SUMMARY

Flooding is a huge problem in Jakarta. Each time torrential rains pour, flood events appear in the media. Most of these river floods occur during the wet months of December, January and February; these are the months in which the city prepares for flood damages. The most recent large flood occurred in January 2013, causing economic damages estimated at US$ 3 billion, with 47 fatalities, and over 100,000 houses destroyed or damaged. Other major floods in the 21st century occurred in 2002 and 2007, with estimated direct damages of ca. US$ 1.5 billion and US$ 890 million respectively.

Flood damages may increase in the future as a result of various physical and socioeconomic drivers, such as land use change, climate change, subsidence, urbanisation, and an increase in the number of people living in flood-prone areas. Therefore, it is important that the city takes measures to reduce the damages and other negative impacts caused by flooding. This can be achieved through flood risk management, whereby flood risk refers to the probability of a flood multiplied by its consequences. Flood risk is composed of three elements (UNISDR, 2013): hazard, which refers to "...dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage"; exposure, which refers to "...people, property, systems, or other elements present in hazard zones that are thereby subject to potential losses"; and vulnerability, which refers to "...characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard". In order to reduce risk, measures can be taken to reduce either of these elements, or a combination of different elements. In order to design effective flood risk management, methods are needed to assess both current and future flood risk, and the risk that can be avoided by taking flood risk reduction measures.

To respond to these issues, the main objectives of this Thesis are: (a) to develop a model for assessing river flood risk in Jakarta; (b) to use the model to assess the impacts of changes in physical and socioeconomic drivers on flood risk; and (c) to use the model to assess the impacts of various adaptation measures on flood risk. In order to address these objectives, the Thesis addresses the following research questions:

- Can we develop a model to rapidly assess river flood risk in Jakarta, and how well does it simulate reported flood damage?
- How sensitive is the flood risk model to the use of different vulnerability curves?
- What are the possible future changes in river flood risk in Jakarta as a result of climate change, land subsidence, and land use change?
- How much could flood risk in Jakarta be reduced under current and future conditions by upgrading and installing polder systems, and what are the costs and benefits?
- What is the potential reduction in flood risk that could be achieved in Jakarta through the implementation of an SMS-based Flood Early Warning System?

In this Thesis, a flood risk model for rapidly assessing flood risk in Jakarta has been set up using information on hazard, exposure and vulnerability, namely Damagescanner-Jakarta. In the model, hazard is represented by inundation maps showing the flood extent and depth for floods with different probabilities and of different severity. Exposure is represented by land use maps, whereby each land

use class is assigned a maximum damage value in US Dollars (US$). This value reflects the potential damage that could occur for each land use type if a flood occurs. Vulnerability is represented by depth-damage curves, which show for each land use class the percentage of the maximum damage value that would actually occur for floods of different depths.

The initial development, setup, and validation of Damagescanner-Jakarta are described in Chapter 2. Here, hazard maps were developed using the 1D/2D SOBEK Hydrology model; the model schematization represents the hydrological situation of Jakarta in 2007. Exposure is represented using an official land use map of the situation in 2002. For each land use class, the maximum potential damage due to flooding was estimated based on a workshop and series of expert meetings held in 2012. During the same workshop and expert meetings, depth-damage curves were also developed for each land use class, based on expert knowledge from practitioners in Jakarta. Using these model settings, the expected annual damage (EAD) due to river flooding in Jakarta is estimated at US$ 321 million per year (Chapter 2). The simulated damages are of the same order of magnitude as the reported damages in 2002 and 2007. We also show that the spread of the damages across different land use classes is similar to those reported. These findings give confidence in the use of the model for flood risk assessment in later chapters.

One of the key challenges faced in developing Damagescanner-Jakarta was deriving the depth-damage curves to represent vulnerability. Given the lack of local information on vulnerability, many flood risk studies simply use depth-damage curves developed for other cities. Therefore, depth-damage curve from five existing studies carried out in south-east Asia are applied. The results show that the implementation is highly sensitivity to the selected curve; there is a factor 8 difference in simulated EAD when using the different curves. Hence, for this Thesis locally tailored curves were developed through a series of expert meetings and a workshop with local stakeholders. The simulated damages based on these curves were closer to reported damages than when using the curves transferred from other studies. This finding has important implications for flood risk assessments around the world, and demonstrates that flood risk assessments need to pay close attention to the selection, development, and testing of vulnerability curves.

In Chapter 3, several improvements are made to Damagescanner-Jakarta. Firstly, hazard maps are used from an updated schematization of the 1D/2D SOBEK Hydrology model. In this version, the hydraulic schematisation was updated to include flood protection measures implemented between 2007 and 2013, including flood gates and weirs, and most importantly the newly completed Eastern Flood Canal. Secondly, a more recent land use map was used to represent exposure, namely the official land use map 2009. The updated version in Chapter 3 estimates an EAD of US$ 186 million. This seems reasonable given the changes in the hydrological and hydraulic situation during the intervening period. Therefore, the updated model setup was used as the baseline for making projections of future flood risk in 2030 and 2050 in Chapter 3, and for assessing the effectiveness of flood risk reduction measures in Chapters 4 and 5.

In detail Chapter 3 described the use of Damagescanner-Jakarta to assess flood risk in Jakarta in 2030 under several scenarios of climate change (both changes in precipitation and sea level rise), land subsidence, land use change, and economic development. Combining all of these scenarios, the median projected increase in flood risk between baseline and 2030 is 180% (+111% to +262% for the 5th to 95th percentiles). The single driver with the largest contribution to overall increase in risk is land subsidence; alone it leads to an increase by +126%. The influence of changes in precipitation only is highly uncertain (-94% to +104% for the 5th to 95th percentiles). However, the signal of change on sea level resulting from climate change is clear. Using two scenarios of sea level rise (high and low), the results suggest an increase in risk due to sea level rise alone of between +7% and +20% by 2030. If land use change continues at the same rate as it did over the period 1980-2009, this could lead to an increase in risk of +45% by 2030. However, under an "idealized" land use change scenario, which assumes that the official Jakarta Spatial Plan 2030 is fully implemented, risk could be reduced by -12%. In summary, Chapter 3 concludes that whilst the influence of climate change on precipitation intensity in the region is uncertain, when combined with the other drivers of risk, the increase is always large, and hence adaptation and flood risk reduction measures are imperative, irrespective of the chosen climate scenario or projection.

Therefore, Damagescanner-Jakarta is applied in Chapter 4 and Chapter 5 to assess the potential decrease in risk that could be achieved through two risk reduction measures, namely a polder system in Chapter 4 and an SMS-based Flood Early Warning System in Chapter 5.

In 2012, plans were developed for a polder system that would divide the northern part of Jakarta into 66 polders. Using Damagescanner-Jakarta, the potential reduction in risk that could be achieved through this system was assessed, and the avoided risk (benefits) were compared with a first order estimation of the costs (Chapter 4). Such a benefit/cost analysis was carried out for each polder, using both current conditions and future scenarios of climate change, land use change, and land subsidence. Overall, it is shown that the implementation of the polder system could greatly reduce flood risk compared to the current risk. Benefit/cost ratios greater than 1.0 exist at 21 out of 66 polders under current conditions, and at 31 out of 66 polders under the future scenario (for a return period of 2 years). In the current condition, even if polders were designed for a 2 year return period flood, they could reduce risk by 25%. In the future scenario, the system could reduce risk by 52%. Much of this risk reduction could be achieved in just 3 polders in the onshore areas. The three polders contribute to 50% of the total risk reduction under current conditions and 31% of risk reduction under the future scenario. Adding 9 polders of importance could reduce risk by 56% under the current scenario and 81% under the future scenario. The study also shows the importance of considering future conditions when planning for such structural measures with a long lifetime, since the overall benefits of the projects are much higher when the potential future changes are included.

In Chapter 5, the potential risk reduction that could be achieved by implementing an SMS-based Flood Early Warning System (FEWS) is presented. If warnings are received in time, residents can take actions to reduce the potential damages, such as moving valuable items upwards and moving vehicles outside the potential flood zone. Using the results of a survey of inhabitants along the Pesanggrahan river in South and West Jakarta, the depth-damage curves were adjusted to reflect the damage that inhabitants could potentially avoid. Damagescanner-Jakarta was then run with the original and adjusted depth-damage curves to examine how much risk could be avoided. The analysis suggests that the FEWS could decrease flood risk by 1.9% in a realistic scenario and 12% in an optimistic scenario. In the realistic scenario, it was assumed that risk reduction measures would be taken only by the percentage of households that currently take adaptation measures according to the survey. In the optimistic scenario, it was assumed that all households would take measures to avoid damage based on the warning. Limiting the calculation to the residential areas only, which is the land use class that the proposed system targets, the potential decrease is 13% in the realistic scenario and 84% in the optimistic scenario. The Chapter acknowledge that the FEWS is still hypothetical and the approach makes many simplifications. However, it does demonstrate that risk reduction may be possible at relatively low costs.

Next to the model development, the Thesis discusses the possible use of the results in practice for the government, private sector, and citizens. An important product is the Damagescanner-Jakarta model itself and the resulting flood risk maps. This model can now be used by stakeholders in Jakarta to carry out flood risk assessments. Indeed, Damagescanner-Jakarta and the resulting maps are already being used in practice in Jakarta. For example, the use of the model for assessing the risk in several polders was sponsored by CTC-N/UNEP (Project Number 65800016), carried out jointly by DHI and the Jakarta Research Council, resulting in risk-based policy recommendations on flood management at polder scale. Recently, a risk study approach passed the second assessment by the Korea International Cooperation Agency, which aims to assess polder-based flood management. Our results can provide valuable information to citizens in flood prone areas on how individual actions that they take can reduce damage to their own assets. For example, in Chapter 5 it was shown that taking actions based on an SMS-based Flood Early Warning System (FEWS) can reduce damage to an individual's property and/or assets. The application of the model to assess the potential reduction of risk that could be achieved by implementing the polder system and an SMS-based Flood Early Warning System are two examples of concrete assessments that can be carried out to assess the potential effectiveness of flood risk reduction measures. In future studies, the effectiveness of further measures could be assessed.

Finally, the Thesis reflects on the main limitations and provides recommendations for future research. First, due to a lack of officially mandated scenarios of climate and environmental change for Jakarta, the scenarios used to carry out the future projections in this Thesis were selected on an ad hoc basis. We recommend that the future development of official tailored scenarios for Jakarta (or indeed Indonesia) should be a research priority. Second, whilst this Thesis assesses the sensitivity of flood risk to different variables, no formal uncertainty assessment has been carried out. For future studies it would be beneficial to attempt to capture the uncertainty of the risk estimates to a large range of model parameters, for example using Monte Carlo modelling techniques. Third, in this Thesis flood risk has only been assessed from river flooding. Coastal and pluvial flooding are also important processes in Jakarta, and future research would benefit from examining the risks from all of these kinds of flooding, both separately and where they occur simultaneously (i.e. compound flooding). Fourth, the representation of vulnerability in this Thesis using static depth-damage functions is a large simplification, and does not include social vulnerability or changes in vulnerability over time. The development of future projections of (social) vulnerability is a research priority for the flood risk community as a whole, as well as in Jakarta. Fifth, simplifications have been made in the simulation of the effectiveness of the polder systems and SMS-based Flood Early Warning System, and therefore these should be considered as first order estimates. More generally, the flood risk assessment has been carried out a spatial resolution of 50m x 50m; future studies would benefit from using a finer modelling resolution.

Despite these limitations, the Thesis has shown the ability of Damagescanner-Jakarta to assess current and future flood risk, and the effectiveness of several risk reduction measures. We recommend the use of Damagescanner-Jakarta to assess other risk reduction measures in Jakarta. For example, Jakarta is planning and implementing a giant sea wall to prevent coastal flooding, as part of the National Capital Integrated Development (NCICD); river normalization works are planned or being carried out under the Jakarta Urgent Flood Mitigation Project/Jakarta Emergency Dredging Initiatives (JUFMP/JEDI); canals are planned to divert excessive water from the Ciliwung to Eastern Flood Canal; and upland retention lakes are planned at Ciawi. These measures could be parameterized in Damagescanner-Jakarta to assess their potential contribution to flood risk reduction.