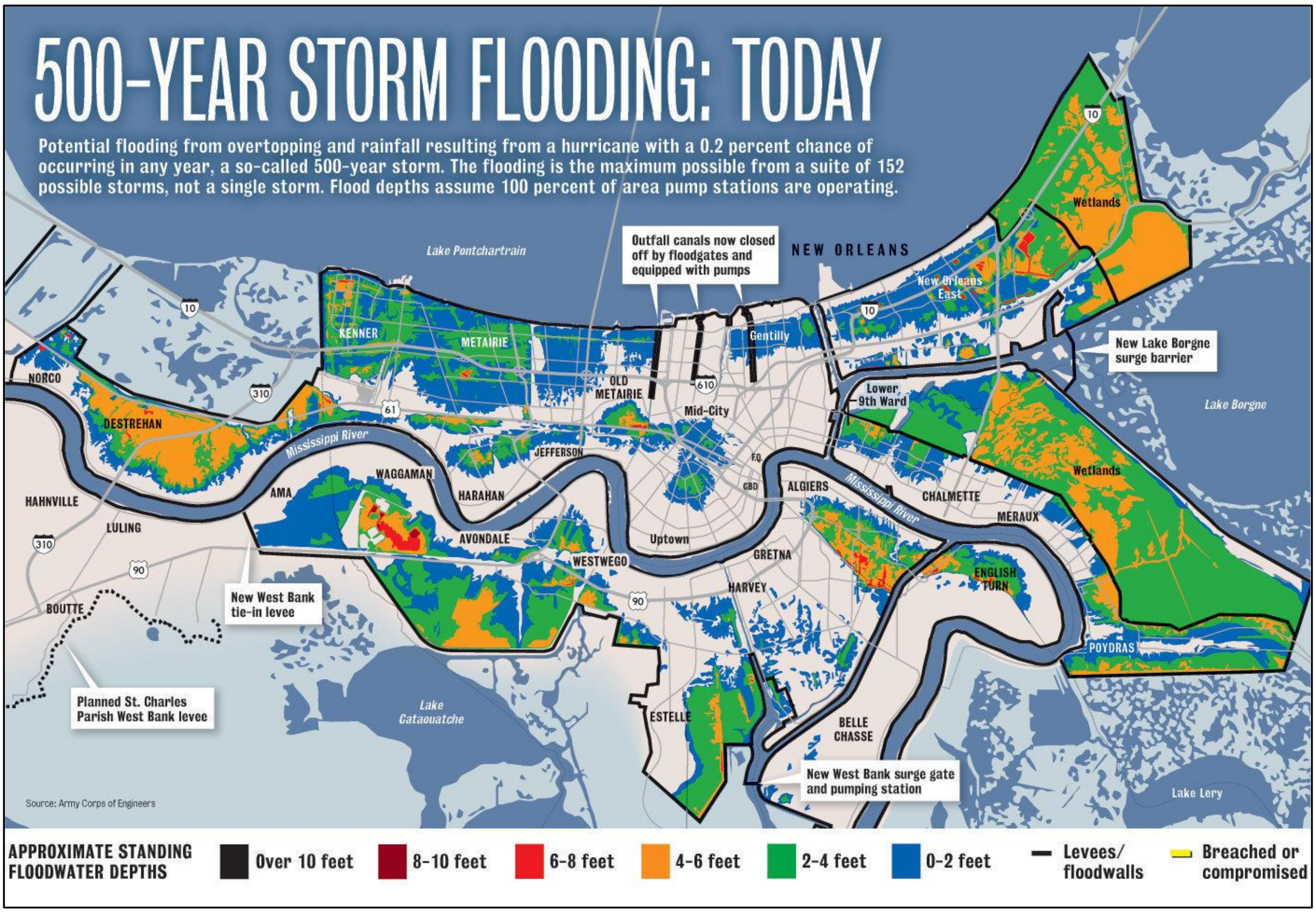

Figure 19: *Potential flooding due to a 500-year storm flooding nowadays in New Orleans. (US Army Corps of Engineers)*

Flood experience can play a big role in the behaviour of a human, also it is mostly a wake-up call as well for the government. The experience that one can have during a flood is that people are getting more interested in floods and are more likely to study the natural phenomena. This studies can lead to better behaviour next time a flood happens. The government is influenced by the fact that the protection standards were not high enough and they should invest. Also they experience the effectiveness of the evacuation plan. This can only be tested in a real situation. Significant floods in New Orleans have happened quite often over the last years. Perfect example is hurricane Katrina, but also in 1927 due to excessive rainfall the Mississippi overflowed its banks and in 1969 hurricane Camille came by (Perry, 2000). So it can be said that the city of New Orleans is experienced with floods.

Louisiana State, FEMA or New Orleans itself, no one was prepared for rebuilding a city. (Olshansky et al., 2008). Multiple problems had to be tackled before the real planning could start. A lot of ingredients were missing, there was no cooperation between city and state, no strong local leadership and there was no pre-existing planning institute. All these missing items caused delay (Olshansky et al., 2008). Finally there was a structure and there could be started discussing and planning. Two methods were encouraged for reducing the effects of future floods. Elevating structures and clustering buildings at higher elevations. Subsequently there had to be dealt with housekeepers and construction techniques that were not well enough for this kind of measurements. People had to leave their homes and has to take several deals to compromise them. But it can be concluded that the government of New Orleans had a big wake-up call. Next time such a drama occurs, there will be a clear structure available. Everybody can be pointed to his responsibilities and there is the experience of a recent flood.

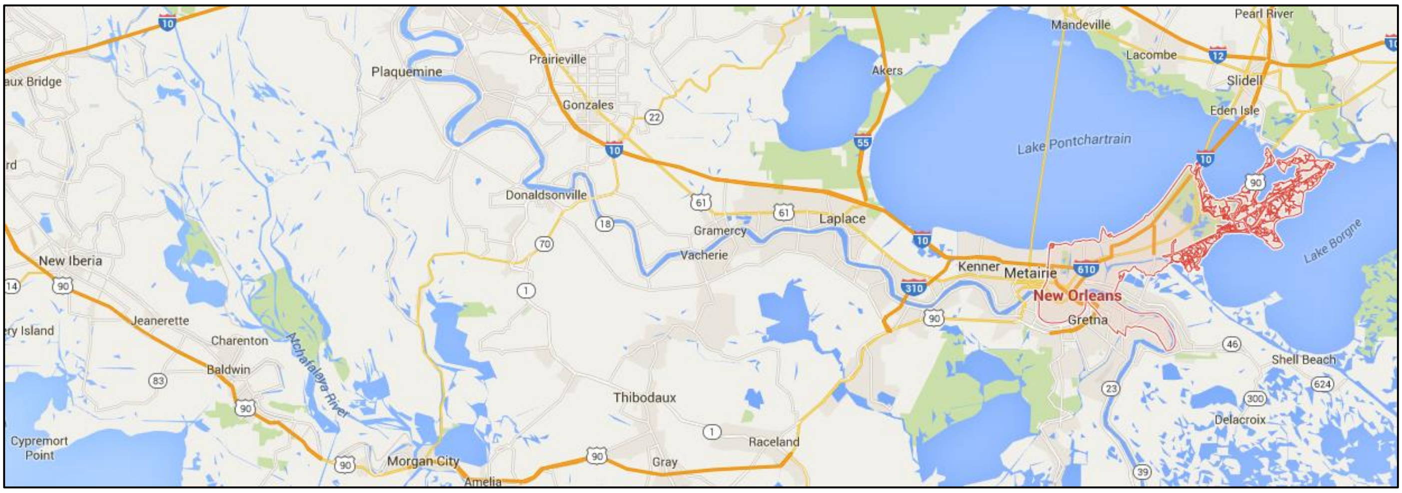

Figure 20: Roads leading landward from New Orleans (Google Maps, 2016).

From a traffic management point of view the options of New Orleans are quite limited. When trying to 'escape' New Orleans there are only three main roads going landward. Which includes one were the Mississippi has to be crossed, most likely this is not possible at the time of a flood. When inhabitants all get into a car this will cause traffic jams. Therefore, the evacuation management should start as early as possible, otherwise not everybody can leave the city.

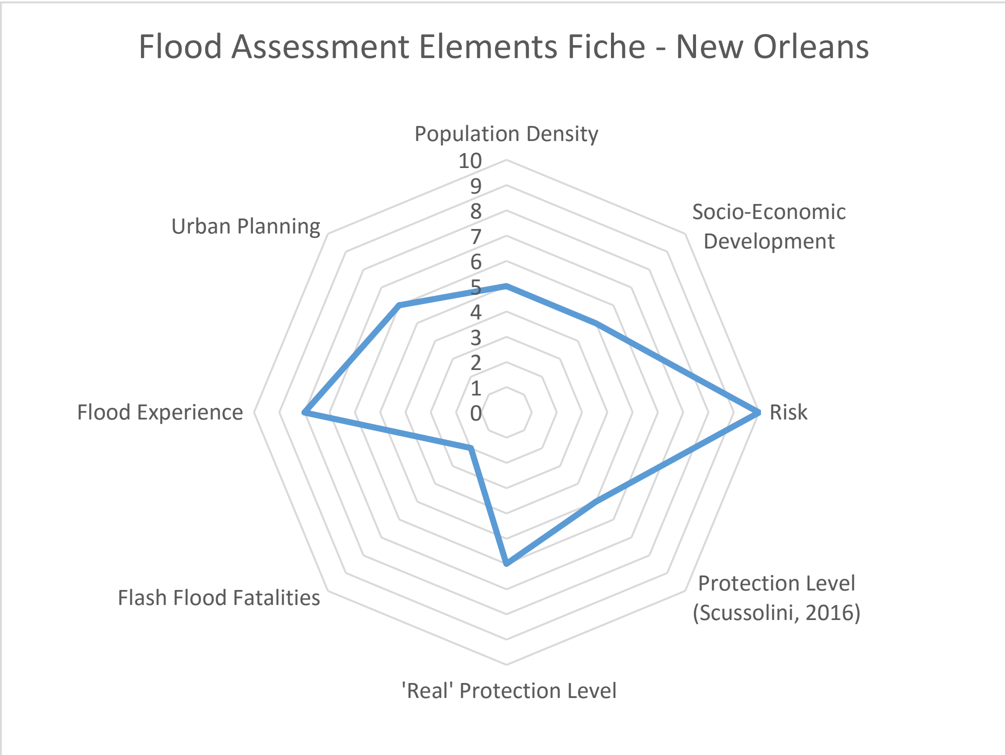

Figure 21: Flood Assessment Elements Fiche of New Orleans

The Flood Assessment Elements Fiche (FAEF) of New Orleans is shown in Figure 21. Several elements should be highlighted. The risk is outstanding high, obviously, but the factor that is highly reducing this risk is the Protection Level, which seems to be higher in real than Scussolini et al. (2016) stated. The amount of flash flood fatalities plays no role, but the flood experience does. This could be of help for further floodings for government and citizens.

5.11.3 Los Angeles, California

The expected annual damage for Los Angeles without the protection standards taken in to account equals 13.2 billion euros. Compared to the damage occurring in New Orleans this looks like nothing, but 13.2 billion euros is still significant. The difference can be explained with the fact that Los Angeles will not be covered completely by the flood hazard extent.

The amount of flood fatalities following from (Ashley & Ashley, 2008) is 81, compared to the maximum of 240 this is more significant than New Orleans. Although it is not shocking, it could be something that could be taken in to account in the future, for Los Angeles.

Los Angeles is one of the densest populated areas in North America. Due to this density the amount of fatalities and assets exposed are increasing. Therefore the risk is rising, although it is not taken in to account in the Flood Impact Assessment Tool. As a result of this high density there is less room for expansion. The socio-economic development will be limited. This follows from figure 13, the growth rate is approximately <1%.

In the beginning of the 20th century Los Angeles was plagued with two major floods. At first in 1938 when two cyclones moved through the Los Angeles region and one year later due to a tropic storm that let the Los Angeles River exceed its bounds. These floodings took place a long time ago and aren't very likely to be experienced by current inhabitant. Hurricane Marie however took place recently. In 2014 this destructive natural hazard moved past the coast of California. This recent hurricane also came with an excessive amount of water, but only a swirl of this hurricane hit Los Angeles. This swirl caused some high water levels, but nothing out of proportions. So it can be said that Los Angeles isn't very experienced with recent destructive floods. However the South Californian coast has to deal with El Niño storms. These storms are caused by a flow of warmed water which has influence on the weather. So Los Angeles has to be on guard all the time. Soon the US Army Corps of Engineers starts to improve the vulnerable parts of the Los Angeles River due to those El Nino storms (USACE, 2016).

The policy layer of the FLOod PROtection Standards (FLOPROS) shows protection standards for the 100-years flood, just like most of the states in the United States of America (Scussolini et al., 2016). This protection level isn't equal to some other countries. Like mentioned earlier, the standards in the Netherlands reach 1/10000 yr^{-1}. According to Federal Emergency Management Agency (FEMA) the areas marked in Figure 22 are vulnerable for flooding. The flood zones are marked for the 100-years flood and the 500-years flood. This mapping is done by FEMA for insurance issues. For the 100-year flood zone an insurance is obligatory. It should be noted that there are definitely areas that are protected against a 500-year flood. Only it is doubtful to what extend these maps are reliable. In 2011 FEMA asked people to contact the company when they had information to share about: digital mapping data, structural elements at risk, historic information about flood hazards and current flood studies (FEMA, 2011). So the data is still being gathered and analysed. This raises questions about the reliability.

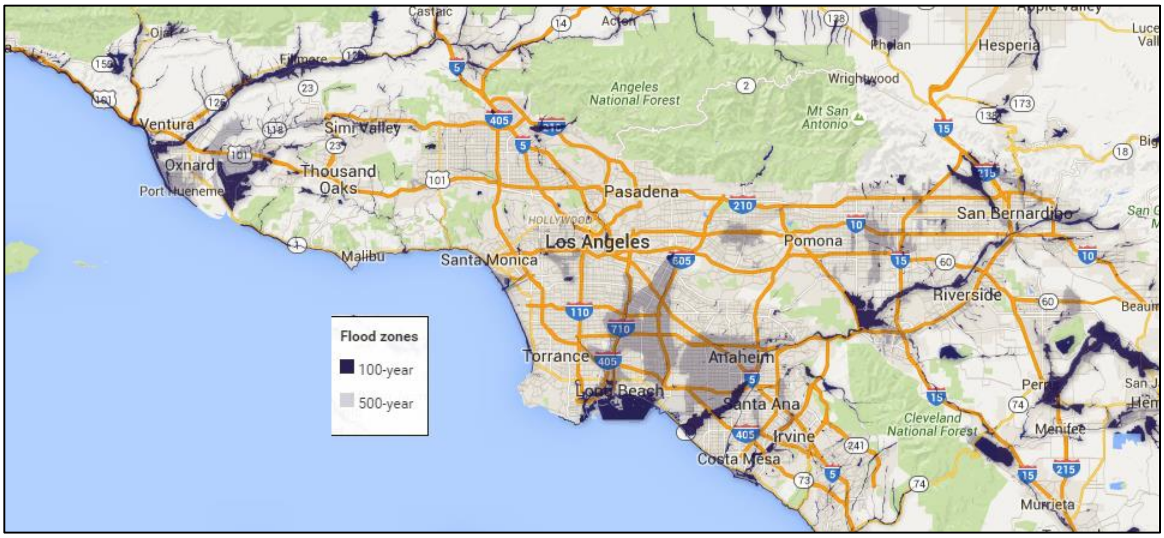

***Figure 22**: Flood areas in Los Angeles area (FEMA, 2015).*

The flood control authority for Los Angeles can be divided in three layers. The first upper layer is the US Army Corps, they are responsible for construction of structures and flood control systems all over the United States. Second layer is the LA County Department of Public Works. This Department is designing and maintaining the flood control drainage facilities, which should provide for the 100-years and 500-years floods. Third layer is the City Bureau of Engineering, the responsibility of this Bureau is to construct and maintain the structures that mitigate 50-years storms (City Planning Los Angeles Department, 1996). It is clear to see that the responsibilities are defined in a proper way.

Land use planning is an essential point in protection the inhabitant against flood events. In the United States of America the Flood Zone Maps are quite decisive for the land use planning. Several legislations encourage the fact of using those maps as guideline (City Planning Los Angeles Department, 1996). This is because compliance with the National Flood Insurance Act (NFIP) makes the government eligible for the FEMA funds. In this way the municipality looks mandatory to manage its land use planning.

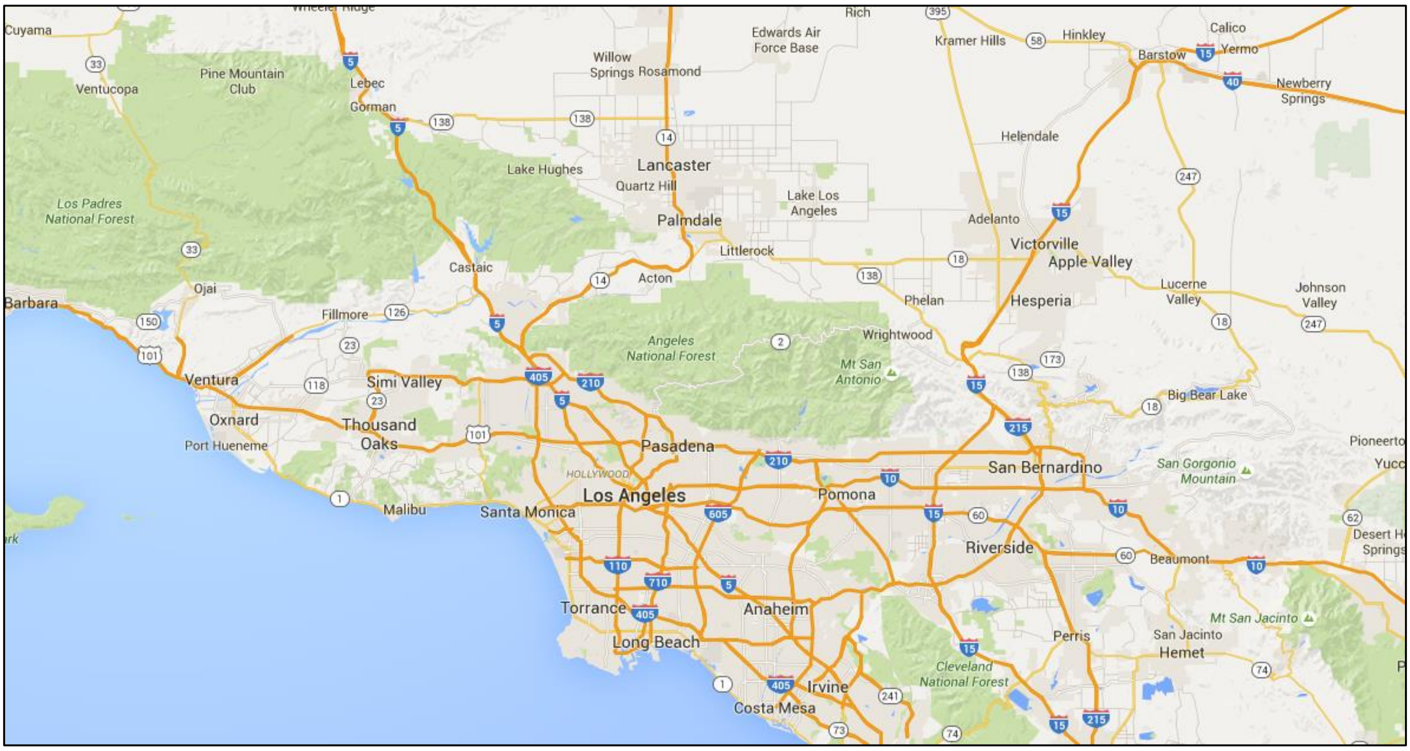

Figure 23: Roads leading landward from Los Angeles (Google Maps, 2016)

As can be seen in Figure 23 there are multiple options to get landward when living in Los Angeles. Compared to New Orleans the amount of options increased a lot, but that is necessary because the number of inhabitants in Los Angeles is much higher than in New Orleans.

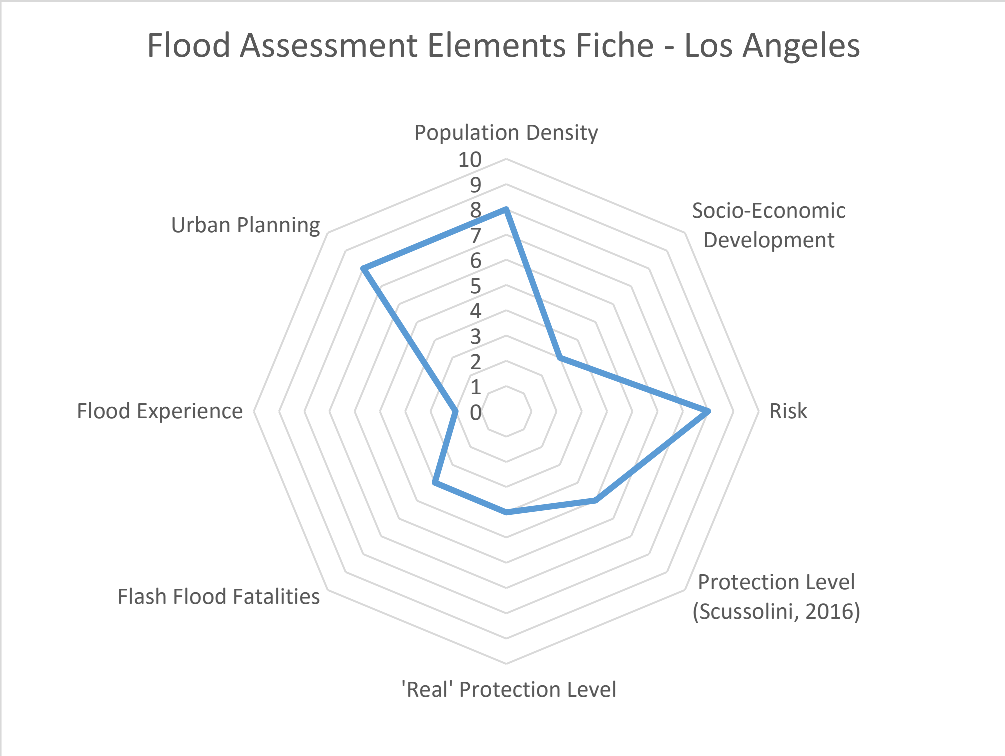

Figure 24: *Flood Assessment Elements Fiche of Los Angeles*

The FAEF of Los Angeles is shown in Figure 24. A remarkable element in this overview is the low score on flood experience in combination with the high risk levels. People do not know how to react on a flood and are more likely to make wrong decisions. Although it is good to see that the Los Angeles Government is preparing for a flood by having their responsibilities divided over multiple institutes. Remarkable is the lower score for the real protection level compared to the value of Scussolini et al. (2016). The data of FEMA is very questionable, because they asked civilians to deliver input for these maps.

5.11.4 New York City, New York

The damage that should be expected yearly in New York is 9.9 billion euros. Again it is a big difference with New Orleans, but that can be explained in the same way as for Los Angeles. Interesting to see is that when the protection standards are implemented the risk reduces with 98%. The influence of this parameter is enormous for the single land use method.

Eleven, is the number of flood fatalities due flash floods (standardized per 100000 inhabitants). Again the influence of flash floods is minimal. Unlike the assumptions earlier in this section, the influence of the flash flood fatalities is limited. The assumption made by Nootenboom (2015) looks to be right.

New York City is the densest populated area in North America. The impact of a flood could be huge. Already can be seen that four out of the five cities reviewed are in the top 20 of the population-weighted density by distance from city hall of North America presented by Census Bureau (2015). Immediately can also been said that an already high population density will lead to a lower socio-economic development. With a lot of people packed on a square mile, there is less place to expand. For New York City this is also the case. Just like Los Angeles the growth rate is <1%.

Most recent flooding in New York City occurred in 2014 as well. This was due an official record of precipitation during 24h that was set at that moment (National Weather Service, 2014). This amount of water couldn't be handled by the drainage system and this resulted in an excess of water. Hurricane Sandy came by in 2012, this storm followed the east coast of North America and by this also came past the New York area. Storms and floodings are quite common the last few years in New York. The governments takes his lessons from this and evacuates people preventive. The evacuation zones of the 2012 flood are shown below, and these zones are still being used for upcoming threats. Note has to be made that due to high wind speeds there was a higher need for evacuation, than in case of just a flooding. Figure 25 is subtracted from a tool that can be used by inhabitants to check in which area they are and the tool also provides tips for preparation. It can also be downloaded for Android and Apple devices. This provides a handle for the public to raise their awareness. People can find out themselves, they're in a flood prone area and react to that. The accessibility threshold is quite low, because everybody owns a mobile device nowadays.

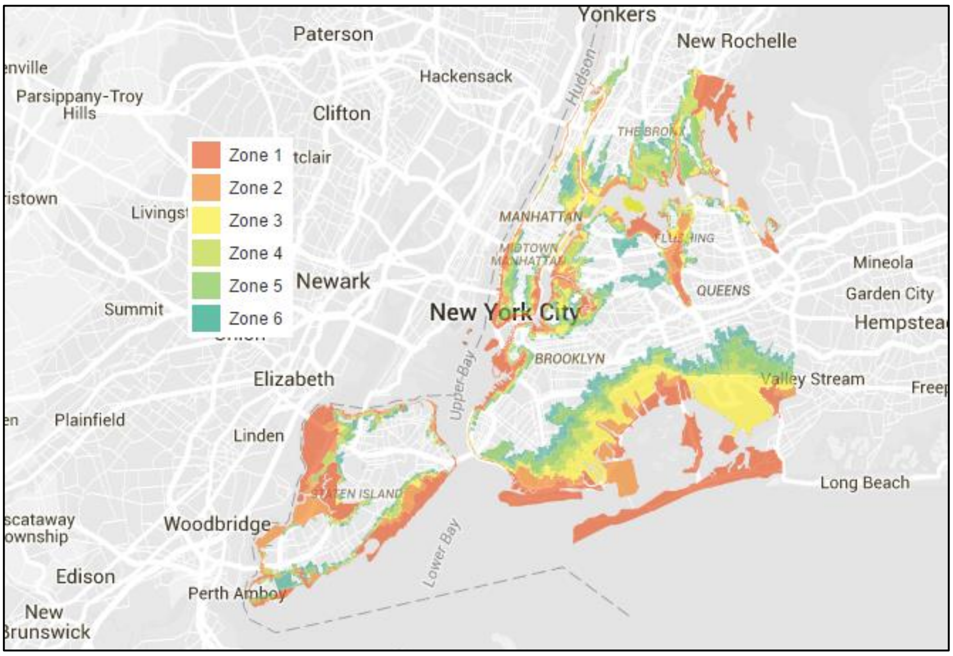

Figure 25: Flood Zone New York City, zones ranked in degree of priority for evacuation. Zone 1 first priority. (FloodZoneNYC.com, 2016)

Just like the two cities mentioned earlier, the protection standards maintained are to protect against the 100-years flood. But also the New York City government can see the fact of future developments. Due to hurricane Sandy New York City had great damages to buildings and infrastructure. Also flooded neighbourhoods and dangerous erosions took place. And due to, amongst others, climate change, more damage, more flooding and more erosion are likely in New York. In response the government is already developing plans to protect the city even more. The FEMA maps shown below do also in New York count as a guideline.

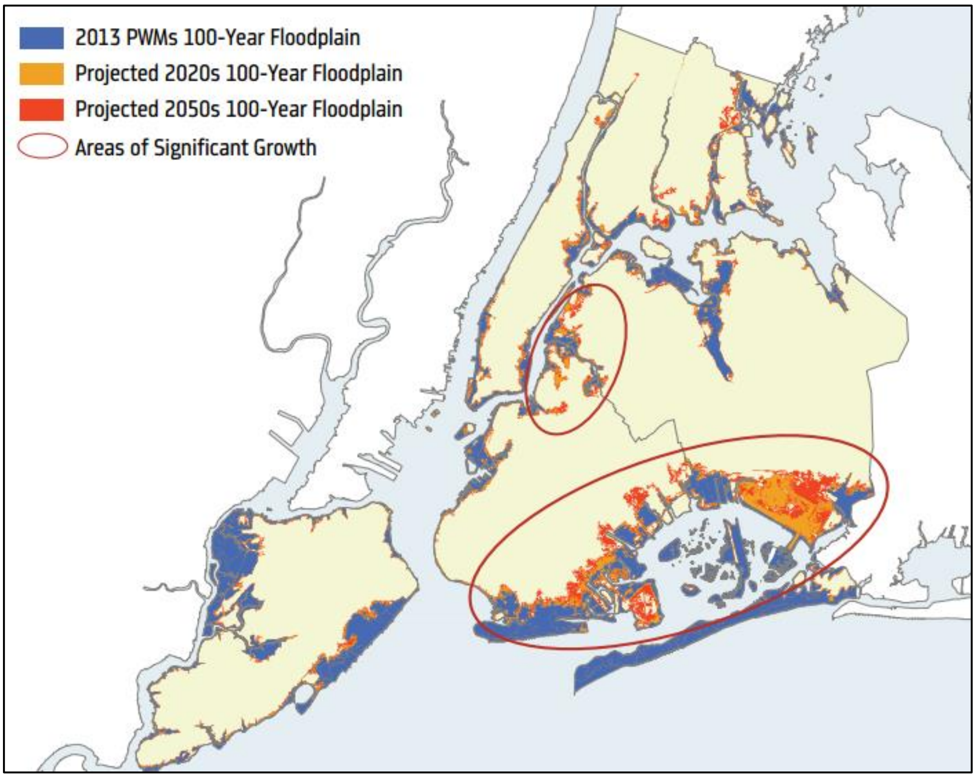

Figure 26: *Future Flood Maps for New York City (FEMA, 2014)*

Very interesting to see here is the shaded yellow/grey areas. These areas represent the 500-year floodplain. This is the area that will be flooded when a 500-year flood happens. This area consist of almost whole New York City. The damages would be outrageous. That's why there are several plans to protect against coastal floodings: increase the coastal edge elevation, storm surge protection, improve coastal designs and maintaining these designs and minimize the wave zones (Coastal Protection, n.d.). To execute these steps New York introduced PlaNYC in 2007, just after hurricane Sandy. These flood protection measurements were just part of this, because PlaNYC was set up in a broader perspective. To develop 'A Stronger, More Resilient New York'. Reducing greenhouse emissions, improve road capacity, provide more powerful energy suppliers is a selection of the long-term goals set by PlaNYC. This is all to improve the long-term sustainability of the city of New York. Their goal is to revitalize these systems to be able to comply the city's needs in 2030 (PlaNYC, 2007). This report and numerous progress reports show that New York City is definitely planning for keeping the water out.

Figure 27: Roads leading landward from New York City (Google Maps, 2016)

As mentioned, the city of New York is quite keen on his urban planning, including traffic management. This can be supported by the current infrastructure. As can be seen in the figure above, there are multiple roads that lead inhabitants to dryer grounds.

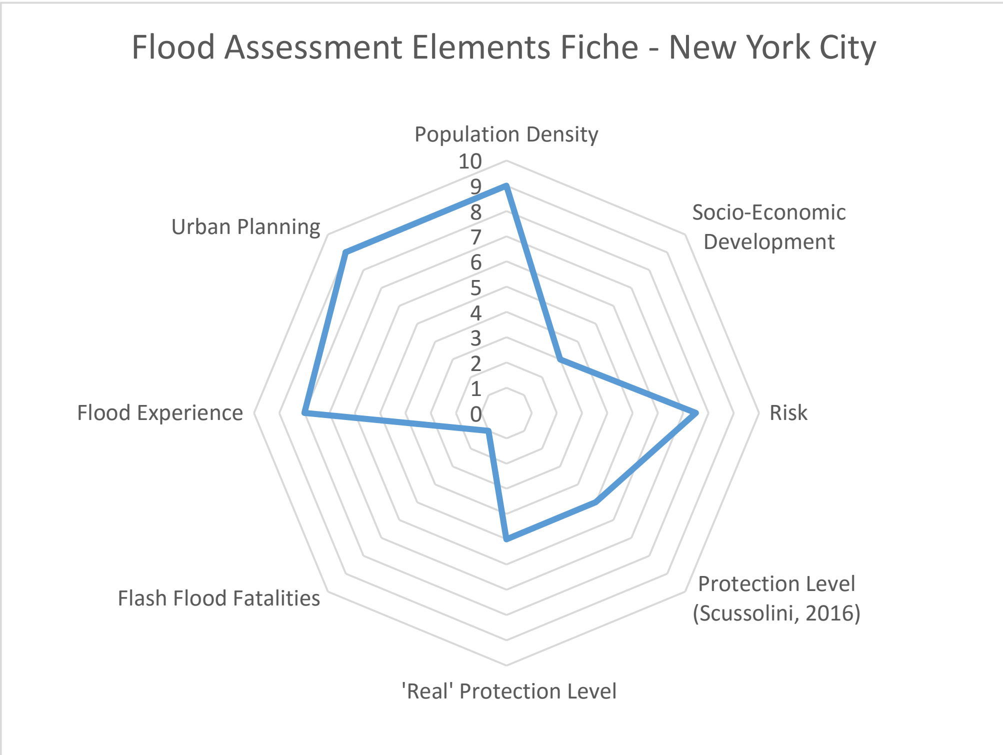

***Figure 28**: Flood Assessment Elements Fiche of New York City*

New York City seems to have everything right in the Flood Assessment Elements Fiche. There is experience with a recent flood, hurricane Sandy, and this let to reaction of the government. There is a comprehensive plan for the urban mapping and there are many roads leading to safer grounds. Scussolini's Protection Level seems to be equal to the protection level that is really used in New York, although the standards could be higher to protect a bigger part of New York City. And in addition a high population density goes together with a low grow rate in the future.

5.11.5 MIAMI, FLORIDA

Expected damage for Miami, Florida is around 9.4 billion euros. This is comparable with the expected damage of New York and Philadephia, which is discussed in the next section. The similarity can be related to the geographic location of these cities. New York City is located at the Hudson River, Philadephia on the shore of the Delaware River and Miami is located by the sea. Loads of water surround those cities.

Miami has had just seven flash flood fatalities over the timespan 1959 to 2005 (Ashley & Ashley, 2008). This number is negligible for this global flood risk assessment. Again the influence of these fatalities is limited. It can be concluded that flash flood fatalities have no relation with the flood risk assessment performed nowadays.

Miami is quite densely populated. Like mentioned in the paragraph above, Miami is placed in the top 20 of most dense populated cities on the continent North America. Again the relation with the socio economic development is shown, the prospects are minimal. The <1% is almost negligible as well.

Miami isn't a place that is often affected by floods. The most threats come from sea. This is only the case when storms cause high water and thereby threaten the beach of Miami. These events are in case of Miami marked as tidal flood events, these events are not taken in to account in this flood risk assessment, but looking at Miami this could be of influence. The University of Miami (2016) states that the number of tidal flood event has increased by 400 percent over the last decade (Wdowinski et al., 2016). Real river floodings haven't happened yet, but yet Miami is one of the states that is least prepared for potential flooding (Floodlist, 2015). This goes hand in hand with the great flood risk following from the Flood Impact Assessment Tool. Maybe the connection between little experience and high risk values can be supported.

Also Miami is protected against a 100-year flood, but as mentioned above Miami is under great risk. Gomez (2014) refers to Miami as a huge sitting duck for the next hurricane. He also mentions that multiple political leaders have failed to see the upcoming problem and that the budget available isn't well spend on flood control structures. In the same article FEMA Administrator Craig Fugate is quoted, he says that federal funding isn't a realistic option, because focus of Congress is mainly on recovering cities and not preparing cities like Miami. So the protection measurements of Miami are prepared for a 100-year flood, but they are for several years already. No progress is made, only minimalistic actions like dredging canals. Lack of development will cause problems in the future.

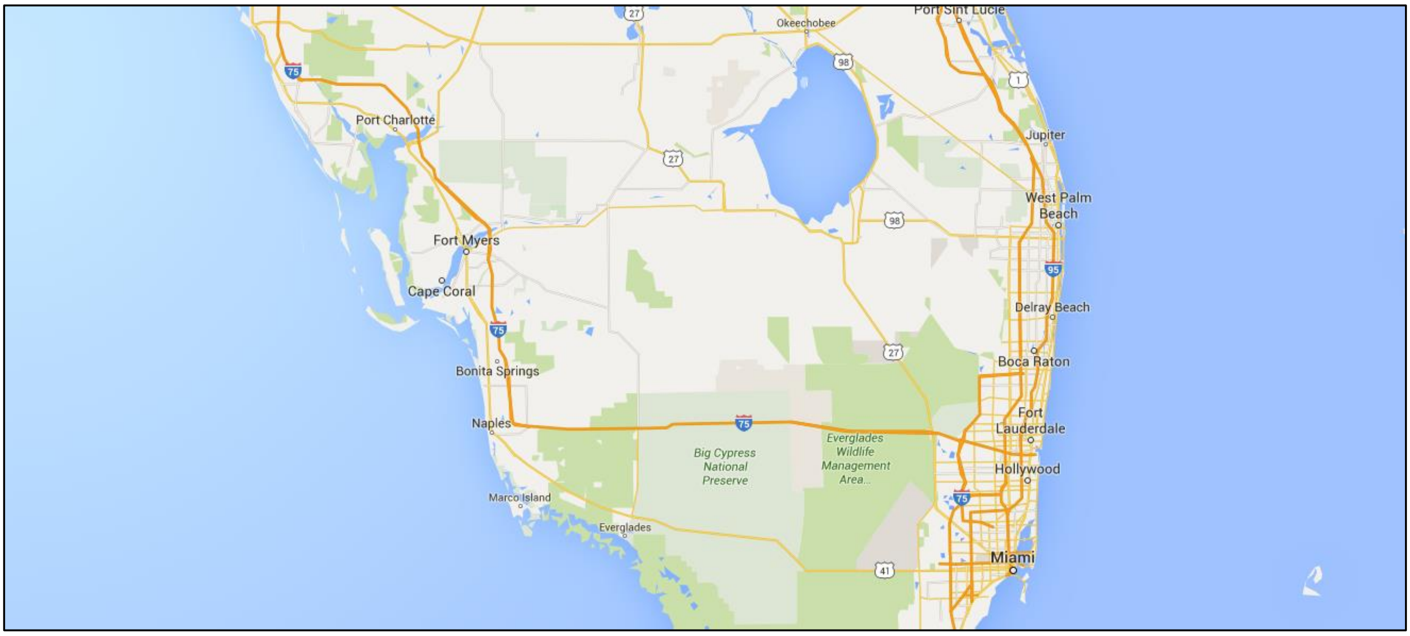

Figure 29: *Roads leading landward from Miami (Google Maps, 2016)*

As can been seen in Figure 29 above, there are only two high roads leading away from the Miami coast. One of these roads is parallel to the coast and will most likely been flooded as well during a heavy storm or flooding. The other one will be the only main option. With this the term ‘sitting duck’ is confirmed. Miami’s citizens have nowhere to go when something happens. It looks like living the luxury live comes with a price.

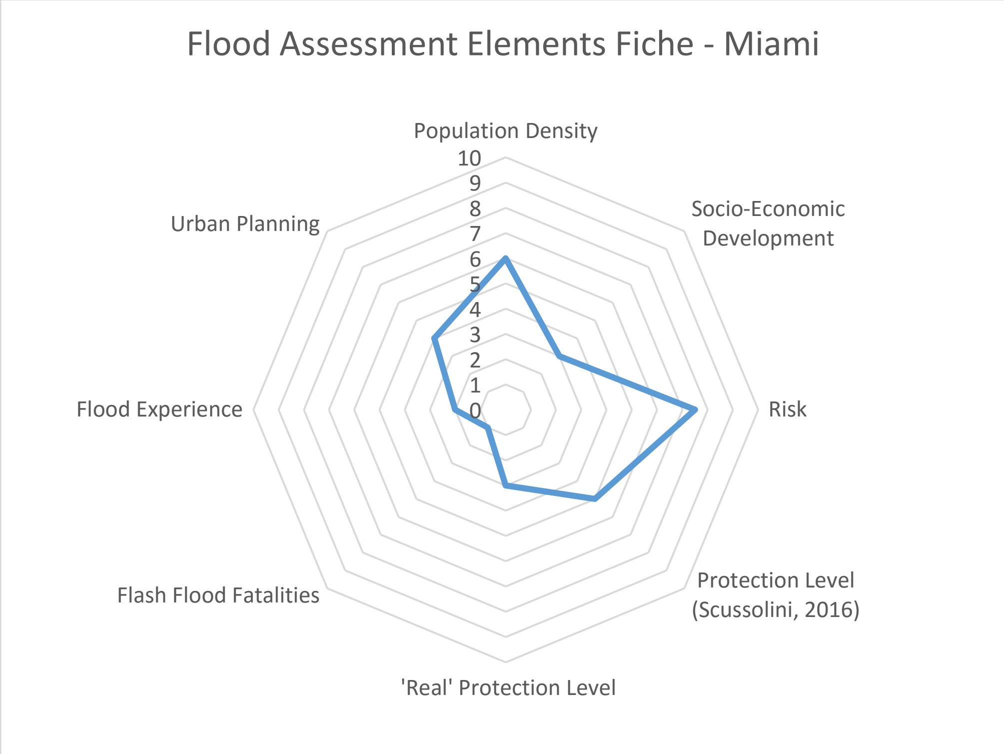

***Figure 30**: Flood Assessment Elements Fiche of Miami*

As already mentioned, Miami seems to be the sitting duck of these five cities. In Miami they do not consider a future flood, maybe because of the lack of recent river floods. Protection measures aren’t updated over the years and only little maintaining work is done. Miami seems to be the least prepared for floods, in combination with the few escape routes available, this should worry people. Note has to be made that flood protection data for Miami is limited.

5.11.6 PHILADELPHIA, PENNSYLVANIA

The damage that can occur yearly in Philadelphia is quite equal to the number presented for Miami and New York City. The 8.8 billion euros damage are still significant. Notion has to be made that the single land use method overestimates the risk in most of the cases. This has been confirmed by multiple studies (Schilder, 2016; Nootenboom, 2015).

Flash flood fatalities are quite rare in Pennsylvania. Just five fatalities per 100.000 inhabitants in the time period 1959 till 2005. Again the conclusions drawn earlier are confirmed. It is easy to say that flash floods don't play a role in the current design of the flood risk assessment. However, when the focal point changes from structures to persons, flash flood fatalities will be more critical.

Philadelphia is part of the most dense populated areas in North America. Therefore the number of people and assets that can be exposed is big. The assumption that a densely populated area at the moment is less likely to increase with big numbers can be accepted as right. The socio-economic development expected by United Nations (2015) is less than 1%.

Figure 31: Flood Zones Philadelphia (City of Philadelphia, 2009)

Protection level for Philadelphia is 1/100 yr^{-1}. It is emphasized by the Office of Emergency Management that FEMA requires an update of the City of Philadelphia's Hazard Mitigation Plan. This is to get the information up to date. The last version is of 2012 (City of Philadelphia, 2012). This report consists of multiple elements like socio environment, land use management, mitigation strategy and risk assessment. Interesting to see is that also Philadelphia, just like Los Angeles, invites the public for input-meetings. This is to involve the public and at the same time make them more aware of the risk. The report refers to FEMA for the flood-hazard maps, but they are very unclear. An outdated map of the Philadelphia Office of Emergency Management is available and is shown in Figure 31. This overview also comes with a clear idea about how many assets being vulnerable for a 100-year flood zone and which neighbourhoods are most prone. It looks like Philadelphia Government has a clear overview of the risks it is facing. Only note that could be made is that data provides for the action for the upcoming four years, while a lot could change in this timespan. Interesting to see as well is that there is a clear division of the responsibilities for existing and potential mitigation actions. Possible funding sources are named already and the leading agency has already been appointed.

Simultaneously good projects regarding floods are running. Philadelphia Water (n.d.) is an organisation that makes good use of stormwater. Stormwater is the water that runs over impervious surfaces, like rooftops or streets. These elements prevent infiltrating. This water mostly runs off to the closest drain and thereby picks up pollutions that eventually will end up in the Delaware River. The Delaware River is a source for drinking water and this polluted water can be of impact on the health of the users of this water. This is good in an environmental perspective, but also in flood perspective. In heavy precipitation periods the sewer system will be overflowed with water and thereby automatically run over the impermeable areas, this will result in basement and street floodings. The solution implemented by Philadelphia Water is a combined sewer system which will act as back up during intensive rain periods. This back up will reduce the inundation depth. For an extensive explanation of this Combined Sewer System, one is referred to the Philadephia Water website. Another program started by the Philadelphian government is the Basement Protection Program. This is in combination with the sewer systems mentioned above. Philadelphia seems to focus on the small floods. The sewer system will not be able to handle the volume of water that follows from a major dike breach.

Another measurement that the Philadelphia Office of Emergency Management has taken is a notification system that provides inhabitants with notifications and alerts about emergencies (City of Philadelphia, n.d.). It is possible for users to set five different locations to get an alert on, because alerts can be targeted very specifically. You can sign up for free for the ReadyPhiladelphia Application.

Just like New York, also Philadelphia has a city wide vision for the future, Philadelphia2035 (CityWideVision, 2011). ‘Philadelphia2035 strives for coordinated policies for vacant land and structures, sensitive lands such as steep slopes and floodplains, and municipal support facilities’. This project is focussing on multiple items, with attention for floods as well. Also as is shown in Figure 32, the 500-year floodplains are taken in to account. The presence of these floodplains is limited, so it can be said that the 100-year protection standard proposed by Scussolini et al. (2016) is right.

Philadelphia is located on the banks of the Delaware River. This location isn’t contributing in a positive way. On several occasions the Delaware Rives caused problems. In 2004 and 2006 the river showed high water levels multiple times and this was one of the reasons to protect the cities around even better (USACE Philadelphia District, 2008). This can only be cheered, Philadelphia sees the upcoming risks of flooding.

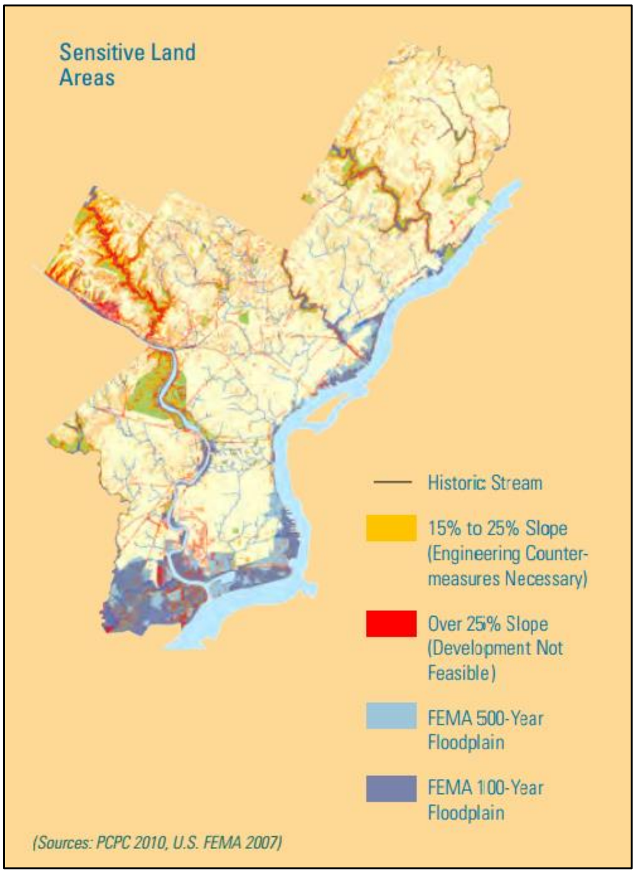

Figure 32: *Sensitive Land Areas in Philadelphia (CityWideVision, 2011)*

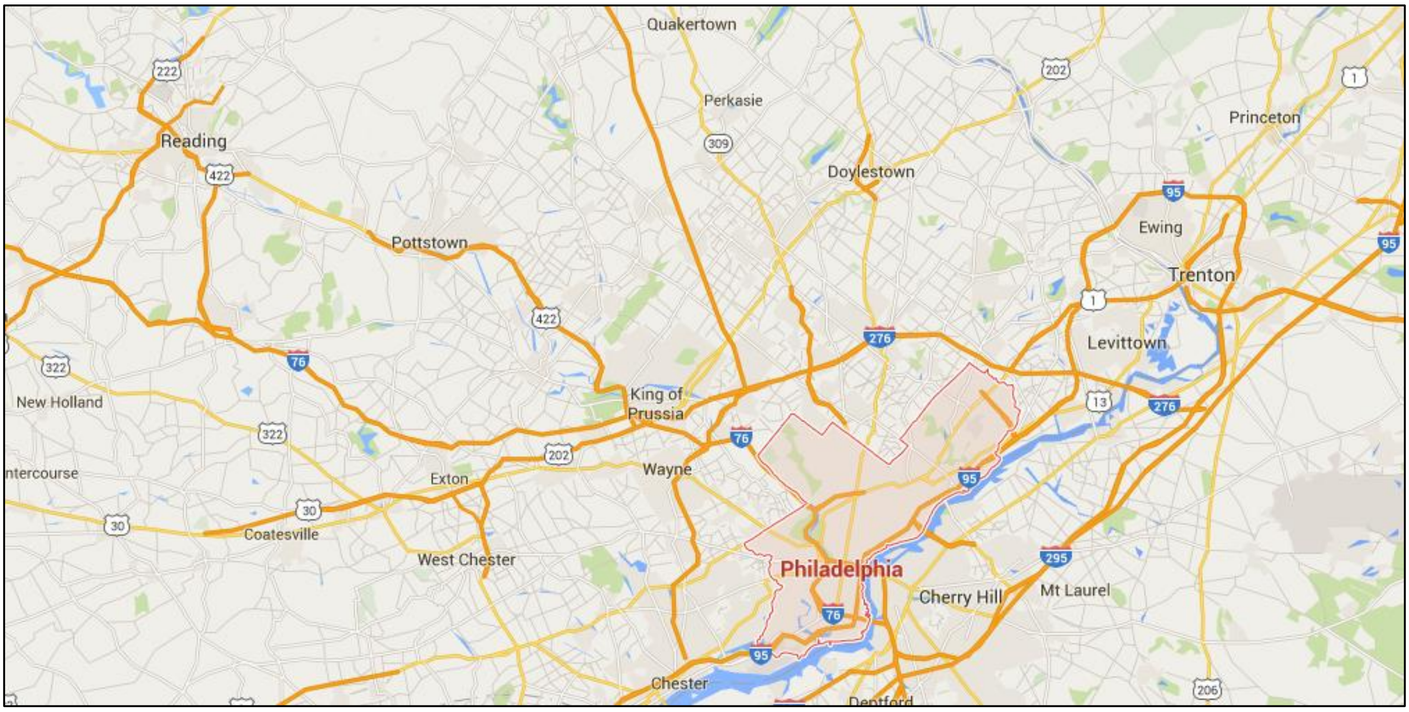

Figure 33: Roads leading landward for Philadephia (Google Maps, 2016).

Shown in Figure 33 is the main infrastructure of Philadelphia. What can be seen is that Philadelphia, just like Los Angeles and New York, features multiple escaping routes away from the Delaware River. Multiple options, again, provide enough capacity to evacuate all inhabitants in case of an extreme flooding.

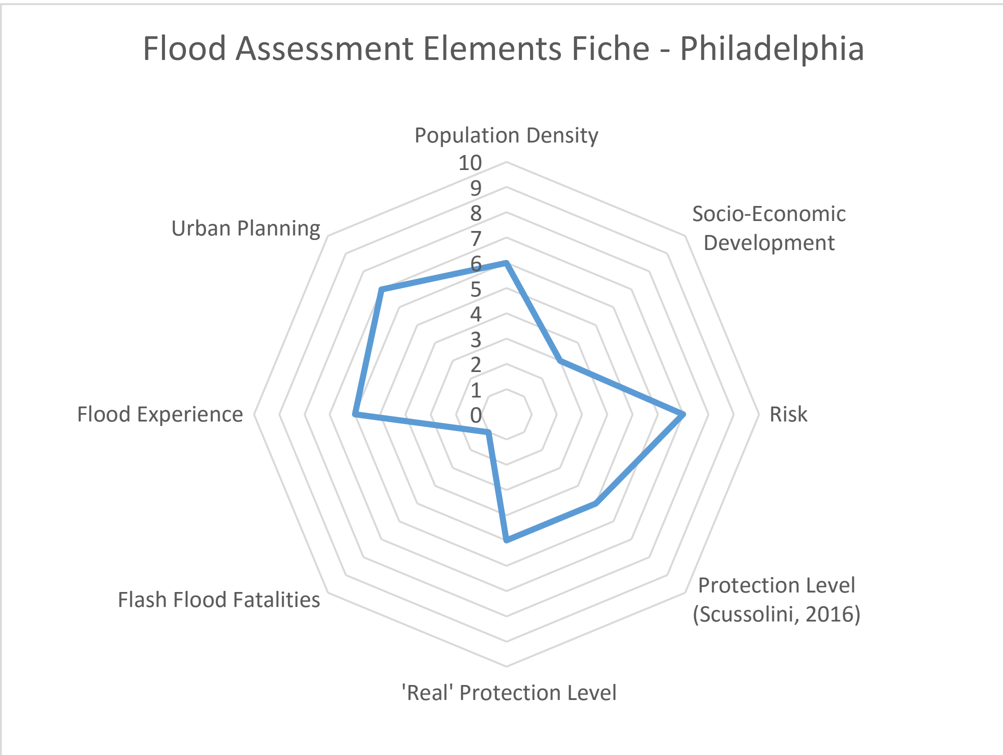

Figure 34: Flood Assessment Elements Fiche of Philadelphia

As can be seen in Figure 34 the Fiche looks quite average. Philadelphia anticipates on recent flood experiences due to Delaware River floodings. An extensive report is written every four years and the responsibilities and ambitions of the government are clear. Flash flood fatalities are again no factor in the risk assessment and the Protection Level of Scussolini et al. (2016) is similar to the 'real' protection maintained in the city.

5.11.7 Integrated flood assessment elements fiche

In Figure 35 below the Flood Assessment Elements Fiche of all five cities is shown. As can be seen there is a clear pattern to see in the radar chart. This pattern is going to be explained in this section.

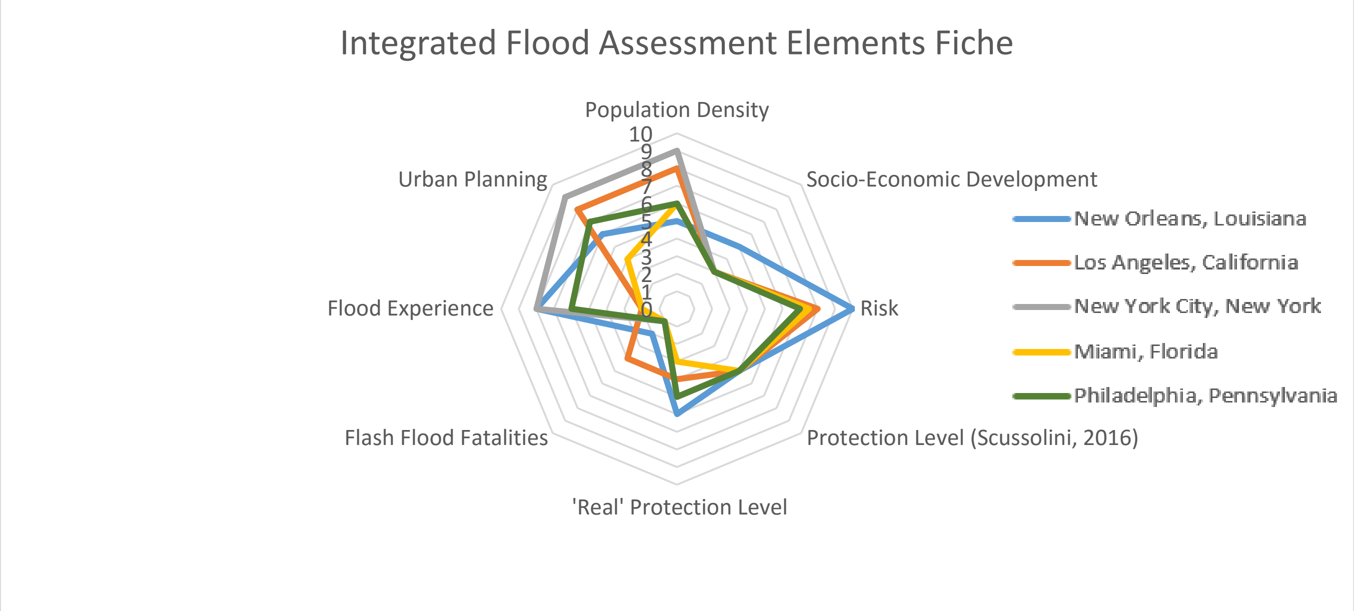

Figure 35: *Integrated Flood Assessment Elements Fiche with the following cities: New Orleans, Los Angeles, New York City, Miami & Philadelphia*

At first the Flash Flood Fatalities. Before the composition of the radar charts there was the idea that flash floods should be included in flood risk assessment due to the destructive character. But this figure shows that in cities with high risk values the number of fatalities is reasonable low. The assumption of Nootenboom (2015) can be validated with this data.

With exception of Los Angeles, it can be stated that much experience with floods leads to a higher score on urban planning. Most governments see recent floods as a wake-up call and after a destructive flood a land use management proposal is compiled. This action-reaction mentality looks common in North America. New Orleans, New York City and Philadelphia all went into action after floods happened. If urban planning is mapped accurately one could make a difference between residential areas that are built more flood-proof and less flood-proof. This can lead to a, for example, different depth-damage functions for both components. This would make the assessment even harder and maybe impossible, because there had to come information available that identifies flood-proof buildings and less flood-proof buildings.

A high population density in combination with a lower socio-economic development is an easy conclusion. In dense populated areas there is less room for expansion and so there will be a lesser grow rate. There could be need for mapping this precisely, because Nootenboom (2015) shows that for example the GDP of India would grow a tenfold. This is significant, although in North America these grow rates will not be that excessive. Nootenboom (2015) shows an increase for around 10-15% for New Orleans.

Last is the protection level parameters. Schilder (2016) and Nootenboom (2015) already showed the influence of this parameter on the flood risk value. And from the FAEF can be concluded that the protection standards data used isn't as exact as we would like to. In three of the five cities the protection levels seem to differ from the used 1/100 yr^{-1} standard used all over North America by Scussolini et al. (2016). Further investigation on this subject could be of huge influence for future risk assessments, because a superficial search for these cities already showed differences with the used data.

Although in this study the Flood Impact Assessment Tool wasn't put to use, due to multiple problems, still is suggested that an exact derivation of land use maps should lead to more accurate results. The overestimation by the single land use method already shown by multiple studies for other continents (Schilder, 2016; Suijkens, 2015; Nootenboom, 2015). This will most likely be also the case for North America.

6

DISCUSSION

Several aspects of this thesis has been marked as questionable or doubtful. In this chapter these aspects are further illustrated.

At first there is the Open Street Map discussion. Open Street Map is used as main source for the derivation of the land use maps. This is because it is freely accessible. However several question marks are raised. Open Street Map is freely accessible and edible, everyone can make a change to the maps so it's really questionable if the data is valid or not. Also, changes made are questioned by users and 'mappers' as well. There are several discussions going on about which tags are to general and which are too specific. Every editor has its own view on things, so it is really an own opinion matter. All this does not help to get a very specific and precise assessment. In addition, OSM is a valuable source for this assessment, but it is far from complete, around 75% is marked as no-data.

Second point of discussion is the definition of the city boundaries. These are derived from MODIS data and are very roughly. When you take a closer look it is easy to see that not everything, or too much, is taken in to account for a city. This affects the assessment. When the city boundaries are not well defined, the assessment will also deviate from the 'real' answer. This all be prevented by editing the given shapefile. This can be done very precise, hours of work can be spend. But also when that is done it is questionable 'how far' you should go. Which areas belong to the city and which not?

Next up is the most valuable part of the assessment, the land use maps. These maps form basically the whole assessment. When these maps are derived for the whole area with no question marks or doubts then the assessment will potentially be the most exact. Problem is that this isn't the case at all. As mentioned earlier a lot of data is missing. This information gap can be filled in numerous ways. For example you can appoint a weighted average depth damage function to this layer. In the assumption that the land is divided the same as the data present. This option is quite a gamble, because the depth damage functions of Huizinga already contained uncertainties. But it is also possible to leave this no-data 'empty'. Ignore it and calculate only the parts that are available. These different options will also give a different outcome of the assessment.

Other input parameters which were provided also raise question marks. The protection data set of Scussolini et al. (2016) is a commonly used parameter to derive the risk when protection standards are taken in to account. Only, which is already mentioned in chapter five, this data is not as sure as was thought. Just like Huizingas depth damage functions, these protection levels contain a lot of uncertainties. The information of United States of America for example is based on a study where the authors not even mention their source. So the results of earlier studies are doubtful as well. When the dataset available for North America isn't correct, what is left of the reliability of datasets of other continents? Also the hydrologic model PCR-GLOBWB introduced in chapter two does not contain the exact data. Again this is an approximation, but this model is one of the pillars of this concept. So multiple input parameters can be defined in a better way, and thereby the assessment could be much better.

Also the types of floods taken in to account are doubtful. Nootenboom stated that the river and coastal floodings produce the most damage, because of their destructive behaviour. This conclusion is most likely based on damage on items. But if you check the fatalities per flood, flash floods are the most destructive. This could mean that when the focus of the flood risk assessment changes to a person perspective, this could lead to much different results. A method to calculate the impact of flash floods would be of real help.

7

CONCLUSION

The goal of this thesis was to produce a list of North American cities based on flood risks. This list had to be produced with the support of the Flood Impact Assessment Tool. Unfortunately multiple and major problems and computer performances issues this did not work out. Instead of that this report provides the reader with tips and tricks to prevent the mistakes made already.

Second part of this thesis consisted of a literature study. Aim was to figure out which parameters should be taken into account for flood risk assessments and how big is the influence of these parameters. What should really be mapped accurate to develop an even better method for global flood risk assessments? Multiple input parameters were mentioned and described. Traffic Management, Urban Planning, Types of Floods, Flood Experience and so on. A selection of these aspects were used for the Flood Assessment Elements Fiche. This tool, designed as a radar chart, could be used for a quick overview of a cities flood risk profile. Which parameters are of influence and which are not?

From the Flood Assessment Elements Fiche of New Orleans, New York, Philadelphia, Miami and Los Angeles conclusions could be drawn. The protection level data set used for earlier flood risk assessments attached a 100 yr^{-1} return period for the whole American country. But further research on this subject revealed that this 100 yr^{-1} return period is not always the right value. For several cities the protection level return period deviated from this value. Considering the big influence that this data has on the monetary risk values following from the FIAT it is really necessary to map the protecting data accurate. This could improve the outcome of the assessment.

Another interesting conclusion that can be drawn from the fiches is that the assumption to let flash floods out of the calculation is validated. The top five cities following from the single land use results showed very big risk values, but very few fatalities due to flash floods. Only if the focal point of flood risk assessments changes to persons instead of objects, flash floods should be taken in to account.

Last remarkable thing that can be concluded from the Flood Assessment Elements Fiches is that Flood Experience and Urban Planning do have a connection. In the United States of America is it a habit to start acting when it is too late. New York, New Orleans and Philadelphia weren't prepared before the flood and after the storm occurred they started to develop plans and organisations for flood preventing. So a high value for flood experience most likely resulted in a high value for urban planning, which includes emergency management and traffic management.

But we have to keep in mind: zero preparation ensures 100% risk, but 100% preparation will not take the risk to zero.

8

Recommendations

This chapter contains suggestions for further research that could improve flood risk assessments for North America in the future.

- At first it is suggested that other sources could also be used for the derivation of land use maps. At the moment only the Open Street Map data is used, but it could be an opportunity to combine different sources in to one map. By this it is more likely to get a more complete map and this will decrease the effect of the uncertainties of the data gaps.

- The method for filling these data gaps needs further investigation as well. At the moment data is extrapolated with the existing data as source. Is this method exact enough and realistic? There should be found a method to define the unknown areas in a less uncertain matter. With the method used now deviations are stacked.

- Also definition of the boundaries of the cities should have a guideline. At the moment we work with the MODIS data, but this data is very rough. Editing by hand is a very time consuming process and this work is also very 'own-opinion' focused. Where should one decide where the city ends? Maybe instead of the boundaries based on densely-populated areas one could use a different definition and thereby the city boundaries could be acquired more accurately. Using the administrative city borders could be the solution. What does the city itself marks as its border.

- At the moment the depth-damage functions are continent specific, except of Europe. For small countries like Sri Lanka this is not a problem. But a function for the whole United States of America is much more generalized. Country- or state-specific depth-damage functions would lead to a more accurate flood risk assessment.

- A validation of the model is carried out for different countries and floods already, but for North America this hasn't been done. To see if the model is actually accurate enough for North America it could be checked by simulating for example the flood after hurricane Katrina. For this type of validations one can specify the borders more exact and maybe edit the data by himself. Such a validation covers a smaller area then the global flood risk assessment performed in this thesis. The input parameters could be optimized by this work and thereby it is more likely the tool will give a 'true' answer within its possibilities.

- Flood protection data should be defined very precisely. The impact of this parameter is huge and thereby it should be accurate. Already a superficial study showed differences with the values used by the FLOPROS dataset. This could be done by a literature study per state, city or country. One of the main aspects could be to check if the rules set by the government are respected by the engineers.

- The computer that is going to be used should be quite powerful. Especially for areas that are large, and in developed countries it can be assumed there is more data available. Also there should be time available to let the computer running, for short term deadlines it is not recommended to perform a global flood risk assessment. Maybe it is an option to cooperate with a Deltares or HKV employee to set up the model instead of experience errors for several weeks.

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Appendices

A

Research Proposal

Research Proposal
Bachelor Thesis

Identyfing delta regions most vulnerable for flooding
Global flood risk assessment

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April, 2016

1. Introduction

Floods have always played a role during the existence of the human race. People have been fighting against the water for a long time and this fight isn't over yet. It will continue for a long time, because the Earth's surface consists for approximately 70 percent out of water. Due to, among other things, the climate changes over the last decades the world has changed and is changing. For example the sea level rose by a world average of 19 centimeters over the period 1901 to 2010 (Stocker et al., 2013), and it's very likely that these climate changes will continue during the 21st century. Different studies also showed that climate change alters the discharge of the Rhine. The winter discharge at Lobith can increase by 0 – 30% by 2050 and the probability of extreme flood events will increase (Ward et al., 2014). This will also be the case for other rivers and delta regions.

Another factor is the socio-economic development. According to the United Nations the population of the world increases every year and will continue to do so for the upcoming years. This will result into more people living in urbanized areas that are vulnerable for flooding and this will lead to more losses in terms of euros and lives due to flood events.

There has also been a development in acceptance for disasters. People are less likely to accept the consequences of a disaster like an earthquake or a flood risk. For example the earthquakes in Groningen, the Netherlands. People know of the cause of those and are not accepting that they have to deal with damage to their houses. This can be translated to the flood risk issue. Most of the countries have a certain policy against floods. In the Netherlands for example, there is a focus on preventing floods. But in other cities there is more of a 'wait-and-see' attitude. They don't want to invest in prevention, but they are ready to pay for all the damages when it happens. It's interesting to see how diverse countries want to react on dangers.

The factors that are mentioned above play a very big role in our look on global flood risks. It's easy to see that gaining knowledge about flood risks can be of very good help in the future. So with the right methods we will be able to make right decisions about flood protection issues and thereby maybe save thousands of lives. And those right decisions include the policy that a certain country or city have against such disasters.

2. Problem Statement

Deltares and HKV have been developing methods to investigate the global flood risks based on rapid assessments tools and open data. These methods consist on the definition that flood risk is the product of vulnerability, flood hazards and exposure.

Up until recently only a global method was defined. This method is called the 'GLObal Flood Risk with IMAGE Scenarios' (GLOFRIS) (Winsemius et al, 2013). This method uses only two land use categories, urban and non-urban, and one damage function. The GLOFRIS method is applicable all over the world. But compared to the developed method by Huizinga in 2007 this is a very simplified model, because of the limited number of land use categories. The Huizinga Model (Huizinga, 2007), called 'Bottom-Up Climate Adaption Strategies for a Sustainable Europe' (BASE), uses five land use categories and five damage functions. These five land use categories are Residential buildings, Commerce, Industry, Roads and Agriculture. This method gives a more specific result, however it's only applicable in Europe.

In 2015 Nootenboom compared the two methods that were available at that moment, the global and the European method. He found out that the results of the methods did not differ that much as you would expect, only that the global method overestimated the flood risk compared to the European method. (Nootenboom,T., 2015). But professionals are always interested in the most precise result and thereby the European method is potentially the most valuable method for flood risk assessments. Potentially, because this in only the case when the input data is defined in a good way. This method is very dependent of the land use maps and damage functions used. When those are not correct, this method isn't more valuable than the method of Winsemius.

For that purpose Huizinga recently developed damage functions for all other continents. He performed a literature study to scale the BASE method up to all over the world. This gives the possibility to get more precise estimations of global flood risks. However, land use maps were still missing for the other continents. Recently several Bachelor Civil Engineering students derived land use maps for Asia, Australia and South-America. After that they applied the multiple land use damage functions from Huizinga. The land use maps of North America are still missing and therefore the damage functions of Huizinga haven't been applied on this continent yet. This will be part of this Bachelor Thesis.

In addition to that I would like to broaden the general scope of this subject ('identifying delta regions most vulnerable for flooding'). I would like to dug into the policy of North America against flood risks and put this in perspective. There are several attitudes against disasters like floods, shortly mentioned in the Introduction, and those will most likely influence the risk for a certain city. When you take for example the existence of emergency plans, the protections levels and the special development in account, how does the city prevents himself against flood disasters and what will be the consequences of those parameters?

All this, together with the damage functions, can be wrapped up in a radar chart. This can be a visual tool to see quickly what the policy against floods is and what will be the damage. This is another way of 'ranking' the cities then used by the previous Bachelor students that have been dealing with this subject.

3. Research Questions

The objective of this thesis is to give an advice for the future. This advice can be a direction for the main focus of further flood risk assessments. We all know that we can approximate the damage by certain water heights, but is that really the most important thing in flood risk assessments. It could be that from the radar charts it follows that the existence of emergency plans plays a huge role in reducing the risk that follows from flood hazards. One of the main goals of this Bachelor Thesis is to produce a list of North American cities from most to least vulnerable to flooding. This list will be created out of the up scaled European Method of Huizinga and will be compared to the global method. This list will also contain the so called radar charts. Maybe a different ranking will follow out of it. The problem can be subdivided in several research questions:

- How to derive land use maps for North America?

- What is the most important aspect / input-parameter with respect to the expected annual damage?
    - What are the differences between the Global Method, with two land use categories, and the model with five land use categories in the calculated flood risk in North America?
    - What is the influence of implementing climate change scenarios on the calculated flood risk in North America?
    - What is the influence of implementing socio economic scenarios on the calculated flood risk in North America?
    - What is the influence of implementing both scenarios, climate change and socio economic scenarios, on the calculated flood risk in North America?
    - What is the influence of sub-aspects, like emergency plans or existence of flood protection, on the total flood risk?

4. Methodology

To be able to answer these research questions several steps have to be taken. In this chapter the steps are going to be explained briefly to give an idea of the work that has to be done.

4.1 Land use maps

As already briefly mentioned the land use maps for the continent North-America are still missing. Deriving the land use maps can be a very time consuming job. It's basically classifying all land in North America to the following categories: residential, commercial, industrial, infrastructure and agriculture. To be able to compare the two methods (global and European method) it is a correct choice to use the same classification system as Nootenboom.

To perform this several sources could be used. An interesting source is Open Street Map. Most likely not all land can be covered by Open Street Map on its own. It could be useful to use multiple sources and apply the available information as layers over each other. This is an idea by SDI4Apps and the methodology is quite simple. Basically they use all sort of sources and put them together. For the Czech Republic for example they used: Digital cadaster data, Land Parcel Identification System (LPIS), the Urban Atlas and CORINE Land Cover. This method could be useful for deriving land use maps for North America.

Most likely a lot of land cannot be fitted in a category. There are multiple solutions to this problem. A first option is to determine the percentages of a specific land use category and extrapolate these to the rest of the country. A less favorable, second option, would be to derive a new damage function for the unknown part of the country. This would be something like an average of all sorts of land use.

As already said in the beginning of this chapter this work can be a time consuming job. It's not the intention of this Bachelor Thesis to make the land use maps perfect. Deriving the land use maps are a sub-goal of this Thesis, and time can be spend elsewhere.

4.2 Analyzing results

After the runs with the Flood Impact Assessment Tool (FIAT) the results have to be analyzed. This will most likely be the comparison between the two methods. It is expected that the method introduced by Huizinga will result in a more reliable assessments, because of the multiple land use classes. The effects of the different changes in the world, like socio-economic and climate development, will also be reviewed.

4.3 Flood policy

Next up is more of a literature study for the American policy against flood risk. This is also a part in the flood risk assessment, because here the results of the tool can be declared. For example when a city is likely to expect a lot of damage during a flood, it can be explained by the policy against floods. When a city chooses for a 'wait-and-see' strategy and they're willing to pay for the damage that follows then it can be verified.

4.4 Radar Charts

All of above mentioned steps can be summarized in radar charts. In this radar chart several factors can be mentioned and thereby show a quick overview of what the city stands for and what the results of that are. Maybe it can be concluded that a certain factor has a huge influence on the outcome of the damage part, derived from the FIAT.

5. Time planning

	Week 1 *18 April - 24 April*	**Week 2** *25 April – 1 May*	**Week 3** *2 May – 8 May*	**Week 4** *9 May – 15 May*	**Week 5** *16 May – 22 May*	**Week 6** *23 May – 29 May*	**Week 7** *30 May – 5 June*	**Week 8** *6 June – 12 June*	**Week 9** *13 June – 19 June*
Literature Research	x	x							
Exploring FIAT, qGIS, OpenStreetMap	x	x							
Writing Research Proposal	x	x							
Making land use maps			x						
Collecting flood hazard data, damage functions			x	x					
Calculating Flood Risks			x	x					
Analyze results				x					
Writing Intermediate report				x	x				
Presenting Intermediate report					x				
Calculating Flood Risks with scenarios					x				
Literature study flood policy					x	x			
Radar charts					x	x			
Analyze results						x			
Writing Final Report							x	x	
Presenting Final Report									x

In the table presented above it becomes clear what I want to achieve on which moment. This table is just a guideline so it's possible to deviate from it. However some dates are fixed, like the dates for the presentations and the dates for handing in the reports. Also there will be weekly meetings between the author and the supervisors to keep an eye on the progress. The moments for these meetings still have to be determined.

6. References

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B

CITIES TAKEN IN TO ACCOUNT

Aguascalientes
Albuquerque
Alington
Atlanta
Austin
Baltimore
Boston
Calgary
Charlotte
Chicago
Chihuahua
Cincinnati
Guatemala
Cleveland
Coatzacoalcos
Colorado Springs
Columbus
Cuernavaca
Culiacan
Dallas
Denver
Detroit
Edmonton
Fort Worth
Fresno
Guadalajara
Hamilton
Hermosillo
Honolulu
Houston
Indianapolis
Jacksonville
Juarez
Juarez
Kansas
Kingston
La Habana
Las Vegas
Leon
Los Angeles
Los Mochis
Managua
Memphis
Merida
Mesa
Mexicali
Mexico City
Miami
Milwaukee
Minneapolis
Monterrey
Montreal
Morelia
Nashville
New Orleans
New York
Oakland
Oklahoma
Omaha
Ottawa
Philadelphia
Phoenix
Pittsburgh
Port-au-Prince
Portland
Zaragoza
Quebec
Queretaro
Sacramento
Saltillo
San Antonio
San Diego
San Francisco
San Jose
San Luis Potosi
San Salvador
Santo Domingo
Seattle
St. Louis
Tegucigalpa
Tijauna
Toledo
Toronto
Tucson
Talsa
Vancouver
Virginia Beach
Washington
Wichita
Winnipeg

C

OBTAINING OPENSTREETMAP DATA

One of the Python, a program software, modules that has to be installed for the Flood Impact Assessment Tool can be used for the conversion of the files obtained from planet.osm.org. The module is called Geospatial Data Abstraction Library (GDAL). The file format that can be downloaded from this website is .osm.pbf. This file contains all Open Street Map data packed in a reduced form. To make this file manageable for the Geographic Information System programs like qGIS and ArcGIS this file has to be converted to a .db file. Which can be done by the following procedure:

For Mac OSX:

Install GDAL: http://www.kyngchaos.com/software:frameworks or use qGIS

Launch Terminal and type:
Export PATH=/Library/Frameworks/GDAL.framework/Programs:$PATH

Type in Terminal:
ogr2ogr -f "SQLite" -dsco SPATIALITE=YES -spat -82 -57 -32 14 africa.db planet-latest.osm.pbf

Wherein the numbers stand for the coordinates of the crop. In this case for the continent Africa. Africa.db stands for the output file and the planet-latest.osm.pbf stands for the input file.

For Windows:

Install GDAL Library of make use of the QGIS Library. The QGIS Library can be accessed by using the program ogr2ogr.exe in the QGIS dir. The links can be activated by using the following batch file. This batch file has to be executed in the Windows Command Prompt in the directory C:\Program Files\GDAL.

```
rem GDALShell.bat:
@echo off
@echo Setting environment for using the GDAL Utilities.
set SDK_ROOT=%~dp0
set SDK_ROOT=%SDK_ROOT:\\=\%
SET "PATH=%SDK_ROOT%;%PATH%"
SET "GDAL_DATA=%SDK_ROOT%gdal-data"
SET "GDAL_DRIVER_PATH=%SDK_ROOT%gdalplugins"
SET "PROJ_LIB=%SDK_ROOT%projlib"
SET "PYTHONPATH=%SDK_ROOT%python"
```

Last step is to convert the osm file to SQLite by making use of the following line:
ogr2ogr -f "SQLite" -dsco SPATIALITE=YES -spat -125 14 -61 60 D:\FIAT\NorthAmerica.db D:\FIAT\planet-latest.osm.pbf

This line can be executed in the Windows Command Prompt on every location. (for example C:\). The number stand for the coordinates of the crop, in this case North America. These coordinates can be found in Google Earth and they are lined up as follows: X_{min}, Y_{min}, X_{max}, Y_{max}. The next components are the location of the output file and the location of the input file.

Note has to be made that there is no explanation of the installation of FIAT. This has been left out because all data has been handed over by a HKV or Deltares employee. By this transfer the explanation of the installation will be included.

D

CREATING LAND USE MAPS

In order to create the land use maps the data extracted from Open Street Map needed to be filtered. A lot of unnecessary data for this study is included in the extracts from OSM. It was also needed to categorize the land use of a certain area. To filter these classes the following inputs were used.

Classification	Filter Command
Residential	
Residential_land_use	"landuse" != 'null' AND "landuse"='residential'
Residential_building	"building" != 'null' AND ("building" = 'apartments' OR "building" = 'residential' OR "building" = 'house' OR "building" = 'yes')
Commercial	
Commercial_amenity	"amenity" != 'null'
Commercial_craft	"craft" != 'null'
Commercial_building	"building" != 'null' AND ("building" = 'school' OR "building" = retail' OR "building" = 'office' OR "building" = 'commercial')
Commercial_historic	"historic" != 'null'
Commercial_shop	"shop" != 'null'
Commercial_land_use	"landuse" != 'null' AND ("landuse" = 'raceway' OR "landuse" = 'military' OR "landuse" = 'commercial' OR "landuse" = 'retail')
Commercial_military	"military" != 'null'
Commercial_sport	"sport" != 'null' AND "leisure" != 'pitch' AND "leisure" != 'track'
Industrial	
Industrial_land_use	"landuse" != 'null' AND ("landuse" = 'quarry' OR "landuse" = 'construction' OR "landuse" = 'industrial')
Industrial_man_made	"man_made" != 'null'
Industrial_building	"building" != 'null' AND ("building" = 'industrial')
Agriculture	
Agriculture_natural	"natural" != 'null'
Agriculture_Sport	"sport" != 'null' AND ("leisure" = 'pitch' OR "leisure" = 'track')
Agriculture_leisure	"leisure" != 'null'

The different layers can be merged into the official categories, residential, commercial, industrial and agriculture. This can be done in QGIS with the function *Merge shapefiles to one*, this tool can be found in the *Data Management Tools* in the tab *Vector.* This will result in the asked land use maps.

OVERLAP LAND USE MAPS

The next issue that popped up was the overlap between and within layers. This basically means that there are areas that are marked as residential and as commercial at the same time (between layers). And that within a layer an area is marked as residential but each building is marked as residential as well (within a layer). This results in double counting. For the 'between-the-layers'-issue the layers should be subtracted with the option *difference* within QGIS. *Difference* can be found in the tab *Geoprocessing Tools* under *Vector*. Below the sequence of subtracting is shown:

Input	Difference	Output
Residential	Agriculture	Residential minus Agriculture
Residential minus Agriculture	Commercial	Residential minus Agriculture minus Commercial
Residential minus Agriculture minus Commercial	Industrial	Residential minus Agriculture minus Commercial minus Industrial
Industrial	Commercial	Industrial minus Commercial
Industrial minus Commercial	Agriculture	Industrial minus Commercial minus Agriculture
Agriculture	Commercial	Agriculture minus Commercial

The resulting layers become:

- Residential minus Agriculture minus Commercial minus Industrial
- Industrial minus Commercial minus Agriculture
- Agriculture minus Commercial
- Commercial

Within these layers the second problem occurs. This is the 'double counting' problem and this can be solved by using the option *dissolve* within QGIS. This gets rid of the overlap within the layer. *Dissolve* can also be found in the *Geoprocessing Tools* under *Vector.*

F

Rasterizing

QGIS

Pre-processing provided data	
Function	Effect
Function: clip raster by extend	Clip all data to the surface of North America. The following coordinates are used (-125 14 -61 60)

ARCGIS (PRO)

Shapefile to raster (*perform for every layer*)	
Function / Step	Effect
Add column to the attribute table of the shapefile with a value of 1, can also be done in QGIS	
ArcGis: Polygon to raster, cellsize 0.00083333 tilesize (Environment): 120	Raster to a 100 meters x 100 metres resolution. Select the column with value 1 under the option valuefield. The output is a raster with value 1 when a layer is present and with a value of 0 if no layer is present.
Function: is null, with input: raster of previous step.	Create a raster with value of 1 where data is present and a value of 0 where data is not present
Function: con, with input: previous raster. Expression: value = 1, Input true raster or constant value = 0. Input true raster or constant value: previous raster.	The step creates the wanted raster with a value of 1 where data is present and a value of 0 where no data is present
Function: aggregate, input: previous raster. Cell factor: 10. Aggregation technique: sum	The aggregate function all cells within the 1 km^2 cell are summarized. The output is a raster with a value corresponding to the coverage per cell
Function: raster to other format, input: previous raster	This converts the rasters in .tif format.

Correcting area coverage (*Repeat for all land use layers followed out of previous steps*)	
Function / Step	Effect
Function: con, input raster: no-data raster, expression: value ≤ 7, Input constant value = 0. Input true raster: no-data raster	Adds all counts of 1-7 to 0 for to no data layer
Function: con, input raster: land use raster, expression: value ≥ 75, input constant value = 75. Input true raster: land use raster	Adds all counts above 75 to the value of 75.

G

Flood risk North American cities – single land use method

City	Flood Risk without Protection standards [billion euros]	Flood Risk with Protection standards [billion euros]
New Orleans	184.9	2.4
Los Angeles	13.2	0.5
New York	9.9	0.2
Miami	9.4	0.9
Philadelphia	8.8	0.4
Winnipeg	7.7	0.8
Boston	7	0.1
Chicago	6.3	0.5
Kansas	5.5	0.4
Minneapolis	3.6	0.2
Cincinnati	3.5	0.2
Detroit	2.8	0.2
Pittsburgh	2.5	0.1
Indianapolis	2.5	0.1
St. Louis	2.4	0.2
Atlanta	2.3	0.2
Columbus	2.1	0.1
Nashville	2	0.3
Seattle	1.8	0.2
Calgary	1.7	0.2

H

Flood Assessment Elements Fiche – Scores

	New Orleans	Los Angeles	New York City	Miami	Philadelphia
	Louisiana	California	New York	Florida	Pennsylvania
Population Density	5	8	9	6	6
Socio-Economic Development	5	3	3	3	3
Risk	10	8	7,5	7,5	7
Protection Level (Scussolini et al., 2016)	5	5	5	5	5
'Real' Protection Level	6	4	5	3	5
Flash Flood Fatalities	2	4	1	1	1
Flood Experience	8	2	8	2	6
Urban Planning	6	8	9	4	7