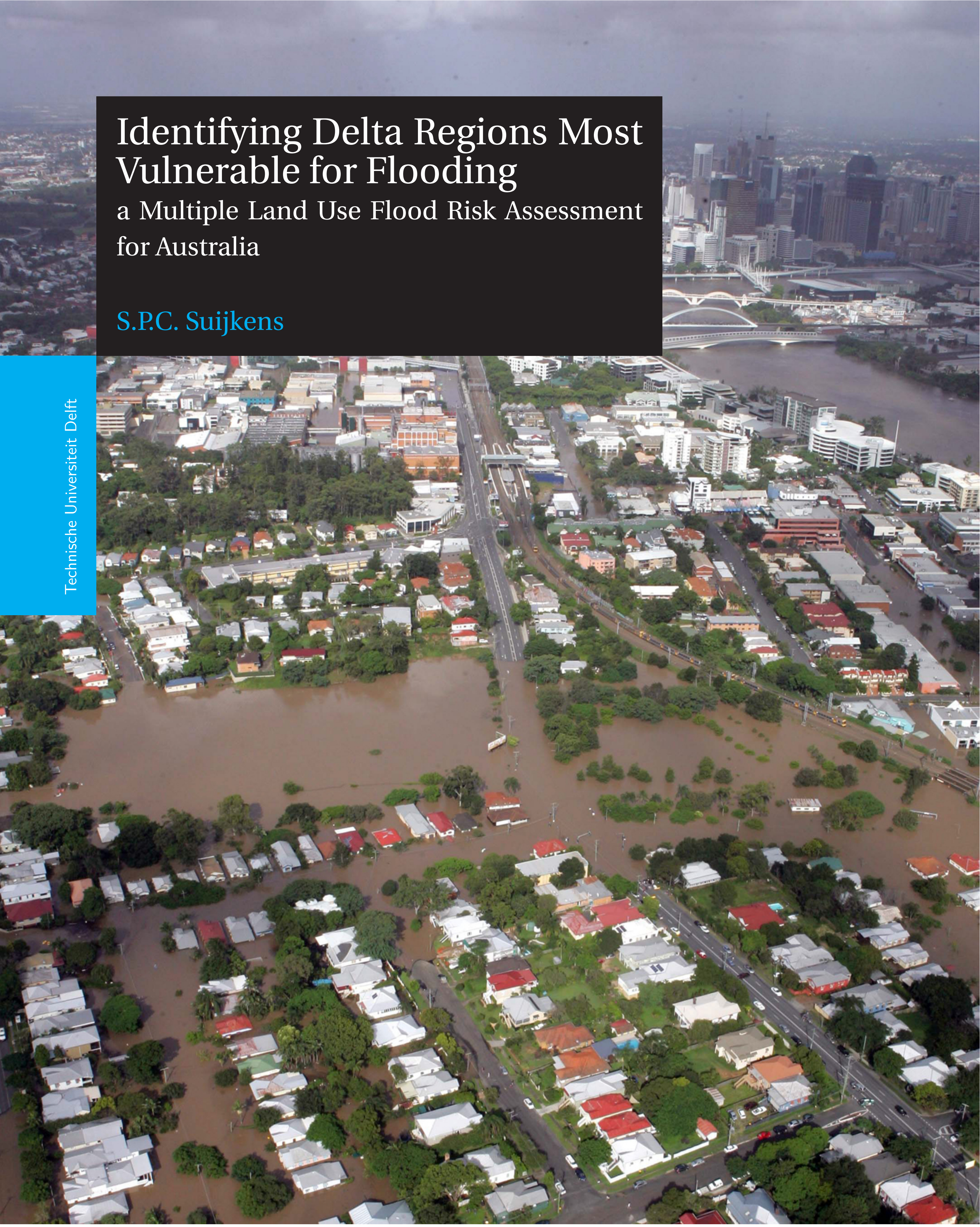
Identifying Delta Regions Most Vulnerable for Flooding

a Multiple Land Use Flood Risk Assessment for Australia

S.P.C. Suijkens

Technische Universiteit Delft



Delft University of Technology

Challenge the future

Identifying Delta Regions Most Vulnerable for Flooding

A Multiple Land Use Flood Risk Assessment for Australia

by

S.P.C. Suijkens

in partial fulfillment of the requirements for the degree of

Bachelor of Science
in Civil Engineering

at the Delft University of Technology,

Supervisor:	dr. ir. S. van Vuren,	TU Delft
Secondary supervisor:	Prof. dr. ir. M. Kok,	TU Delft

TU Delft
Delft University of Technology

Abstract

The global economical losses caused by flooding have increased over the last 50 years (IPCC, 2014; UNISDR, 2013). Deltares and HKV are developing new methods to quantify flood risk on a global scale. A Flood Risk Assessment Tool (FIAT) is used to perform calculations. The definition of risk is hazard x exposure x vulnerability. FIAT is able to combine these elements and calculate the Expected Annual Damage (EAD) for each city.

Currently two methods are used on a global and continental scale. For Europe a flood risk analysis is performed based on five land uses categories and five depth-damage functions, this method is referred to as the Multiple land use method. On a global scale an analysis is performed based on one land use and one depth-damage function, this method is referred to as the Single land use method. Nootenboom (2015) investigated the difference between the two methods for Europe. He described a good correlation of 0.97. Deltares and HKV want to extend the Multiple land use method to a global scale.

A flood risk assessment for Australia is performed with the Multiple land use method. Brisbane, Adelaide, Melbourne, Perth and Sydney are reviewed. Recently derived depth-damage functions by Huizinga (2015) were used. Australian functions are available for residential and commercial land use. For other land use classes European functions are used instead. As a source for flood hazard the PCR-GLOBWB hydrological model is used. Exposure maps for Australia are made with OpenStreetMap (OSM). Metadata from OSM was filtered and processed in such a way five land use classes were formed. A total coverage of 52% was achieved. The areas where no data could be recovered was filled in with ratios of the retrieved data. A sixth layer, named the no-data layer is formed. Visual analysis shows that the assumptions made in the no-data layer are most accurate in densely populated areas.

When the results of the Multiple land use method are compared to the Single land use method a correlation of 0.99905 is found. For every city there was a decrease in flood risk. The depth-damage function for Australia is investigated. Typical for the Australian function is the steep shape compared to the European function. A sensitivity research shows that each city reacts different to changes in the depth-damage function. Especially for cities with low inundation depths the risk is strongly influenced by the use of Australian functions. Cities with high inundation depths, such as Brisbane, are far less susceptible for changes in the depth-damage function. The use of European functions for certain land uses classes is therefore acceptable in Brisbane, as long as the dominant residential and no-data layer have continent specific functions.

PREFACE

Hereby I present to you my Bachelor thesis at the faculty of Civil Engineering (TU Delft). Together with three other students a global flood risk analysis was performed. Main goal was to identify urbanized delta regions most vulnerable for flooding. The flood risk assessment is performed with a Multiple land use method. This thesis is relevant for those who are interested in the possibilities of OpenStreetMap as a source for exposure maps.

During the thesis I have learnt a lot about flood risk assessments. I want to thank supervisors Saskia van Vuren and Matthijs Kok for their feedback and support. It was an extra motivation to work closely with HKV and Deltares. On top of that I was able to extend my knowledge of GIS-software. The knowledge gained with this project will be very useful in future projects. For this I want to thank Jan Huizinga for his intensive help with Qgis. Furthermore many thanks to Nadine Slootjes, Dennis Wagenaar and Andreas Burzel for their support and help with FIAT. And Tobias Nootenboom who provided us his research data and was always able to assist us with questions.

Finally I want to thank Machiel, Anna and Jelle for the good cooperation during the project.

S.P.C. Suijkens
Delft, June 2015

Contents

1 INTRODUCTION

1.1. BACKGROUND

The global economical losses caused by flooding have increased over the last 50 years (IPCC, 2014; UNISDR, 2013). To prepare cities around the world for this increasing flood risk, policy makers are facing difficult decisions about investments necessary for their cities. Deltares and HKV are developing new methods to quantify the flood risks in urban areas around the world. Calculations can be performed with an application that uses public available data to derive world-wide flood risk maps. The urbanized delta regions with the highest flood risk can be listed in a ranking list. This list acts as an rough indication for the flood risk in these areas. Further, more detailed, studies can be performed for these areas in order to reduce flood risk.

Two flood risk assessments developed by Deltares are currently used on a global and continental scale. The first method is "Global Flood Risk with Image Scenarios" (GLOFRIS) (Ward *et al.*, 2013; Winsemius *et al.*, 2013), hereafter named "Single land use method". The second method is "Bottom-Up Climate Adaption Strategies for a Sustainable Europe" (BASE), hereafter named "Multiple land use method". The Single land use method is a globally applicable method that uses one land use class and one damage function. The Multiple land use method is currently only applicable for Europe and based on five land use classes and five damage functions. These damage functions have been derived by Huizinga (2007) for Europe.

Nootenboom (2015) investigated the difference between the two methods for Europe. He described a good correlation between the two methods of at least 0.97. HKV and Deltares want to extend the Multiple land use method, based on five land use classes, to a global scale. Huizinga (2015) derived damage functions for all other continents. According to the same procedure as Nootenboom (2015) a comparison between the two methods can be made.

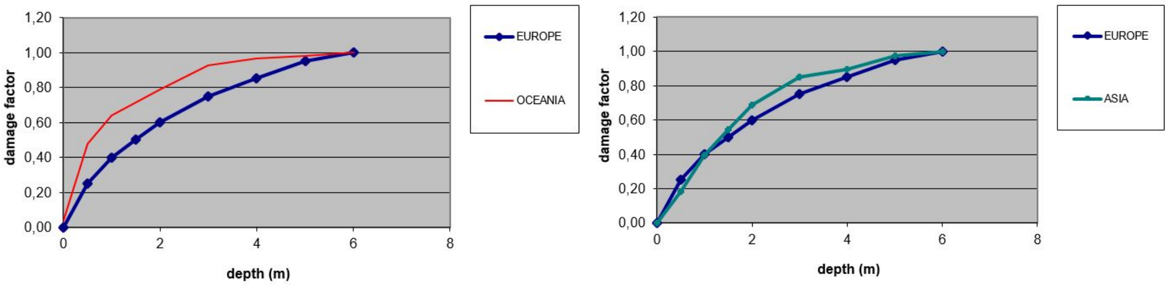
Four students of the faculty of Civil Engineering (TU Delft) will be working closely together to make this comparison globally. Each student will focus on a continent which ultimately will be combined in a global comparison. The work of Nootenboom (2015) will form a basis for this thesis. Also each student will be addressed an additional topic for their continent. This study focusses on the continent of Australia.

1.2. PROBLEM STATEMENT

In order to extend the Multiple land use method to a global scale, detailed land use data is necessary. For Europe CORINE [1] land cover data is available with a 100x100m accuracy. With this information it is possible to create a land use map based on the five land use classes necessary for the Multiple land use method. These detailed land use information is lacking for other continents. In order to derive land use maps for Australia additional data is necessary. There are multiple datasets available which contain land use information, such as Openstreetmap and Google Maps. However, a close view to the accuracy and reliability of these datasets is needed. At first available datasets have to be collected . Applicable datasets have to be merged together in such a way a land use map can be made for urbanized areas in Australia. For Australia five cities will be considered. These are Sydney, Melbourne, Adelaide, Brisbane and Perth.

[1] Coordination of Information on the Environment

Huizinga (2015) derived damage functions for a number of countries and continents from a literature study. If the shape of the functions of Europe and Asia are compared, they seem very similar. However the shape of the functions of Australia is very different if compared to the European and Asian functions. As can be seen in figure 1.1. Similar shapes of the depth-damage functions can be found for other land use classes. Further analysis has to show which factors contribute to this difference.



(a) Australian-European

(b) European-Asian

Figure 1.1: Residential depth-damage functions (Huizinga, 2015)

1.3. OBJECTIVE

The main goal of this thesis is to perform a flood risk analysis for the continent of Australia with the Multiple land use method. Secondary goal is to describe the difference in shape of the depth-damage function between Australia and Europe.

1.3.1. RESEARCH QUESTIONS

Question A:

- How does the Multiple land use method, applied to Australia, behave in comparison with the Single land use method?

Question B:

- How can the differences in shape of the damage functions between Australia and Europe be described?

Sub questions A:

- Which data is available containing land use information for Australia?
- What is the accuracy of this data?
- What is the reliability of this data?
- How can this data be processed to create a land use map?

Sub questions B:

- Based on what information are the damage functions defined?
- How do these differences contribute to the risk?

1.3.2. RESEARCH PROCEDURE

Question A: The final analysis will be made with the Flood Impact Assessment Tool (FIAT). FIAT is a tool that combines data for flood hazard, exposure and vulnerability. FIAT is able to work with data from different sources, but the data has to be pre-processed in a consistent format in order to work properly. Flood hazard data is globally available with hazard maps derived with PCR-GLOBWB by Winsemius *et al.* (2013). Damage functions of Huizinga (2015) will be used. Land use maps will be made with qGIS and Arcgis Pro. With these GIS programmes it is possible to view and merge land use data from different sources. Despite the use of multiple sources, it is impossible to avoid data gaps. Analysis of the known data has to show how these data gaps can be handled with.

Creating land use maps is a time costly procedure and takes a lot of computer power. In order to make a good comparison to the work of Nootenboom (2015) and to reduce time the same cities will be reviewed. For Australia this is a total of five cities: Brisbane, Sydney, Perth, Adelaide, Melbourne.

Question B: This part of the BSc thesis will be a literature study. An analysis of the different sources of the damage function will provide better insight in the origin of the functions. Furthermore features that contribute to the occurring damage are described. Not for every land use specific information was found by Huizinga (2015). The use of European depth-damage functions and values for the Australian continent will be analysed. A sensitivity study has to show what the effects of the use of European functions for some land use classes are.

Socio-economic and climate change scenarios will not be calculated in this study. All results are calculated with implementation of protection standards. For Australia the protection standard is assumed to be the same for the whole continent.

1.3.3. REPORT STRUCTURE

In chapter 2 an overview of the basic theory of flood risk assessments is given. Both methods used by Nootenboom (2015) will be explained and the difference is discussed. Chapter 3 will focus on the procedures to make flood risk maps for Australia. Programs used to derive maps and calculate flood risk are explained. In chapter 4 the results of the Multiple land use method are presented. Chapter 5 contains a literature study on the depth-damage functions and the sensitivity for changes. This is followed by a discussion and conclusions in chapter 6 and chapter 7. Finally some recommondations are listed in chapter 8.

2

THEORY OF FLOOD RISK ASSESMENT

This chapter includes the basic theory and definitions of flood risk assessments. The use of depth-damage functions is explained. Some insight in the uncertainties of flood risk assessments are given. Finally two methods for a flood risk assessment will be discussed including their results.

2.1. FLOOD TYPES

Depending on the origin of a flood, three main types of floods can be described. *Storm surges* generally occur along coast lines an often cause the largest damage. *River floods* are mostly the cause of excessive rain fall. These floods can affect a large area if the location of a flood is in a flat area. More upstream the affected area is often smaller, but the flow velocities will be higher. With these conditions sediment transport can be a additional factor in the total damage. *Flash floods* are also the cause of excessive rain fall, but the affected area is most of the times relatively small. Flash floods can occur very rapidly and last in the order of minutes to hours. Because of the local character of these floods they are are incredibly hard to predict, but can cause large damage. In valleys flood waves propagate with a high speed. But also in flat areas flash floods can occur and will cause water accumulation on the surface. (Kron, 2002)

Nootenboom (2015) discovered that "the most common flood types regarded in large scale assessments are river and coastal flooding". These type of floods have the largest share in economic flood damages in Europe (MunichRE, 2013). Because flash floods are hard to predict, these type of floods are not taken in account in most flood risk assessments.

2.2. DEFINITION OF FLOOD RISK

In this study the same definition of flood risk as Nootenboom (2015) is used. The flood risk is defined by Kron (2002) as:

Risk = Hazard x Exposure x Vulnerability

Figure 2.1: Flood risk definition (Nootenboom, 2015)

Hazard is defined as the potential occurrence of a event that can cause damage and loss to property and infrastructure. *Exposure* refers to the presence of resources and infrastructure that could be affected by a flood. Exposure also refers to the presence of people in the affected area. In this study loss of life will not be considered. And last *vulnerability* can be described as the magnitude of which assets are affected by a flood, or as the lack of resistance to a flood (Field *et al.*, 2012; Kron, 2002; Merz *et al.*, 2014; Nootenboom, 2015).

2.2.1. HAZARD

Hazard data is provided with the PCRaster Global Water Balance (PCR-GLOBWB) hydrological model. It was developed at the Department of Physical Geography, Utrecht University. Return periods of 5, 10, 25, 50, 100, 250, 500 and 1000 years are provided. For each return period the inundation depth is given in decimetres. In figure 2.2 large inundation depths are seen in red. This model uses "explicit routing of surface water flow using the kinematic wave approximation, dynamic inundation of floodplains and a reservoir scheme" (Nootenboom, 2015). The model has an output with a spatial resolution of approximately 50km^2. This coarse resolution isn't applicable for flood risk assessments in cities. A produced rastercell will completely cover a city and thus provide only one inundation depth for the whole city. Therefore the model is downscaled to a 1km^2 resolution by Winsemius *et al.* (2013). This resolutions is better applicable in cities (Holz, 2014; Winsemius *et al.*, 2013).

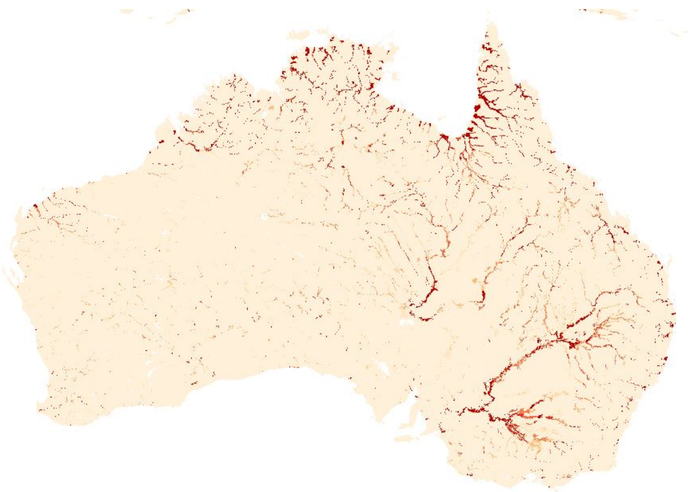


Figure 2.2: PCR-GLOBWB for Australia

2.2.2. EXPOSURE

For the exposure the value of an asset affected by flood is expressed. This can be done for a single object or for an aggregated area. This study uses exposure on an aggregated level and thus summarized in land use classes. (Nootenboom, 2015). Land use maps of Australia, which will be discussed in chapter 3, are the input for the exposure.

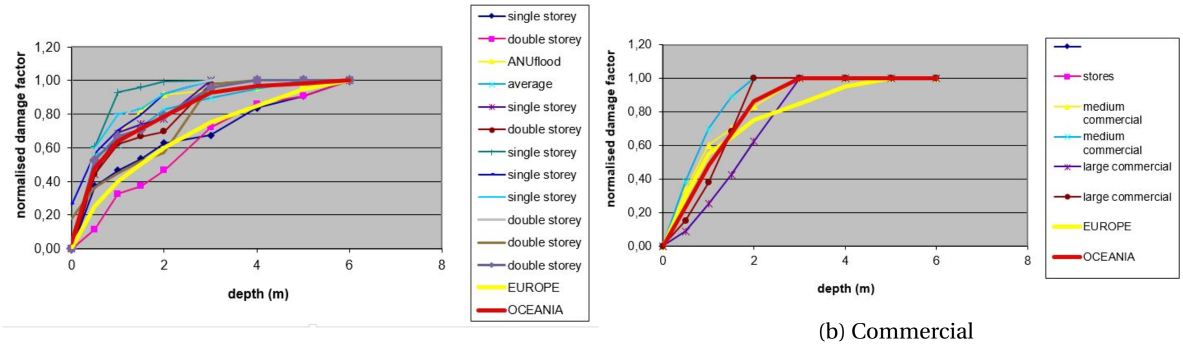
2.2.3. VULNERABILITY

Vulnerability can be described with a depth-damage function. These functions indicate what factor of the maximum damage is reached at a given inundation depth. A flood has numeral characteristics such as flow velocity, duration, water level rise rate and inundation depth. To derive damage functions only the inundation depth is used in this analysis. Huizinga (2007, 2015) derived depth-damage functions and maximum damage values per m^2 for five land use classes in Europe and all other continents. Where information on other continents was lacking, European functions have been used.

Although it is possible to distinguish numeral land use classes, these can be narrowed down to five. Considered are residential, commercial, industrial, agriculture and infrastructure land use classes. These five classes combined lead to an average of at least 80% of the total damage (Huizinga, 2007).

Huizinga (2007, 2015) performed a intensive literature study in order to obtain reported damage of floods for all countries. For Europe he was able to find detailed information of 11 countries. Damage values for specific depths were derived from literature and reports. With these specific damage values he was able to created a normalised depth-damage function. He used several procedures to extend this information on an European scale. The result was an average depth-damage function and average maximum damage value applicable for whole Europe. With the same approach he derived depth-damage functions for all other continents.

Huizinga (2015) used a total of five sources for Australia. Maximum damage values are found for residential, commercial and infrastructure land use classes. For industrial and agriculture land use a maximum value is lacking. Depth-damage functions have been derived for residential and commercial land use classes, see figure 2.3. Since only a maximum damage value for infrastructure was found no function could be created. If an Australian function couldn't be derived the European function was used instead. The use of the European functions for Australia will be discussed in chapter 5.



(a) Residential

(b) Commercial

Figure 2.3: Depth-damage functions Australia (Huizinga, 2015)

2.2.4. RISK

The damage calculated for each return period of the flood hazard is plotted and forms a damage-probability curve (Nootenboom, 2015). "Flood risk is the integral of these damages as a function of the probability of exceedance" (Nootenboom, 2015; Verkade and Werner, 2011). Risk itself can be expressed in expected annual damage (EAD), resulting from the damage caused by a flood (Nootenboom, 2015).

2.2.5. DAMAGE CATEGORIES

Damage can be divided in direct and indirect damage. Where direct damage is described as the result of physical contact of assets with the flood itself. Indirect damage is the effect of the flood outside the flood prone area or after the flood event, such as business interruption. A second subdivision for direct and indirect damage can be made, resulting in tangible and intangible damage. Where tangible damage can be expressed in an absolute value in money. Intangible damage is difficult to express in an absolute value in money. (Merz *et al.*, 2010) In this study only direct tangible damaged is considered.

Table 2.1: Damage examples (Merz *et al.*, 2010)

Direct, tangible	damage to buildings, infrastructure, livestock
Direct, intangible	loss of life, negative effect on ecosystem
Indirect, tangible	induced production losses outside flooded area
Indirect, intangible	trauma

2.3. UNCERTAINTIES IN FLOOD RISK ASSESSMENTS

Large differences between flood risk assessments can be seen. The assessments contain several uncertainties. This section is based on the research by Wagenaar *et al.* (2015). First he distinguishes aleatory and epistemic uncertainty. Aleatory uncertainty is introduced when average data is used. This is especially important when small floods occur. Some houses will be damaged differently than the estimated average. For local floods the estimated damages differ the most. When large floods are assessed these uncertainties cancel out because a sufficient number of houses is affected.

"Epistemic uncertainty is the lack of understanding a system" (Wagenaar *et al.*, 2015). Flood data is mostly available from small case studies. Results from these case studies can have large differences and are difficult to explain. When damage-functions, based on a small case study, are used for other areas an uncertainty is introduced. For this study this uncertainty is relevant. Not for every land use continent specific functions were found and European functions are used instead. Results from these calculations contain an epistemic uncertainty.

There is also an uncertainty in the land use data. In the ideal situation the affected land use should be connected to the exact hazard at that location. To achieve this, geographical data with high accuracy is necessary. In this manner local elevations can be taken in account. Especially when the hazard is unevenly distributed over an area large uncertainties will be introduced when a coarse model is used.

2.4. PREVIOUS FLOOD RISK ASSESSMENTS

2.4.1. SINGLE LAND USE METHOD

As an input for the Single land use method the global hydrological model PCR-GLOBWB is used. To define the exposure in the Single land use method Nootenboom (2015) used a method described by Winsemius *et al.* (2013). Urban land cover data from MODIS [1] with a 500m resolution is used in combination with urban extent data from GRUMP [2]. With this data it is possible to identify two categories of urban land cover: high density urban area and peri-urban area. Rural area is not considered in this method. In the high density urban area 75% is assumed to be of residential land use. In the peri-urban area 25% is assumed as residential land use.

To express the vulnerability in the Single land use method both urban areas have an maximum damage value derived from DamageScanner. DamageScanner is a flood damage model which simulates flood damage based on the inundation depth (Jongman *et al.*, 2012). Values are adjusted using an worldwide average GDP [3] per capita. Finally one depth-damage function for both land use classes is used.

2.4.2. MULTIPLE LAND USE METHOD FOR EUROPE

The Multiple land use method uses the same input from the PCR-GLOBWB model. To define exposure the five land use classes mentioned in section 2.2 are considered. To identify the presence of the land use classes, detailed information of land use is necessary. CORINE land cover (CLC) data with a resolution of 100m is able to identify 44 types of land use. CLC is combined with Land Use/Cover Area (LUCAS) data. LUCAS data provides statistics about land use coverage. With CORINE and LUCAS combined Nootenboom (2015) calculated for each CLC class the presence of Residential, Commercial, Industrial, Agriculture and Infrastructure land use classes. Each CLC class that contained one ore more of these land use classes were used in the assessment. This procedure is described by Nootenboom (2015).

The maximum damage values per land use differ throughout Europe. To obtain a average damage value Huizinga (2007) harmonized these values. GDP per capita is used to perform this harmonization. This procedure is discussed by Huizinga (2007) and Nootenboom (2015). Depth-damage functions discussed in section 2.2 are used. For the input in FIAT the relative depth-damage function is used. Using a relative depth-damage function means that the damage varies between zero and one. Where 'one' is consistent with the maximum damage value itself.

2.4.3. RESULTS NOOTENBOOM

Nootenboom (2015) performed several analysis. First he compared the results of both methods. After this he performed a global flood risk assessment using the Single land use method. For the global assessment he first performed a base scenario and then used a climate-change and socio-economic future scenario.

When the two methods are compared a large overestimation with the Singe land use method can be seen. Nootenboom (2015) found that "the differences are in the order of billion Euro and increase with a severity of the flood event". The correlation between both methods varies between 0.974 and 0.983. The high correlation between both methods can be described by the dominant residential land use class. Both methods contain a depth-damage function for residential land use that is quite similar (Nootenboom, 2015).

[1] Moderate Resolution Imaging Spectroradiometer
[2] Global Rural-Urban Mapping Project
[3] Gross Domestic Product

The global assessment started with a base scenario. Most important conclusion was that the implementation of protection standards lead up to a decrease in flood risk with a factor 10. Implementing a flood protection standard with a non-exceedance of 1/5 years already results in a reduction of 60% of damage.

Assessments considering a climate change didn't always lead to an increase in flood risk. Some areas will receive more precipitation, but other areas will become dryer. Especially in countries with low protection standards a small increase in flood hazard resulted in a immediate increase in flood risk.

Socio-economic development had a high impact on the flood risk. Especially in Indian cities the flood risk increased rapidly. This can be explained by the expected growth in GDP per capita by 2030. An combination of socio-economic development and climate change gives an more realistic view on future flood risk, but is still dominated by Indian cities.

To compare flood risk among countries flood impact indicators were used. This way results were transformed to a uniform output. Several indicators are possible. When the GDP per capita is multiplied by the affected people, the exposed GDP is calculated. This is a norm for the economic exposure. It is also possible to calculate the flood risk relative to the city size. And the last flood indicator investigated by Nootenboom (2015) was the flood risk relative to the number of residents in a city.

Depending on the used flood risk indicator the ranking list of cities worldwide varied. When compared to the city size in the base scenario Russian cities dominated the ranking list. This is explained by the relatively larger fraction of the areas that were flood within these cities. Flood risk compared to the number of residents also resulted in a ranking list largely dominated by Russian cities, although some cities from the United States were present.

The use of mentioned flood risk indicators was also investigated for future scenarios. All results collected by Nootenboom (2015) can be found in Appendix A.

3
Procedure Flood Risk Assesment Australia

In this chapter the creation of land use maps for Australia is described. The available data and processing is explained. The results of found data are presented with coverage percentages. It is explained how the areas where no data was available were filled. A visual analysis of the accuracy of the "No-data layer" is performed. Finally some limitations of the used methods are discussed.

3.1. Available Datasets

Multiple datasets are freely available on the internet. Specific data for land use maps are for example the Global Land Cover map for the year 2000 (GLC2000) with a resolution of 1km. Also ESA made a Global Land Cover map (GLOBCOVER) with a resolution of 300m and distinguishes 23 different land use classes. Unfortunately a resolution of 300m is not accurate enough to describe land use classes within urbanized areas. Therefore GLOBCOVER is only useful to identify the location of urbanized areas or to determine city boundaries.

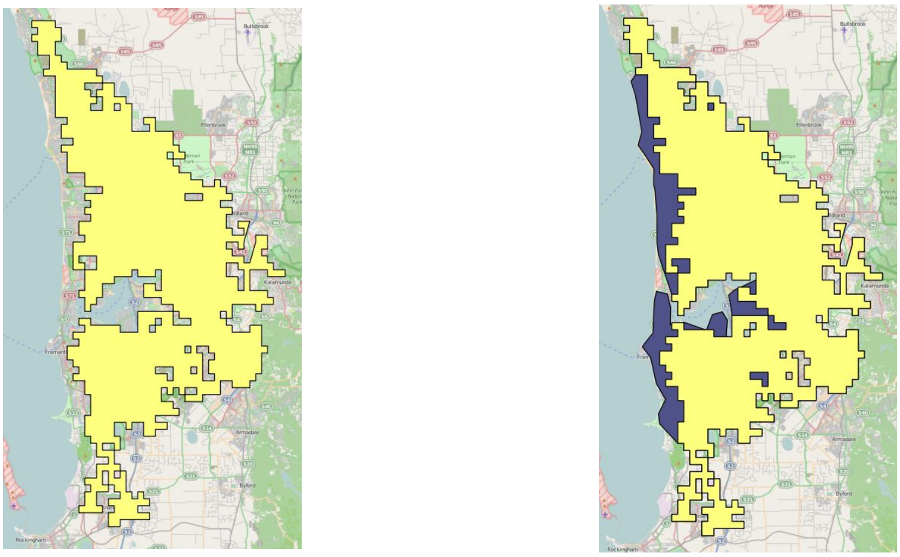
Most common known is Google Maps. It contains maps with a high detail of cities world wide. In order to derive land use maps, underlying data has to be available and processed. This data is stored in the attributes of the map. Attributes contain additional information about, for example, the type op building, shops, land use, etc. For Google Maps these attributes are not freely accessible. An alternative is Openstreetmap (OSM). It is a collaborative project to create a map of the world. OSM is editable by its users and freely available. From OSM it is possible to extract attributes and categorize them in a land use class.

Because every user is able to edit information in OSM its reliability is more unsure compared to commercial maps. Fortunately the reliability of OSM is improved with a control system. Major map changes are reviewed by other users and have to be accepted. OSM users that can accept these changes are often long term users of OSM with a good reputation. For this study it is assumed that all available data is trustworthy. Important to note is that due to a licensing change in OSM some data is deleted from OSM. Globally more than 99% of data has been retained. However, for Australia and Poland the retained data was less (OSM, 2012). It can take some extra time before all data that was available for Australia is once again added by users of OSM. Despite 600.000 contributors there are still large areas where no data is available. An alternative for these areas has yet to be found. In section 3.2.1 it is discussed how the data gaps in Australia are handled.

Data from GLC2000, GLOBCOVER, Google Maps, Openstreetmap, Google Earth and Bing Maps were viewed in qGIS. A qualitative analysis showed that the coverage of the cities in Australia was maximal with Openstreetmap. An extract from Planet OSM was used to download all data from Australia. Planet OSM is a file with weekly updated OSM maps containing all layers and attributes. A separate extract containing only roads is used to complete the data.

3.2. FORMING LAND USE MAP AUSTRALIA

To form land use map from the attributes found with Openstreetmap mostly qGiS and also ArcGis Pro are used. Because the OSM extract for Australia is nearly 2GB qGIS and ArcGis have performance problems. Therefore the extract is clipped in such a way that only the data for the five studied cities remain. So called City Shape Files, used by Nootenboom (2015), were used as a boundary to clip. Where necessary these Shape Files were manually edited to obtain a higher accuracy.

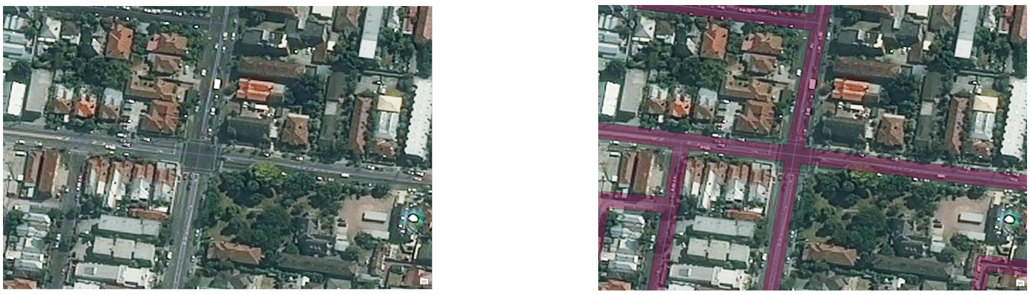


(a) Original Shapefile (b) Edited Shapefile

Figure 3.1: Difference between Shapefiles

With qGIS the most common attributes are filtered, such as schools, apartments, etc. This filtering procedure leads to 16 layers in qGIS which finally are merged in four land use layers. Analysis showed that some of the layers have an overlap. For example when a school is located in a residential area. These overlaps were deleted in a specific order.

The infrastructure layer is completely formed with the separate extract containing only roads. In the OSM extract these roads are presented as lines, which have no area. Therefore all roads are given an estimated width of approximately 6 meters to obtain an area of all roads. This is shown in figure 3.2. Finally the infrastructure layer was subtracted from all other layers.



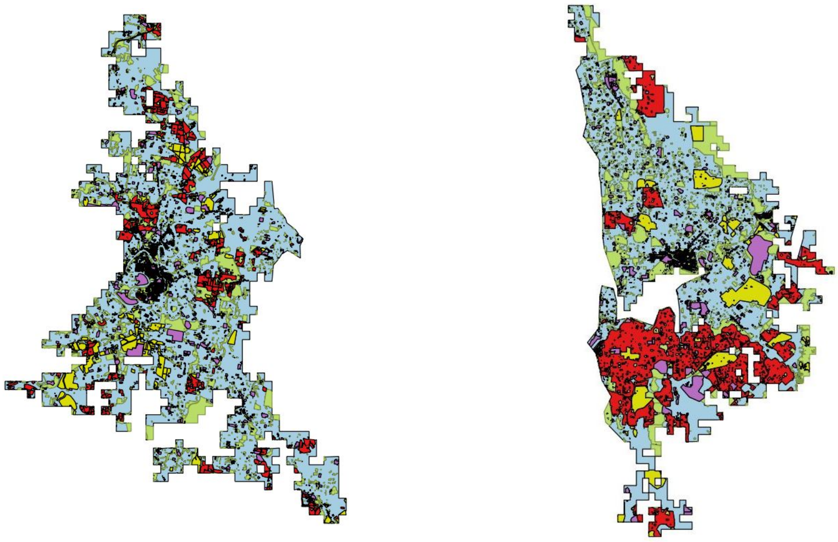
(a) Roads as line (b) Buffered roads

Figure 3.2: Buffering process

With this procedure all five land use classes are described with the highest possible accuracy. The remaining area is named as the no-data layer. Appendix B gives a more detailed explanation on the inputs and programmes that were used to derive the land use maps. Table 3.1 gives an overview of the land use coverage. Shown coverages represent the coverage of each layer for all five cities combined. A graphical representation of these coverages are given in figures 3.3 and 3.4. Finally table 3.2 shows the data coverage per city.

Table 3.1: Land use coverage Australia

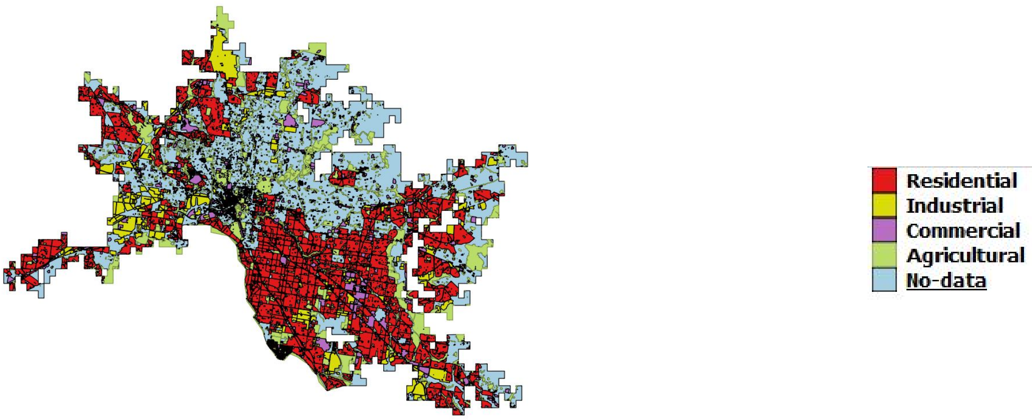
Land use [km^2]	Coverage [%]
Residential	16
Industrial	5
Commercial	1
Agriculture	12
Infrastructure	12
No data	48



(a) Brisbane

(b) Perth

Figure 3.3: Land use map (1:200.000)



(a) Melbourne

Figure 3.4: Land use map (1:200.000)

Table 3.2: Coverage per city

City	Data [%]	No data [%]
Brisbane	42	58
Perth	56	44
Sydney	43	57
Adelaide	40	60
Melbourne	65	35

3.2.1. FILLING DATA GAPS

With the method described in section 3.2 five land use classes were obtained for five cities in Australia. When only the area with known land use is considered, the ratio between the five land use classes can be found. This ratio can be used to fill in the area of the no-data layer. Because the agriculture layer is accurately described within the cities, this layer isn't used in the ratio. Otherwise there will be an overestimation of agriculture within to no-data layer. For the same reason the infrastructure layer isn't used in the ratio as well. Because of the very high accuracy of the infrastructure layer it is unlikely that there will be additional roads in the no-data layer. Table 3.3 shows the ratio in percentage of the land use coverage used within the no-data layer.

Table 3.3: Ratio land use coverage

Land use	Coverage [%]
Residential	61
Industrial	19
Commercial	20

With known maximum damage values for the land uses, a weighted maximum damage value for the no-data layer can be calculated. Each land use has a share in the damage value based on the same relations as in table 3.3. With this procedure the damage value for the no-data layer is set at 560 EUR/m^2.

The depth-damage function for the no-data layer is created in a similar way. The functions of the residential, industrial and commercial layer are plotted. With the same ratios an average depth-damage function is formed for the no-data layer. This function is plotted in red in figure 3.5.

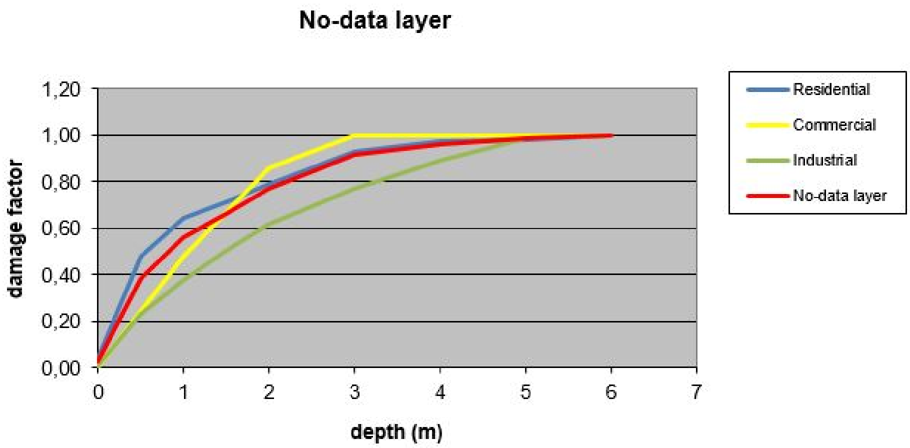


Figure 3.5: No-data layer depth-damage function

3.3. REVIEW OF NO-DATA LAYER

For all five cities a visual analysis of the no-data layer is performed. The areas where hazard is present are viewed. If the hazard covers the no-data layer, Google satellite images are used to estimate the actual land cover.

BRISBANE

The largest inundation depths are found along the Brisbane River. The river flows through the city centre and high density residential areas. In figures 3.6 and 3.7 the hazard raster is shown in red. In figure 3.6 the no-data layer (blue) is present where flooding occurs. In figure 3.7 the satellite images are shown. It is visible that the majority of the land cover consist of residential area. For this area the no-data layer gives a good approximation of the actual land cover. Further from the city centre there is a small forest that is flooded. In this area also a part no-data layer is present. Here the damage will be overestimated. However, on average the no-data layer gives a good approximation of the actual land use.

Figure 3.6: Hazard Brisbane including no-data

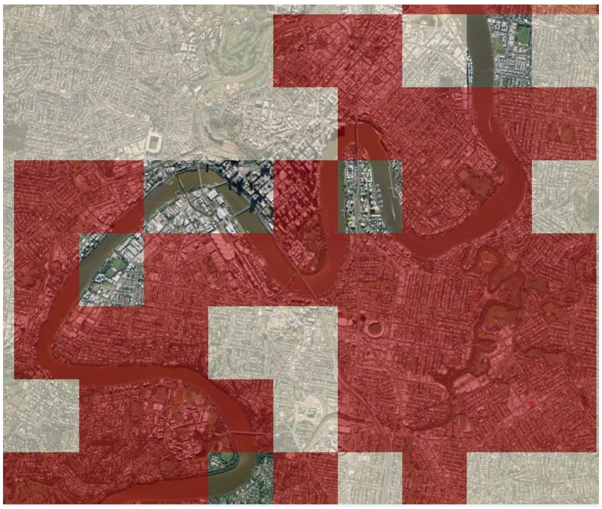


Figure 3.7: Hazard Brisbane including satellite image

PERTH

The hazard in Perth is found along the Swan River. Before the river widens to a width of 4 kilometres there are a several narrow bends through a residential area with high density. Buildings are located closely to the river. The no-data layer that is present gives a good estimation of the actual land use. For Perth the hazard is concentrated in this area. There are no areas found where assumptions made in the no-data layer didn't match the actual situation.

SYDNEY

When the hazard data is reviewed is it visible that only a small suburb of Sydney is prone to river flooding. The flooded area is approximately 15km^2. The land cover based on satellite images shows a mix of residential and commercial area with low density. It is estimated that the no-data layer gives some overestimation in this area. Because of the small area that is affected by flooding the absolute damage overestimation is not relevant on a continental scale.

ADELAIDE

The hazard model doesn't show hazard within the shapefile used for Adelaide. Approximately 30 kilometres north of the city centre the Gawler River can cause flooding with inundation depth of up to 0.8 meters. This is mainly an agricultural area. Therefore it is not relevant to extend the shapefile of Adelaide. However, the River Torrens flows through highly populated areas of Adelaide. Flooding of the River Torrens has occurred in the past. It is advised to use a model which includes the flooding within the city itself.

In Adelaide the coverage of found data is the lowest. Along the river the no-data layer is dominantly present, see figure 3.8. The no-data layer gives a good estimation of the actual land use. If hazard data for Adelaide is available, it is estimated that the damage can be calculated with a good approximation.

(a) No-data layer (b) Satellite image

Figure 3.8: No-data Adelaide

MELBOURNE

Main flooding occurs along two rivers, the Yarra River and Maribyrnong River. The Maribyrnong River flows into the Yarra river at the city centre of Melbourne. At this location the largest inundation depths are found. Buildings are located close to the river. In this area the no-data layer gives a good estimation. More upstream the Yarra River has more agricultural land along the river. This is well described with the created land use maps. Upstream of the Maribyrnong river there is also more agricultural land present along the river. However, some of these agricultural areas are covered with the no-data layer. Along this river a overestimation of the damage is caused by the no-data layer. See figure 3.9.

(a) Yarra River (b) Maribyrnong River

Figure 3.9: No-data Adelaide

SUMMARY

Visual analysis shows that when flooding occurs along rivers in densely populated areas the no-data layer gives a good estimation. Buildings are located close to the flooded river. When the flooded river flows through the suburbs, more agriculture land along the river is present. It is seen that some of this agricultural land is marked as no-data. Because the no-data layer consist of 61% residential area, a large overestimation is made.

In general it can be said that close to the city centre the assumptions made in the no-data layer are more accurate than in the suburbs.

3.4. RASTERING AND IMPLEMENTATION IN FIAT

3.4.1. RASTERING

All created layers are vector files. For use with FIAT is it necessary to convert these vector files to a raster format. FIAT can only work properly with raster files with the same resolution. The hydrological model PCR-GLOBWB has a resolution of 1km^2. This resolution is indicative for all other raster files.

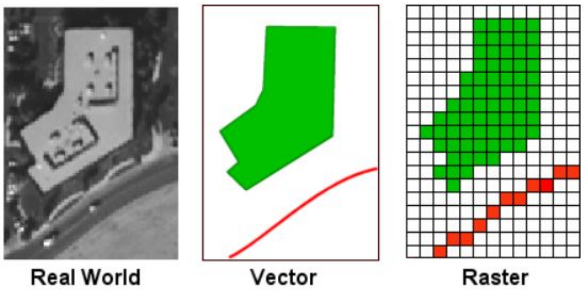


Figure 3.10: Example raster process (Geography Hunter, 2015)

When qGIS rasterizes it will fill a raster cell entirely with only one land use if this land use fills the 1km^2 for more than 50%. When the vector files are rasterized with this resolution a great amount of detail will be lost. New methods have to be created to remain a high accuracy used with a 1km^2 resolution.

Therefor the vector files are first rastered with a resolution of 100x100 meters. This accuracy is comparable with the CLC data. Every layer will be separately rasterized with the 100x100 meter resolution. If a land use class is present the raster cell will be given a value of 1, if not 0. The sum of all raster cells within 1km^2 will be calculated. This corresponds to a coverage expressed in percentage of a raster cell on a 1km^2 resolution. A series of functions is used in Qgis en ArcGis to create these exposure rasters. A detailed description of all used functions is described in Apendix C.

3.4.2. IMPLEMENTATION IN FIAT

FIAT is setup to work with multiple land use classes. With the introduction of the no-data layer a sixth land use is added to FIAT. Every input in FIAT needs to be of the same extent and resolution. All provided hazard, protection levels and GDP per capita data is clipped to the extent of Australia.

The resolution of a rastercell is 30 arcseconds, which corresponds to 1km^2 on the equator. Rastercells that are located further away from the equator will deviate from 1km^2. To correct for this deviation an area factor has to be used for every city. FIAT is able to correct for this automatically when a rasterfile containing these factors is provided. FIAT will correct for each individual rastercell with the area factor. Because of memory problems this rasterfile isn't available on a global scale. The correction is done manually in Excel with factors provided by Nootenboom (2015). For every city the centroid of the shapefile was calculated with Qgis. With the latitude of each centroid the corresponding area factor is found. It is assumed that this area factor is consistent within the boundaries of the city.

3.4.3. COVERAGE ADJUSTMENT

MAXIMUM COVERAGE

The rasters for each layer contain a data band which gives a value of 0-100%. For each coverage percentage the amount (counts) of raster cells is given. Practically it is not possible to have a value of 100%. This will correspond to $1km^2$ full of (for example) residential buildings. There will always be some additional other land cover such as gardens, sidewalks, etc. A distribution of the found coverages for the residential layer is shown in figure 3.11.

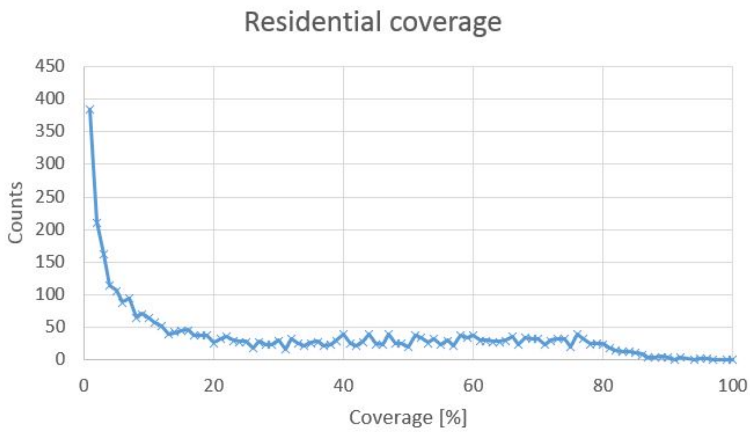


Figure 3.11: Residential coverage distribution

Nootenboom (2015) used a maximum coverage of 75% in the high density urban area. For the exposure maps of Australia the counts of 75 and above contribute to $303km^2$. This corresponds to 8.4% compared to the total amount of counts where a residential area is present. A more realistic approach is to convert all counts of 76 and above to 75. For the base results counts from 0-100 were still taken into account. In section 4.3 the layers are updated with a maximum coverage of 75%.

BUFFER WIDTH ROADS

Roads are buffered with a visually estimated width of 6 meter. Based on satellite images this gives a good estimation in residential areas. When divided roadways and highways are buffered a small error occurs, see figure 3.12. The median strip isn't included in the buffer. Because no other land use is present, the median strip will be included in the no-data layer. Similar errors occur when other land use layers are located just too far from the roads. For example the sidewalk isn't included by either the residential area or the road. This also results in a small no-data area, where in reality a sidewalk is located. This error can be seen along all major roads. Because the total length of the roads is estimated at several thousand kilometres this could potentially lead up to significant overestimation. When the raster files of the no-data layer are analysed it is estimated that the buffer error can lead to a coverage with a maximum of 7% of a square kilometre. A more realistic approach is to convert all counts of 1-7 to 0. For the base results counts from 1-7 were still taken into account. In In section 4.3 the layers are updated with the counts from 1-7 removed.

Figure 3.12: Buffer error

4
Results Flood Risk Assessment Australia

4.1. Results Multiple land use method

In table 4.1 the results of the Multiple land use method (MLUM) for Australia, compared with the Single land use method (SLUM) are presented. The correlation is 0.99905. Results from table 4.1 are referred to as base results. All results are with implementation of protection standards.

Table 4.1: Comparison methods

City	SLUM [million €]	MLUM [million €]	Ranking	SLUM	MLUM
Brisbane	1037	401	1	Brisbane	Brisbane
Perth	169	67	2	Perth	Melbourne
Sydney	9	6	3	Melbourne	Perth
Adelaide	0	0	4	Sydney	Sydney
Melbourne	159	79	5	Adelaide	Adelaide

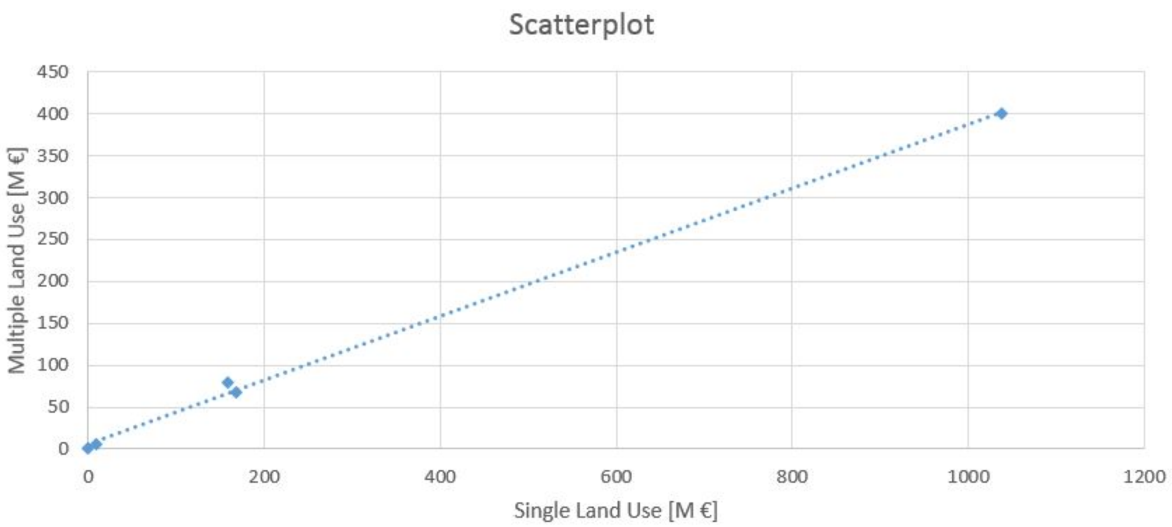


Figure 4.1: Scatterplot

Effectively only four cities are compared to the Single land use method. With four cities it is difficult to give a definite conclusion about the correlation. Although it can be said that when the risk of a city is deviating from these results, the correlation drops rapidly.

4.2. Comparison with Single land use method

When compared to the Single land use method three properties change. The amount of land uses, the depth-damage function and the maximum damage values. In Appendix D an overview is given of a number of FIAT runs. In these runs each time one of the properties is changed.

The following FIAT runs, with the Multiple land use method, are performed:

- Australian value, Australian function
- Australian function, European value
- European function, Australian value
- European function, European value

Combinations of European and Australian functions and vulues contain large uncertainties. However, with these FIAT runs the individual effect of a change of each property can be identified. It can be derived that the use of multiple land uses alone already gives a decrease in flood risk. The use of Australian values gives the most significant change in the calculated risk compared to the Single land use method. For each city there is a constant drop in risk. The use of different depth-damage function gives more irregular results. An overview is given in Appendix D, table D.1 and table D.2.

Update shapefiles

For the Multiple land use method the shapefiles created by Nootenboom (2015) were updated. In table 4.2 the risk is calculated with the Multiple land use method for each of the shapefiles. An increase in flood risk of up to 9.1% is seen, which otherwise was neglected. The updated shapefiles proof to be an added value.

Table 4.2: Comparison shapefiles

	Risk [million EUR]		Difference [%]
City	Shapefile Nootenboom	Updated shapefile	
Brisbane	370	401	+8.2
Perth	61	67	+9.1
Sydney	6	6	0.0
Adelaide	0	0	0.0
Melbourne	79	79	0.0

4.3. Raster file adjustment

First the results are presented when all corrections for the area coverages are implemented. Second the individual effect of correction for the buffer error is given.

4.3.1. Corrected area coverage

As discussed in section 3.4.3 the base results contain unrealistic coverages. The coverage of the residential, industrial and commercial layer was set to a maximum of 75%. In theory the coverage of the industrial and commercial layer could be slightly higher than the residential layer. This is because of large warehouses or factories. For practical reasons they are also set to a maximum of 75%, so the maximum coverage of the no-data layer will also be fixed at 75%. For infrastructure a correction was not necessary, since this layer didn't contain unrealistic high coverages. Also the agriculture layer wasn't corrected because a coverage of 100% would be possible when large parks or nature areas are rastered. Compared to the Single land use method of Nootenboom (2015) the corrected results give a correlation of 0,99880.

Table 4.3: Results corrected coverage

	Risk [million EUR]		Difference [%]
City	Base coverage	Corrected coverage	
Brisbane	401	384	-4.17
Perth	67	64	-3.68
Sydney	6	6	-4.45
Adelaide	0	0	0.0
Melbourne	79	77	-1.59

Especially for cities where the collected land use data was low the risk decreases most with corrected coverage. For Melbourne, where most land use data was retrieved, the decrease in risk is less. This indicates that the corrected coverages have the largest impact in the no-data layer. The decrease in risk is also strongly dependant on the exact location of the raster cells with a high coverage. If hazard is present in an area with high density, the decrease will be more significant. The maximum value of 75% is not specifically derived for Australia, but can give an indication of the impact on the results when corrections are taken into account. For the ranking list the corrected data doesn't have any influence. But the results do present a more accurate estimate of the absolute value of the risk.

4.3.2. CORRECTION BUFFER ERROR

As discussed in section 3.4.3 there is an error introduced with the buffer process. Table 4.4 shows the difference in risk when the coverages of 1-7% in the no-data layer are not taken into account.

Table 4.4: Results correction buffer error

	Risk [million EUR]		Difference [%]
City	Base	Corrected for buffer error	
Brisbane	401	399	-0.47
Perth	67	66	-0.74
Sydney	6	6	-1.97
Adelaide	0	0	0.0
Melbourne	79	78	-0.34

It is concluded that the buffer error doesn't have a significant impact on the calculated risk.

5

DAMAGE FUNCTION RESEARCH

In section 5.1 more insight in the forming and background of the depth-damage functions is given. In section 5.2 the sensitivity for changes in the depth-damage function is described. This is particularly relevant to explain the possible effects of the use of European depth-damage functions for several land use classes.

5.1. LITERATURE STUDY

5.1.1. SOURCES DEPTH-DAMAGE FUNCTIONS

Huizinga (2015) derived depth-damage functions for Australia based on five sources and reviewed more than twenty sources. For specific depths damages were derived. Different building types, such as single storey and double storey are distuinghised. It can be seen that depth-damage functions for single storey residential buildings have the steepest shape. From these damages a normalised damage-function was created. The average of all sources and building types is calculated and used in FIAT, see figure 5.1.

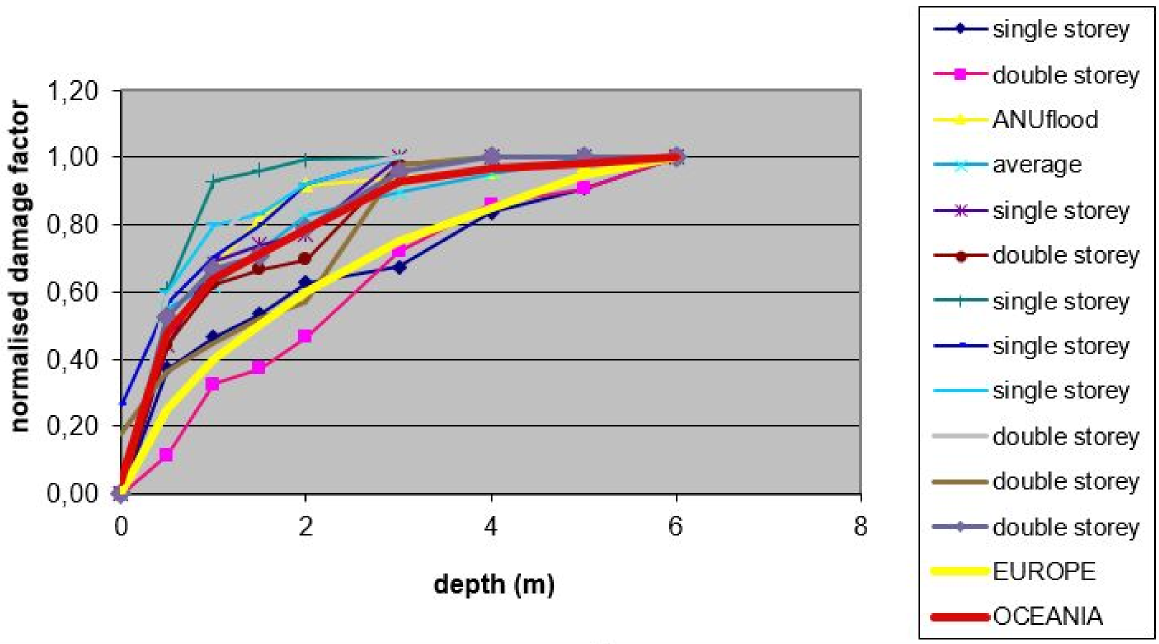


Figure 5.1: Residential depth-damage function (Huizinga, 2015)

Often these damages are derived from small case studies. This can cause local characteristics to transfer to the function used on a continental scale.

One of the case studies used as a source is about the Belongil creek and is discussed by Huxley (2011). The Belongil creek is a small river with a lenght of 3km an a floodplain of 30km^2. Depth-damage functions for residential area were derived from the Department of Infrastructure, Planning and Natural Resources (DIPNR) (Huxley, 2011). For the industrial and commercial area ANUFLOOD functions were used.

ANUFLOOD is a software program containing several functions and is specially designed for Australia (Sargent, 2013). The curves are only applicable in water with a flow velocity less than 1m/s. The ANUFLOOD models are more than 30 years old and give an underestimation of the damages. Several updates of the model are used in flood risk assessments in Australia and are discussed by Sargent (2013). For fast flowing waters Dale *et al.* (2011) derived functions including the flow velocity, at this moment these functions are not widely used. Currently new functions are being derived based on the 2011 Brisbane floods (Sargent, 2013).

Most of the data for the functions of Huizinga are provided by Sargent (2013). Sargent (2013) indicates external damage, content damage and structural damage. External damage, such as cars, is derived from WRM Water and Environment (2006) damage functions. Internal damage is also based on damage curves from WRM (2006). WRM indicates a damage of $59,000 for a single storey detached house at a depth of 2 meters. Since the average house contents insurance is around $80,000 the curves are adjusted. The maximum contents value is set at $60,000. Structural damage is based on rebuilding costs. To indicate these costs an online cost estimating website (Cordell Residential Valuer, 2015) is used. Cordell is a company specialised in building cost information (Cordell, 2015).

5.1.2. INFLUENCES ON DAMAGE

Several properties contribute to the damage induced by flooding. The most important features are listed in this section. Where possible continent specific characteristics are described.

WARNING TIME

The warning time for a flooding event is of great importance to the occurring damage. When residents are warned early for floods they are able to move valuable contents to higher floors or other areas. Also for the commercial sector early warnings are important if stock can be moved. A contributing factor of the warning time is at what time a flood occurs. During business hours more people can be warned in time compared to floods at night and in the weekend. Surveys for the Tamworth area show different responses amongst flood victims about the warning time. Some people found the warnings to be satisfactory while others thought otherwise. For some areas, the decline in the number of local radio stations has been identified as a possible cause for shorter warning times (BTE, 2001). For a widespread country as Australia it can be difficult to make sure detailed information reaches the potentially affected people in time.

FLOOD EXPERIENCE

One of the most important factors for decreasing flood damages is the flood experience. Earlier experiences with flooding provides a lot of knowledge. In areas where flooding occurs regularly residents are adapted to the risks. Often houses are elevated or build on local high grounds. Differences in flood experience can lead to great differences in flood damage. For example Wagenaar *et al.* (2015) described a decrease of the damages of more than 50% for the 1995 Rhine floods compared to 1993. Preferably the flood experience is included in the function. In practice this is almost impossible to achieve on a continental scale, since the flood experience has a strong local character. An example of flood experience can be seen in Brisbane. With Google Streetview residential buildings within and outside the flood prone area were observed. Most buildings within the flood prone area have their front door and living room on a elevated level accessible by stairs. On higher grounds this typical building style is seen much less.

CLIMATE

Australia has a varied climate. There are six climatic zones and two main seasonal patterns (Australia.gov.au, 2013). Brisbane with the highest flood risk has a subtropical climate. There is a dry and wet season, with the highest rainfall from January to March. Tropical cyclones can occur in this period. A mean rainfall of 400mm is recorded in this period, with a mean of 154mm in January. The highest recorded rainfall for Brisbane was in 2012 with 343.4mm in January (bom.gov.au, 2015). Compared to European cities the total rainfall is relatively high and more concentrated.

In the 2011 flooding of Brisbane a maximum 3-day rainfall of 648mm was reached. This caused severe flooding in the area. Two major flood events are described by Van den Honert and McAneney (2011): in

Toowoomba a severe flash flood occured when a severe storm with a 40-50mm rainfall in 30 minutes flooded the area. Because the ground was saturated by previous rainfall the runoff was very high. Eventually a flash flood with an inundation depth of 11 meters hit the city centre of Toowoomba. The warning time for this flood was 1.5 hours. Further downstreams complete buildings were destroyed or pushed of their foundations. In Grantham a depth of up to 2.5 meters was reached within 15 minutes. Flow velocities are estimated between 2 to 3 m/s.

The geographical position of Brisbane with the occurrence of tropical cyclones causes a high risk for flash floods. Typically these floods already result in high damages for low inundation depths. This could be an explanation for the relatively steep shape of the depth-damage function

5.2. SENSITIVITY STUDY

For the industrial, infrastructure and agriculture land use classes Australian functions were lacking and European functions are used instead. This section describes their possible effect on the risk. First it is derived at what depth changes in the function have the most effect. This can be named as the area where changes have the most influence. Than it is described how the European and Australian functions differ.

INFLUENCE AREAS

The functions of Europe and Australia show a significant difference. The results of the Multiple land use method in figure D.1 give a more detailed view how these differences affect the risk. Each city responds differently to the use of Australian functions compared to European functions. In table 5.1 the differences between the Multiple land use method with Australian and European function for all land uses is given.

Table 5.1: Comparison functions

City	EUR function [million €]	AUS function [million €]	Difference [%]
Brisbane	374	401	+7.3
Perth	54	67	+23.3
Sydney	3	6	+95.9
Adelaide	0	0	0
Melbourne	57	79	+38.8

To give a better insight how these differences can occur the function is further investigated.

The areas where the depth-damage function have the most influence on the risk are determined. This is done with a stepwise manipulation of the depth-damage function. In the first step the first 0.5 meter of the depth-damage function for all land uses is deleted. With this partial function the remaining risk per city is calculated. In each next step additional meters are deleted from the functions. This is continued until only a depth of 6 meter is considered in the functions. The results are presented in figure 5.2. The right axis shows the amount of risk in percentage that is left compared to the use of the complete depth-damage function. The horizontal axis shows the amount of meters that is deleted from the functions.

From figure 5.2 it is seen that Sydney reacts quick in the first 1.5 meters. Brisbane shows another trend and reacts slow to changes in the depth-damage function. Melbourne and Perth show a similar trend and react moderate to changes. When the graph reaches 0% further changes to the function do not have any effect. The graph reaches 0% when the maximum inundation depth in the city is reached. In yellow an average for Australia, based on four cities, is plotted.

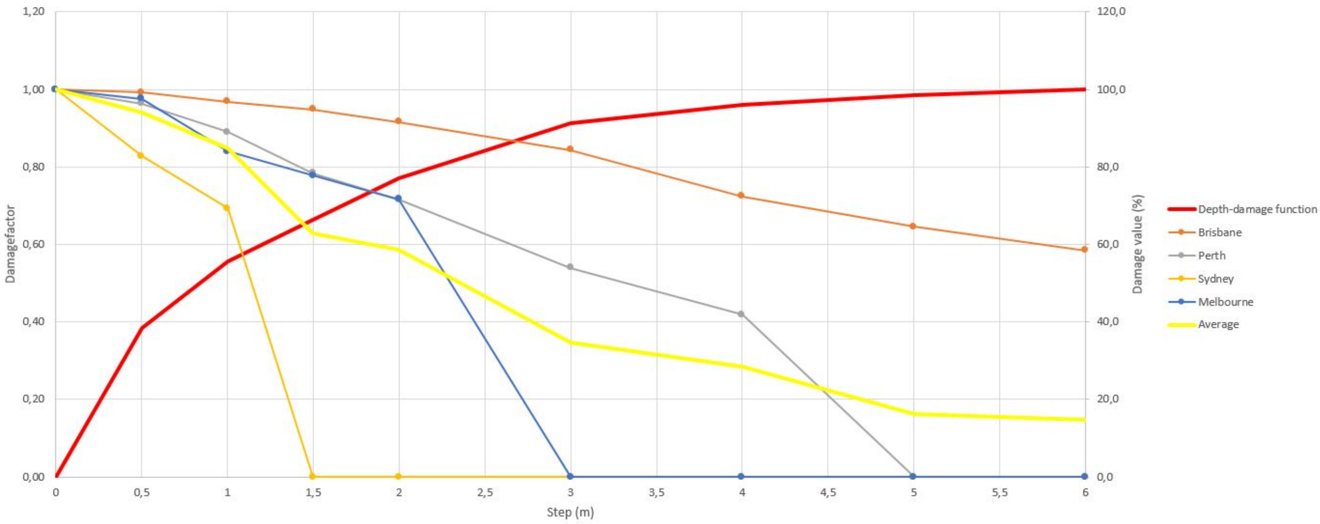
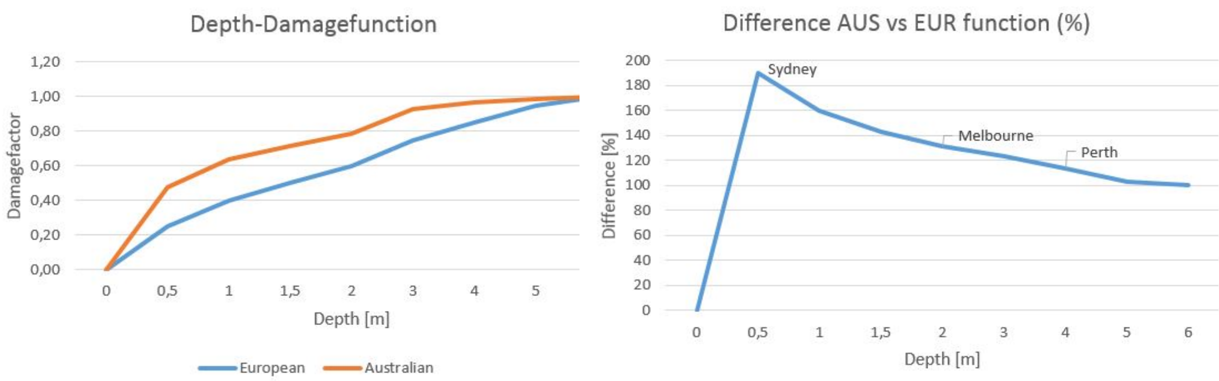


Figure 5.2: Influence areas

USE OF EUROPEAN FUNCTIONS

With the Multiple land use method, European depth-damage functions are used for the agricultural, industrial and infrastructure layer. It is analysed what the effect is of the use of European functions in Australia.

To describe the differences in the functions the European and Australian are plotted in figure 5.3a. In figure 5.3b the percentage difference with each other is shown. The largest difference occurs at a depth of 0.5 meter where the Australian function has a value of 190% of the European function. From the hazard data the most occurring and average inundation depth is determined, see table 8.1. The average inundation depth and corresponding cities are added to 5.3b.



(a) EUR & AUS function

(b) Difference

Figure 5.3: Difference between Shapefiles

Table 5.2: Inundation depths per city

City	Inundation depth [m]	Average depth [m]
Brisbane	5-9.5	7.3
Perth	3-4.9	4.0
Sydney	0.2-1.4	0.8
Adelaide	0	0
Melbourne	1.2-2.8	2.0

It is directly visible that for Sydney at 0.8 meters the Australian function almost has a maximum difference with the European. From figure 5.2 it can be seen that for 0.8 meters Sydney reacts strong to changes in this area. On the contrary for Brisbane the Australian and European function have no difference around the average inundation depth. Differences in risk are the result of differences in the first 6 meters. From figure 5.2 it is seen that Brisbane reacts very slow to changes in this area.

SUMMARY

With the relation between the average inundation depth, the influence areas and the differences of the functions it is explained why cities react different to the use of Australian and European functions. For Australia and the use of European functions a direct link can be made with the inundation depth. In general when the inundation depth increases, the difference in calculated risk is less.

Table 5.3: Relation between depth and difference

City	Average inundation depth [m]	Difference AUS/EUR function [%]
Brisbane	7.3	+7.3
Perth	4.0	+23.3
Melbourne	2.0	+38.8
Sydney	0.8	+95.9
Adelaide	0.0	0.0

The importance of continent specific damage functions is therefore dependant on the city considered. For this Multiple land use method, European functions for the industrial, agriculture and infrastructure layer were used. In Sydney this will result in an underestimation of the actual flood risk. The significance can be questioned, since the total flooded area in Sydney is relatively small. When flooding with a small inundation depth occurs over a larger area the use of Australian functions will be more important.

On a global scale Brisbane is the most important city in Australia. The difference in risk for Brisbane when European functions are used is 7.3%.Therefore it is concluded that for Brisbane the use of European functions for certain land uses is acceptable, as long as the dominant residential and no-data layer has its Australian function. For Brisbane the maximum damage value is of more importance to describe the risk accurately.

6
Discussion

No data layer

As discussed in section 3.3 the assumptions made in the no-data layer do not always match the actual situation. In some areas an overestimation can be made by the no-data layer. These areas are not manually edited or corrected for the actual situation. The ratio of the no-data layer is determined by the known data. Table 3.2 shows that data from Melbourne is most available. Specific local characteristics of Melbourne will be dominantly present in the ratio of the no-data layer.

The depth-damage function for the no-data layer is derived by a weighted average of the other depth-damage functions. The depth-damage functions derived by Huizinga (2015) already contain uncertainties. These uncertainties transfer to the constructed depth-damage function for the no-data layer. When calculations are made with this depth-damage function the uncertainties of the function, assumed ratios and geographical location of assets within the no-data layer are combined. It is unsure how these uncertainties contribute to the calculated risk.

Another limitation is the used filter method. A standard filter method is described in Appendix B which is consistent with the method used for other continents. Some continent specific characteristics are neglected in this filtering process. For Australia some parts of the flooded rivers itself are seen as no-data. This causes an overestimation.

Finally it is seen that the no-data layer is less accurate in the suburbs. The accuracy of the no-data layer can be improved if two separate layers are used. Parts of the no-data layer outside the city centre should contain less residential area or a lower maximum coverage.

Raster coverage

To correct the maximum coverage of a raster cell a maximum density of 75% is suggested. This maximum is not specific for Australia. Also possible differences between the residential, industrial and commercial layer were not taken into account. Further study of the maximum land cover per land use could increase the accuracy of the estimated risk. In addition, when correcting the maximum coverage per rastercell with 75% only the rastercells with high coverage are corrected. It is still possible rastercells with lower coverages also contain some overestimation. If the land use layers are rastered with an initial resolution of 10x10 meters before upscaling to $1km^2$ a better accuracy is achieved. Further study has to show if coverages per rastercell can be described more accurately with this resolution.

GDP data

GDP per capita data is used to express economic differences amongst different areas. Because the data was available at a NUTS0 accuracy, only GDP per capita data per country is known. For this study all viewed cities are located within Australia. With this accuracy of the GDP per capita data no further differences between cities in Australia are expressed. It would be more accurate to collect and process regional GDP per capita data.

GEOGRAPHICAL UNCERTAINTY

Because the PCR-GLOBWB model was normative, all raster files were created on a 1km^2 resolution. On a city level this resolution is acceptable but still coarse. Areas where data from OSM was retrieved contained very high detail. To maintain this detail the first raster step was on a 100x100 meter resolution which was later upscaled to 1km^2. After upscaling it isn't possible to identify where land uses are located within the raster cell of 1km^2 . With this procedure a geographical uncertainty is introduced.

REVIEWED CITIES

In this study the same cities as Nootenboom (2015) were reviewed. Of the five cities there was one without a risk. Although sufficient calculations and analysis could be performed, a definitive conclusion is difficult to form. When more and smaller cities are taken into account a better understanding of the Multiple land use method performed for Australia can be achieved.

7

CONCLUSIONS

MULTIPLE LAND USE METHOD

OpenStreetMap is most suitable to distinguish land use classes in Australia. It is possible to extract specific land use information and attributes. This data can be processed to an exposure raster file. In Australia 52% coverage was found within the five reviewed cities. The most accurate city is Melbourne with a coverage of 65%. Areas where no data could be retrieved were filled with ratios based on the known data. A no-data layer is introduced which consist of 61% residential, 19% industrial and 20% commercial land use. The maximum damage value is 560 EUR/m^2. The no-data layer describes the actual land cover most accurate in densely populated areas. In the suburbs there is a higher change of overestimating the damage caused by the no-data layer.

When compared to the Single land use method the Multiple land use method shows a correlation of 0.99905. For every city there was a decrease in flood risk. Adjusting the city boundaries resulted in a maximum difference of 9.1% compared to city boundaries used by Nootenboom (2015). In the base results the maximum coverage per raster cell has a maximum of 100%. When adjusted with a maximum coverage of 75% a decrease in flood risk up to 4.45% is achieved. The decrease is strongly dependant on the precise location of raster cells with a high coverage. When more cities are reviewed the maximum coverage correction is expected to be more significant. The error introduced in the no-data layer when buffering roads at a width of 6 meters is negligible.

DAMAGE FUNCTION RESEARCH

Depth-damage functions for Australia are derived based on five sources. The damage values are based on reported damages, rebuilding costs, synthetic damage models and insurance information. Multiple properties are responsible for the occurred damage and depth-damage function. Sufficient warning time can decrease the damage when content is moved to higher floors. Local flood experience is also a factor which decreases the flood risk. Flood experience is usually not processed in the the depth-damage function and has a strong local character.

Australian climate can cause extremely high rainfall, especially in Brisbane. This causes an increased risk of flash floods. These floods can result in large damages at low inundation depths. This can cause the steep shape of the Australian depth-damage function.

Sensitivity research shows that all cities react different to changes in the depth-damage function. For each city the influence areas are described. Sydney reacts strong on changes in the function within the first 1.5 meter. Brisbane is more insensitive to changes in the function. When Australian and European functions are compared the highest difference of 190% occurs at a depth of 0.5 meters. When combined with the average inundation depth and the influence areas a direct link can be found. In cities with small inundation depths the use of Australian functions causes a high increase in flood risk. When large inundation depths occur the difference in function results in small changes in risk. In these cities the maximum damage value is of more importance to describe the flood risk accurately. For Brisbane the use of European functions for the industrial, infrastructure and agriculture layer is acceptable.

8

RECOMMENDATIONS

To improve the accuracy of the calculated risk and decrease the uncertainties some recommendations can be made:

- Use a separate no-data layer for areas located further from the city centre. This no-data layer should contain lower maximum coverages to reduce the chance of overestimation.
- Implement continent specific maximum coverages for each land use.
- Calculate flood risk with a hydrological model of higher resolution. Preferably this hydrological model is made for Australia with more detailed flood hazard. With PCR-GLOBWB flooding in Adelaide could not be calculated.
- Use the OpenStreetMap extract of 2012 before the licensing change. With this extract it is possible more data from OSM can be retrieved. The data of 2012 can be merged with the current data. The extract can be downloaded from the planet OSM website under "cc-by-sa".
- Review more cities in Australia. A better comparison with the Single land use method can be made. Furthermore the significance of changes in the maximum coverage can be described better.
- Improve the used filter method. Exclude rivers from the no-data layer.
- Implement region specific GDP per capita data to express differences within Australia.

Table 8.1: Differences

Adjustment	Difference [%]
Shapefile	+8.20 up until +9.10
Maximum coverage	-1.59 up until -4.45
Buffer error	-0.34 up until 1.97

A

Results Nootenboom

This section gives a summary of all results of Nootenboom (2015). For complete results and explanation see the internship report of T. Nootenboom (Nootenboom, 2015)

Comparison European and Global Method

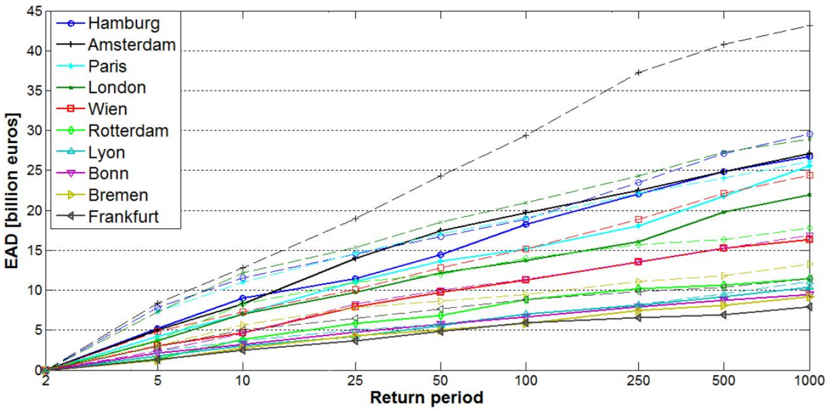


Figure A.1

Correlation between European and Global Method

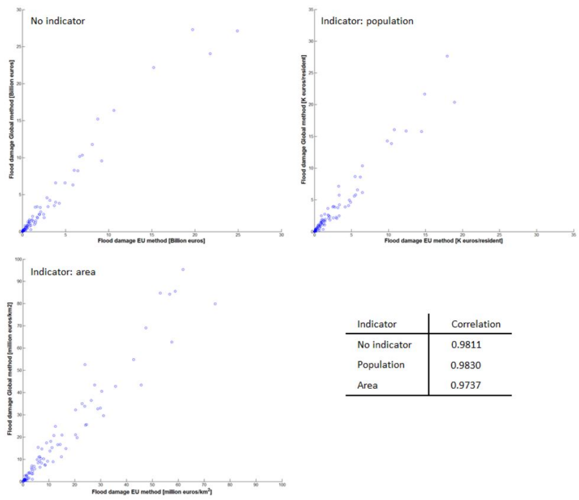


Figure A.2

Result base scenario without protection standards

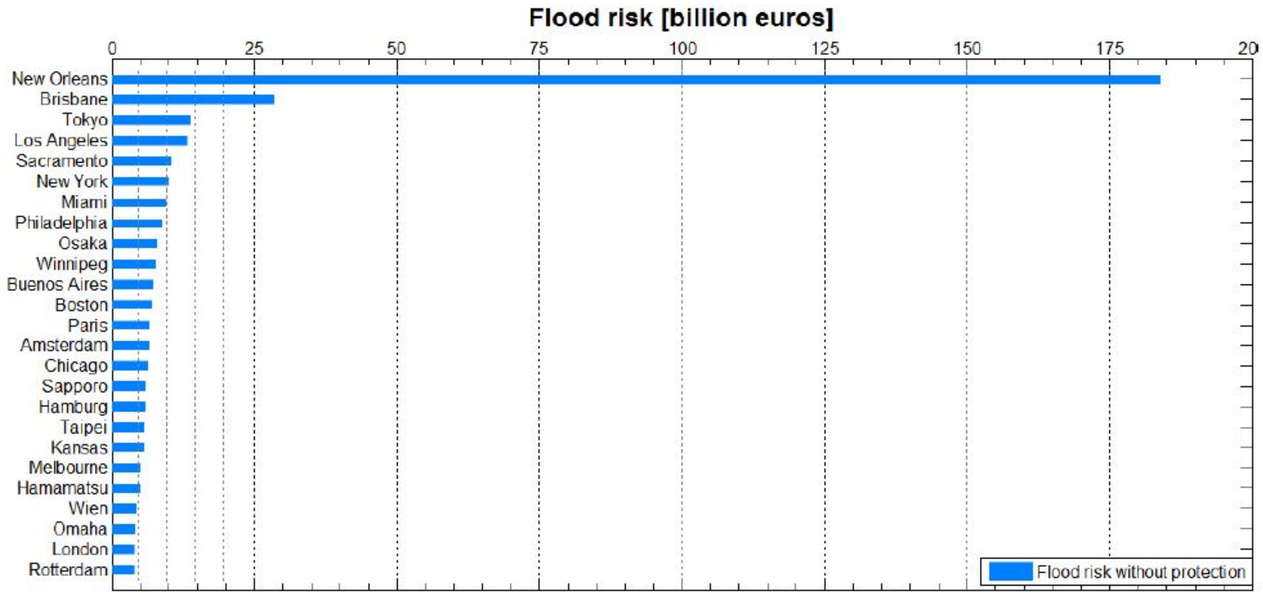


Figure A.3

Result base scenario with protection standards

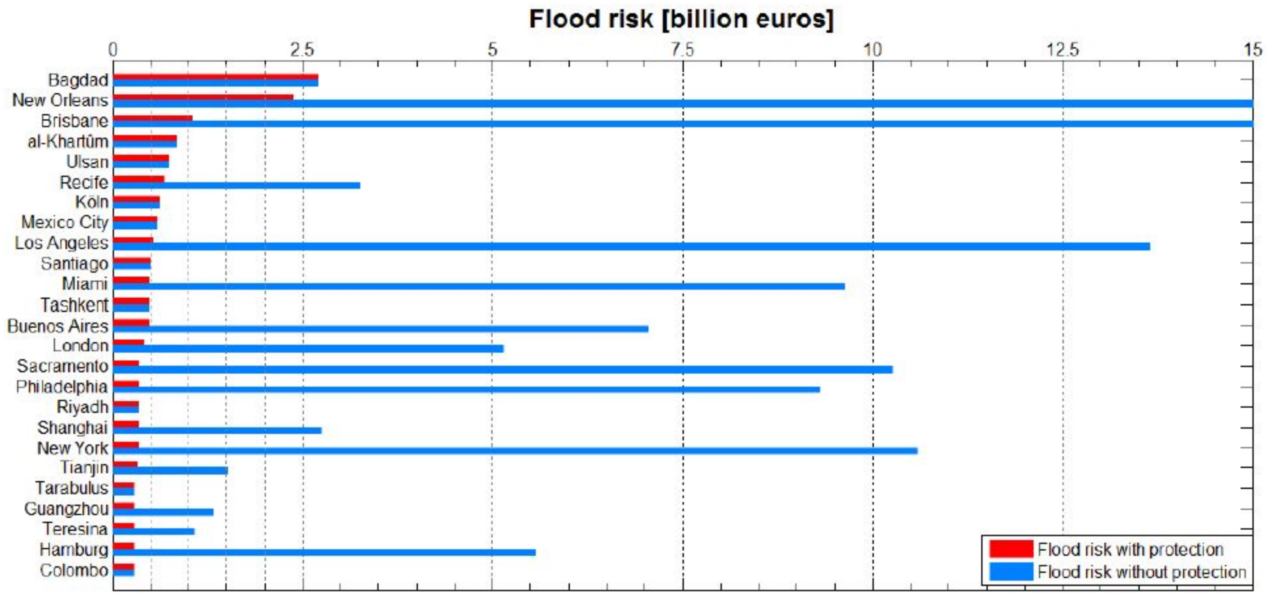


Figure A.4

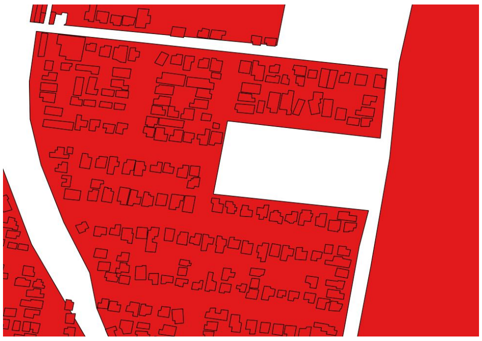
B

CREATING LAND USE MAP

Planet OSM data is used as a map for Australia. Because of the size of nearly 2GB this caused severe performance problems with qGIS and Arcgis Pro. City Shapefiles used by Nootenboom (2015) were used to clip the large Planet OSM data. If necessary these shapefiles were edited to obtain a higher accuracy. Mostly along coastlines and rivers large areas where projected outside the shapefile. To filter the different land use classes the following inputs were used:

Class	Filter script
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_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_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_natural	"natural"!='null'
Agriculture_sport	"sport"!='null' AND ("Leisure"= 'pitch' OR "leisure"='track')
Agriculture_leisure	"leisure"!='null'

This resulted in 16 layers in qGIS. All 16 layers were merged into Residential, Commercial, Industrial and Agriculture land use classes. Due to this filtering process the four layers still had overlap with other layers and overlap within the layer itself. See figure B.1.



(a) Overlap within layer

(b) Overlap with other layer

Figure B.1: Two types of overlap

First the overlap with other layers was removed. Some areas consist of large polygons with the same land use. Often these polygons are a rough indication of where a residential neighbourhood is located. More detailed information about parks, schools and shops within these polygons is available. To achieve a higher accuracy this information was taken into account. This procedure was performed with the difference function in qGIS. By subtracting the commercial, industrial and agricultural layer from the residential layer, the layer was made more accurate. Same procedures were done for other layers. Qualitative analysis showed that the commercial layer was the most accurate layer for Australia. Therefore there was no need to subtract any data from other layers for the commercial layer. The difference procedures used for Australia are described in table B.1.

To remove the overlap within the layer itself the dissolve function was used for all layers. This function makes sure that data will not be taken in account twice when calculating areas of the land use.

Finally the infrastructure layer was created using a separate extract from Planet OSM. The roads were imported and clipped the same way as other layers. Because roads are seen als polylines in qGIS they don't contain an area. Therefore all roads were buffered with a buffer distance of 0.00005 corresponding to a width of approximately 6 meters. The infrastructure layer was also dissolved to remove overlaps due to the buffering process. Ultimately the infrastructure layer was subtracted from the other four layers the achieve the highest possible land use map.

The remaining data is defined as the no-data layer.

Table B.1: Difference order

Input Layer	**Difference Layer**	**Output layer**
Residential	Agriculture	Residential-Agri
Residential-Agri	Commercial	Residential-Agri/Comm
Residential-Agri/Comm	Industrial	Residential-Agri/Comm/Indus
Agriculture	Commercial	Agriculture-Commercial
Industrial	Commercial	Industrial-Commercial
Commercial	No difference	

C

Raster process

To create raster files from the shapefiles a series of steps is performed with Qgis and Arcgis. This Appendix gives a summary of all steps.

Pre-processing provided data:

- Function: Qgis, clip raster by extent
  Clip all hazard data, GDP data, protection rasters to desired extent. For Australia (110,160,-40,-10) is used.

ArcGis procedure shapefile to raster:

- Add a column to the attribute table of the shapefile with a value of 1
- Function: Polygon to raster, cellsize 0.000833333
  Raster to a 100x100m 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 no data if no layer is present

The raster needs to have a value 0 if no layer is present and a value 1 if a layer is present. The next two steps create these values.

- Function: is null, input: previous raster
  This step created a raster with a value of 0 where data is present and a value 1 of no data is present.
- Function: con, input: previous raster. Expression: Value = 1. Input constant value = 0. Input true raster: previous raster.
  This step creates the desired raster with a value of 1 where data is present and 0 where no data is present.
- Function: aggregate, input: previous raster. Cell factor: 10
  With the aggregate function all rastercells within a 1km^2 are summarized. The output is a raster with a value corresponding to the coverage per cell.
- Function: raster to other format, input: previous raster.
  Select a folder where the raster in .tif format can be stored.

These steps need to be performed for every layer.

Correcting area coverage

- 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 the 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 75. Repeat for residential, industrial, commercial and no-data layer from previous step.

D

RESULTS MULTIPLE LAND USE METHOD

Table D.1: Risk in million Euro Multiple land use method

	European function		Australian function	
City	European Value	Australian Value	European Value	Australian Value
Brisbane	869	374	936	401
Perth	128	54	158	67
Sydney	7	3	14	6
Adelaide	0	0	0	0
Melbourne	134	57	191	79

Table D.2: Differences in percentage to Single land use method

	European function		Australian function	
City	European Value	Australian Value	European Value	Australian Value
Brisbane	-16	-64	-10	-61
Perth	-24	-68	-6	-60
Sydney	-21	-67	+56	-35
Adelaide	0	0	0	0
Melbourne	-15	-64	+20	-50

From table D.1 and D.2 some conclusions can be made. First the use of European functions with European value gives a decrease in risk. This indicates that the use of multiple land uses gives a more accurate description of the land cover. When the use of European and Australian values combined with the European function are reviewed a constant drop can be seen. When the use of these values combined with Australian functions is reviewed a likewise decrease in risk is achieved. The use of Australian values gives a constant decrease in flood risk, independently from the used functions.

When the use of European functions is compared to the use of Australian functions more irregular results occur. It is city dependent how the risk behaves compared to the Single land use method.

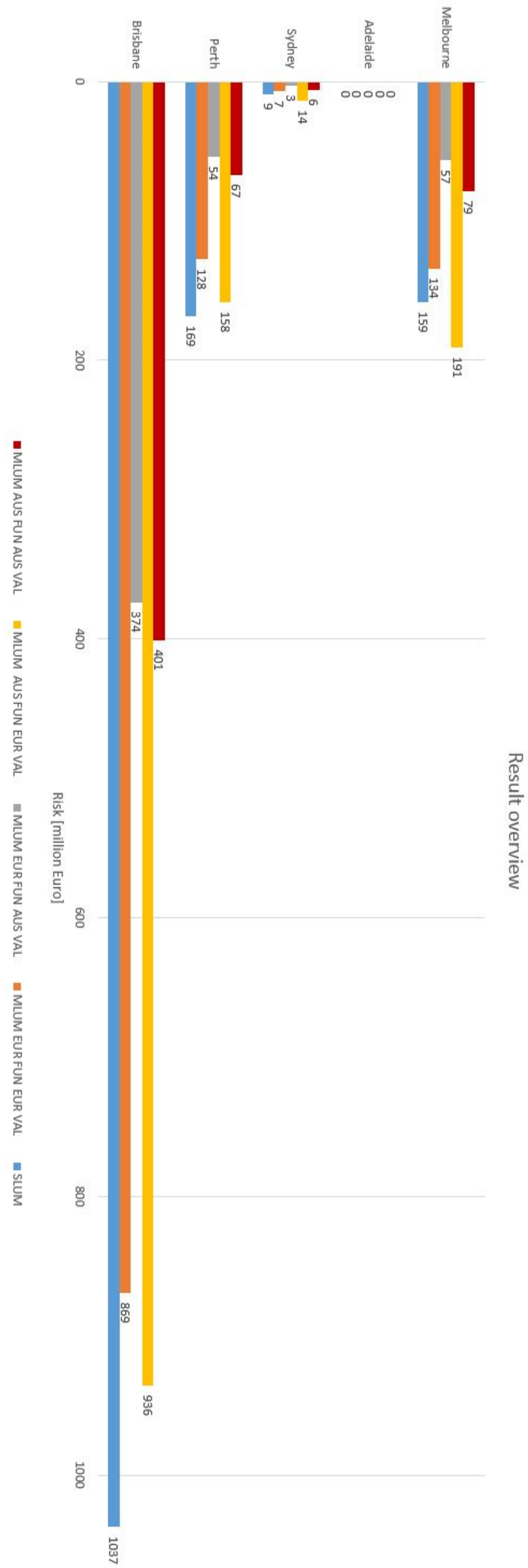


Figure D.1: Overview FIAT runs

Bibliography

Australia.gov.au (2013). Australian weather and seasons – a variety of climates. Retrieved from http://www.australia.gov.au/about-australia/australian-story/austn-weather-and-the-seasons. [Online, Accessed 12-06-2015].

bom.gov.au (2015). Climate data online. Retrieved from http://www.bom.gov.au/climate/data/. [Online, Accessed 12-06-2015].

BTE (2001). Flood damage in tamworth. costs of the november 2000 flood. *Working paper 48*.

Cordell (2015). Retrieved from http://www.cordell.com.au/. [Online, Accessed 12-06-2015].

Cordell Residential Valuer (2015). The price of land is hurting australia. Retrieved from http://homebuilding.cordell.co.nz/. [Online, Accessed 12-06-2015].

Dale, K., Edwards, M., Middelman, M., and Zoppou, C. (2011). Structural flood vulnerability and the australianisation of black's curves risk. *Conference Proceedings Risk Engineering Society*.

Field, C., Barros, V., Stocker, T., Qin., Dokken, D., Ebi, K., Mastrandrea, M., Mach, K., Plattner, G., Allen, S., Tignor, M., and Midgley, P. (2012). Managing the risks of extreme events and disasters to advance climate change adaptation. a special report of working groups i and ii of the intergovernmental panel on climate change. *IPCC*.

Holz, F. (2014). *A European-scale approach to flood risk assessment. A land use based appraisal of present and future flood risk as support for climate change adaptation and disaster risk reduction.* Msc thesis, Christian-Albrechts-Universität zu Kiel.

Huizinga, H. J. (2007). Flood damage functions for eu member states. *Institute for Environment and Sustainability*.

Huizinga, H. J. (2015).

Huxley, C. (2011). Belongil creek floodplain risk management study and plan. discussion paper 2: Flood damages assessments. *BMT WBM Pty Ltd*.

Jongman, B., Kreibich, H., Apel, H., Barredo, J., Bates, P.D., F. L., Gericke, A., Neal, J., Aerts, J., and Ward, P. (2012). Comparative flood damage model assessment: towards a european approach. *Nat. Hazards Earth Syst. Sci*, **12**, 3733–3752.

Kron, W. (2002). Keynote lecture: Flood risk = hazard x exposure x vulnerability. *Flood defence*.

Merz, B., Kreibich, H., Schwarze, R., and Thieken, A. (2010). Assessment of economic flood damage. *Nat. Hazards Earth Syst. Sci.*, **10**, 1697–1724.

Merz, B., Aerts, J., Arnbjerg-Nielsen, K., Baldi, M., Becker, A., Bichet, A., Blöschl, G., Bouwer, L. M., Brauer, A., Cioffi, F., Delgado, J. M., Gocht, M., Guzzetti, F., Harrigan, S., Hirschboeck, K., Kilsby, C., Kron, W., Kwon, H.-H., Lall, U., Merz, R., Nissen, K., Salvatti, P., Swierczynski, T., Ulbrich, U., Viglione7, A., Ward, P. J., Weiler, M., Wilhelm, B., and Nied1, M. (2014). Floods and climate: emerging perspectives for flood risk assessment and management. *Nat. Hazards Earth Syst. Sci.*, **14**, 1921–1942.

MunichRE (2013). Natcatservice.

Nootenboom, T. (2015). *Global flood risk index for urbanized areas near rivers.* Msc thesis, Wageningen University.

OSM (2012). Automated redactions complete. Retrieved from https://blog.openstreetmap.org/2012/07/26/automated-redactions-complete/. [Online, Accessed 13-05-2015].

Sargent, D. M. (2013). Updating residential flood stage-damage curves based on building cost data. *O2 Environmental Pty Ltd*.

Van den Honert, R. and McAneney, J. (2011). The 2011 brisbane floods: Causes, impacts and implications. *Water*, **3**, 1149–1173.

Verkade, J. S. and Werner, M. G. F. (2011). Estimating the benefits of single value and probability forecasting for flood warning. *Hydrol. Earth Syst. Sci.*, **15**, 3751–3765.

Wagenaar, D., de Bruijn, K., Bouwer, L., and de Moel, H. (2015). Uncertainty in flood damage estimates and its potential effect on investment decisions. *Nat. Hazards Earth Syst. Sci*, **3**, 607–640.

Ward, P. J., Jongman, B., Weiland, F. S., Bouwman, A., van Beek, R., Bierkens, M. F. P., Ligtvoet, W., and Winsemius, H. C. (2013). Assessing flood risk at the global scale: model setup, results, and sensitivity.

Winsemius, H. C., Van Beek, L. P. H., Jongman, B., Ward, P. J., and Bouwman, A. (2013). A framework for global river flood risk assessments. *Hydrol. Earth Syst. Sci.*, **17**, 1871–1892.