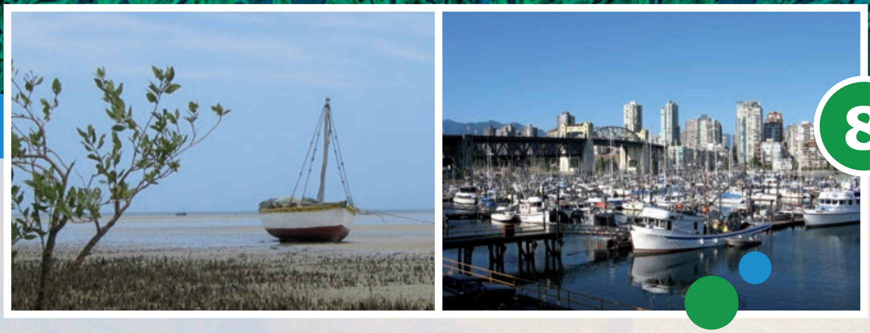
Delta Alliance



8

Knowledge for Climate

Jakarta Climate Adaptation Tools

(JCAT)

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Jakarta Climate Adaptation Tools

(JCAT)

Content

Summary

Background and motivation

Major floods have become commonplace in Jakarta. For example, during the period in which this project was carried out, major flooding occurred in both 2013 and 2014. The flood in January 2013 was one of the most severe on record, and reportedly caused economic losses of ca. US$ 3billion; 47 fatalities; and the damage or destruction of at least 100,000 houses. Historical records show that flooding per se is not a new problem in Jakarta, and that flooding has occurred throughout the city's history. However, the impacts of flooding have increased in recent decades, as a result of changes in both physical (e.g. land subsidence and erosion) and socioeconomic (e.g. population growth and urban expansion) drivers. Moreover, the future flood problems in Jakarta may potentially be exacerbated due to climatic change.

Jakarta Climate Adaptation Tools (JCAT)

In response, the project *Jakarta Climate Adaptation Tools* (JCAT) was set up to contribute to scientific knowledge and the development of methods and tools to assess flood risk in Jakarta. This report summarises the main findings of JCAT.

The specific aims of JCAT are:

- To contribute knowledge and capacity building on flood risk and climate change in Jakarta, including the training of 2 PhD candidates;
- To develop and improve methods and tools for assisting in decision-making on flood risk adaptation, including flood risk assessment and socioeconomic evaluation methods that can serve as a basis for planning and communication with stakeholders and the integration of spatial planning and water management;
- To improve flood risk information by incorporating scenarios of future changes in physical and socioeconomic conditions;
- To assess the impacts of several adaptation strategies in terms of costs and benefits in order to assist in identifying solutions for reducing the risk of flooding;
- To disseminate results to stakeholders in Jakarta, and more broadly to scientists and practitioners in other delta cities worldwide.

Main outcomes

JCAT has contributed to knowledge and capacity building in three main ways, namely through education, workshops and joint research with stakeholders, and scientific research.

In JCAT, we have developed a number of methods that can be used by scientists and decision-makers in assessing issues related to flood risk in Jakarta. Also, a number of existing methods and tools have been adapted or improved so as to be applicable in Jakarta. The models are: a water-balance assessment model (STREAM-Jakarta); an erosion and sediment-delivery assessment model (SDAS-Jakarta); a coastal economic exposure assessment tool; a city-scale river flood risk assessment model (Damagescanner-Jakarta); an economic modelling tool for the selection of flood protection measures; a method for assessing local actual damages for a specific flood event; a cost benefit analysis of flood protection measures; and a national scale probabilistic flood risk assessment method for Indonesia. In this report, these methods are described in Section 3.

In JCAT, we used several of these methods and tools to give a first assessment of the influence of changes in physical and socioeconomic conditions on flood risk related parameters. These simulations are described in Section 4.

- Using Damagescanner-Jakarta, we projected changes in river flood risk between current conditions and 2030. Under future scenarios of climate change, land subsidence, land use change, and economic development, we projected an increase in risk by a factor of 2.2-5.7. The driving factor with the largest influence on this increase in risk is land subsidence, whilst the influence of climate change is highly uncertain.
- Using the coastal economic exposure model, we simulated the potential increase in risk between current conditions and 2100 under future scenarios of sea level rise and subsidence, finding a four-fold increase. The dominant driver of this increase in economic exposure is also land subsidence.
- We carried out a quickscan of changes in flood risk (river and coastal) in Indonesia at the national scale, due to projected changes in urban expansion and climate. We projected that between 2000 and 2030, urban expansion alone may cause annual expected damage as a percentage of total GDP to increase by 76% (river flooding) and 121% (coastal flooding), with the most rapid increases in West Java. Until 2030, the influence of climate change alone on national scale river flood risk is highly uncertain. However, for coastal flooding, projected increases in sea level rise could cause a doubling of the annual expected damage as a percentage of GDP.
- Using the STREAM-Jakarta and SDAS models, we examined the influence of land use change and climate change on river discharge and sediment yield over the last century, and found that the impact of land use change has been greater than the impact of changes in climate. We also assessed the influence of projected future climate change on annual and monthly river discharge. The results show that the influence of climate change on discharge is highly uncertain: half of the

simulations led to projected increased discharge, and half led to decreased discharge.

Whilst the main aim of JCAT was to develop methods and tools to assess flood risk related parameters, we also demonstrate the potential use of some of these by applying them to assess a number of adaptation strategies or measures (Section 5).

- We assessed the potential impacts that a full implementation of the spatial planning decree Perpres 54/2008 would have on river discharge and sediment yield. A full implementation could lead to modest decreases in mean annual river discharge, and very large reductions in erosion and sediment yield. These findings are important for water and flood management in Jakarta and its surroundings. Sedimentation of Jakarta's waterways has greatly exacerbated the flood problem in recent years. Here we show that good spatial planning practices have the potential to reduce the amount of sediment delivered to the city, thus reducing the flood risk.
- We used Damagescanner-Jakarta to assess the potential impact that a well implemented spatial planning could have on river flood risk, by assessing the potential change in risk if the Spatial Plan 2030 were fully implemented. Under this scenario, flood risk would increase by only a factor of ca. 1.1 between present and 2030. Given that changes in exposure through urban development are seen as one of the main drivers of risk in cities in most developing countries, such a small increase is positive. However, achieving this would entail very strong governance structures, strong spatial planning laws, and implementation.
- Through surveys with households and businesses in flood prone areas along the Pesanggrahan River, and in-depth interviews with inhabitants and stakeholders in northern Jakarta, we inventorised a number of household-level and community-level adaptation measures that are already being employed to reduce flood risk. A useful next step would be to assess how much flood risk is already avoided by the adoption of such measures, and how much more flood risk could be avoided if their adoption was increased.
- Finally, we examined the potential reduction in flood risk at the national scale that can be achieved by the implementation of two risk reduction strategies: strategic urban planning and enhanced flood protection. The results presented in this report show that both of these strategies could lead to a very large decrease in risk. Future research should examine both the benefits and costs of such strategies in more detail.

1 Introduction

1.1 Background

Floods are the most commonly occurring natural disasters in Asia. Recent studies on flood risk at the global scale show many regions of Asia to be amongst the most high risk regions in terms of potential damages and affected population [e.g. UNISDR, 2011; Hirabayashi et al., 2013; Ward et al., 2013a].

One of the countries in Asia with the highest impacts from flooding is Indonesia, and in particular its capital city Jakarta. In recent years, major floods have become commonplace. For example, during the period in which this project was carried out, major flooding occurred in both 2013 and 2014. The flood in January 2013 was one of the most severe on record [Sagala et al., 2013]. It was caused by heavy seasonal rainfall that led to flooding, and was exacerbated by the collapse of a dike. According to Munich Re [2013], the economic losses were ca. US$ 3billion. In addition, there were 47 fatalities, and over 100,000 houses were either destroyed or damaged. Other major floods in the 21st century include those of 2002 and 2007, which are estimated to have caused direct losses of ca. US$ 1.5 billion and US$ 890 million (both in US$ 2012 values) respectively [Bappenas, 2007; cited in Budiyono et al., 2014a].

Historical records show that flooding per se is not a new problem in Jakarta. Due to its naturally flood-prone location and seasonal rainfall intensity, the city has a long history of coastal and riverine flooding [Caljouw et al., 2005, Steinberg, 2007]. Moreover, Jakarta has a long and rich history in managing and dealing with floods. Traditionally, this has focused on flood management based on technical measures to keep water away from the people and buildings [Texier, 2008]. Caljouw et al. [2005] provide an extensive overview of historic flood management practices in Jakarta.

However, the impacts of flooding have increased in recent decades, as a result of changes in both physical and socioeconomic drivers. Budiyono et al. [2014a] and Ward et al. [2011a] summarise a number of these drivers, and more details can be found in Section 2.2. Examples of physical drivers include land subsidence as a result of groundwater extraction [Abidin et al., 2011]; and a low drainage and/or storage capacity of the waterways in the city, due to them being clogged with solid waste and by sediments eroded from upstream [Steinberg, 2007]. At the same time, socioeconomic developments have caused rapid changes in Jakarta over the last half century. For example, the population has risen rapidly, from 2.7 million to 9 million between 1960 and 2007 respectively [BPS, 2010]. Over the same time period, there has also been a rapid growth in GDP. As a result of these rapid increases in wealth and population, the land use of the city and its surroundings has changed extensively [Verburg et al., 1999]. Such land use change can affect flood disasters in Jakarta in two main ways: (a) by increasing river discharge and the delivery of sediment to Jakarta's rivers; and (b) by increasing the value of assets and number of people potentially exposed to floods if they do occur [Ward et al., 2011b].

Moreover, the future flood problems in Jakarta may be exacerbated due to climatic change. The majority of climate change studies in Southeast Asia suggest that extreme rainfall events will increase in their frequency and severity during the 21st Century [e.g. IPCC, 2007]. Potentially, this could lead to increased extreme river discharges. Moreover, the frequency and intensity of coastal flooding may be exacerbated by sea level rise in the Bay of Jakarta. Observations of sea level rise in the Jakarta area suggest that the mean sea level has risen at a rate of ca. 3-4 mm per year over the period 1993-2009 [Nurmaulia et al., 2010].

1.2 Framework

As a result of the ongoing and large physical and socioeconomic changes outlined above, there is a growing recognition that it will become increasingly expensive to defend against floods. Also, the chance of flooding can never be completely removed. Hence, adaptation measures are required that both reduce the chance of flooding and the consequences should a flood occur. This is facilitated by a flood risk approach, whereby flood risk is defined as a function of hazard, exposure, and vulnerability [e.g. UNISDR, 2011].

The risk framework, and disaster risk reduction in general, are increasingly recognised as being key to international development and adaptation in a broader sense. For example, the Hyogo Framework for Action (HFA), whose main goal was to substantially reduce disaster losses by 2015, is generally seen to have been a great success. Also, the last decades have seen the development of key institutions in the field of disaster risk management, such as the United Nations International Strategy for Disaster Reduction (UNISDR) and the World Bank's GFDRR (Global Facility for Disaster Reduction and Recovery). Key documents and activities of these organisations, such as the bi-annual Global Assessment Reports (GAR) of the UNISDR [UNISDR, 2009, 2011, 2013], and the Understanding Risk reports and forum [e.g. World Bank GFDRR, 2012, 2014a, 2014b, 2014c] provide a solid platform and sound scientific concepts in which to carry out flood risk analyses and research.

Hence, in this report we follow the terminology set out by UNISDR (http://www.unisdr.org/we/inform/terminology), whereby:

- *Hazard* refers to a"...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* refers to the: "...people, property, systems, or other elements present in hazard zones that are thereby subject to potential losses"; and
- *Vulnerability* refers to the: "...characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard".

A closely related concept is that of resilience to natural hazards. Whilst definitions and conceptualisations of resilience differ in the scientific literature [see, for example Klein et al., 2003; Manyena, 2006; Zhou et al., 2008; Alexander, 2013; and Garschagen, 2013], the UNISDR glossary defines resilience as: "The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions".

A large body of literature abounds on flood risk management in general, and on examples of successful flood risk management in cities. Thorough reviews of key literature and practical examples include: UNISDR [2009, 2011, 2013], Zevenbergen et al. [2011], Jha et al. [2012], Mehrota et al. [2012], World Bank GFDRR [2014a], amongst others. However, whilst risk assessment and management are already encapsulated in several Indonesian regulations (e.g. the regulation related to risk assessment in Law No. 24/2007 and its descriptives in the Regulation of the Government of Indonesia No. 21/2008), no detailed quantitative flood risk assessment method is currently available for the entire city of Jakarta [Budiyono et al., 2014a].

During the definition phase of Jakarta Climate Adaptation Tools project (JCAT), stakeholders in Jakarta identified the need for information on current flood risk; projections of future risk; and information on the contribution of different physical and social changes to flood risk. Moreover, they expressed the need for methods and tools to be able to assess how various adaptation measures may be able to reduce that risk in the future. An explicit request was for methods to be able to assess and compare the costs and benefits associated with various measures, so that stakeholder and decision-makers are able to make more informed decisions on which adaptation measures to employ. These requests are very much in line with recent literature on the first requirements for integrated flood risk management and adaptation planning. For example, Jha et al. [2012] point out that the first step in integrated flood risk management is to understand the causes and risks of flooding. Then "…with a solid understanding of the causes and impacts of urban flooding […] and knowledge of both the potentials and the limitations of various flood risk management approaches, policy makers can adopt an integrated approach to flood risk management". They point to several methods and tools that can be extremely helpful in this regards, including flood risk and hazard maps, and economic cost-benefit analyses that can make the decision-making process more transparent and accountable. Similarly, Ranger and Garbett-Shiels [2011] describe a number of first steps that are required for planning adaptation, including: understanding current risk; scoping future risks related to climate change and the uncertainties involved; and identifying potential adaptation options.

1.3 Aims and objectives

In response, the Jakarta Climate Adaptation Tools (JCAT) project was initiated to contribute to scientific knowledge and the development of methods and tools to assess flood risk in Jakarta, and to use these to compare and optimise options for climate adaptation in the city. This report summarises the main findings of the JCAT project. JCAT is a joint project of the Dutch Knowledge Programme Knowledge for Climate, and the Delta Alliance. The research consortium consists of VU University Amsterdam, Gadjah Mada University Yogyakarta, Wageningen UR, and Bogor Agricultural University. The research has been carried out in close collaboration with LIPI (The Indonesian Institute of Sciences), and several stakeholders in Jakarta.

The overarching goal of JCAT is to contribute to the development of methods and tools to assess, compare, and optimise options for climate adaptation in Jakarta. This was achieved through PhD research carried out by two Indonesian PhD candidates, and complementary research at the partner institutes.

The specific aims of JCAT are:

- To contribute knowledge and capacity building on flood risk and climate change in Jakarta, including the training of 2 PhD candidates;
- To develop and improve methods and tools for assisting in decision-making on flood risk adaptation, including flood risk assessment and socioeconomic evaluation methods that can serve as a basis for planning and communication with stakeholders and the integration of spatial planning and water management;
- To improve flood risk information by incorporating scenarios of future changes in physical and socioeconomic conditions;
- To assess the impacts of several adaptation strategies in terms of costs and benefits in order to assist in identifying solutions for reducing the risk of flooding;

- To disseminate results to stakeholders in Jakarta, and more broadly to scientists and practitioners in other delta cities worldwide.

1.4 Setup and scope of the report

This report is intended to provide an overview of the different activities, methods, and tools carried out in JCAT. It does not provide exhaustive details on each of the methods and tools, nor does it provide extensive analysis of all aspects of the research. For details on specific aspects of the research, and on the methods and tools, we refer the reader to the detailed publications cited in the text.

The report is setup as follows. In Section 2, we describe the study area, Jakarta, and provide an overview of past and projected future trends in physical and socioeconomic trends relevant to an analysis of flood risk. Section 3 describes the methods and tools that have been developed and/or applied as part of the JCAT project. These methods and tools were then used to assess trends in flood risk related parameters in the past and/or future; these results are summarised in Section 4. In Section 5, we examine the potential contribution of several adaptation measures for reducing flood risk and related issues. Section 6 describes a number of governance aspects that are of importance in the flood risk management of the city. Examples of the ways in which the knowledge generated in JCAT have been, are being, or could be used in practice are summarised in Section 7. Finally, conclusions and recommendations are given in Section 8.

1.5 Key scientific results from HSINT02a

Below is a list of key scientific publications from this project; a full publication list can be found in Annex 1.

- Budiyono, B., J.C.J.H. Aerts, J. Brinkman, M.A. Marfai, P.J. Ward, 2014. Flood risk assessment for delta mega-cities: a case study of Jakarta. Natural Hazards, online first, 10.1007/s11069-014-1327-9.
- Poerbandono, M. Julian & P.J. Ward, 2014. Assessment of the effects of climate and land cover changes on river discharge and sediment yield, and adaptive spatial planning in the Jakarta region. Natural Hazards, 2, 507-530, doi:10.1007/s11069-014-1083-x.
- Wijayanti, P., X. Zhu., P. Hellegers, & E. C. van Ierland, 2014a. Economic modelling for selection of flood protection measures in Jakarta: an optimization approach. Manuscript in prep.
- Wijayanti, P., X. Zhu., P. Hellegers, & E. C. van Ierland, & Y. Budiyono, 2014b. River flood damage estimation in Jakarta, Indonesia. In review.

- Marfai M.A., A.B. Sekaranom & P.J. Ward. Community Response and Adaptation Strategies towards Flood Hazards in Jakarta-Indonesia. Natural Hazards, online first, doi: 10.1007/s11069-014-1365-3.
- Jeuken, A., M. Haasnoot, T. Reeder, T. & P.J. Ward. Lessons learnt from adaptation planning in four deltas and coastal cities. Accepted for publication in Journal of Water and Climate Change.
- Ward, P.J., W.P. Pauw, A.W. van Buuren & M.A. Marfai, 2013. Governance of flood risk management in a time of climate change: the cases of Jakarta and Rotterdam. Environmental Politics, 22, 518-536, doi:10.1080/09644016.2012.683155.
- Ward, P.J., M.A. Marfai, F. Yulianto, D.R. Hizbaron & J.C.J.H. Aerts, 2011. Coastal inundation and damage exposure estimation: a case study for Jakarta. Natural Hazards, 56, 899-916, doi:10.1007/s11069-010-9599-1.
- Ward, P.J., M.A. Marfai, Poerbandono & E. Aldrian, 2011. Climate adaptation in the City of Jakarta. In: Aerts, J., W. Botzen, M. Bowman, P.J. Ward & P. Dircke, P. (eds.), Climate adaptation and flood risk in coastal cities. Oxford, Earthscan.

1.6 Key societal results from HSINT02a

Below is a list of the key societal results from this project. For further details see Section 7.

Interaction with stakeholders

- JCAT co-organised the session '*Strengthening Local Capacity for Disaster Risk Reduction*' at the 5th Asian Ministerial Conference on Disaster Risk Reduction (AMCDRR) in Yogyakarta, Indonesia, in October 2012. The results of this discussion contributed to the outcomes of the conference.
- JCAT organised a workshop at the World Delta Summit in Jakarta, Indonesia, in November 2011. The workshop was highly oriented towards policy and decision-makers, and was attended by approximately 40 representatives from international government and research institutes, NGOs, and consultants.
- A project definition kick-off workshop was held in Jakarta, Indonesia, in January 2011, to co-develop the research goals with a large range of stakeholders.
- In August 2014, JCAT held a final workshop in Jakarta, together with the Jakarta Research Council (Dewan Riset Daerah DKI Jakarta; DRD) and the Indonesia International Institute for Urban Resilience and Infrastructure (i3URI). The results and tools of JCAT were presented, and their possible uses discussed with delegates. Also, the concept of flood risk management in Jakarta as a Delta City was discussed in the wider framework of a Green Metropolis Jakarta 2050 Concept. Both JCAT and the Green Metropolis Jakarta 2050 Concept were discussed in the light of several over ongoing activities in Jakarta, including the Garuda Project. The opening speech was delivered by His Excellency Ir. Basuki Tjahja Purnama, Vice Governor of Jakarta.
- JCAT has contributed to several important reports and books aimed towards policy and decision makers, and the insurance industry, including the Connecting Delta Cities network, UN-HABITAT, and Munich Re.
- In October 2013, the PhD researchers conducted a workshop in Jakarta to discuss the results of flood damage assessment in the Pesanggrahan River. It was attended

by academics (from IPB and UI), BMKG, and representatives from South Jakarta Government, West Jakarta Government, as well as DKI Jakarta Gorvernment.

Education

- Two Indonesian PhD candidates are working towards the completion and defence of their PhD theses. Through JCAT, these candidates have developed strong networks with the Indonesian policy and scientific community, which will lead to the longevity of the knowledge developed once the project ends.
- Next to the training of 2 PhD candidates, JCAT has contributed to knowledge and capacity building by placing a special emphasis on education. Examples from JCAT have been used in BSc and MSc course in both the Netherlands and Indonesia. Dr. Aris Marfai (UGM) has written a text book to accompany this course (see Section 7.4).

Key societal publications

- Members of the JCAT team contributed a special JCAT-related chapter to the Connecting Delta Cities book 3
    - Marfai, M.A., P.J. Ward, A. Tobing & A. Triyanti, 2013. Jakarta. In: Molenaar, A., J. Aerts, P. Dircke & M. Ikert, (eds.), Connecting Delta Cities. Resilient cities and climate adaptation strategies. Rotterdam, Connecting Delta Cities.
- Members of the JCAT team contributed a JCAT-related section to Munich Re’s Knowledge series publication, *Severe Weather in Eastern Asia*
    - Ward, P.J., Y. Budiyono, M.A. Marfai, 2013. Flood risk in Jakarta. In: Munich Re (ed.), Severe weather in Eastern Asia. Perils, risks, insurance. Munich Re Knowledge Series Natural Hazards. Munich, Munich Re.
- Members of the JCAT team contributed the knowledge developed in the JCAT project to a background report for UN-HABITAT’s report on global water risk.
    - PBL, 2014. Towards a world of cities in 2050 – an outlook on water-related challenges. PBL background report for UN Habitat Global Report. PBL Netherlands Environmental Assessment Agency, The Hague.
- Marfai, M.A, A. Triyanti, 2013. Community based flood disaster management (Comparative study of Jakarta and Surakarta). Proceeding Joint Scientific Program and One day Seminar on Eocsystem Based Disaster Risk Reduction. ISBN 978-602-14856-1-5. Pp 93-134

2 Study area and past research

2.1 Study area

Jakarta, the capital city of Indonesia, is located on the northern coast of West Java (Figure 2.1). It has a population of over 9 million (BPS, 2010) and covers an area of ca. 662 km^2. During the daytime, the city's population increases by another third due to commuters from the suburbs.

In terms of its physical geography, Jakarta is a relatively flat, lowland area, with slopes ranging from 0-2° in the northern and central parts to 0-5° in the southern parts [Abidin et al., 2001]. The lowland area around Jakarta has five main landforms: (1) volcanic alluvial fans around the southern part; (2) landforms of marine-origin around northern parts adjacent to the coastline; (3) beach ridge landforms around the northwest and northeast parts; (4) (mangrove) swamps along the coastal fringe; and (5) former river channels that run perpendicular to the coastline [Sampurno, 2001].

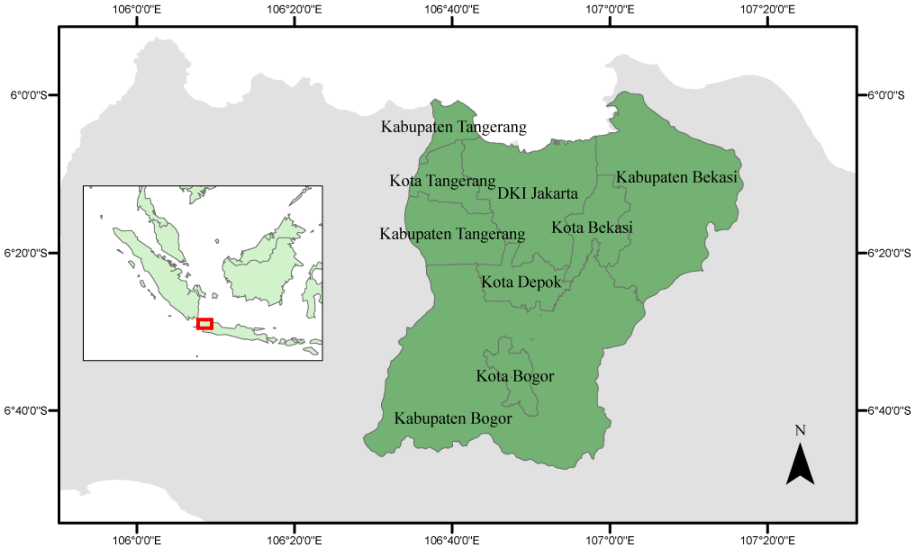


Figure 2.1: Map showing the districts of Jakarta (western Java, Indonesia)

There are 13 rivers that flow into the Jakarta metropolitan area, the main one being the Ciliwung. In terms of climate, Jakarta is characterised by a tropical monsoonal climate. The mean annual temperature is ca. 27°C, with mean temperature variations between 24°C and 29.5°C. Over the period 1978-2007, the average annual rainfall in Jakarta, measured at Tanjung Priok, was ca. 1640 mm. Most of the rain (about 80%) falls in the wet season between November and May (Figure 2.2) [Marfai et al., 2009].

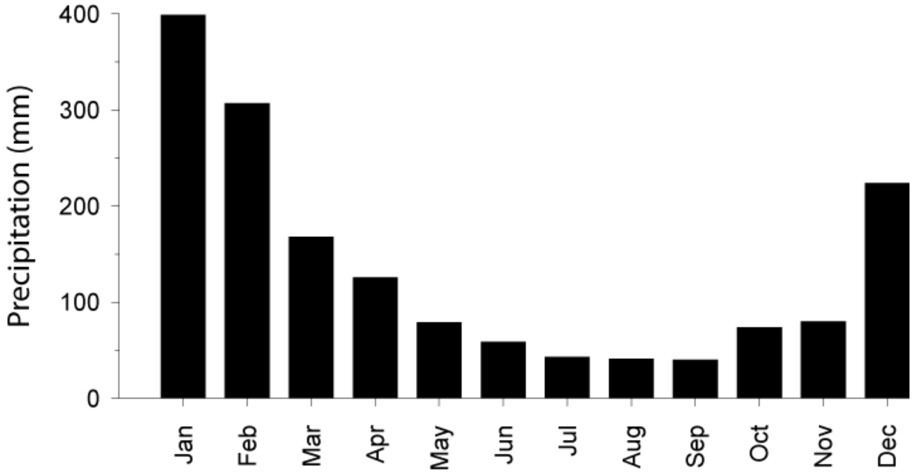


Figure 2.2: Mean monthly rainfall in Jakarta (Tanjung Priok measuring station) between 1978-2007

There are large marked geographical differences in the amount of precipitation falling in Jakarta itself and in the mountainous river catchments to the south. These mountains drain into the rivers that run through Jakarta. There, annual precipitation can be as high as 4500 mm. Climate data for Jakarta also show that high intensity rainfall events occur frequently during the wet season. The most intense rainfall events generally occur around January and February [Aldrian, 2009], and can lead to major riverine flooding. The major floods of 2002, 2007, 2013, and 2014 all occurred at this time of year.

2.2 Physical and socioeconomic drivers of flood risk in Jakarta

In this section, we provide a brief overview of data and studies describing past and possible future changes in the main physical and socioeconomic drivers of risk in Jakarta. The overview is based predominantly on Ward et al. [2011a].

2.2.1 Physical drivers

Land subsidence is an extremely serious problem in Jakarta [Abidin et al., 2011]. Four possible causes have been identified, namely: groundwater extraction, construction loading, natural consolidation of alluvium soil, and geotectonic adjustments [Rismianto and Mak, 1993; Murdohardono and Sudarsono, 1998; Harsolumakso, 2001; Hutasoit, 2001]. The first three, and especially groundwater extraction, are believed to be most dominant [Abidin et al., 2011]. Observed rates of subsidence in Jakarta are generally about 1-15 cm/year. Recent estimates of Abidin et al. [2011] suggest that the northern part of the city experiences an average subsidence rate of 4 cm/year. However, there are also ‘cones of subsidence’ where subsidence is occurring more rapidly.

Another major driver of flood risk in Jakarta is the lack of drainage and/or storage capacity in the city’s waterways [Deltares, 2009]. This contributes to the flood problem in two main ways: (a) the design capacity of the water infrastructure does not have the capacity to deal with the amount of water, and/or

(b) the actual waterways' actual discharge capacities are lower than their design capacities as a result of being clogged up by solid waste and/or sediments eroded from upstream. Figure 2.3 shows an example of garbage and solid waste clogging up drainage channels at the Manggarai Gate in Jakarta.

Figure 2.3: Accumulation of solid waste in Manggarai Gate, Jakarta

Moreover, future flood risk in Jakarta may also be influenced by climate change. During the 20th century, the mean annual temperature in Indonesia as a whole increased by ca. 0.3°C [Hulme and Sheard, 1999]. For Jakarta, the increase over the same 100 year period was ca. 1.07°C in January and 1.40°C in July [source: BMKG, cited in Ward et al., 2011a]. Similar research indicates that there has been no clear trend in mean annual rainfall totals for Jakarta over the second half of the 20th century. Across the country as a whole, observations suggest that mean annual rainfall over the same period decreased by ca. 2-3%, mainly in the wet season from December to February [Cruz et al, 2007]. Several climate models project a temperature increase of ca. 0.1° to 0.3°C per decade over the 21st century [Hulme and Sheard, 1999]. The same projections suggest that mean annual rainfall may increase in the future across most of Indonesia, although in Java it may decrease.

Jakarta will also be affected by climate change due to projected sea-level rise. Sea-level rise is currently taking place at a rate of ca. 1-3 mm/year in most parts of coastal Asia [IPCC, 2007]. In the Bay of Jakarta, observations based on altimetry satellite detection also show mean sea-level rise of ca. 2-4 mm p.a. between 1992 and 2005 [Prijatna and Darmawan, 2005]. Detailed projections of climate change's impacts of on sea-level rise specific to the Jakarta Bay are not yet available. Nevertheless, these observed changes over recent decades are inside the range of global rise reported by IPCC [2007]; i.e. a likely minimum and maximum global mean sea-level rise until 2100 of between 18 cm and 59 cm.

2.2.2 Socioeconomic drivers

The physical changes outlined in the section above are in turn driven by changes in socioeconomic factors from the household to the global level. At the global level, socioeconomic developments determine the rates of greenhouse gas emissions, a key component of global climate change and sea-level rise. At scales more local to Jakarta and its surrounding region, Jakarta's population has risen rapidly from 2.7 to 9 million between 1960 and 2007 [BPS, 2010], and is projected to increase further still in the future. At the same time, the GDP of Indonesia has also increased rapidly, and is projected to increase further.

The rapid growth of population and economic developments have led to extensive changes in land use in Java as a whole [Verburg et al, 1999], and in Jakarta in particular [Firman, 2009]. Over the last three decades, land has experienced conversion from prime agricultural land to newly urbanised and industrialised areas [Verburg et al, 1999, Firman, 2000]. At the same time, many former residential areas in the centre of the urban area have been converted to offices and business spaces, and green space has greatly decreased, for example from 28.8% of the total land area in 1984, to just 6.2% in 2007 [Firman, 2009]. These changes in land use affect flooding in Jakarta in two main ways: (a) by increasing river discharge and the delivery of sediment of Jakarta's rivers; and (b) by increasing the value of assets and number of people potentially exposed to floods if they do occur [Ward et al., 2011b].

Of course, the physical and socioeconomic drivers interact. The increased population and economic development have played a major role in lowering drainage capacity in drainage channels and waterways of the city. Moreover, socioeconomic developments continue to put pressure on the city's water supply system, leading to increasing water demand. As stated above, the over-extraction of groundwater is one of the main causes of the city's rapid land subsidence. Meanwhile, rapid urban development is being accompanied by increasing slum settlements, especially along river channels; this condition leads to an increased vulnerability of people living there to river flooding.

3 Methods and tools

3.1 Introduction

In the JCAT project, we have developed a number of methods that can be used by scientists and decision-makers in assessing issues related to flood risk in Jakarta. Also, a number of existing methods and tools have been adapted or improved so as to be applicable in Jakarta.

In this section, we give an overview of each of these. Note that the information provided here is deliberately succinct, giving the main features of the development and setup of these methods, along with the main input and output datasets. More details can be found in the relevant papers and reports, produced as part of JCAT, and cited per method. These are:

- STREAM: water-balance assessment model
- SDAS: erosion and sediment-delivery assessment model
- Coastal economic exposure assessment tool
- Damagescanner-Jakarta: city-scale river flood risk assessment model
- Economic modelling tool for selection of flood protection measures
- Method for assessing local actual damages for a specific flood event
- Cost Benefit Analysis of flood protection measures
- National scale probabilistic flood risk assessment tool for Indonesia

3.2 STREAM: water-balance assessment model

For this project, we used a version of the STREAM (Spatial Tools for River Basins and Environmental and Analysis of Management Option) model to simulate the water balance in the watersheds draining through Jakarta. In this report, we refer to this as STREAM-Jakarta. STREAM-Jakarta is described in detail in Poerbandono et al. [2014a].

STREAM is a raster-based spatially distributed water balance model. In STREAM, the hydrological cycle is described as a series of storage compartments and flows [Aerts et al., 1999]; these are shown in Figure 3.1. The water balance is calculated using the so-called Thornthwaite [1948] and Thornthwaite and Mather [1957] equations for potential evapotranspiration and actual evapotranspiration respectively. The major inputs to these equations are temperature and precipitation. STREAM can be run on different time-steps, for example daily, monthly, or annual. For each time-step, the model generates the following variables: runoff, groundwater storage (shallow and deep), snow cover, and snow melt. Water flows between raster cells according to the pathway with the steepest descent, based on a digital elevation model (DEM).

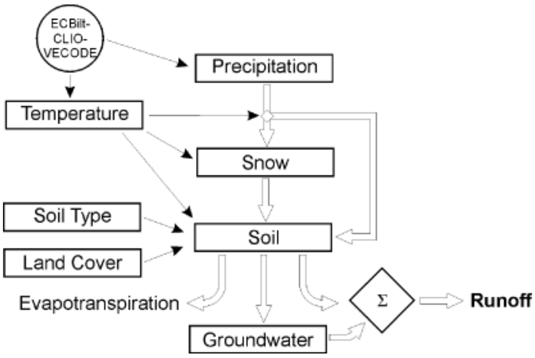


Figure 3.1: Flowchart showing the main storage compartments and flows of the STREAM model.

STREAM-Jakarta has a spatial resolution of 100m x 100m, and runs on a monthly time-step. The model was calibrated and validated against observed river discharge at six gauging stations. Information on this calibration and validation, as well as details on the model's setup, can be found in Poerbandono et al. [2009]. The agreement between modelled and observed river discharge was generally good, with discrepancies in annual discharge ranging between -8% and 5%, depending on the location.

3.2.1 Input data

The main input data are: climate data; land use data; soil water holding capacity data; and a Digital Elevation Model (DEM). Here, we summarise the main inputs; more details can be found in Poerbandono et al. [2014a].

Climate Data

In JCAT, we used monthly temperature and precipitation maps with a horizontal resolution of 100m x 100m. Firstly, we took monthly temperature and precipitation time-series for 1901-2005 from the CRU TS3.0 dataset of the Climate Research Unit (CRU) of the University of East Anglia, United Kingdom [New et al., 2002]. This dataset has a spatial resolution of 30’×30’. This resolution is too low for modelling the water balance of Jakarta, and therefore we downscaled these to a horizontal resolution of 10’×10’ [Poerbandono et al., 2014a].

Land use data

In STREAM, a land use map is used to derive the ‘crop factor map’, which is used to calculate potential evapotranspiration (PE). The crop factor is a dimensionless factor by which reference PE is multiplied to account for the difference in PE over different land use types. In STREAM-Jakarta, land use maps for different time periods are based on different original sources (see Section 4.1.1). All maps were resampled to the 100m x 100m resolution.

Soil Water Holding Capacity

A map showing the maximum water holding capacity (WHC) of the soil is used in STREAM in the calculation of evapotranspiration, runoff, groundwater seepage, and baseflow. The values of WHC are derived from the land use, using values from the look-up table in Aerts et al. [1999].

Digital Elevation Model

A Digital Elevation (DEM) is used to derive slope and the direction of flow between grid cells, based on the pathway of steepest decent. The DEM used in STREAM-Jakarta is the SRTM (Shuttle RADAR Topography Mission) DEM from 2003 [Rodriguez et al., 2005]. This has a native horizontal resolution of 90m × 90m, but was first resampled to the 100m x 100m resolution used in STREAM-Jakarta.

3.3 SDAS: erosion and sediment-delivery assessment model

We used SDAS (Spatial Decision Assistance of Watershed Sedimentation) to simulate erosion and sediment yield of the watersheds draining through Jakarta. SDAS is described in Poerbandono et al. [2014a,b].

SDAS calculates the sediment yield (*SY*) for the watersheds studied. Sediment yield is the total mass of sediment passing a specific location during a given time interval. In SDAS, sediment yield is considered as the product of the erosion rate (*e*) in the watershed and the sediment delivery ratio (*SDR*). SDAS applies the empirical Universal Soil Loss Equation (USLE) [Wishmeier and Smith, 1978] to calculate the rate of erosion (*e*) per grid cell. This erosion rate is controlled by slope, land cover, soil type, precipitation, and flow length. The SDR represents the efficiency of surface water in terms of transporting eroded sediment. An overview flow chart of SDAS is shown in Figure 3.2.

The outputs of SDAS-Jakarta were validated against observed data at the outlet of the upper Citarum catchment, namely at the Nanjung measuring station [Poerbandono et al., 2014b]. Observations of sediment yield are available as total annual magnitudes for 1976, 1981, 1993, 2003, and 2004 [Poerbandono et al., 2006]. The computed sediment yield agreed with the observation data with a 7% mean relative accuracy.

3.3.1 Input data

The main input data required are: rainfall, soil type, land cover, and a DEM. Here, we summarise the input data used to force SDAS-Jakarta in this project. For a more detailed description see Poerbandono et al. [2014a,b].

Climate data

In SDAS, approximations are required for determining average rainfall duration and effective rainfall duration. Here, it is assumed that these variables are directly proportional to mean annual rainfall (MAR), following Lu et al. [2006]. Estimates of mean annual rainfall were derived from the same climate data as described in Section 3.2.

Land cover data

Land cover data for different time periods are taken from different sources, as listed in Table 4.1.

DEM

Since SDAS runs at a spatial resolution of 30m x 30m, we used the so-called ASTER GDEM datasets (Advanced Space-borne Thermal Emission and Reflection

Radiometer Global DEM) [ERSDAC, 2009]. This dataset is available at the 30m×30m resolution required.

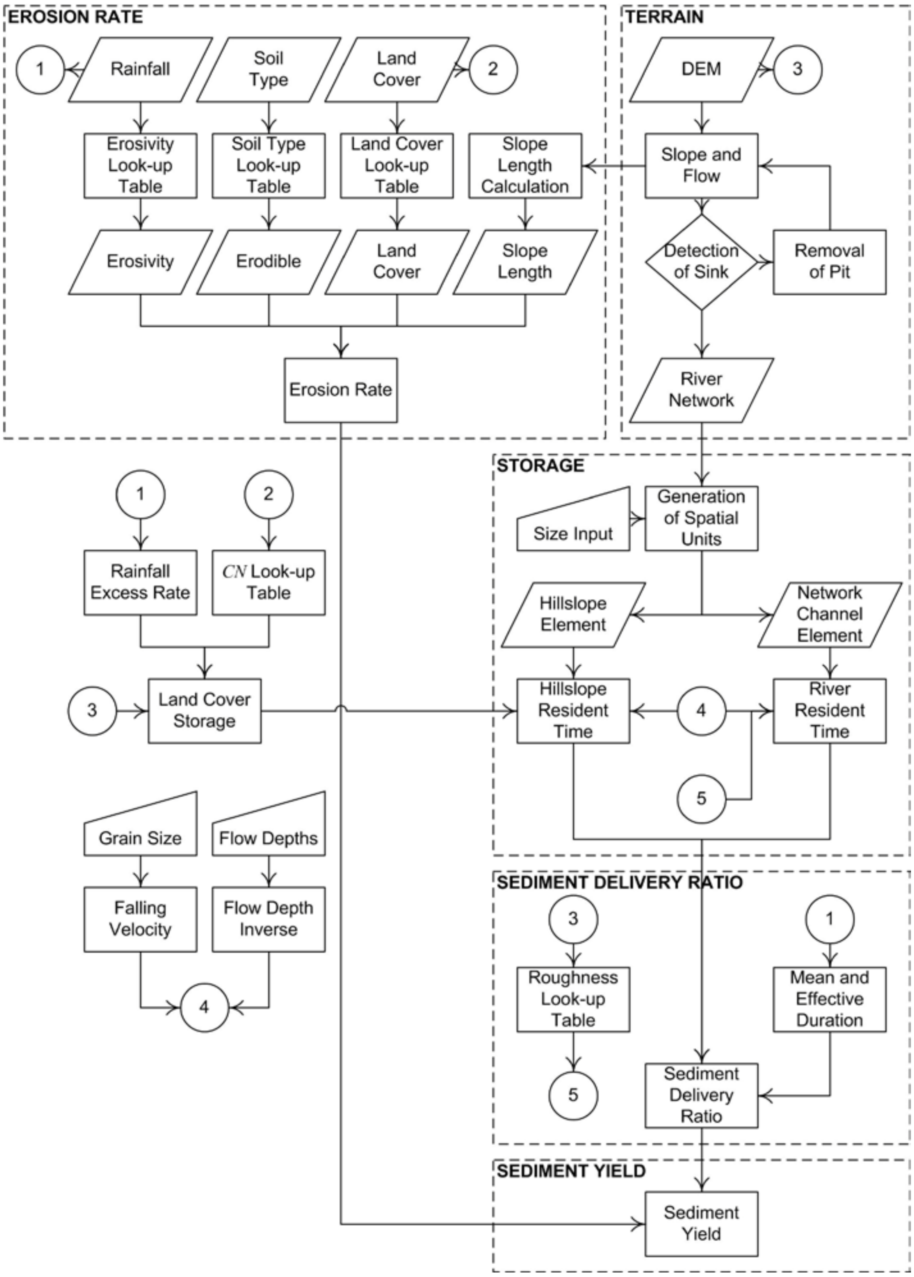


Figure 3.2: Operation flow chart of the SDAS model. (Source: Poerbandono et al. [2014b])

3.4 Coastal economic exposure assessment tool

We developed a methodology for rapid inundation mapping and economic exposure estimation under future scenarios of extreme coastal flood events. The setup of the model is described in detail in Ward et al. [2011b]. The model provides estimates of the economic value of assets potentially exposed to coastal floods with different return periods.

3.4.1 Modelling approach

The overall approach is based on that of Nicholls et al. [2008], but using more localised datasets. Firstly, a GIS-based inundation model is used to produce inundation maps for given coastal floods under both current environmental conditions, and under scenarios of future environmental change. The GIS-based inundation model produces a map of grid cells that would be inundated for a given coastal flood (inundation map), for example the inundation area that would be caused by a storm surge with a recurrence period of 100 years. The input required by this inundation model are a digital elevation model (DEM), and the difference in sea-level between a given flood scenario and current mean sea-level (hereinafter referred to as ‘flood water level’, and given in metres above current mean sea-level (masl)). The output inundation map is then overlaid with a map of land use, and each land use is assigned an economic value, in order to calculate the maximum economic exposure per grid-cell.

An overview of the overall modelling chain is shown in Figure 3.3. Details of the inundation model can be found in Marfai and King [2008] and details of the economic exposure model can be found in Ward et al. [2011b].

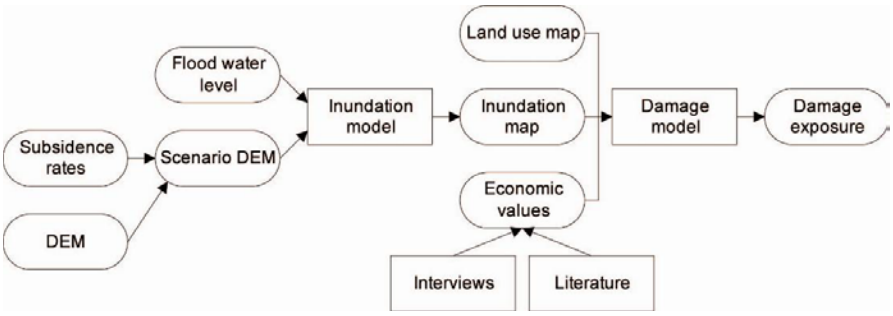


Figure 3.3: Flowchart showing the methodology.

3.4.2 Input data

One of the main inputs required by the model is a DEM. The DEM for the current conditions was generated at a resolution of 5 m x 5 m from the topographic maps of BAKOSURTANAL (Indonesian Survey and Mapping Coordination Agency) (scale 1:25,000).

A flood water level (masl) is then given as input to assess which land cells would be inundated should such a coastal flood event with that water level occur. Estimates of flood water level associated with a return period of 100 years under current conditions were derived from the DIVA (Dynamic Interactive Vulnerability Assessment) model [Dinas-Coast Consortium, 2006].

Each grid cell is also assigned a land use, and each land use is assigned an economic value. This value represents the estimated market value of the buildings and material assets per hectare for each land use class. By overlaying the inundation maps on the land use maps we estimated the total inundated area in each land use class, and also the total value of exposed assets (economic exposure) per land use class; this represents the maximum potential economic exposure. The land use map is based on an updated version of detailed topographic maps of the Jakarta local government (Pemerintah Kota Jakarta, Dinas Pertanahan dan Pemetaan) for the year 2004 (based on aerial photography in the year 2003), updated by means of visual image analysis based on an IKONOS image from 2007 (see Figure 3.4). For each land use class we assigned an average market value of buildings and tangible assets based on interviews, literature review, and statistics [DPB, 2002; DGEM, 2004, Marfai and King, 2008]: business areas (€2.5 million/ha.); uniform settlements (€1.2 million/ha.); ununiform settlements (€1.0 million/ha.); agriculture (€80,000/ha.); fishponds (€95,000/ha.); and open areas (€1,700/ha.).

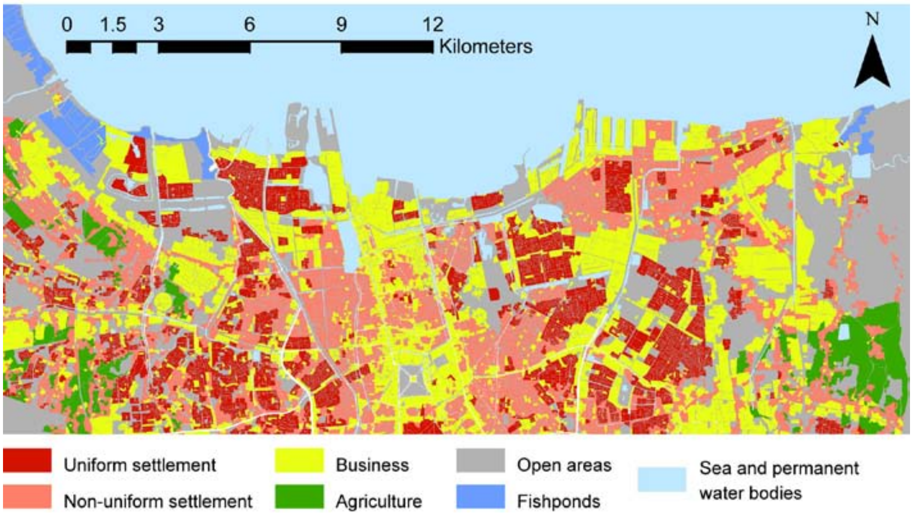


Figure 3.4: Land use map used in the coastal flood exposure analysis. Source: Transavia Consultancy (image taken from Ward et al. [2011b]).

3.5 Damagescanner-Jakarta: city-scale river flood risk assessment model

We developed a rapid flood risk assessment model, which can be used to simulate river flood risk in Jakarta. The model simulates flood risk in terms of annual expected damage, and is based on the Damagescanner model (Klijn et al., 2007; Aerts et al., 2008). In this report, we refer to this version of the model as Damagescanner-Jakarta. The model setup is described in detail in Budiyono et al. [2014a].

3.5.1 Modelling approach

The modelling approach considers flood risk to be a function of hazard, exposure, and vulnerability. An overview of the framework is presented in Figure 3.5. Originally, Damagescanner was developed for flood risk assessments in the Netherlands, and has subsequently been applied to several European basins (e.g. Aerts and Botzen, 2011; Aerts et al., 2008; Bouwer et al., 2010; De Moel and Aerts, 2011; Klijn et al., 2007; Te Linde et al., 2011). Since the overall conceptual framework has been described in several papers, we here only briefly summarise the main points of relevance to the setup for Damagescanner-Jakarta.

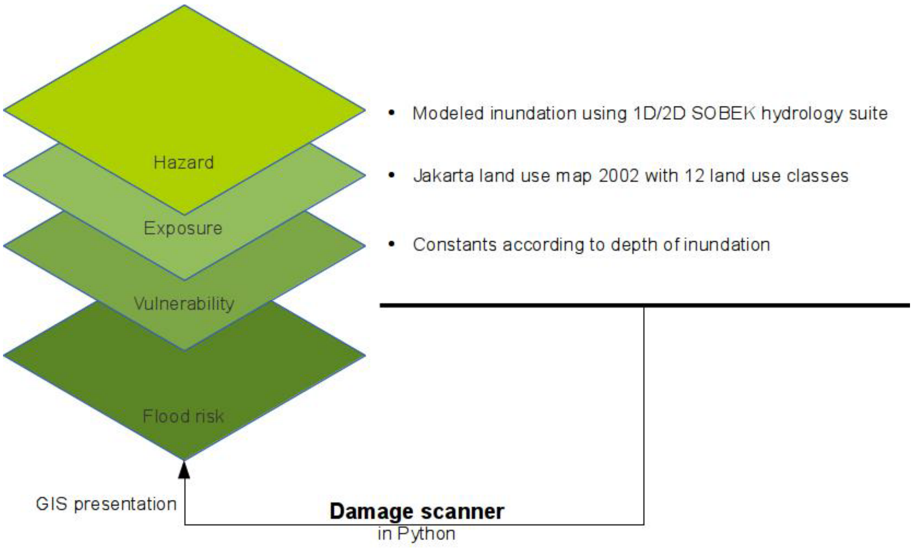
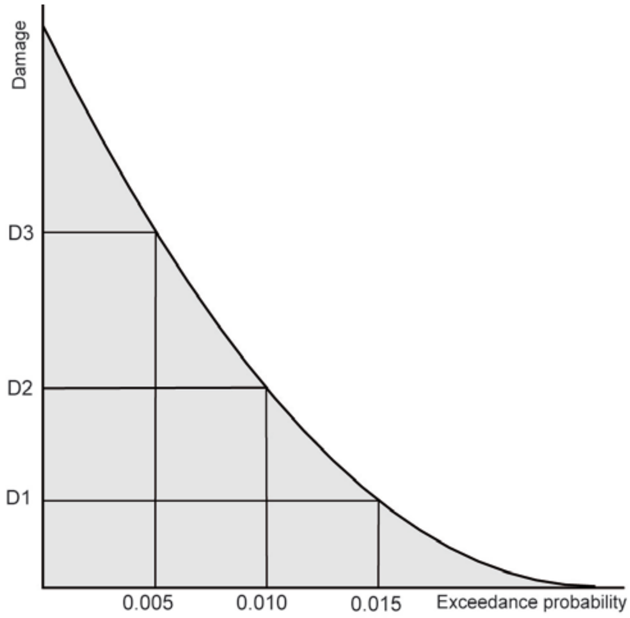


Figure 3.5: Flow diagram representation of Damagescanner-Jakarta [adapted from Budiyono et al., 2014a].

Damagescanner-Jakarta calculates direct damages for floods of different return periods (or exceedance probabilities). Annual expected damages are then calculated as the integral of the area under an exceedance probability-damage curve (risk curve); this is shown in Figure 3.6. For this study, a new version of Damagescanner was developed in Python code. The horizontal resolution of Damagescanner-Jakarta is 50m x 50m.

Figure 3.6: Theoretical risk curve; the area under the curve (in grey) represents the risk, expressed as the average expected annual damage.



3.5.2 Input data

To run Damagescanner-Jakarta, three input datasets are required: (a) maps showing inundation extent and depth for different return periods to represent the hazard; (b) a land use map, with associated economic values per land use class, to represent exposure; and (c) depth-damage functions to represent the vulnerability. Depth-damage functions estimate the damage that would occur for a given inundation depth and for a given land use. Damagescanner-Jakarta can be used to estimate current flood risk [Budiyono et al., 2014a], and flood risk in future conditions [Budiyono et al., 2014b]. In the following paragraphs we briefly describe the datasets used to set up Damagescanner-Jakarta under current conditions. Information on the scenarios used for the future simulations can be found in Section 4.4.1.

Hazard

In Damagescanner-Jakarta, we represent flood hazard using maps showing inundation depth and extent for the following return periods: 1, 2, 5, 10, 25, 50 and 100 years. The spatial resolution of the hazard maps is 50m x 50m, and the depths are given for increments of 1cm. An example of one of the flood hazard maps is shown in Figure 3.7.

These inundation maps were produced using the Flood Hazard Mapping (FHM) framework, developed by Deltares in 2007 and 2009, and the Flood Management Information System (FMIS) projects by Deltares, the Research & Development Center For Water Resources (Pusair), and the National Office for Climate (BMKG) in 2012. These were produced for DKI Jakarta and the national government of Indonesia. The FHM framework uses the SOBEK model to simulate hydrological and hydraulic processes in Jakarta. For further details, see Budiyono et al. [2014a].

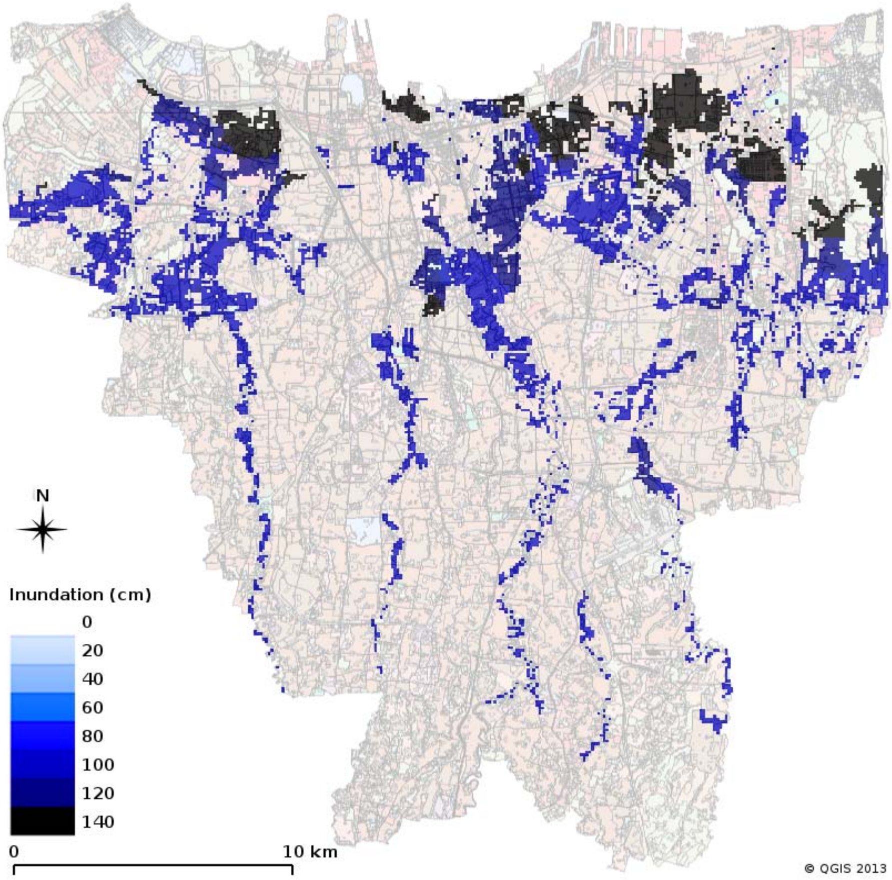


Figure 3.7: Map of Jakarta showing the modelled hazard for a 50 year flood return period.

Exposure
In Damagescanner-Jakarta, we represent exposure using a map showing economic exposure for each cell. In turn, this is based on a map of land cover. For the current conditions we used a map for the year 2002, supplied by the office of city planning in Jakarta [DTR DKI, 2003]. This map has a horizontal resolution of 50m x 50m, and includes 12 land cover classes, namely: agriculture and open space; low density urban kampung; swamp, river and pond; industry and warehouse; commercial and business; planned house; education and public facility; government facility; high density urban kampung; transportation facility; and park and cemetery.

For the model setup, we initially used two approaches to assign economic exposure values to each land cover type. Firstly, we carried out a literature review of past studies in Jakarta that have provided or mentioned the economic value of different land use classes. However, the estimates in these past studies are very approximate and associated with high uncertainty. Hence, as part of JCAT we also held a series of workshops to develop new estimates of maximum economic damage based on expert judgment. This process is described in detail in Budiyono et al. [2014a]. Damagescanner was run using both input datasets, and the results compared with reported flood losses. The results of this analysis are discussed in Section 4.4.2. The results based on the workshop values gave the most realistic risk results. Hence, these were used in the subsequent analyses, and are shown in Table 3.1.

Table 3.1: Maximum economic exposure per land use class used in Damagescanner-Jakarta.

Land use class	**Economic exposure (thousand US$/ hectare)**
Industry and warehouse	517.9
Commercial and business	517.9
Government facility	517.9
Planned house	341.8
Transportation facility	331.5
Education and public facility	259.0
High density urban kampung	155.4
Low density urban kampung	129.5
Forestry	10.4
Swamp, river and pond	3.8
Park and cemetery	3.1
Agriculture and open space	2.0

** Original values were derived in the workshop in Indonesian Rupiah (IDR) and converted to USD using exchange rate of 9,654 IDR to 1 USD.*

Vulnerability

In Damagescanner-Jakarta, we use depth-damage functions to represent vulnerability; hereafter we refer to these functions as vulnerability curves. Vulnerability curves show the percentage of the maximum economic exposure that would actually suffer damage for different flood depths per land use class [e.g. Merz et al., 2010]. As per the exposure estimates, we initially took two approaches: (i) using vulnerability curves taken from a literature study of flood risk modelling in South-East Asia; and (ii) holding an expert workshop to derive synthetic vulnerability curves specific to the Jakarta case. The results for current conditions using the different sets of curves are discussed in Section 4.4.2, and described in detail in Budiyono et al. [2014a]. Details of the attendants of the workshop are also presented in Budiyono et al. [2014a].

3.6 Economic modelling tool for selection of flood protection measures

We have developed economic models to assess the optimal level of implementation of flood protection measures (FPM). The model is developed based on Walker et al. [1994] and Mays [2011], and is described in detail in Wijayanti et al. [2014a]. Here, we describe the generic model, and provide a hypothetical example of its application. In the final phase of the JCAT project, a real-world example will be developed for Jakarta.

3.6.1 Modelling approach

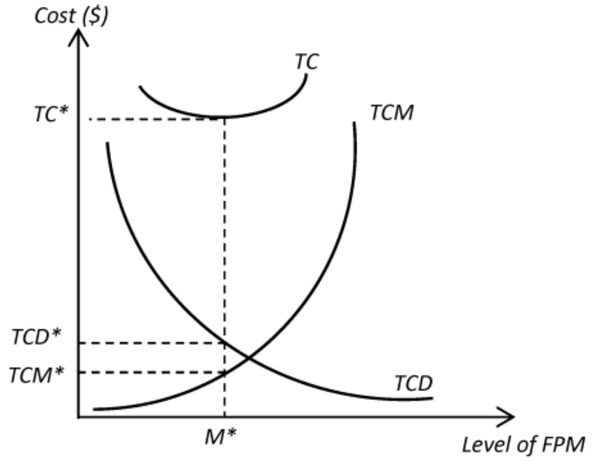
We developed an optimisation model for flood protection measures that considers the following costs: the costs of the measure and the damage costs. The former refers to the cost that is required to prepare, to construct, and to implement the FPM. The latter refers to the direct and indirect flood damages that would occur in a specific area if a flood were to take place. The direct damages refer to damage caused by physical contact between floods and humans, property, or any other objects. The indirect damages refer to losses that are indirectly related to the flood event, such as loss of production or income losses in other sectors of the economy [Merz et al., 2010].

To reduce the flood risk in a specific flooded area, the government may implement a single FPM or a combination of FPMs. Therefore, the total costs of implementing all FPMs in one area are called the total measure costs (*TCM*), and the flood damages that would occur after implementing such FPMs are identified as total damage costs (*TCD*).

Implementing FPMs benefits the flooded areas by reducing its expected flood damages. Therefore, to maximise those benefits, ideally, a FPM should be developed to minimise the sum of total measure costs and total damage costs. The optimal design level indicates the design level where its costs still can be borne by the government and the expected damage is acceptable by the society. Indeed, the optimal level, *M**, is indicated by a design level, *M*, that results the minimum total costs (*TC*) [Mays, 2011], which is the sum of *TCM* and *TCD*. Economically, both *TCM* and *TCD* depend on *M*.

As illustrated in Figure 3.8, the objective is to find the minimum *TC*; at that point *M** will be reached. The *TCM* curve has a positive slope, which means that higher costs are involved to achieve higher levels of the FPM. While *TCD* has a negative slope, less damage will occur for lower levels of FPM.

Figure 3.8: Objective function of the minimisation total costs of flood protection measures (FPM).



TCM depends on *M* and the cost parameter α. To show the relationship between *TCM* and *M*, we adopted the study of Eijgenraam [2006], which employed a convex cost function. Meanwhile, *TCD* is calculated by subtracting the expected annual flood damages in an area without any FPMs, D_0, with the expected flood damage reduction resulting from implementation of those FPMs. In detail, D_0 is determined by combining three categories of information, namely: (1) the economic exposure per land-use category; (2) stage-damage functions that express the fraction of economic exposure that would occur for different depths for each land-use category; and (3) the flooded area of each land-use category [Jonkman et al., 2008]. The expected flood damage reduction is determined by *a* parameter of flood damage reduction from a FPM β.

The objective function of the model is to minimise *TC*, where *M* is the decision variable. This model is subject to several constraints, and one of these is the available budget, *B*, where *TCM* should not exceed *B*. Whilst the objective function here is to minimise costs, optimisation methods developed in economics can also be used for objective functions, such as robustness, or indeed in terms of multiple objectives. Such approaches can, for example, be found in the work of Woodward et al. (2014).

In implementing this model, we consider both spatial and temporal issues of FPM. The spatial issues discuss how *FPMs* in one area can contribute to reducing flood damage in other areas. For example, an upstream dam can reduce run-off and discharge, hence reducing flood damage downstream. Regarding the temporal issue, flood measures can be classified as short-term and long-term [Ghosh, 1997]. This classification indicates the time horizon of implementing the FPM, which includes the construction period and the utilisation period.

Several FPMs in Jakarta need a longer period to build, and they will benefit society for a long period, such as dams and flood defences.

3.6.2 Economic models

Below, we provide a step-wise approach to illustrate conceptually how the economic model can be used in identifying the best options of FPM. Firstly, we illustrate the simplest case, which focuses on only one area. Secondly, we illustrate a more complicated case where multiple flooded areas are taken into account. Finally, we illustrate conceptually how the model can be used to include both spatial and temporal issues, in which multiple flooded areas and different time horizons of the FPM are considered.

Case 1: focusing on selecting optimal FPM in single area

Let us consider a flooded area, with a given number (*N*) of FPMs, indexed by *i*=1,2,…, *N*. Each FPM is constructed to a level, M_i, with investment costs C_i. The objective function is to minimize *TC* under the level of FPMs.

$$\min_{M_i} TC = TCM + TCD \qquad \text{(Eq. 1)}$$

This is subject to the three constraints. Firstly, the *TCM* should not exceed the total budget, *B*.

$$TCM \leq B \qquad \text{(Eq. 2)}$$

Secondly, the TCM is the sum of all measure costs, *i*, that depends on the level of the measure M_i. For the quadratic cost function, this can be presented as:

$$TCM = \sum_{i=1}^{N} \alpha_i \, (M_i)^2 \qquad \text{(Eq. 3)}$$

where α_i is the cost parameter.

Thirdly, the *TCD* is calculated by current flood damages in an area without any flood measures, D_0 minus the reduction of the flood damage under measure M_i.

$$TCD = D_0 - \sum_{i=1}^{N} \beta_i M_i \qquad \text{(Eq. 4)}$$

where β_i is the parameter of flood damage reduction from a flood measure *i*.

Case 2: Selecting the optimal level of several FPMs in multiple areas

Based on the previous case, we further extend the model by considering more than one flooded area. Let us consider a catchment area that consists of upstream, middle stream, and downstream areas. Due to heavy rainfall in the upstream area and bad conditions in the upstream and middle stream catchment, water flows quickly to the downstream area. Therefore, to reduce the flood damage, the government provides several FPMs in the upstream, middle stream, and downstream areas.

Let K describe a number flooded areas, indexed by j=1,2,..,K, and each area consists of N FPMs, indexed by i=1,2,…,N. Now, the level of FPM is written as $M_{i,j}$ that represents the level of FPM i in area j. Providing all combinations of FPMs in their highest level will be very expensive, whilst decision makers only have a total budget, B. This model has an objective function to minimize TC. Eventually, it will result in providing the optimal level of $M_{i,j}$. The model can be presented as follows.

The objective function is to minimise the total cost of measures in all areas, TC, which is sum over areas of total costs of measures in area j, TCM_j and total costs of damages in area j, TCD_j.

$$\min_{M_{i,j}} TC = \sum_{j=1}^{K} TCM_j + \sum_{j=1}^{K} TCD_j \qquad \text{(Eq.5)}$$

Subject to the following constraints:

The sum of all TCM_j should not exceed the total budget, B.

$$\sum_{j=1}^{K} TCM_j \leq B \qquad \text{(Eq.6)}$$

TCM_j as the sum of all the measure costs i in area j is given by

$$TCM_j = \sum_{i=1}^{N} \alpha_{i,j} \left(M_{i,j}\right)^2 \qquad \text{(Eq.7)}$$

Where $\alpha_{i,j}$ is the cost parameter of measure i in area j.

The TCD_j is calculated by current flood damages in an area j without any flood measures, $D0_j$ minus the reduction of the flood damage under measure $M_{i,j}$.

$$TCD_j = D0_j - \sum_{i=1}^{N} \beta_{i,j} M_{i,j} \qquad \text{(Eq.9)}$$

Where $\beta_{i,j}$ is parameter of flood damage reduction from a measure i in area j.

Case 3: Selecting the optimal level of FPM in multiple areas with different time horizon of each FPM

Now, we improve the model by including the specific time horizon of the measures. Normally, FPM projects need several years to be constructed and the projects' benefits occur in the ensuing years. In this model, we assume the time horizon of FPM covers the construction period and the utilisation period. The construction period represents the duration when the FPM is built and the costs incurred in this period are called the investment costs. The other costs after the construction period represent the maintenance costs. Mostly, the higher cost occurs in the beginning of the construction period. Meanwhile, the utilisation period represents the duration when the FPM is built completely until its project life is finished. In this period, the FPM reduces flood damage and the amount of reduction can be higher from year to year at a specific rate.

Let T indicate the years of time horizon of FPM indexed by t=0,1,2,...T, in which normally, the construction period is shorter than whole time horizon. Then, decision makers need to assess the measure costs and the damage costs of FPM over its time horizon.

In comparing several FPMs with different time horizons, decision makers calculate the future measure costs and future damage costs that arise in different time horizons. To do this, their calculation should be in the common metric known as the present value (PV) [Boardman et al., 2006]. Therefore, future measure costs and future damage costs of FPM should be discounted to find their PVs by dividing those that arise in year t with $(1+r)^t$, in which r is a discount factor.

The objective function is to minimise the *NPVTC,* under the level of FPMs. *NPVTC* is the discounted sum of the future stream of total measures cost in year t, TCM_t, and the future stream of discounted total flood damages in year t, TCD_t.

$$\min_{M_{i,j,t}} TC = \sum_{t=0}^{T} \frac{1}{(1+r)^t}(TCM_t + TCD_t) \qquad \text{(Eq.10)}$$

Subject to the following constraints:

TCM_t should be less than the available budget every year, *Bt*. However, there are two possibilities in presenting this constraint and we can choose one of them which more relevant with the real situation of government investment. First, if the government provides the whole budget in the beginning of FPM project, in which it should be spent during the time horizon of the project, then the constraint is presented as: the sum of all PV of TCM_t, should not exceed the sum of all PV of B_t, which is written as follows:

$$\sum_{t=0}^{T} \frac{1}{(1+r)^t} TCM_t \leq \sum_{t=0}^{T} \frac{1}{(1+r)^t} B_t \qquad \text{(Eq.11)}$$

Second, if the government provides B_t for every year during the time horizon, then the constraint is presented as: the TCM_t should not exceed B_t, which is written as follows:

$$TCM_t \leq B_t \qquad \text{(Eq.12)}$$

In this model, we use the second option of budget constraint, because this condition is suitable for the condition in Jakarta, in which the government provides budget for FPM every year.

In detail, each FPM has a different time horizon, *T*, which includes the construction period, T_c and the utilisation period, T_u. For example, one FPM might be constructed for T_c years and might be utilised for T_u years ($T_c < T_u$), while another FPM might be constructed and utilised for a longer or shorter period than in the previous example. This situation occurs in applying combinations of FPM in multiple areas. Then, we should apply the equation (c_2) for every single FPM. The TCM_t is the sum of $C_{i,j,t}$ for all measures and all areas:

$$TCM_t = \sum_{i=1}^{N} \sum_{j=1}^{K} \alpha_{i,j} (M_{i,j,t})^2 \qquad \text{(Eq.13)}$$

Where $\alpha_{i,j}$ is the cost parameter of measure *i* in area *j*.

TCD_t is subtractions of current flood damages in an area *j* without any flood measures, $D0_j$ with the reduction of the flood damage under measure $M_{i,j,t}$ for all areas:

$$TCD_t = \sum_{j=1}^{K}\left(D0_j - \sum_{i=1}^{N}\beta_{i,j} M_{i,j,t}\right) \quad \text{(Eq.14)}$$

Where $\beta_{i,j}$ is parameter of flood damage reduction from a measure *i* in area *j*.

3.6.3 Result: The numerical examples

In order to show how cases one, two, and three could work in practice, we here show results using example dummy numbers and types of FPMs.

Case 1

There is a flooded area with current flood damages of \$600, and the government is planning to implement three FPMs, namely a dike, river normalisation, and a polder. The maximum budget to implement those FPMs is \$1,000. Engineers inform that the coefficients of the cost functions for those FPMs are 0.6, 0.5, and 0.4, respectively, and that the coefficients of flood reduction for each FPM are 5, 3, and 6, respectively. For this case study, we do not consider the time horizon of each FPM.

Applying the optimisation model for case 1 (see Eq.1 to Eq. 4 in Section 3.6.2), one can use the tool to estimate the optimal conditions. For the design level of the dike, the normalisation of the river, and construction of polder areas, the numerical values in the hypothetical example are found to be 4.2, 3.0, and 7.5, respectively. Those levels would require *TC* of about \$562.5. The numerical values could be interpreted in the numerical example respectively as the height of the dike in decimetres, the number of kilometres of river normalisation and the hectares of polder area to be constructed.

Case 2

Here, the example can be advanced to introduce the spatial issue. Let us assume that there are three flooded areas, i.e. upstream, middle stream and downstream. Each area has different initial flood damage as follows: \$100, \$500, and \$1,000, respectively. To reduce those numbers, the central government is planning to implement three FPMs in each area with maximum budget \$5,000. To make it simple, we assumed the types of FPMs in each are similar i.e. dike, normalisation, and polder. Again, we do not consider the time horizon of FPMs. Therefore, there will be nine FPMs in total. Each FPM in each area has a different coefficient cost function and a different coefficient for flood reduction, as indicated in Table 3.2.

Table 3.2: Coefficients of cost functions and flood reduction

FPM	Coefficient for cost function			Coefficient for flood reduction		
	US	MS	DS	US	MS	DS
Dike	2	4	5	5	5	5
Normalisation	8	6	3	2	3	6
Polder	4	6	9	8	6	4

Where: US: Upstream, MS: Middle stream, DS: Downstream

We employed the optimization model for case 2 (see Eq.5 to Eq. 8 in Section 3.6.2). We found that the optimal condition will require TC about USD 1,584 and the optimal level for each FPM is indicated by Table 3.3.

Table 3.3: The optimal level of FPM, TCM and TCD

FPM	Optimal level of FPM			TCM	TCD
	US	MS	DS	(USD)	(USD)
Dike	1.250	0.625	0.500	7.250	85.500
Normalisation	0.125	0.250	1.000	3.437	493.125
Polder	1.000	0.500	0.222	4.694	990.611

Where: US: Upstream, MS: Middle stream, DS: Downstream

Case 3

Here we included spatial and temporal issues of implementing FPMs. There are three flooded areas, i.e. upstream, middle stream and downstream. Each area has different initial flood damage as follows: USD 160, USD 150, and USD 200, respectively. Again, to make it simple, we assumed the types of FPMs in each are similar i.e. dike, normalisation, and polder. The coefficient cost function and coefficient for flood reduction are the same as we gave in Table 3.2. The 9 FPMs have different construction and utilisation periods. Furthermore, the government provides a different budget, in which those budgets decrease over the years with a specific rate. Table 3.4 describes the time horizon of each FPM and its initial budget including its decreasing budget rate. Here, we assumed a specific year when all FPMs in one area will be finished, i.e. 2017 (upstream), 2018 (middle stream), and 2019 (downstream). To calculate the present value, we used a 10% discount rate.

Table 3.4: Time horizon of each FPM and its initial budget including its decreasing budget rate in the numerical example.

	Upstream			**Middle stream**			**Down stream**		
	D	**N**	**P**	**D**	**N**	**P**	**D**	**N**	**P**
Time horizon	2014-2030	2014-2025	2014-2035	2014-2040	2014-2055	2014-2035	2014-2040	2014-2055	2014-2020
Initial budget (USD)	100	200	150	100	200	300	200	100	150
Decreasing rate over years (%)	1	10	15	20	1	5	15	5	10

Where: US: Upstream, MS: Middle stream, DS: Downstream

It is then possible to employ the optimisation model for case 3 (see Eq.9 to Eq. 14 in Section 3.6.2), to estimate the optimal costs. We found that the optimal level path to be that shown in Figure 3.9, which results in a value of NPVTC of about $36,179.

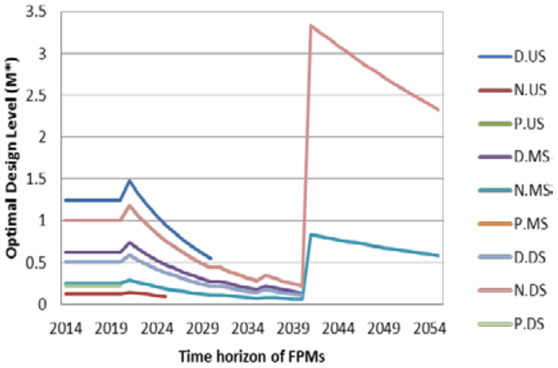


Figure 3.9: The optimal level path of FPMs for hypothetical case 3.

3.7 Method for assessing local actual flood damages for a specific flood event

In Section 3.5, we described the tool that has been developed in JCAT (Damagescanner-Jakarta) to assess current and future changes in direct flood risk at the city scale. However, methods are also required by local decision makers to develop more precise estimates of flood damages for specific flood events at the more local scale, including both direct and indirect damages. Hence, we have also developed a method to assess localised actual flood damages (AFD), which include direct and indirect tangible damages. The direct damage covers building-structure damage and contents damage. The indirect damage in residential sectors includes clean-up costs, loss of income, costs of evacuation, and costs of illness during the flood, while in business sectors it includes the loss of turnover during the flood, which measures the lost productivity cost due to the flood.

The loss of income is calculated by multiplying the number of absent days from work due to flood, with the daily income. The costs of evacuation and temporary accommodation are the sum of the total costs for travel, food, and lodging due to evacuation. Cost of illnesses represent costs for visiting the doctor, staying in the hospital, and buying medicines due to the flood event.

The data used to develop the model were collected following the flood event of January 2013. This flood occurred between 17-19 January 2013 along the Pesanggrahan River area, where 1,706 houses were inundated. In this area, we carried out face to face interviews with flood-affected households and business units: the area in which the surveys were conducted is shown in Figure 3.10.

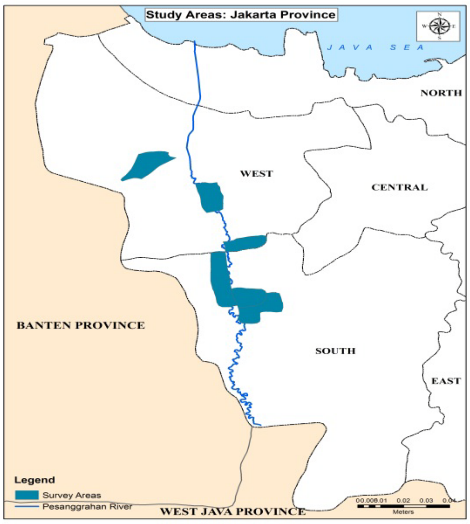


Figure 3.10: Area in which interviews and surveys were conducted.

Samples for the surveys were selected by using a multi-stage sampling method, which included two stages. First, villages along the river were listed and the number of flooded neighbourhoods within each village was identified. Second, the samples of neighbourhoods were selected by purposive sampling, and samples within those neighbourhoods were selected by using simple random sampling. The total number of surveys taken was 300 households and 150 business units.

Based on the results of the surveys, we derived an estimate of the actual flood damages (AFD) in the area, as well as the physical and socioeconomic conditions of the respondents. We then used these data to develop a numerical model to understand the relationship between AFD and its causes, i.e. the physical and socioeconomic factors included in the survey. The physical factors are represented by flood depth and flood duration, while the socioeconomic factors are represented by the location of buildings, distance of buildings from the river, and income. Here, for the residential sector, income is represented by the monthly income of households, while for the business sector it is represented by monthly turnover per business unit.

We estimated the flood damage function by multiple regression analysis, using the ordinary least squares (OLS) method. We regressed the AFD as the dependent variable and the physical and socioeconomic factors as the independent variables. We presented the model as follows.

$$AFD_i = \beta_1 DEP_i + \beta_2 DUR_i + \beta_3 ARE_i + \beta_4 INC_i + \beta_5 DIS_i + \varepsilon_i$$

$$AFD_i = \beta_1 DEP_i + \beta_2 DUR_i + \beta_3 DARE_i + \beta_4 INC_i + \beta_5 DIS_i + \varepsilon_i$$

(Eq.15)
Where:
AFD = actual flood damage (thousand IDR)
DEP = flood depth (cm),
DUR= flood duration (hours),
INC = income (IDR/month),
ARE = building area (m^2),
DIS = distance from house to the river (m),
E = error.

After deriving the coefficients, we subsequently used the numerical model to estimate the AFD of the entire region affected by the 2013 floods (see Section 4.5).

3.8 Cost Benefit Analysis of flood protection measures

In the final phase of JCAT, we will implement a cost-benefit analysis (CBA) to compare the costs and benefits of several planned or implemented FPMs in Jakarta. Hence, here we only describe the framework that will be used, and the envisioned applications.

3.8.1 CBA framework

The CBA will be carried out based on the framework of Mays [2011], which indicates the net benefits of an FPM as the contribution to national economic development. However, we will here refer to the regional net benefits, instead of national net benefit.

The net benefit is calculated as the sum of the location benefit, intensification benefit, and flood-inundation reduction benefit, minus the total costs of implementation (operating, maintenance, repairing, replacing, and rehabilitating) of the FPM. The location benefit is the increased net income of additional floodplain development due to a FPM project. The intensification benefit is the increased net income of existing floodplain activities. The inundation-reduction benefit is the FPM-related reduction in physical economic damage, income loss, and emergency cost.

Therefore, the net benefit of a FPM project can be written as follows:

$$NB = (B_L + B_I + B_{IR}) - C \qquad \text{(Eq.16)}$$

Where:

B_L : location benefit (IDR)
B_I : intensification benefit (IDR)
B_{IR} : flood-inundation reduction benefit (IDR)
C : total costs of implementation (IDR)

Since the B_{IR} is the economic flood damage without implementation of FPM minus economic flood damage if the FPM is implemented, equation (1) can be written as:

$$NB = (B_l + B_I + E[D_{without} - D_{with}]) - C \qquad \text{(Eq.17)}$$

Where: $E[D_{without} - D_{with}]$ is the expected value.

Furthermore, because CBA assesses all costs and benefits for the entire time horizon of the FPMs, the benefits and costs that arise in different years should be aggregated. Therefore, those benefits and costs will be discounted relative to present benefits and costs in order to find their present value [Dixit and Pindyck, 1994]. Therefore, the total net benefit (*TNB*) for the entire time horizon of a FPM is given by:

$$TNB = \sum_{t=0}^{T} \frac{1}{(1+r)^t} NB_t \qquad \text{(Eq.18)}$$

The FPM will be accepted if the net present value (NPV) is positive [Pearce et al., 2006]. The project also will be implemented if the Internal Rate of Return (IRR), the rate at which the total NPV of a whole time project is equal to zero [Perman et al., 2003], is higher than its interest rate.

$$NPV = \sum_{t=0}^{n} \frac{B_t}{(1+i)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+i)^t} \qquad \text{(Eq.19)}$$

3.8.2 Envisaged study in Jakarta

The envisaged implementation of the CBA in Jakarta will employ secondary data related to costs and benefits of the implementation of FPMs available in several agencies in Jakarta. The costs data will be collected from two agencies under the Ministry of Public Works, namely BBWSCC (agency of *Ciliwung* and *Cisadane* Rivers) and Pusair, as well as Jakarta governments. The benefits data will be gathered from several agencies. First, the flood extent and flood characteristics will be produced by the SOBEK model (Deltares et al., 2012; Tollenaar et al., 2013). Second, the hydrology and hydraulic data about flood discharge will be obtained from BBWSCC. Third, the economic value of land and buildings in flooded areas will be gathered from the National Land Authority Office (BPN). Finally, future projections of changes in population and economic growth will be acquired from the Java spatial model.

Based on the CBA analysis, a sensitivity analysis will be conducted by using scenarios of changes in both physical and socioeconomic conditions. The physical factors will be represented by changing rainfall in upstream areas and changes in river discharge. Socioeconomic factors will be represented by changes in economic growth and population. These scenarios will be employed to investigate their impacts on the net benefit of the various FPMs.

At present, the following potential FPMs are envisaged for the investigation, although this will be decided in collaboration with the stakeholders named above:

1. Two new dams in upstream Jakarta. These would serve as flood control reservoirs and reduce the magnitude of peak discharge.
2. River diversion in the Ciliwung River, in the middle stream area of Jakarta. This would reroute or bypass flood flows from South Jakarta to the Eastern Flood Canal, in order to reduce the peak flow at the damage centres.
3. River normalisation of the Pesanggrahan River in the downstream area of Jakarta. River normalisation, also referred to as channel modification, could improve the conveyance characteristics and carrying capacity of the natural stream system. This could increase flow velocities, aimed at reducing flood stages or water surface elevations for a given storm event at a given location.

3.9 National scale probabilistic flood risk assessment tool for Indonesia

To rapidly assess the risk of urban areas to coastal and river flooding on a national scale, we combine a global inundation model and global land use model with local data on economic values and vulnerability. Despite its importance for policy-makers in Indonesia, a comprehensive quantitative flood risk assessment on the national scale is lacking. A national scale assessment can identify the most vulnerable regions, which can be very useful for policy-makers to effectively allocate their resources for risk reduction. Moreover, such an assessment provides a benchmark against which possible future changes can be assessed. One major benefit of the use of relatively simple global models is the possibility to calculate flood risk under a wide range of climate change and socio-economic scenarios in a relatively short time. The scenarios used are discussed in Section 4.6.1. Another advantage is that most input data are available on a global scale. Hence, the model is not dependent on the availability of local data, which is often scarce in developing countries.

3.9.1 Modelling approach

The overall approach is similar to the global approach of Ward et al. [2013a], but using more local datasets for exposure and vulnerability. Basically, the three flood risk components (i.e. hazard, exposure and vulnerability) are combined to calculate risk, which is expressed as the Expected Annual Damages (EAD). As is the case for Damagescanner-Jakarta, EAD is calculated in two steps: (1) the economic damage is estimated for floods with different return periods to establish an exceedance probability-damage curve (risk curve); (2) the EAD is then calculated by estimating the area (i.e., the integral) under the risk curve [Figure 3.6].

3.9.2 Input data

To calculate potential urban flood damages, we set up an impact model, which requires three datasets: (1) hazard: inundation maps showing the extent and depth of flooding; (2) exposure: urban extent and the corresponding maximum economic damages for each urban grid-cell; and (3) depth-damage curves representing vulnerability to flooding.

Hazard

In this assessment, both river flooding and coastal flooding are analysed. For each flood type, different inundation models are applied to produce maps showing the extent and depth of certain flood events at a spatial resolution of 30” x 30” (ca. 1km x 1km at the equator). For both inundation models, a Digital Elevation (DEM) is one of the main inputs. The DEM used in this assessment is the so-called SRTM dataset [Lehner et al. 2008]. The resolution of the DEM is

30” x 30”. Inundation maps for river flooding are produced using flood volumes derived from PCR-GLOBWB, which is a global distributed hydrological model with a resolution of 0.5^o x 0.5^o (approximately 50km x 50 km at the equator) [Bierkens and van Beek, 2009; van Beek en Bierkens, 2011]. The coarse resolution flood volumes are converted into high resolution inundation depth maps using an adapted version of the GLOFRIS downscaling model [Ward et al., 2013a; Winsemius et al., 2013]. Coastal inundation is calculated using a GIS-based planar approach similar to that described in 3.4, which uses the tidal water level and a DEM as input. Inundated areas are defined as areas that have an elevation lower than the water level, and have a direct connection to the sea. Extreme water levels are derived from the database of the DIVA (Dynamic Interactive Vulnerability Assessment) tool [Dinas-Coast Consortium, 2006] (see Section 3.4).

Exposure

Flood exposure is represented by the maximum economic damage for each urban grid-cell. Thus, one of the main inputs is a land use map indicating urban areas. We used the MODIS land cover map [Friedl et al., 2010]. To represent the maximum damages for one uniform urban land use class, we used the (spatially) weighted average of the maximum damages for 12 different urban land use classes in Jakarta as reported by Budiyono et al. [2014a] and Section 4.4, which equals 6.7 million 2000USD/km^2. For the other Indonesian provinces, we assume that the regional differences in maximum damages are proportional to differences in GDP per capita in 2010 [BPS, 2013]. The GDP per capita in Jakarta is the highest of the country and 4.4 times higher than the national average. Consequently, estimates of maximum damages in the other provinces are much lower. This methodology does not fully capture the regional differences in maximum damages, however it does account for the fact that higher values of maximum economic damages are more likely to be encountered in areas with a higher GDP per capita.

Vulnerability

Vulnerability is represented by a depth-damage function, or vulnerability curve (see also Section 4.4). The function used in this study is based on the work in Jakarta of Budiyono et al. [2014a] (see Section 3.5) that established vulnerability curves for 12 different urban land use classes. To come up with one curve for one uniform urban land class, we took the weighted average of the curves for the different classes. The weight is based on the spatial distribution of each land use class. By using this curve for the national assessment, we assume that the land use distribution in Jakarta is representative for the distribution in other urban areas in Indonesia, and that these urban areas have an equal vulnerability to floods.

4 Past, present and future assessments

We used the methods and tools developed in JCAT, and described in Section 3, to assess the current status of variables related to flood risk, as well as how some of these have changed in the past, or may change in the future. Since no officially mandated scenarios of climate and environmental change are available, scenarios were used on an *ad hoc* basis. The idea of JCAT is to develop the methods that can be used for such assessments, once such scenarios are developed in ongoing and/or future efforts. As official scenarios of climate change (e.g. nationally mandated climate change projections, land subsidence projections, etc.) become available, the end-users in Jakarta will be able to use the JCAT-models to assess the impacts of these scenarios on the water balance, erosion and sediment delivery, coastal flood exposure, and flood risk.

In this section, we provide an overview of the main findings of JCAT on current, past, and future variables related to flood risk. More details can be found in the accompanying and upcoming JCAT papers, which are cited in the text.

4.1 River discharge

We used STREAM-Jakarta to simulate the discharge of four rivers draining into the Bay of Jakarta, namely the Ciujung, Cisadane, Ciliwung, and Citarum. Using the model, we simulated a time-series of monthly discharge over the period 1901-2005. We used this to assess the following research questions:

- What are the historical trends in river discharge over the 20th century?
- What are the relative influences of climate and land use change on changes in river discharge during the 20th century?
- What is the projected impact of climate change on future discharge?

The results in this section are based on Poerbandono et al. [2014a], in which they are described and discussed in more detail.

4.1.1 Scenarios

Climate data

The baseline climate data used was a time-series of monthly precipitation and temperature, at a horizontal resolution of 10’ x 10’. First, we retrieved the time-series at 30’ × 30’ from the CRU TS 3.0 dataset of the Climate Research Unit (CRU) [New et al., 2002]. We downscaled this to a horizontal resolution of 10’ × 10’, using the method described in Bouwer et al. [2004]. The first step is to resample the low resolution (30’ × 30’) time-series onto higher resolution grids, namely 10’ × 10’. The second step is to statistically downscale these using change factors (for precipitation multiplicative, for temperature additive) of the difference in mean monthly precipitation and temperature between the CRU TS 3.0 dataset, and a higher resolution monthly climatological dataset, namely CRU TS 2.0 [Mitchell et al., 2004]. The verification of the climate data with observations has been previously described in Poerbandono et al. [2009].

To project the influence of future climate change on discharge, we applied a so-called delta change method [e.g. Prudhomme et al., 2002; Lenderink et al., 2007]. In essence, this method involves deriving “change factors” that show the change in statistical properties of climate model variables between simulations for present and future, and then applying these change factors to the baseline climate dataset.

For this study, the baseline climate dataset was that described above, using the period January 1960-December 1999. The change factors were then derived from General Circulation Model (GCM) simulations, bias-corrected as part of the ISI-MIP project (Inter-Sectoral Impact Model Intercomparison Project [Hempel et al., 2013]. We used the bias-corrected daily data on temperature and precipitation for 5 GCMs, namely: GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-

LR, MIROC-ESM-CHEM, and NorESM1-M, and for the following Representative Concentration Pathway (RCP) scenarios: RCP2.6, RCP4.5, RCP6.0, and RCP8.5. These data have been bias-corrected [Hempel et al., 2013] based on the baseline reanalysis datasets developed by EU-WATCH for the period 1960-1999 [Weedon et al., 2011]. Both the ISI-MIP GCM data and the EU-WATCH data have a spatial resolution of 0.5°x0.5°. We developed the "change factors" as the difference in monthly mean precipitation and temperature between the EU-WATCH data (monthly means over the period 1960-1999) and the future scenarios for the year 2030 (represented by monthly means over the period 2010-2049 from the future bias-corrected GCM simulations from ISI-MIP). For precipitation the change factors are multiplicative, and for temperature the change factors are additive. Finally, these "change factors" were applied to the baseline dataset described above and in Poerbandono et al. [2014a].

Land use data

Land use maps were derived from various sources for 1891, 1950, 1963, 1980, 1987, and each year from 2001 to 2005. The source of each land use map can be found in Table 4.1. The land use data were reclassed to the following land use classes: forest, agricultural, and built-up area. These maps were then used to simulate the influence of land use change on discharge.

Table 4.1: Sources of land use data used in STREAM-Jakarta and SDAS-Jakarta for different time periods

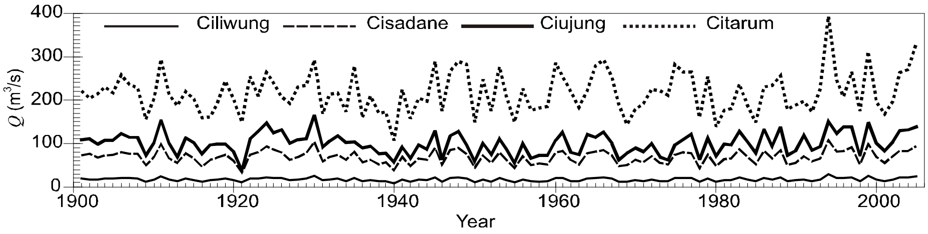
Year	Title of map	Source
1891	Natural forest cover of Java	Whitten et al. [1996]
1950	Vegetation of Indonesia	US Department of Forest Service
1963	Land cover map of Java and Madura	Food and Agriculture Organization
1980	Land cover map	Ministry of Interior Indonesia
1987	Natural forest cover of Java	Whitten et al. [1996]
2001-2005	MODIS land cover type product	Wei et al. [2009]

4.1.2 Key results

Changes in river discharge over the course of the 20th century

Firstly, we assessed how discharge has changed over the course of the 21st century. The annual time-series per basin can be seen in Figure 4.1.

Figure 4.1: Simulated annual discharge over the period 1901-2005. Source: Poerbandono et al. [2014a].



We also assessed whether (significant) linear trends in discharge could be found in different time-periods in the basins studied. Statistical significance was assessed using the Mann-Kendall test. The linear trends are shown in Table 4.2, as well as the results of the significance test. Here, the trends are shown for the last 105-, 55-, 30-, and 15-year periods. The results show positive trends in discharge over all time-periods studied. However, the trends only show strong statistical significance ($p < 0.05$) over the period 1950-2005 in three basins (Ciujung, Cisadane, Ciliwung). In the most recent period, the trends show moderate statistical significance ($p < 0.10$) for the Cisadane and Ciliwung rivers.

Table 4.2: Linear trends in simulated sediment yield (in m^3s^{-1}/year) over the time-periods shown. Source: Poerbandono et al. [2014a].

	Trend			
	1901-2005	1950-2005	1975-2005	1990-2005
Ciujung	0.04	0.70**	0.92*	1.38
Cisadane	0.02	0.33**	0.50	0.94*
Ciliwung	0.01	0.10**	0.13*	0.25*
Citarum	0.19	0.60	1.33	3.18

** Significance level, α<0.10; ** Significant trend, α<0.10*

The relative influence of climate and land use change on changes in river discharge over the course of the 20th century

Next, we assessed the relative influence of changes in climate and land use on these overall changes in discharge. The results are shown for the Ciliwung and Cisadane in Table 4.3, whereby changes in annual discharge (%) are shown for different time-periods compared to 1901-1920. The results show the individual impacts of changes in land use and climate. The influence of changes in climate are further split into the relative influences of changes in precipitation and temperature.

Table 4.3: Change (%) in simulated discharge per time-period, compared to 1901-1920. Adapted from Poerbandono et al. [2014a].

	Ciliwung				Cisadane			
Time-period	Land use	Climate	Temp.	Precip.	Land use	Climate	Temp.	Precip.
1921-1940	0	-2	-2	0	0	1	-1	+2
1941-1960	-1	-2	-3	+1	+2	-4	-3	-1
1961-1980	+3	-5	-3	-2	+4	-4	-2	-2
1981-2006	+12	-1	-6	+5	+10	+2	-4	+6

In the most recent period (1981-2006), the simulated discharge of the two watersheds is greater than in 1901-1920, by +11% and +12% for the Ciliwung and Cisadane respectively. Almost all of this change can be accounted for by the changes in land use used to force the models. The influence of climate change on discharge over this period appears to have been small, leading to a -1% reduction in the Ciliwung and a +2% increase in the Cisadane. The results also show that changes in precipitation in the watersheds alone, would have led to increases in discharge of +5% and +6% respectively. However, this simulated increase in discharge is compensated by reductions due to increased temperature, which leads to increased evapotranspiration in the model.

The projected influence of climate change on discharge
Next, we assessed the influence of the projected climate change scenarios on the monthly discharge of the Ciliwung river. Here, we first show the change in temperature and precipitation in the middle section of the basin, compared to the baseline, for the different climate projections for 2030.

All scenarios project an increase in mean annual temperature, ranging from 0.9°C to 1.5°C. In Figure 4.2 we show the monthly temperature in the baseline, and under each GCM-RCP scenario combination. The temperature increase is fairly constant over the months of the year. As may be expected, the largest increases are in the RCP8.5 scenario (which represents the highest degree of warming at a global scale), and the smallest increases are in the RCP2.6 scenario (which represents the lowest degree of warming at a global scale). Generally, the differences in projected temperature increase are greater between the different GCMs than between the different RCP scenarios. The difference between the different GCMs can be seen more clearly in Figure 4.3, which shows the average per GCM across the four different RCP scenarios.

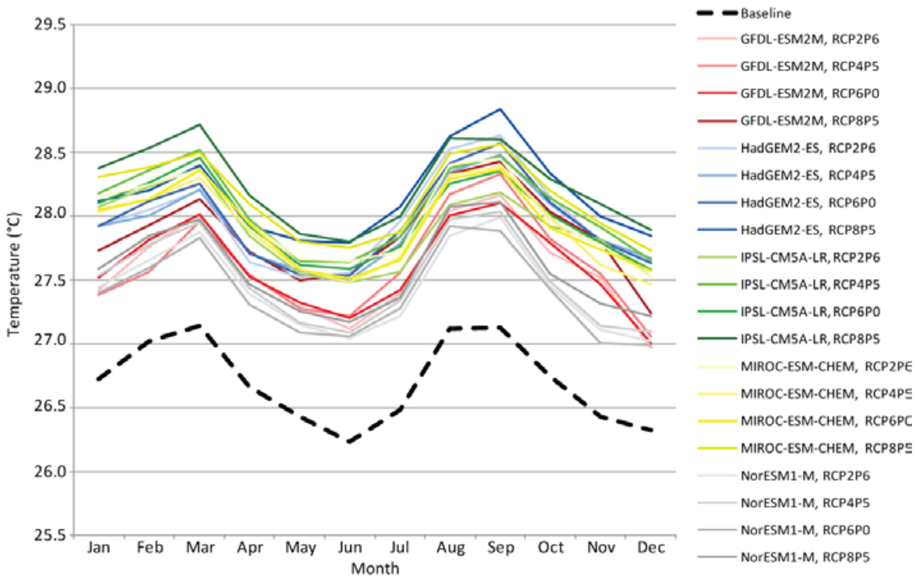


Figure 4.2: Simulated mean monthly temperature (baseline and projections for 2030) for all GCM and RCP scenario combinations.

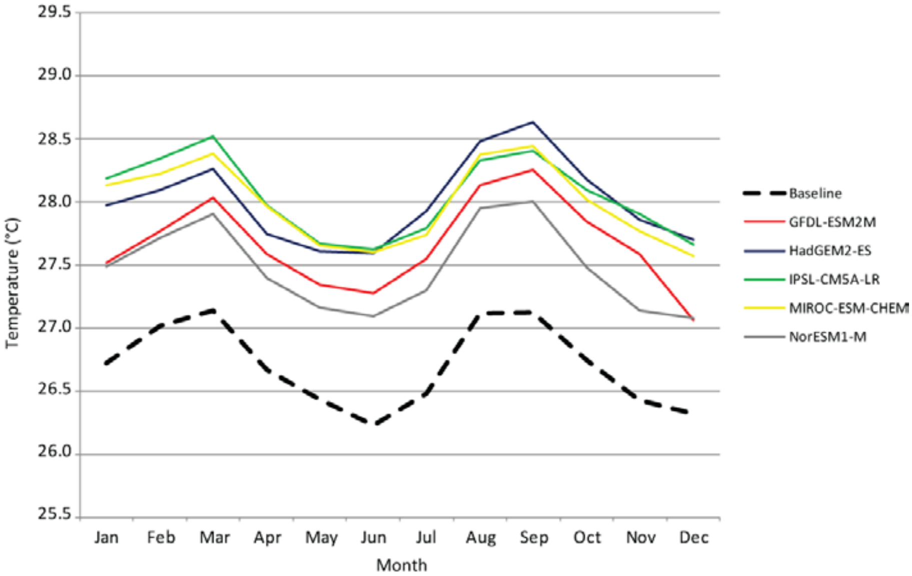


Figure 4.3: Simulated mean monthly temperature (baseline and projections for 2030) per GCM (average values across RCP scenarios).

Next, we calculated the change in precipitation between baseline and 2030 under the different GCM-RCP combinations. The changes in annual precipitation range from -21% to +12%, with increases in 10 GCM-RCP combinations and decreases in the other 10 GCM-RCP combinations. In Figure 4.4 we show the monthly precipitation for the baseline and all future scenarios. This figure also shows large discrepancies in the direction and magnitude of change in precipitation between the different models and between the different RCP scenarios. The differences in projected precipitation tend to be the greatest in the second half of the year.

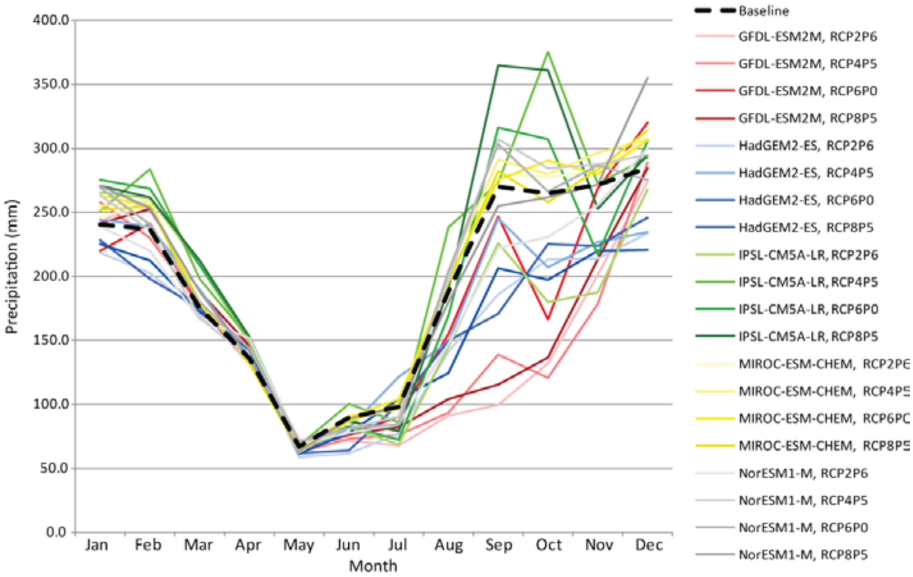


Figure 4.4: Simulated mean monthly precipitation (baseline and projections for 2030) for all GCM and RCP scenario combinations.

Finally, we examined the influence of these changes in climate on the discharge of the lower Ciliwung river. Compared to the baseline, projected mean annual discharge changes by between -52% and +9%. The mean annual discharge decrease under 13 GCM-RCP combinations, increases under 6 combinations, and shows no change under 1 combination. As shown in Figure 4.5, the changes in discharge are spread throughout the year. There is no particular signal between the different RCP scenarios, i.e. by 2030 we do not see a more clear change in discharge under the stronger RCP8.5 compared to the RCP2.6 scenario.

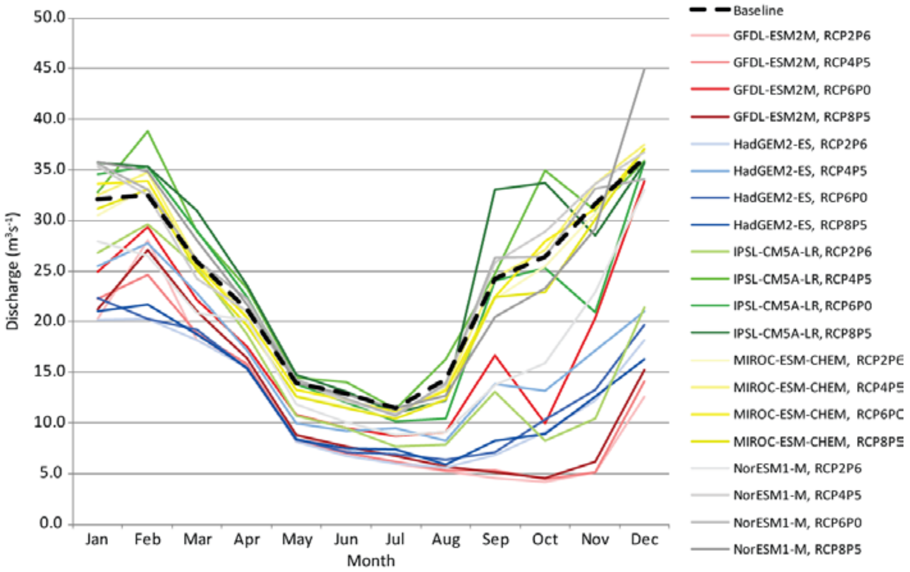


Figure 4.5: Simulated mean monthly discharge for the Ciliwung (baseline and projections for 2030) for all GCM and RCP scenario combinations.

In Figure 4.6, we show the mean monthly discharge for the baseline scenario, and for the future projections according to each GCM. Here, the mean values are shown for each GCM for the different RCP scenarios. The figure shows little change in discharge for the IPSL-CM5A-LR, MIROC-ESM-CHEM, and NorESM1-M climate models, but large decreases in discharge in all months for the GDFL-ESM2M and HadGEM2-ES climate models.

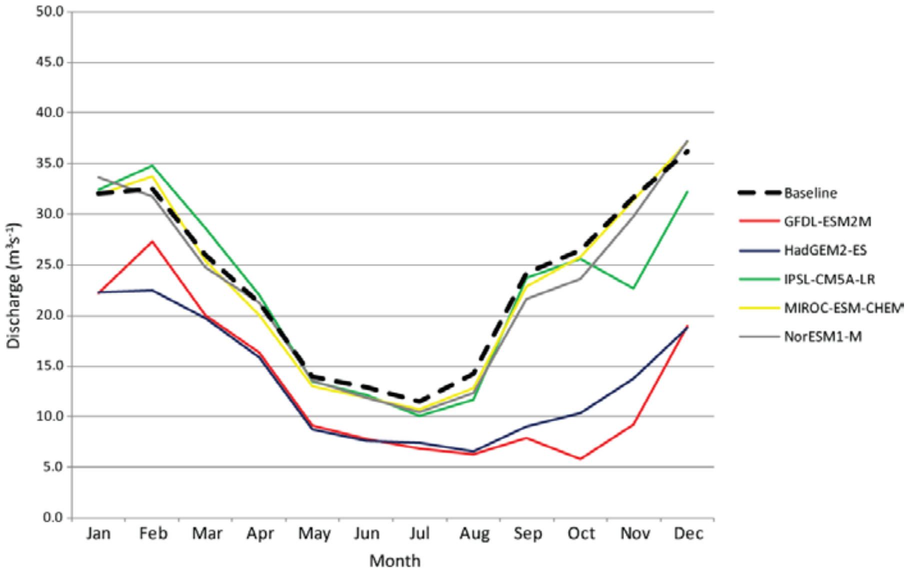


Figure 4.6: Simulated mean monthly temperature (baseline and projections for 2030) per GCM (average values across RCP scenarios).

4.1.3 Key findings of relevance to flood risk assessment

- We investigated trends and changes in river discharge over the period 1901-2005 using the STREAM-Jakarta model.
- The results suggest that over the entire time-period, there has been no significant trend in discharge in any of the basins. However, in the basins draining through the city of Jakarta, i.e. the Ciliwung and Cisadane, significant trends are simulated over the last half century.
- We also investigated the individual effects of changes in climate and land use on river discharge. Overall, we found that changes in land use had the strongest affect on discharge over the period 1901-2006, leading to increased discharge. The influence of climate change over this time scale was small.
- The influence of projected future climate change on precipitation and discharge is still highly uncertain. Two of the GCMs project a large decrease in discharge throughout the year. If this were to occur, this would have a large influence on water resource management of the basin. Only a few GCM-RCP combinations project an increase in discharge, and the projected increases are relatively small (compared to the simulated decreases in other GCM-RCP combinations). However, for flood risk management it would be necessary to assess the influence of climate change on daily discharges, based on daily precipitation data. The STREAM-Jakarta model can facilitate this.

4.2 Erosion and sediment delivery

Using a similar approach to that described in Section 4.1, we used SDAS-Jakarta to simulate erosion and sediment delivery in the Ciliwung and Cisadane watersheds. The model was used to simulate a time-series of annual erosion and sediment yield over the period 1901-2005. We used this to assess the following research questions:

- What are the historical trends in erosion and sediment over the 20th century?
- What are the relative influences of climate and land use change on changes in erosion and sediment yield during the 20th century?

The results in this section are based on Poerbandono et al. [2014a], in which they are described and discussed in more detail.

4.2.1 Scenarios

In order to simulate the time-series of erosion and sediment yield, we used the same data on past climate and land use change as described in Section 4.1.1.

4.2.2 Key results

Changes in erosion and sediment yield over the course of the 20th century

In Table 4.4, we show the trends in simulated sediment yield over different time-periods, as well as their statistical significance according to the Mann-Kendall test. Over the entire time-period, 1901-2005, we see a significant increasing trend for both basins, although for the Ciliwung the magnitude of the increase is small. Due to decreases in sediment yield in the mid 20th century, no significant trends are simulated over the periods 1950-2005 or 1975-2005. The strongest trends are simulated over the most recent period, 1990-2005, showing that the rate of erosion and sediment yield appears to have increased by a large amount in recent decades. This is corroborated by examining the overall change in sediment yield between the beginning of the 20th century (1901-1920) and the period 1981-2005. Over this period, the sediment yield increased by 61% in the Ciliwung basin, and 64% in the Cisadane.

Table 4.4: Linear trends in simulated annual sediment yield (in 10^3/year) over the time-periods shown. Source: Poerbandono et al. [2014a].

	Trend			
	1901-2005	**1950-2005**	**1975-2005**	**1990-2005**
Ciliwung	1**	0	0	6**
Cisadane	6**	-3	-4	23*

** Significance level, α<0.10; ** Significant trend, α<0.10*

As well as assessing changes in erosion at the aggregated basin scale, we also produced maps showing the geographical distribution of erosion per grid-cell. These maps can be found in Poerbandono et al. [2014a], and are very useful for identifying “erosion hotspots”. In Table 4.5, we show the aggregated statistics of these maps, whereby we show the percentage of each basin affected by low to medium erosion (i.e. annual erosion ≤ 3000 tons) and medium to high erosion (i.e. annual erosion > 3000 tons). The area affected by medium to high erosion has increased by more than a factor of 3 in the Ciliwung, and a factor of ca. 2.5 in the Cisadane.

Table 4.5: Percentage of area per watershed for which the erosion is low to medium or medium to high in 1901 and 2005 [Poerbandono et al., 2014a].

	Ciliwung		**Cisadane**	
Erosion rate	**1901**	**2005**	**1901**	**2005**
Low to medium (≤3000 tons/year)	98.8	96.2	98.4	95.9
Medium to high erosion (>3000 tons/year)	1.2	3.8	1.6	4.1

The relative influence of climate and land use change on changes in sediment yield over the course of the 20th century

Finally, we examined the relative influence of changes in land use and climate (precipitation) on the sediment yield of the Ciliwung and Cisadane basins. As stated above, the increase in sediment yield for the Ciliwung between 1901-1920 and 1980-2005 was 61%. The individual contribution of land use change was an increase of 55%, whilst that of climate change was an increase of 6%. For the Cisadane basin, the increase between 1901-1920 and 1980-2005 was 64%. The individual contribution of land use change was an increase of 35%, whilst that of climate change was an increase of 8%. Hence, over this timescale, the influence of land use change on sediment yield has been much stronger than the influence of climate change, although both factors have contributed significantly to the upward trend.

4.2.3 Key findings of relevance to flood risk assessment

- We investigated trends and changes in erosion and sediment yield over the period 1901-2005 using the SDAS-Jakarta model.
- The results suggest that over the entire time-period 1901-2005, there has been an upward trend in sediment yield in the Ciliwung and Cisadane basins, with particularly strong trends in the last 25 years. Mean annual sediment yield has increased by 61% and 64% in the Ciliwung and Cisadane basins respectively, between the periods 1901-1920 and 1981-2005.
- Both land use change and climate change have contributed to the increase in sediment yield. Between the periods 1901-1920 and 1981-2005, the relative influence of land use change was approximately fac-

tor 9 larger than the influence of climate change in the Ciliwung. In the Cisadane, the factor difference was ca. 4.

- Increasing erosion and sediment yield can contribute to increasing loads of sediment in Jakarta’s waterways, and hence reduced drainage capacity. This has been identified as one of the key drivers of flood risk in Jakarta. Hence, actions are required to limit erosion and sediment yield in the watersheds upstream of Jakarta. The results show that land use planning may be able to contribute to a reduction in erosion.
- Maps of “erosion hotspots” have been developed, which could be used to target adaptation strategies in terms of erosion reducing measures in those areas.
- Future research should assess the influence on projected future changes in climate and land use on the erosion and sediment yield of rivers flowing through Jakarta. The SDAS-Jakarta model can facilitate this.

4.3 Coastal flood economic exposure

We used the rapid coastal economic exposure assessment tool described in Section 3.4 to address the following research questions:

- What is the current level of economic exposure to extreme coastal flood events in Jakarta?
- How may this economic exposure change in the future under scenarios of sea level rise and land subsidence?

The results in this section are based on Ward et al. [2011b], in which they are described and discussed in more detail.

4.3.1 Scenarios

Our approach requires a flood water level in metres above mean sea level (m.a.s.l), which is used as input to assess which land cells would be inundated if such a flood event occurs. For this study, we used estimates of flood water level associated with return periods of 100 years (1:100) and 1,000 years (1:1,000). For the current conditions, we derived these water levels from the database of the DIVA (Dynamic Interactive Vulnerability Assessment) model [Dinas-Coast Consortium, 2006]. This database provided water levels of 1.596 masl and 1.880 masl for the current 1:100 and 1:1000 events respectively.

To assess the impacts of future sea level rise on the flood levels we followed the method of Nicholls et al. [2008]. As such, we assumed that future sea-level rise can be added to these flood water levels. For example, a rise in mean sea level of 0.5 m would lead to an increase in the 1:100 flood water level to 2.096 masl. Since detailed projections of sea-level rise in the Jakarta Bay are not yet available, we used two scenarios to give a range of possible sea level rise by 2100, namely the minimum and maximum *likely* global mean sea-level rise estimates of IPCC [2007] (18 and 59 cm respectively).

We also developed one scenario of future land subsidence. To do this, we used the subsidence rates described in Abidin et al. [2011] (i.e. 4 cm/yr on average, with spatial distribution). These were then used to adjust the elevations shown in the DEM.

An overview of the scenarios use can be found in Table 4.6.

Table 4.6: Description of the scenarios used to run the model. Source: Ward et al. [2011].

Scenario name	Return period (years)	Sea-level	Storm enhancement factor	DEM
SL2009: 1:100	100	Current	1	Current
SL2009: 1:1000	1000	Current	1	Current
SL2100low: 1:100	100	+18cm (IPCC low)	1.1	Land subsidence
SL2100low: 1:1,000	1000	+18cm (IPCC low)	1.1	Land subsidence
SL2100high: 1:100	100	+59cm (IPCC high)	1.1	Land subsidence
SL2100high: 1:1,000	1000	+59cm (IPCC high)	1.1	Land subsidence

4.3.2 Key results and discussion

Current conditions

Under current conditions, we simulated that an area of ca. 3400 ha would be inundated by a flood with a return period of 100 years. The corresponding economic exposure is ca. €4.0 billion. These values are shown in Figures 4.7 a and b respectively. In comparison, for a coastal flood with return period of 1000 years, the inundated area and economic exposure are approximately 1.3 times higher. In both cases, inundated area is made up of about one-third business area and one-third residential (Figure 4.7c). However, the highest economic exposure is associated with business areas (72%), due to the higher market value of this land use class.

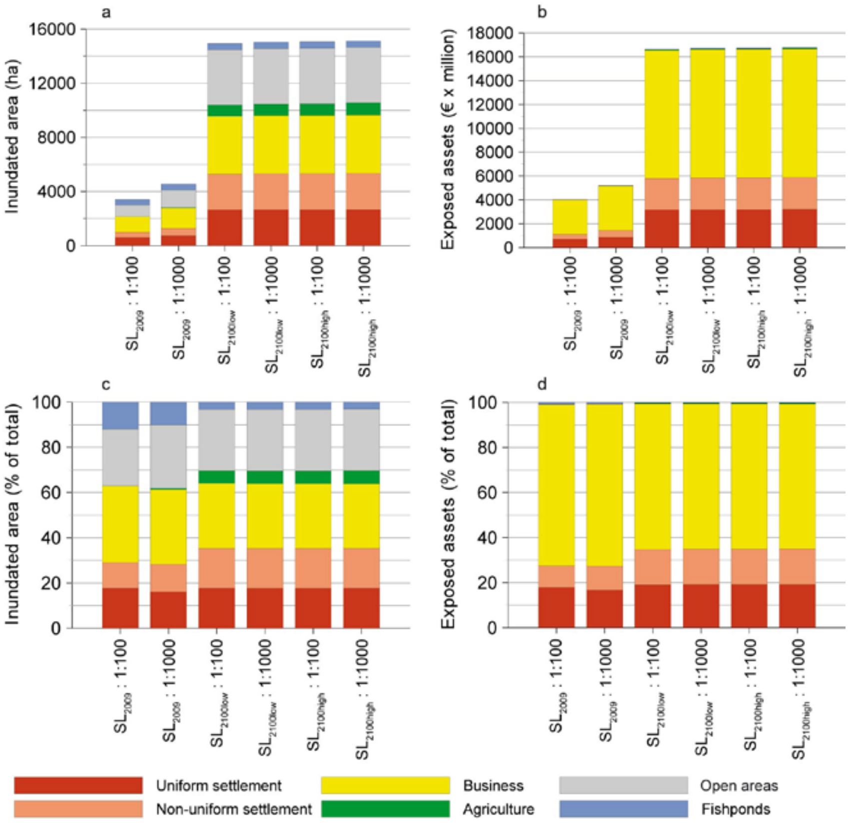


Figure 4.7: Simulation results for the six inundation scenarios: (a) inundated area (ha); (b) exposed assets (million Euros); (c) inundated area as a percentage of total inundated area; and (d) exposed assets as a percentage of total exposed assets. Source: Ward et al. [2011].

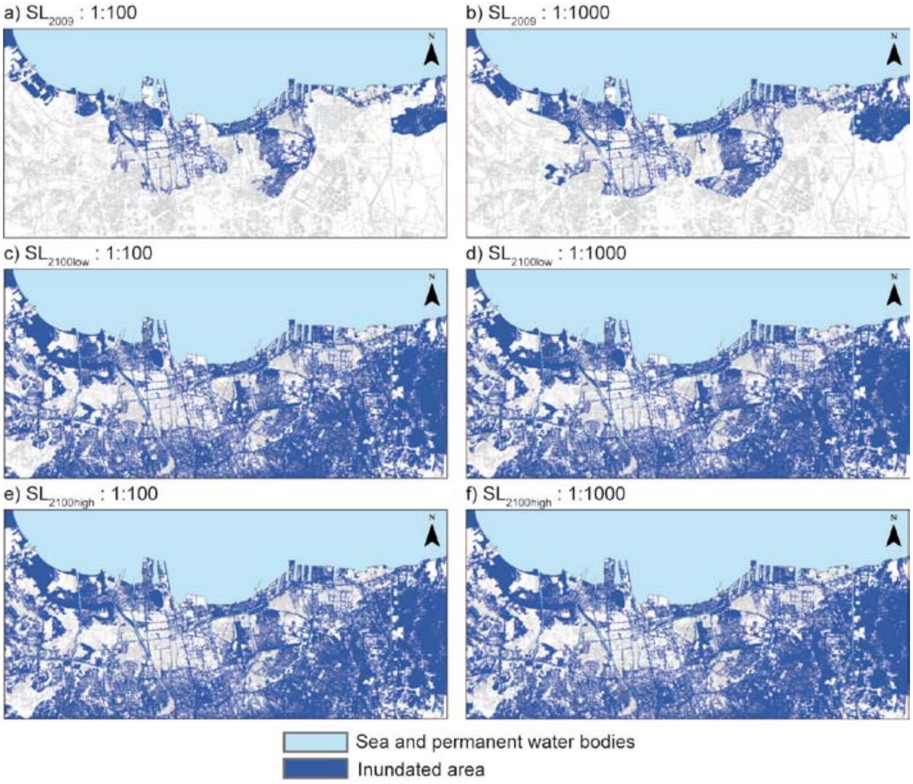


Figure 4.8: Simulated inundation extents for the six inundation scenarios. Source: Ward et al. [2011].

Future scenarios

By 2100, the simulated maps of inundation extent (Figure 4.8) show a very large increase in inundated area, both under the low and high flood water level scenarios, and for flood events with return periods of 100 and 1000 years. In contrast, between the different future scenarios, the maps show minimal differences. The total inundated area in the future scenarios ranges between 14,900 and 15,100 ha., which is more than a four-fold increase compared to current conditions. Similarly, the corresponding economic exposure increases by a factor exceeding four.

The share of inundated residential area relative to total inundated area increases between current and future conditions, from ca. 28% to ca. 36%. There is a disproportionate increase in inundation extent in non-uniform settlement areas when compared to uniform settlement areas.

Implications of scenario results

Even under current conditions, the value of assets exposed to extreme coastal floods is high. The estimated maximum value of exposed assets in northern Jakarta to 1:100 year and 1:1000 year floods represent ca. 1.2% and 1.5% respectively of the country's national GDP. Hence, the results show that even without environmental and/or socioeconomic changes, the need for improved coastal protection measures is critical.

The future scenarios described here are intended to provide a first order assessment of the relative influences of long-term changes in sea level and subsidence on economic exposure in Jakarta. In all of the future scenarios, we see very large increases in both inundation area and economic exposure, with little difference between the scenarios. This shows that under the assumed scenario of an unbridled continuation in land subsidence, the impacts of that land subsidence greatly dominate the increase in potential impacts, with climate change induced sea-level rise playing only a minor role in relative terms. However, this may not be true for lower levels of subsidence.

Detemporalised scenario
A problem with the scenario approach used here is that it does not give information to decision makers that is of use within the decision making timeframe. Many (infrastructural) adaptation measures use much shorter timeframes (e.g. 20-40 years, World Bank [2010]). Moreover, the projections used are subject to very large uncertainties, particularly in terms of timing. For example, even if we assume that sea level will eventually rise by 59 cm, it is uncertain at what point in time this will be reached. Since the same is true for land subsidence, it is impossible to 'predict' dates at which critical flood water levels will be reached. Hence, we also provide simple scenarios of inundation extent and economic exposure based on a detemporalised future trajectory.

To do this, we ran further simulations with flood water level scenarios from 0.0 to 6.0 masl, at intervals of 0.5 m. These refer to theoretical flood water levels (relative to mean current sea level) as a combination of all driving factors. As a result, we are able to show potential economic exposure values based on different extreme flood levels (Figure 4.9).

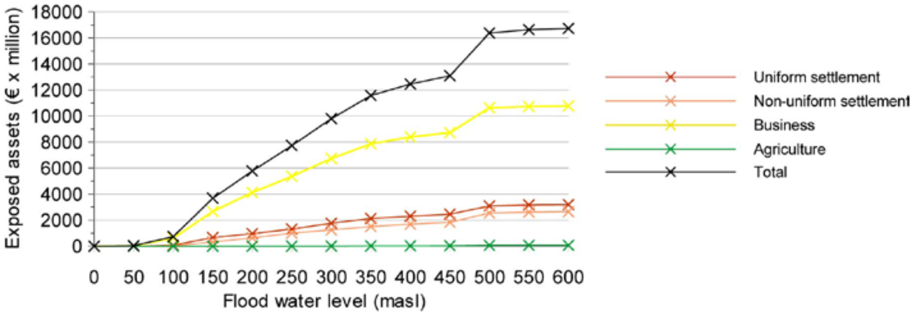


Figure 4.9: Exposed assets for flood water levels between 0.0 and 6.0 masl. Source: Ward et al. [2011].

4.3.3 Summary of key findings

- We have developed a GIS-based tool for rapid inundation mapping and economic exposure estimation for extreme coastal flood events in Jakarta.

- We show the potential increases in flood extent and economic exposure to extreme coastal flood events between current conditions and future scenarios of sea level rise and land subsidence in 2010. Under current conditions, the economic exposure estimates to extreme flood events is high: ca. €4.0 billion for 1:100 year events and €5.2 billion for 1:1000 year events. Under the scenarios for 2100, the economic exposure estimate increases to ca. €17 billion.
- Land subsidence is the dominant driver of increasing economic exposure. However, there is great uncertainty in the land subsidence scenario. Indeed, the scenario used is a very pessimistic one. As a result, the possible impacts of sea level rise are masked.
- Nevertheless, the findings highlight the need for urgent attention to the land subsidence problem. A continuation of the current rate into the future would result in catastrophic increases in economic exposure. On the other hand, the research shows that measures to reduce land subsidence could have a great effect on reducing the value of assets and people exposed to floods.
- We developed a method for the rapid assessment of economic exposure under these uncertainties, by detemporalising the future scenarios. In terms of coastal flood adaptation, such a rapid assessment technique is useful since it could allow planners to assess the effectiveness of measures against concrete estimates of the impacts of inundation.
- It should be stressed that this study only assessed the impacts of land subsidence and sea level rise on future economic exposure, and socio-economic developments were not included. Future research should also assess the influence on projected changes in socioeconomic conditions (e.g. population growth, growth in wealth) on economic exposure and risk. The tool presented here can facilitate this.

4.4 River flood risk at the city-scale

We used Damagescanner-Jakarta (Section 3.5), to assess current and future flood risk in Jakarta. The following research questions are explored:

- What is the current level of flood risk in Jakarta?
- How may flood risk change in the future due to climate change, land subsidence, land use change, and economic growth?
- How sensitive are flood risk estimates to the choice of vulnerability curves?

In this section we summarise key findings. The detailed results for current conditions can be found in Budiyono et al. [2014a], and those for the future scenarios in Budiyono et al. [2014b].

4.4.1 Scenarios

To simulate future flood risk, we use scenarios of changes in climate, land subsidence, land use, and economic growth; the data used for these scenarios are described below.

Climate data

In this assessment, climate change is represented by changes in: (a) precipitation intensity for the different return periods used in the risk model; and (b) sea-level rise.

For precipitation, we used the same future climate dataset as described in Section 4.1.1, namely bias-corrected gridded data from the ISI-MIP project for 5 GCMs and 4 RCPs. For this assessment, we developed flood inundation maps for different return periods (1, 2, 5, 10, 25, 50, and 100 years), in the period 2030 for each GCM and RCP combination. In SOBEK, precipitation for each of these return periods is prescribed for 29 gauging stations, based on extrapolation of daily gauged precipitation data. The extrapolation is carried out by fitting the Gumbel distribution to time-series of annual maximum precipitation at each gauging station, whereby the Langbein correction [Langbein, 1949] is applied for return periods lower than 10 years. We carried out this statistical process for each of the GCM and RCP combinations for the period 2010-2049, which we use to represent average conditions in 2030. We then carried out the same procedure for baseline climate (1960-2000). This allowed us to calculate a change factor between baseline and future climate for each GCM-RCM combination, and for each return period. These change factors were then applied to the standard input of the SOBEK model.

In SOBEK, sea-level is used as a boundary condition for discharge to be able to reach the sea. On top of the current baseline sea-level in the original SOBEK setup, we developed two simple scenarios of sea-level rise by 2030. These scenarios are low and high, which refer to increases in sea-level between 2010 and 2030 of 3 cm and 11 cm respectively. These low and high scenarios represent the 5th and 95th percentiles of the global sea level rise projections of the IPCCs Fourth Assessment Report (AR4) [IPCC, 2007], using the method of Meehl et al. [2007].

Land subsidence

A simple scenario of land subsidence was developed by Deltares [Tollenaar et al., 2013]. This scenario assumes that current land subsidence continues at its current rate until 2025. This simple approach is used in the absence of more detailed scenarios of land subsidence in Jakarta, in order to provide indicative results of the potential influence of this important factor on changes in future flood risk. To implement the scenario in the flood risk modelling chain, the original DEM of the city is first adjusted according to the projected scenario of subsidence. Then, in SOBEK, the original DEM is replaced by this DEM according to the future scenario, and the hydrological-hydraulic simulations are repeated. This results in new flood hazard maps showing the flood inundation and extent under the land subsidence scenario, which are then used as input to the Damagescanner-Jakarta model.

Land use change

Ideally, land use change in Jakarta would be projected with a high resolution gridded land use change model. However, at present no such model is available. Hence, we represent land use change in 2030 by using the land use maps of the Rencana Tata Ruang Wilayah 2030 (Jakarta's urban land use plan 2030). This scenario represents an idealised situation, in the case that the land use planning envisioned for the coming decades is successfully implemented, rather than a scenario of unplanned development.

Economic development

Most of the results in this section are carried out assuming the same asset values in the baseline (2010) and future (2030). This allows for a comparison of the relative influence of the driving factors named above on risk. However, due to the rapid economic development of Indonesia in general and Jakarta in particular, we also provide results where we assume that the value of assets, and therefore the economic exposure, increase at the same rate as projected growth in GDP. To do this, we extracted OECD projections (version 9; 25 March 2013) of economic growth between 2010 and 2030 under five so-called Shared Socioeconomic Pathways (SSPs) from IIASA's SSP database (https://secure.iiasa.ac.at/web-apps/ene/SspDb/dsd?Action=htmlpage&page=about). We then calculated the mean projected increase in GDP between 2010 and 2030 between the 5 SSPs, namely 244% (or an increase of factor 3.4). We used this increase factor of 3.4 to estimate damages and risk in 2030 under economic development.

4.4.2 Key results

Current flood risk

Firstly, we setup up Damagescanner-Jakarta to estimate river flood risk under current conditions. As described in Section 3.5, this was carried out using hazard maps from SOBEK and economic exposure values taken from a workshop in Jakarta.

A more challenging aspect was the representation of vulnerability. In Damagescanner, as in most flood damage models, vulnerability is represented by depth-damage functions (vulnerability curves). However, site-specific vulnerability curves are not usually available. As a result, many studies often apply generic vulnerability curves from studies in other cities [e.g. Beckers et al., 2013; Messner et al., 2007; Muto et al., 2010; Pillai et al., 2010; Te Linde et al., 2011]. However, this may be problematic for flood risk assessments, since vulnerability is known to be highly heterogeneous [Jongman et al., 2012a; UNISDR, 2013]. Little is known to date in the scientific community on the sensitivity of flood risk assessments to the use of different vulnerability curves transferred from elsewhere. Hence, as part of JCAT, we developed new vulnerability curves specific to Jakarta, based on a series of expert meetings and a workshop [see Budiyono et al., 2014a for details], and compared the flood risk results using these curves with results using generic curves derived from past flood risk studies in South East Asia. For the generic vulnerability curves, we used the following: curves for specific localities in the Kampung Melayu village of East Jakarta [Marschiavelli, 2008]; curves for Bangkok [World Bank, 2009]; curves for Ho Chi Minh City (HCMC) [Dickens, 2011], and curves for Manila [Muto et al., 2010, Pillai, 2010].

In Table 4.7, we show the damages for the different return periods, and the annual expected damages (risk), based on the vulnerability curves from our workshops and based on the generic vulnerability curves from past studies. Using the vulnerability curves based on our workshop, the annual expected damage is estimated at US$ 321 million/year. This is very similar to the results using the vulnerability curves based on past studies in specific parts of Jakarta. The results based on all three sets of vulnerability curves for Jakarta are significantly higher than the results based on the vulnerability curves derived from studies in Bangkok, Ho Chi Minh City, and Manila.

Table 4.7: Flood damage (US$ millions) and flood risk (US$ millions/year) in Jakarta based on different vulnerability curves. The damage values are show for different return periods (1-100), and the risk is shown in terms of annual expected damage.

	Flood damage (US$ millions)					
Flood return period	**Bangkok**	**Ho Chi Minh City**	**Jakarta, Northern**	**Jakarta, Kampung Melayu**	**Manila**	**Workshop**
1	0	0	0	0	0	0
2	29	121	218	247	76	208
5	71	302	530	592	181	511
10	106	461	785	874	267	764
25	160	698	1,190	1,318	401	1,151
50	197	838	1,465	1,629	494	1,415
100	237	994	1,768	1,963	595	1,702
	Flood risk (annual expected damage; US$ millions/year)					
EAD	45	191	333	373	114	321

To validate the model, we compared these results with reported damages from past flood events. Bappenas [2007] estimated the direct economic damages of the 2002 and 2007 floods to be USD 1,510 million and USD 890 million respectively. The flood of 2007 is estimated to have had a return period of about 50 years [Van der Most et al., 2009]; in terms of precipitation intensity the 2002 event was a little more severe, whilst in terms of inundated area it was a little less severe. Hence, we compare our modelled results for a 50 year return period with the reported losses of Bappenas (USD 1,510 million and USD 890 million for 2002 and 2007 respectively). The damage results based on all three sets of vulnerability curves for Jakarta (based on our workshop, and based on past surveys in Kampung Melayu and northern Jakarta) give damages for a 50 year return period of the same order of magnitude as the reported losses in 2002.

The reported damages of Bappenas for 2007 also give some information on the distribution of damage between different land use categories, which can be used to further verify the model outputs. Therefore, in Figure 4.10, we show the percentage distribution of annual expected damage per land use class, based on the vulnerability curves taken from the literature as well as those derived from our workshop.

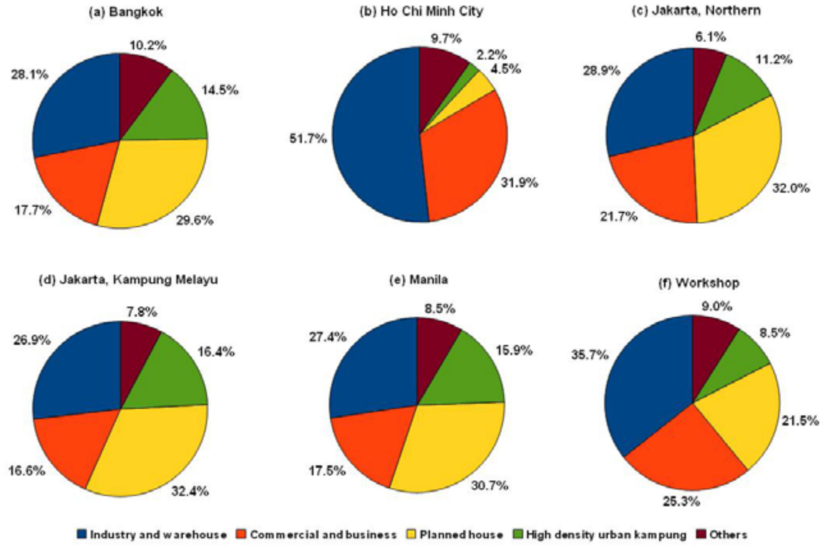


Figure 4.10: Pie-charts showing the percentage of total annual expected damage resulting from each land use class.

The figure clearly shows that the majority of the damage occurs within these four land use classes. Broadly speaking, these four land use classes can be split into two categories: (a) commercial, represented by ‘Industry and warehouse’ and ‘Commercial and business’; and (b) residential, represented by ‘Planned house’ and ‘High density urban kampung’. Bappenas (2007) estimate that for the 2007 flood, approximately 56% of damages occurred in ‘commercial’ activities, whilst about 25% occurred in ‘housing’. Reference to the pie-charts in Figure 4.10 shows that this distribution of damages is most similar to the modelled distribution of risk based on the vulnerability curves developed in our workshop. Using these curves, commercial activities accounted for ca. 57% of total damages, and residential for 29%. Whilst the overall modelled damage estimate for a 50 year return period flood using the vulnerability curves from northern Jakarta and Kampung Melayu were similar to those based on the workshop, the latter gave a better distribution of the damage between categories.

In summary, the results based on the Jakarta-specific economic exposure values and vulnerability curves appear to produce the most reliable damage estimates, since they have both a similar order of magnitude to reported losses, and a similar distribution of those losses over the categories commercial and residential. None of the other combinations of economic exposure values and curves provide damage estimates satisfying both of these criteria.

Future flood risk

In this subsection, we summarise the results of our assessment of future flood risk in Jakarta. All results are shown in terms of change factors compared to current conditions. Hence, a change factor of 1 represents no change, and positive and negative change factors indicate increases and decreases in flood risk respectively.

Climate change

Firstly, we show the potential influence of climate change only on future flood risk, compared to current flood risk (Table 4.8). Here, we show the change in risk as a result of different combinations of precipitation intensity (represented by the RCP scenarios) and sea level rise (low and high). The maximum, minimum, and standard deviation of the results from each of the five GCMs is shown for each combination of RCP and sea level rise scenario. There is no clear signal of change in future flood risk as a result of climate change. Generally, the risk is higher for the more severe RCPs, but the difference in the results forced by the five GCMs is very large. In total, we carried out 42 simulations based on different model and scenario combinations (5 GCMs x 4 RCPs x 2 sea level rise scenarios). Our results indicate that a decrease in flood risk compared to current under 21 of these simulations, with an increase under the other 21 simulations. The impact of climate change on flood risk in Jakarta is therefore highly uncertain. Nevertheless, this does not mean that it is not an important factor. As shown in Table 4.8, some simulations indicate an increase in risk of a factor >3 as a result of climate change alone.

Table 4.8: Simulated change factor in flood risk between current situation and 2030 due to climate change. Results are shown for the different RCP scenarios (representing changes in precipitation), and the two sea-level rise scenarios.

	Change factor		
	Minimum	**Maximum**	**Standard deviation**
Low sea level rise			
RCP2.6	0.5	2.0	0.6
RCP4.5	0.4	2.7	0.9
RCP6.0	0.5	2.8	1.1
RCP8.5	0.5	2.8	1.0
High sea level rise			
RCP2.6	0.7	2.2	0.6
RCP4.5	0.7	2.9	0.9
RCP6.0	0.7	3.0	1.1
RCP8.5	0.7	3.1	1.0

Land subsidence

Under the land subsidence scenario, assuming no change in other physical and socioeconomic factors, flood risk would increase between the current situation and 2030 by a factor of 2.7.

Land use change

As stated previously, the land use map for 2030 represents an idealised situation. Under this scenario, assuming no change in other physical and socioeconomic factors, flood risk would increase between the current situation and 2030 by a factor of 1.1.

Combined impacts of scenarios

In Table 4.9, we show the projected change in risk between baseline and 2030 under the combined scenarios of climate change, land subsidence, and land use change. On the left hand side, we show the changes assuming no increase in asset values, whilst on the right hand side we show the changes whereby asset values increase proportional to GDP. The latter gives an indication of the absolute increase in annual expected damages. However, since the size of the economy is also growing, the risk does not necessarily increase relative to total economic wealth.

Table 4.9: Simulated change factor in flood risk between current situation and 2030 due to the combined impacts of climate change, land subsidence, and land use change.

	Change factor			
	Current asset values		**Asset values under economic growth**	
	Minimum	**Maximum**	**Minimum**	**Maximum**
Low sea level rise				
RCP2.6	2.2	3.9	7.5	13.2
RCP4.5	2.2	4.7	7.5	16.0
RCP6.0	2.2	4.8	7.6	16.3
RCP8.5	2.2	4.9	7.5	16.5
High sea level rise				
RCP2.6	3.2	4.6	11.0	15.5
RCP4.5	3.2	5.5	11.0	18.8
RCP6.0	3.3	5.7	11.1	19.3
RCP8.5	3.2	5.7	11.0	19.5

Assuming current asset values, risk is projected to increase by a factor 2.2 to 4.9 under the scenario of sea level rise, and 3.2 to 5.7 under the scenario of high sea level rise. Considering increased asset values due to economic growth, these values rise to factors of 7.5-16.5 and 11.0-19.5 respectively. Hence, despite the large uncertainty of the impact of climate change alone on flood risk, all of these future scenarios show strong increases in risk. This emphasizes the need for urgent adaptation, regardless of the driver.

As demonstrated earlier, the driving factor with the largest individual influence is land subsidence. Hence, measures to decrease or halt the rate of subsidence are urgently required.

4.4.3 Summary of key findings

- We have developed a model to simulate flood risk from river flooding, expressed as annual expected damages, under current and future conditions.
- We used the model to estimate current flood risk in Jakarta, obtaining an estimate of US$ 321 million/year. Of this, 57% is associated with the commercial sector, and 29% with the residential sector.
- We validated the model against reported damages from the 2002 and 2007 floods, and found the modelled and reported damages to be of the same order of magnitude. The distribution of risk between the different sectors was also similar to that reported by Bappenas.
- We assessed the sensitivity of the model to the use of different vulnerability curves taken from other cities in South East Asia. In the scientific literature, the transfer of curves in this way is widespread. Our findings show that this leads to large differences in risk estimates. Hence, flood risk assessments need to pay close attention to the selection, development, and testing of case-specific vulnerability curves.
- We also used the model to assess changes in flood risk between present and future (2030) under scenarios of climate change, land subsidence, land use change, economic development, and a combination of these factors. Under the combined scenarios we projected an increase in risk by a factor of 2.2-5.7, assuming current asset values. If we also projected increases in asset values, this rises to a factor of 7.5-19.5. This highlights the clear need for urgent adaptation, regardless of the driving factor.
- We found no clear signal of change in risk related to the different climate projections alone. The potential impact of climate change on flood risk in Jakarta remains, therefore, highly undertain. However, the projected increase in risk under some of the climate change simulations is large, with a factor increase >3 in some cases. Also, even under the climate change simulations with the largest decrease in risk, this decrease is not enough to cause an overall decrease in projected future flood risk when the other driving factors are included.
- Under the scenarios used for this study, the driving factor with the largest influence on risk is land subsidence. The importance and severity of land subsidence in Jakarta is already well-known and high on the political agenda, but this study provides the first quantitative estimate of its potential impact on flood risk. Until 2030, we project an increase in flood risk by a factor 2.7 due to land subsidence alone.
- To represent changes in land use, we used a single scenario which refers to an idealised plan of the city in 2030, assuming that the land use planning for 2030 is implemented. We have shown that under this

scenario (land use change alone), risk would increase by a factor of ca. 1.1. Given the fact that changes in exposure through urban development are seen as one of the main drivers of risk in developing countries (Jongman et al., 2012b), such a development would be highly positive. However, it should be noted that achieving such development would entail very strong governance structures, strong spatial planning laws, and thorough implementation.

- In the final phases of the JCAT project, the Damagescanner-Jakarta tool will be used to assess the potential of several flood risk adaptation measures to reduce current and future flood risk.

4.5 River flood damages at the local-scale

We used the results of the surveys along the Pesanggrahan River. Described in Section 4.4, to address the following research questions:

- What are the relationships between actual flood damage (AFD) and physical and socioeconomic factors relating to flooding in Jakarta?
- How much flood damage was caused in the residential and business sectors during the January 2013 flood event in Jakarta?

4.5.1 Key results

Residential sector

Based on our survey, which was held in Jakarta in 2013, the average flood damage (AFD) per household was estimated to be US$ 318 (Table 4.10). Of this, direct damages accounted for US$ 236, and indirect losses for US$ 82. The majority of the total damage was composed of direct losses.

Table 4.10: The average AFD per house in 17-19 January 2013 flood event.

Damage type	Value (US$)	% of total
1. Direct		
1.a. Structural damage	43	14
1.b. Content damage (inside and outside)	193	60
2. Indirect		
2.a Clean-up cost	25	8
2.b. Loss of income	30	9
2.c. Evacuation and temporary house	12	4
2.d. Cost of illnesses	15	5
Total	**318**	**100**

The regression analysis between AFD per household and the physical and socioeconomic factors per household revealed that inundation depth, inundation duration, household income, and house area all have positive and significant relationships with AFD, whilst the distance to the river has no significant correlation with AFD (Table 4.11).

In Figure 4.11, we show a scatter plot of flood depth against flood damage, for the different income categories of the residential sector. In Figure 4.11a, the data are shown for all income groups, showing a positive correlation between flood depth and damage. The flood depth is one of five variables that are used as explanatory variables. Hence, these scatter plots provide only an example of one of the model’s explanatory variables. More details on the development of the model and its results can be found in Wijayanti et al. [2014b].

Table 4.11: The estimated parameter values, SE, t values and significance levels for the physical and socioeconomic variables in the AFD function for the residential sector.

Physical/socec. factor	Unstandardised Coefficients			
	β	Standard Er-	t	Sig.
DEP	12.992	3.012	4.313	0.000
DUR	4.434	2.332	1.902	0.058
INC	0.196	0.034	5.767	0.000
ARE	7.951	1.733	4.588	0.000
DIS	2.628	1.721	1.527	0.128

R^2.=0.850, Durbin-Watson=1.805, n=300

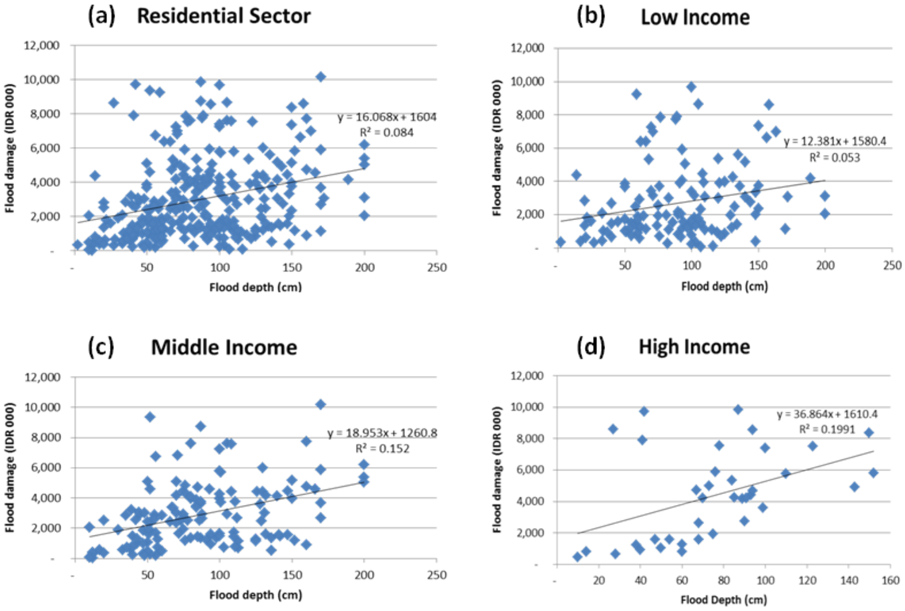


Figure 4.11: Correlation between flood depth (cm) and flood damage (IDR 000) in the residential sectors, for: (a) all income groups; (b) low income group; (c) middle income group; and (d) high income group.

We used the AFD model to estimates the AFD per household, and the total AFD of the residential sectors based on the entire flooded area. The average modelled AFD per household is US$ 308, and the estimated total damage for all areas affected by flooding is ca. US$ 525,000.

We also used the AFD model to estimate damages in three different income groups, as shown in Table 4.12. Here, we see that average damages per household are greater for high income groups than for low income groups. At an aggregated level, the greatest overall AFD in the residential sectors occurs in the middle income group, since households of this income group are more prevalent than households in the high income group in the area affected by the floods of 2012.

Table 4.12: Modelled AFD in the residential sector by income group.

Income Group	Damage per house (US$)	Total damage (US$)
Low	271	194,307
Middle	301	234,479
High	459	96,390
Total		**525,176**

Based on our survey results, flood depths observed during the January 2013 floods in the survey area range from ca. 2 to 210 cm, with an average of 81 cm. These depths are similar to those produced by hydrological modelling in Jakarta, using the SOBEK model described earlier in this report.

We compared the damages in the residential sector for the 2013 flood, obtained using this regression model base on surveys, with the results of the GIS-based Damagescanner-Jakarta model from Section 4.4(Budiyono et al., 2014a). Such a comparison is not straightforward, since the survey based approach is an event-based analysis, whilst the Damagescanner approach simulates damages based on return periods. In reality, return-period based approaches usually lead to larger estimates of flood damage than event-base approaches. This is because the Damagescanner approach assumes that, for a given return period (e.g. 50 years), the flood occurs throughout the entire study domain. However, in reality a single flood event does not have the same return period throughout the entire domain. For example, if flooding occurs at one location downstream, less water is available to flood downstream, and therefore whilst the upstream location may experience a 50 year return period flood, there may be no floodwaters downstream. Nevertheless, it is still a useful exercise to compare the order of magnitude of the results from the two approaches, and examine the differences and possible reasons. The survey approach resulted in damages of ca. USD 0.5 million, whilst Damagescanner-Jakarta estimated damages of ca. USD 1.3 million. Hence, the Damagescanner results are a factor of ca. 2.5 times larger than the survey approach. This seems plausible for several reasons. First, as stated above, return period based estimates of damage are generally higher than event-based estimates. The purpose of a return-period based approach is not to estimate damages in single events, but to derive information on average long-term losses over larger areas. Secondly, in the comparison used here, Damagescanner-Jakarta uses flood hazard maps derived based on the hydraulic situation in 2007. Since then, several measures have been taken to reduce flood damages, such as the deepening and widening of channels. Indeed, new Damagescanner-Jakarta simulations being carried out using an updated schematisation of the hydraulic situation show significantly lower damages (Budiyono et al., 2014b). Thirdly, the Damagescanner approach uses average value of assets and vulnerability curves for the entire Jakarta area, whereas the survey was carried out in a relatively low income area (compared to the average situation in the entire city). Finally, differences in the scale of the analyses will account for some differences. The calculations in Damagescanner are based on 50m x 50m grid cells, whereas the data from the survey approach are based on actual individual residential units.

Business sector

In the business sector, the average AFD per business unit was US$ 882 according to the results of the surveys (Table 4.13). For most business units, the total indirect losses (average US$ 665) are greater than total direct damages (US$216). The highest damages were incurred as a result of the turnover loss, which accounted for about 61% of total damages, dependent on the number of days the businesses had to close due to the flood. About 93 % of the respondents closed their business due to the floods, with an average closure of five-days. Nevertheless, only 4% set up temporary headquarters at another location.

Table 4.13: The average AFD per business during 17-19 January 2013 flood event.

Damage type	**Value (US$)**	**% of total**
1. Direct		
1.a. Structural damage	58	7
1.b. Content damage	158	18
2. Indirect		
2.a. Turnover loss	540	61
2.b. Temporary quarters	6	1
2.c. Labour cost	39	4
2.d. Clean-up cost	81	9
Total	**882**	**100**

The regression analysis between AFD per business and the physical and socio-economic factors per business revealed that inundation depth, inundation duration, turnover per day, and business area all have positive and significant relationships with AFD, whilst the distance to the river makes no significant contribution to AFD (Table 4.14).

Table 4.14: The estimated parameter values, SE, t values and significance levels for the physical and socioeconomic variables in the AFD function for the

Physical/socec. factor	**Unstandardised Coefficients**			
	β	**Standard Er-**	**t**	**Sig.**
DEP	21.732	10.462	2.077	0.040
DUR	26.089	8.037	3.246	0.001
TUR	2.001	0.179	11.189	0.000
ARE	27.073	8.200	3.302	0.001

R2.=0.874, Durbin-Watson=2.031, n=150

We also examined the results for different turnover groups of businesses, namely micro and small-medium turnover groups; the results are shown in Table 4.15.

Table 4.15: Modelled AFD in the business sector by turnover group.

Business Turnover	Damage per unit business (US$)	Total Damage (US$)
Micro	480	192,000
Small-medium	1,210	503,360
Total		**695,360**

4.5.2 Summary of key findings

- A large number of surveys were carried out in an area of the Pesanggrahan River that was affected by the flood of January 2013. This allowed us to gain a better insight into the actual flood damages in this area, and also to gain an understanding of the physical and socioeconomic factors of importance for determining the actual flood damage.
- We found that flood damages in Jakarta in the residential sectors have significant positive correlation with flood depth, flood duration, household income, and house area. For the business sector, actual flood damages show a significant positive correlation with flood depth, flood duration, daily turnover, and business.
- These findings are important for future advances in flood risk modelling. Whilst the current version of Damagescanner-Jakarta only considers flood depth in its representation of hazard, these findings suggest that future hydraulic modelling should also focus on the duration of flooding, since this has been found to have a significant influence on overall damage.
- In the residential sector majority of the actual damage (74%) is related to direct damages. However, in the business sector, the majority of the actual flood damage is related to indirect losses (75%). This is an important finding, since the vast majority of flood risk studies focus on direct damages only. Our results show that future attention should also focus on addressing the indirect losses associated with flooding .A simple way to do this in a rapid risk assessment framework could be to use the percentage splits between direct and indirect damages for different sectors derived from surveys like the one carried out here, and using this to create a simple “add-on” to simulated direct damages.
- The damage estimation for the 2013 flood events based on the survey and regression analysis is lower than that obtained using the GIS-based Damagescanner approach. Four reasons for this difference are discussed. This demonstrates the importance of using several methods to assess flood damage.

4.6 River flood risk at the national scale

We used the national scale rapid flood risk assessment tool described in Section 3.9 to assess how flood risk may change under different future scenarios. We integrate both climate change scenarios and socioeconomic change scenarios.

The main aim of this analysis is to show how probabilistic estimates of new urban land combined with climate change projections can be used to assess the future trends in flood risk. In this section, we briefly describe key elements of these (preliminary) results. The full analysis can shortly be found in Muis et al. [2014].

4.6.1 Scenarios

Here we describe the scenarios used to assess how changes in flood characteristics and socio-economic developments drive changes in flood risk.

River floods

To simulate floods under historical climate conditions, the PCR-GLOBWB model was forced with the EU-WATCH data [Weedon et al., 2011], which contains meteorological parameters (precipitation, temperature, radiation) for the period 1958-2000. Flood volumes are calculated for nine different return periods, namely 2, 5, 10, 25, 50, 100, 250, 500 and 1000 years. To simulate the impact of climate change on river floods, we use future projections from five global climate models (GCMs): NorESM1-M, MIROC-ESM-CHEM, IPSL-CM5A-LR, HadGEM2-ES and GFDL-ESM2M. Each GCM was driven by the following four different Relative Concentration Pathways (RCPs) scenarios: RCP2.6, RCP4.5, RCP6.0, and RCP8.5. Next, PCR-GLOBWB was driven by each of these 20 different simulations proving flood volumes for the period 2010-2049. These future projections are derived from the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) [Warszawski et al. 2013]. The flood volumes were in turn used as input to GLOFRIS to compute inundation maps under the different scenarios. The uncertainties of climate scenarios and GCM outputs are large and inadequate for assessing hydrologic impacts of climate change at regional scales [e.g. Xu et al. 2004]. To overcome this issue we applied the delta change method, which assumes that GCMs simulate relative changes better than absolute values [e.g. Hay et al., 2000; Prudhomme et al., 2002]. Basically, it is the computation of differences between current and future GCM simulations and adding these changes observed climate dataset.

Coastal floods

For the coastal floods, extreme water levels are derived from the DIVA (Dynamic Interactive Vulnerability Assessment) database [Dinas-Coast Consortium, 2006], which provide water levels with return periods of 10, 100 and 1000 years. For the future, the direct effect of sea level rise will be an increase in water level, and thus in the frequency and severity of floods. Detailed projections of the impacts of climate change on sea-level rise in Indonesia are not available. Therefore, we used the global projections of sea level rise published in the most recent report (AR5) of the Intergovernmental Panel on Climate Change [2013]. We applied three different scenarios: the mean, and the upper and lower bound of the likely range of sea level rise [IPCC, 2013]. For 2030, this corresponds to low, mean, and high sea level rise estimates of 0.12, 0.09 and 0.17m, respectively.

Socio-economic developments

To assess the impact of urban expansion on flood risk, we developed spatially explicit probabilistic forecasts of urban expansion. To do so, we used probabilistic projections of urban population and gross domestic product (GDP) growth to estimate the amount of new urban land. Subsequently, a land change model was used to spatially allocate the projected urban expansion and to develop 1,000 projections of urban expansion through to 2030. To obtain probabilistic GDP projections, we assume a uniform distribution based on country-level GDP projections used by the IPCC for their four SRES scenarios [Nakicenovic et al., 2000]. To obtain probabilistic estimates of total population projections, we combined the UN World Population Projections [UN, 2013] with uncertainty estimates published by the U.S. National Research Council [2000] and used this information to fit a probability density curve (PDF). To get the urban population projections for 2030, we then randomly draw values from the PDF of total population projection and multiply them by the projected urban population proportion (i.e. 63.1%) from the UN Urbanization Prospects [UN, 2012]. Next, we used a linear model presented in an earlier study [Seto et al., 2012] to incorporate the increase in per capita urban land due to the increase in per capita GDP and thus to estimate the per capita urban land in 2030. Based on this we estimated the amount of new urban land, which was the input for the land change model. This land change model is based on GEOMOD, a well-known spatially-explicit grid-based land change model developed by Pontius et al. [2008], and described in detail in Seto et al. [2012] and Güneralp and Seto [2013].

4.6.2 Key results

Current flood risk

Under baseline conditions with the urban extent of 2000, the flood risk of river and coastal floods equals 0.017 and 0.007% of the GDP, respectively. This shows that river flood are almost 2.5 times more costly than coastal floods. For coastal flooding, the majority of the damages can be found in the provinces of East Java, Jakarta, and Riau, each responsible for respectively 33%, 32%, 19% of the total damages.

Urban expansion in 2030

The urban simulations show that Indonesia is projected to undergo rapid urban expansion towards 2030. By 2030, over 160,000 km^2 of land has a positive probability (>0%) of becoming urban, and 10% of this land has high probability (>75%). If all areas with high probability are actually converted to urban land, this would result in a 162% increase of urban extent in Indonesia. A large part of this urban growth is projected to take place in Java, which accounts for (on average) 79% of the national increase. This pattern is also clearly illustrated by Figure 4.12. Based on the results of the urban simulations, it can be expected that flood risk will increase most rapidly on Java.

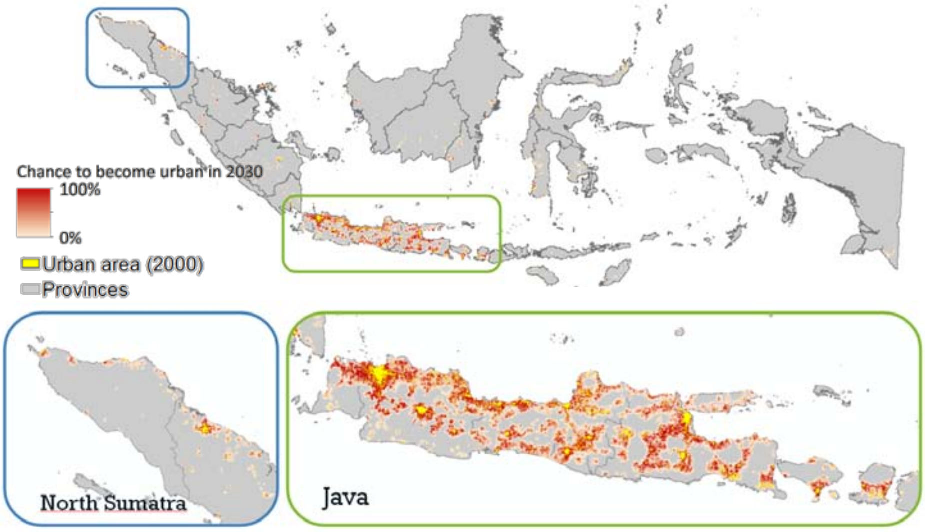


Figure 4.12: Map showing projected probabilities of urban expansion by 2030. There is large spatial variability and much of the projected urban expansion occurs in Java.

Future trends driving changes in flood risk

Figure 4.13 shows projections of how the risk due to river flooding will change from 2000 to 2030. Assuming no climate change, but only urban expansion, the average estimate of flood risk increases to 0.030% of the GDP, corresponding to an increase of 76% compared to 2000. Moreover, all of the urban expansion projections excluding climate change lead to an increase in risk. The impacts of climate change on flood risk are highly uncertain. When climate change is included in the projections, the flood risk by 2030 is estimated to be between 0.01-0.05% of the GDP. Some of the scenarios show an increase in risk, whilst others show a decrease in risk. Evidently, the global climate models do not provide sufficient confidence about what will happen under future scenarios of climate change in the Indonesian archipelago, which stresses the need and importance of regional climate change projections. Thus, whether climate change will cause an increase or decrease in flood hazard, the implementation of effective risk-reducing remains urgent, due to the increasing risk caused by urban expansion. Moreover, from Figure 4.13 it is also clear that though there are high uncertainties, by 2030 risk is still projected to increase for almost all of the projections including climate change (with the exception of 2 RCP scenarios using the NorESM-1M mode).

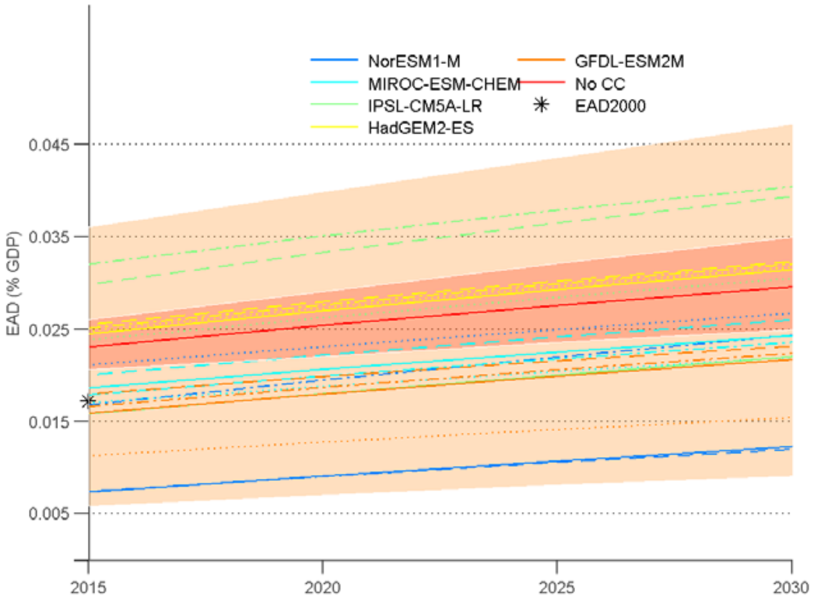


Figure 4.13: Time-series (2015-2030) showing the EAD (as a percentage of GDP) for river floods under different projections of climate change (5 GCMS and 4 RCPs) and for all projections of urban expansion. The red shaded band shows the 5-95 percentiles for the scenario without climate change (i.e. urban expansion only). The orange shaded band shows the 5-95 percentiles when both urban expansion and climate change are included.

For coastal floods we find a more distinctive upward trend (Figure 4.14). Assuming no sea level rise, the average estimate of flood risk increases to 0.016% of the GDP (mean) by 2030, which is an increase of 121% compared to 2000. Including sea level rise exacerbates this increase: in this case the average AED is 0.023% of GDP by 2030. Flood risk is projected to rise particularly rapidly in the province West Java; its share of the total national risk increases from 3% to 21% (under the mean sea level rise scenario). The results show that coastal floods are projected to become increasingly costly relative to the GDP, which implies flood risk will increase more rapidly than the economy. The losses due to coastal floods are also rising more rapidly than river floods, indicating that urban expansion preferentially takes place along the coasts. If we disentangle the impacts of urban expansion and sea level rise, we see that on a national scale, the increases in flood risk are predominantly caused by increasing exposure, thus urban expansion. However, the impact of sea level rise does become more apparent over time and may become the more dominant contributor beyond 2030.

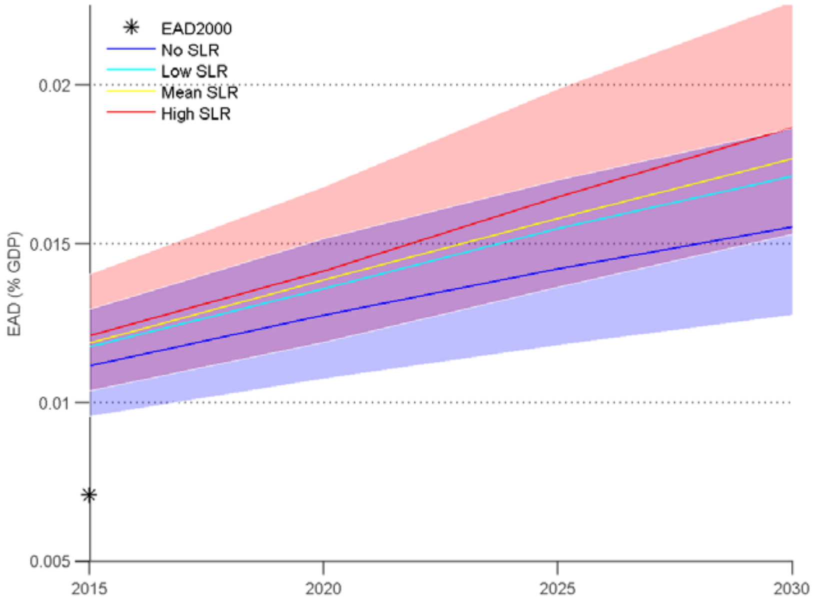


Figure 4.14: Time-series (2015-2030) showing the EAD (as a percentage of GDP) for coastal floods under different scenarios of sea level rise (SLR) and for all projections of urban expansion. The blue shaded band shows the 5-95 percentiles for the scenario with no SLR (i.e. urban expansion only). The red shaded band shows the upper 95 percentile and lower 5% of the high SLR projections (including urban expansion).

4.6.3 Summary of key findings

- We investigated trends and changes in both coastal and river flood risk driven by climate change and urban expansion. If we only look at urban expansion, the results show strong increases in flood risk, particularly along the coast. Expressed as percentages of GDP, the EAD associated with river floods increases by 76% between 2000 and 2030. For coastal floods this increase is 121%. Risk is projected to increase particularly rapidly in the province of West Java.
- Also, climate change is projected to drive changes in flood risk. For river floods, it remains uncertain whether climate change alone may amplify or reduce the upward risk trend caused by urban expansion based on the combinations of GCMs and RCPs used. However, for coastal flooding, projected increases in sea level rise cause an additional increase in flood risk along the coast. By 2030, flood risk may increase to 0.023% of GDP, which is more than double the risk in 2000.

5 Effects of adaptation measures

Whilst the main aims of JCAT are to develop methods and tools to assess flood risk related parameters, we also aim to demonstrate the potential use of some of these by applying them to assess a number of adaptation strategies or measures. By doing so, the intention is that the methods and tools can be used in the future by decision-makers, to assess various adaptation measures and make decisions on which measures could be taken.

Hence, the applications described in this section are not intended to give a comprehensive assessment of flood risk reducing measures in Jakarta. Rather, they are intended to give impressions of the order of magnitude of gains that could be made through several measures, but more importantly to demonstrate how the methods can be used to assist in providing those estimates. Most of the adaptation options described in this section can be considered to score highly in terms of robustness, i.e. they perform well over a range of futures [Woodward et al., 2014]. For example, in Section 5.1 we assess spatial planning measures to control erosion; in Section 5.2 we examine household and community level measures that can help to reduce social vulnerability; and in Section 5.3 we examine urban development controls. According to Ranger and Garbett-Shiels [2011], all of these options have a high robustness to uncertainties. These first example analyses are therefore supposed to be complementary to the important ongoing studies in Jakarta on the possible implementation of large-scale infrastructural measures, such as large sea defences and levees, which often provide high cost benefit ratios, but may have a lower robustness to uncertainties.

In this section, we describe the application of several methods to date. Further applications are planned during the final phases of JCAT. These include, but are not limited to: an application of Damagescanner-Jakarta to assess the effectiveness of an SMS-based flood early warning system in reducing risk. This will be carried out in collaboration with the Indonesian Agency for the Assessment and Application of Technology (BPPT); and an assessment of the costs and benefits of a range of local flood risk adaptation measures (both structural and non-structural, upstream or downstream) using the economic modelling tools. The measures to be assessed will be discussed and decided upon in close collaboration with local stakeholders, including DKI Jakarta.

5.1 Impacts of Presidential Decree on Spatial Planning on water balance and sediment yield

We used STREAM-Jakarta and STREAM-SDAS to examine the potential affect of a land use plan for the Jabodetabek region (a region containing the cities of Jakarta, Bogor, Depok, Tangerang, and Bekasi, and covering approximately 6,400 km^2), namely Perpres 54/2008 (Peraturan Presiden Nomor 54 Tahun 2008 - Perpres 54/2008). Specifically, we addressed the following research question:

- What is the potential influence of Perpres 54/2008 on river discharge and sediment yield?

The results in this section are based on Poerbandono et al. [2014a], in which they are described and discussed in more detail.

5.1.1 Study area and Perpres 54/2008

Perpres 54/2008 is a reference for the implementation of development related to water and soil conservation; the availability of ground water and surface water; flood prevention; and economic development for the welfare of the community. It provides a theoretical land use map for the Jabodetabek region. Perpres 54/2008 is intended to compensate for anthropogenic pressures caused by changes in land cover. Ideally, the implementation of Perpres 54/2008 would lead to increased soil water infiltration capacity, the reduced erodibility of soils, and reduced river flood peaks. This presidential regulation is seen as a possible adaptation strategy through policy making in the field of spatial planning.

The full geographical coverage of Perpres 54/2008 is shown in Figure 5.1. For the JCAT study, we examined the impacts of the policy on river discharge and sediment yield for the watersheds fully covered by Perpres 54/2008, i.e. Ciliwung and Cisadane. These are also shown in Figure 5.1. We chose to assess changes in discharge at three evaluation points for each watershed: one in the upstream region, one in the middle of the watershed, and one upstream (see Figure 5.1).

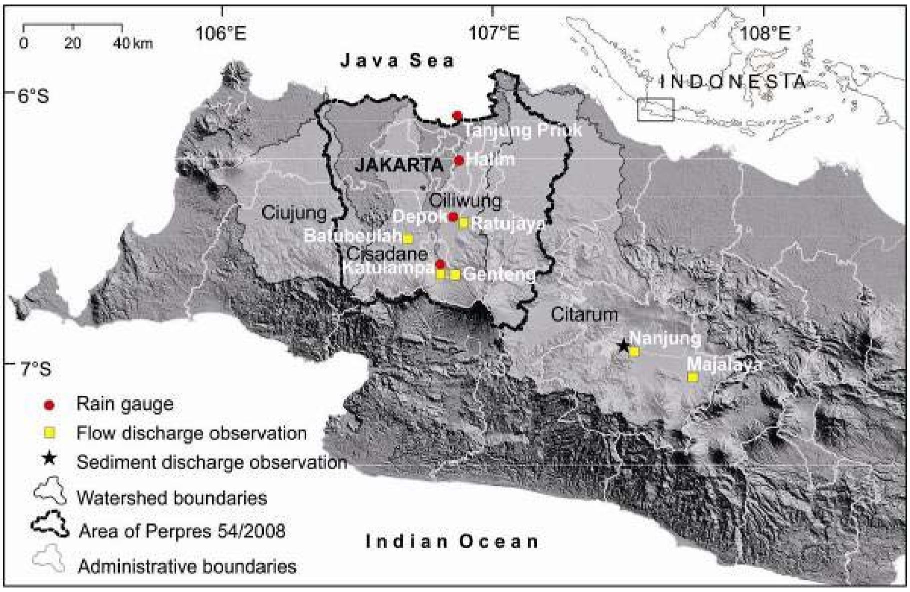


Figure 5.1: Map of the area covered by Perpres 54/2008, and the watersheds examined in this study (Ciliwung and Cisadane). Source: Poerbandono et al. [2014a].

5.1.2 Potential impacts of Perpres 54/2008 on discharge

The results are summarised in Table 5.1. For both rivers, and at all locations (i.e. upstream, middle, downstream), we simulated a decrease in discharge under the Perpres 54/2008 scenario, with the largest decreases in the downstream area.

The decreases in river discharge are related to the increase in the water holding capacity of the soil and increased evapotranspiration due to land cover change. The changes in these factors are seen primarily in the buffer area of Jakarta, where the Cisadane watershed is located. Hence, our simulations of the full theoretical implementation of Perpres 54/2008 cause a greater decrease in river discharge in the Cisadane watershed than in the Ciliwung. However, for both rivers the decrease is reasonably small.

Table 5.1: Simulated monthly river discharge under the actual and Perpres 54/2008 scenarios. Source: Poerbandono et al. [2014a].

Watershed	**Location**	**Monthly discharge (m^{3}s^{-1}) - Current**	**Monthly discharge (m^{3}s^{-1}) - Perpres**	**Δ Change (%)**
Ciliwung	Downstream	55.8	54.6	-2.2%
	Middle	22.6	22.6	-0.8%
	Upstream	10.2	10.2	-0.1%
Cisadane	Downstream	112.5	106.2	-5.6%
	Middle	76.5	72.9	-4.7%
	Upstream	19.0	18.2	-4.4%

5.1.3 Potential impacts of Perpres 54/2008 on erosion and sediment yield

We used a similar approach to investigate the effectiveness of the theoretical implementation of the land cover plan in Perpres 54/2008 in reducing sediment yield, using SDAS-Jakarta. The results, aggregated per basin, are summarised in Table 5.2. Our simulations show a potential decrease in sediment yield for the Ciliwung and Cisadane rivers of 61% and 22% respectively.

Table 5.2: Simulated annual sediment yield under the actual and Perpres 54/2008 scenarios. Source: Poerbandono et al. [2014a].

Watershed	**Annual sediment yield (tons) - Current**	**Annual sediment yield (tons) - Perpres**	***Δ* Change (%)**
Ciliwung	1207	477	-61%
Cisadane	8916	6986	-22%

In Figure 5.2, we also show monthly changes in the sediment yield of the two basins, under the Perpres 54/2008 scenario. These show especially large reductions in erosion and sediment yield during the wet season.

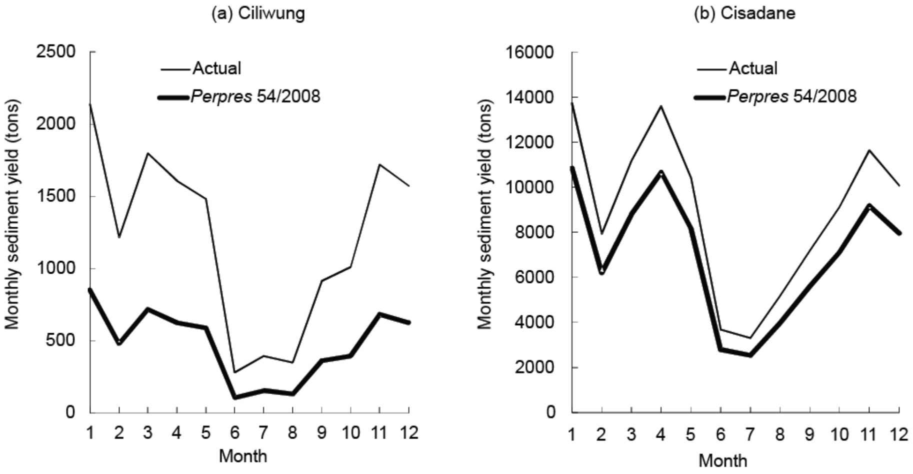


Figure 5.2: Computed mean monthly sediment yield in the Ciliwung and Cisadane watersheds under the actual and Perpres 54/2008 scenarios. Adapted from Poerbandono et al. [2014a].

5.1.4 Concluding remarks and implications for flood risk management

According to the model results, a full implementation of Perpres 54/2008 would lead to a modest decrease in mean annual river discharge of 5.6% in the Cisadane and 2.2% in the Ciliwung watersheds. However, the results for sediment yield show reductions of 22% and 61% for the Cisadane and Ciliwung respectively. These findings are of significance for water and flood management in the city of Jakarta (and surroundings). Although relatively small, the implementation of Perpres 54/2008 could have a significant impact on discharge. It should, however, be noted that here we examined monthly discharge: for flood assessment the study should be extended to assess the effects of Perpres 54/2008 on (sub-)daily discharge. The results do suggest a large benefit for water and flood management due to reduced sediment yield. Sedimentation of the city’s waterways (including the clogging of flood drainage networks) has greatly exacerbated the flood problem in recent years. Good spatial planning practices have the potential to reduce the amount of sediment delivered to the city, thus reducing the flood hazard, and consequently the risk. Moreover, this reduced sediment delivery could reduce to some extent the need for (and cost of) expensive dredging activities.

5.2 Impacts of small scale adaptation measures on flood risk

The household level surveying method described in Section 3.7 was not only used to assess the damages caused by the flood of January 2013, but also to assess a number of small scale adaptation measures taken by the inhabitants to reduce flood risk [Wijayanti et al., 2014b].

5.2.1 Household scale adaptation measures

Here, we describe the household-level adaptation carried out in six villages located along Pesanggrahan River. In this area, during the period April 2012 to April 2013, 53% of respondents experienced floods. As a result, they stated that they are used to living with flooding and the aftermath of flooding, such as muddy and dirty conditions around their houses. Consequently, at the household-level most inhabitants do already conduct several private household-level adaptation measures. These actions are important to minimise their losses since they are frequently exposed to floods. For example, about half of the respondents live in two-floor houses, in which the second floor has been deliberately built as an adaption to flooding.

The survey respondents (who took measures) were asked to state their most preferable household-level adaptation measure: the results are summarised in Figure 5.3, and a number of the measures are illustrated by the photo in Figure 5.4. Figure 5.3 clearly shows that inhabitants use measures designed to reduce their vulnerability to flooding, by moving upwards. Together, the options ‘heightening the first floor of the house’, ‘building the second floor’, and ‘having attic’ were the preferred measures for 75% of the respondents who took measures. After this strategy of moving up, the most popular measure was ‘providing concrete/board outside the door’, in which these small barriers are constructed in front of houses to act as flood retainers. Insurance was found not to be a popular measure in the area.

The respondents were also asked to estimate how much damages they had avoided during the floods of January 2013, as a result of taking these measures: these results can be found in Table 5.3. Clearly, these measures can therefore have a large impact on overall damages. In future research, we intend to examine how much flood risk in Jakarta could be reduced as a whole, if such local measures were to be implemented on a larger scale.

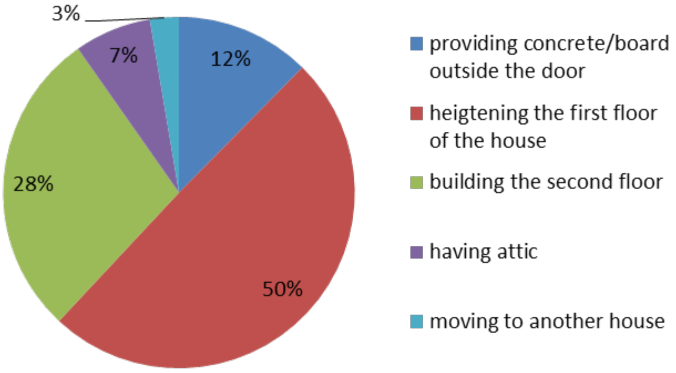


Figure 5.3: Preferred household level adaptation measures of survey respondents.

Figure 5.4: Several examples of household-level adaptation from river flooding along Pesanggrahan River.

Table 5.3: Types of household adaptation measures and their avoided damages.

Household adaptation measures	Percentage (%) of respondents	Avoided damages (US$)
Providing concrete/board outside the door	12.4	1,914.93
Heightening the first floor of the house	49.6	2,672.70
Building the second floor	28.3	2,032.75
Having attic	7.1	3,608.17
Moving to another house	2.7	1,411.32

5.2.2 Local flood warning measures

The inhabitants of the survey area sometimes receive informal flood information prior to flooding from several sources, including television, mosque broadcasts, and families living outside the area. However, prior to past flood events, most households did not take any direct action when they first received information about the coming flood. A reason given by many respondents is that they do not believe that the flood will occur until they see the water heading towards their houses. Consequently, they only started to evacuate their belongings when the water reached their houses.

During the January 2013 flood, the time-lag between the information and flooding was quite short. About 53% respondents received information less than three hours before the flood arrived. They took several preventative measures to reduce flood damage, such as moving belongings to a second floor or higher ground, moving vehicles to higher ground and shutting down the electricity supply. On average, households were able to reduce their damage by saving belongings, by ca. IDR 25 million (USD 2,530) per household, mostly comprised of vehicles. This shows that early warning could be used to significantly reduce flood damage. In the final phase of the JCAT project, we intend to assess the potential effectiveness of an SMS-based flood early warning system in reducing flood risk.

The results of our surveys showed that there is no clear relationship between time lag and the avoided damage (Figure 5.5). We initially expected that time-lag and the avoided damage would have a positive correlation.

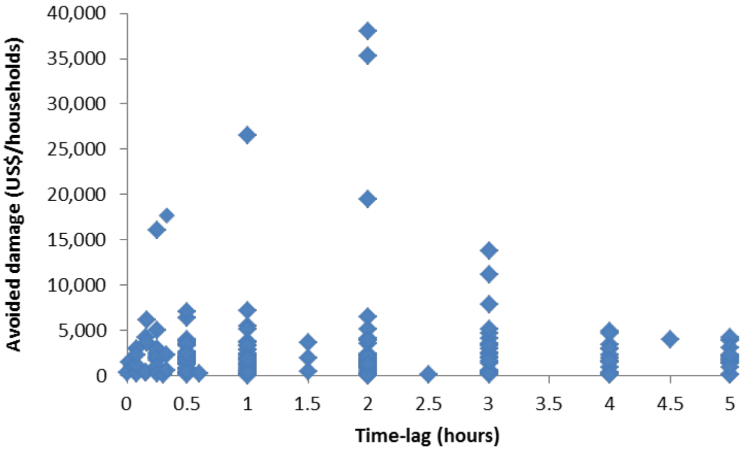


Figure 5.5: Relation between flood awareness and the expected damages.

5.2.3 Community response to flooding in northern Jakarta

Communities and households who regularly face flooding often already employ a range of adaptation measures to cope with those floods. Whilst often not part of the formal adaptation planning and decision-making agenda, such measures can have an important role in risk reduction. Hence, next to quantitative methods and tools to assess the possible impacts of adaptation options taken through the formal decision-making process, it is also important to carry out qualitative research to assess which measures are already being successfully employed at the local level. Hence, we carried out a study to examine community responses to flooding in northern Jakarta. Here, we summarise the main findings; full details can be found in Marfai et al. [2014].

The research was carried out in the flood prone areas of Muara Angke, Kapuk Muara, Penjaringan, Sunter, Bulak Cabe, Cilincing, Pulau Nangka, Kuningan, Kampung Melayu, and Cawang. In-depth interviews were conducted with 128 respondents, with interviewees including both inhabitants and experts, for example, heads of local neighbourhood associations (RTs), heads of higher neighbourhood associations (RWs; consisting of several RTs), Search and Rescue teams, and social workers. The focus of these interviews was to gain information related to the adaptation strategies employed by the local communities.

Through these analyses, we found that local communities already take a large number of small scale adaptation measures to cope with flooding, especially in terms of minimising the damage. These include both physical and non-physical adaptation measures. The most commonly practiced forms of adaptation can be seen in Figure 5.6, along with the percentage of participants who took those measures.

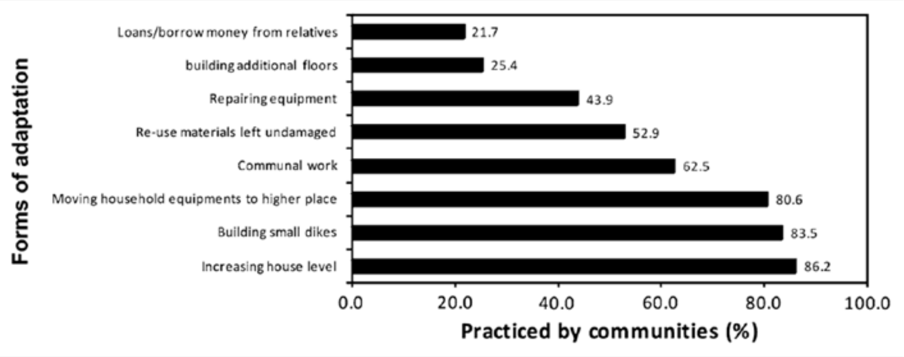


Figure 5.6: Forms of adaptation practiced by the communities interviewed.

Similar to the research of Wijayanti et al. [2014b], it can be seen that moving valuable items to higher levels of a household is a popular household-level adaptation measure. Another important community level adaptation measure is the development of solid works by the community, for example communal works to clean rivers and drainage channels, and the building of dikes around settlements.

The research also identified a lack of concern and passiveness of the community as potential problems for such kinds of adaptation. Hence, in order to foster community level adaptation, it is important to maintain social interaction between inhabitants and other stakeholders.

5.2.4 Key findings of relevance for flood risk management

It is clear that both household-level and community level adaptation can play important roles in reducing flood risk. So far, JCAT has identified several such measures that are being used to reduce flood risk. A useful next step would be to try to assess how much flood risk is already avoided by the adoption of such measures, and how much more flood risk could be avoided if their adoption could be increased. For example, how effective are small scale adaption measures in comparison to larger scale measures such as major dikes, flood canals and so forth. Also, it would be useful to research how government organisations, especially at the municipal level, could harness such local knowledge in its adaptation planning and strategies. By including local knowledge in this process, the acceptance for proposed adaptation measures may be increased. Moreover, local government could potentially play a role in "scaling up" adaptation measures already shown to be effective in some local communities, for example by facilitating the exchange of knowledge between different communities.

5.3 Impacts of large sale adaptation strategies at the national scale

The results of the national scale flood risk assessment described in Section 4.6, projected large increases in risk, particularly for coastal floods. Taking appropriate adaptation measures may offset this upward trend and prevent floods from becoming more costly. We aim to assess the effect of two different adaptation measures: (1) spatial planning; and (2) flood protection. Work is still ongoing and will continue during the final phase of the JCAT project. Therefore, here we show the preliminary results of this analysis for coastal floods only.

5.3.1 Adaptation measures

Strategic urban planning
The results of the national-scale flood assessment described in Section 4.6 showed that urban expansion is the main driving force of increase in flood risk. Hence, the strong upward trend in flood damages could potentially be reduced by limiting the amount of new urban land in flood prone areas. This can be achieved by enforcing building restrictions in flood prone areas. We therefore carried out new urban expansion projections, but reduced the suitability of the grid cells located in flood prone areas, which are defined as areas that are exposed to a 100 year coastal and/or river flood. We applied varying levels of effectiveness of governance. Basically, we reduced the suitability value of pixels, thus lowering the chances of certain locations to urbanise by certain proportions to reflect the effectiveness of governance. Thus, we multiplied each pixel's suitability value by 0, 0.5, and 0.33 to reflect high, medium, and low enforcement respectively.

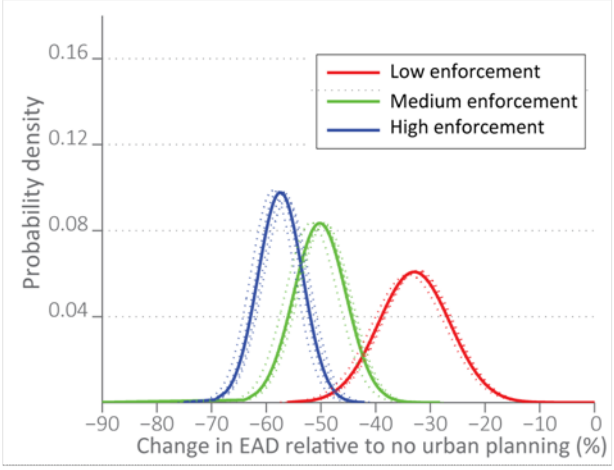


Figure 5.7: Probability density curves showing the effect of building restrictions for three different levels of enforcement.

These (preliminary) results show that urban planning can be highly effective. Even under a low level of enforcement, the projected increase in risk between present and 2030 is 65% lower (56-73%; 5th to 95th percentiles) compared to the scenario with no urban planning (Figure 5.7). A full restriction of any building activity in flood prone areas could reduce the projected increase in flood risk by an average of 80%. The losses caused by coastal floods would still increase due to economic growth and sea level rise, and because of urban expansion in areas which are prone to floods with a lower return period than 100 years. However, as was shown is Section 4.6, urban expansion is a main driver of the upward trend in flood risk. Hence, there is a large potential for spatial planning as a risk-reducing measure.

Enhanced flood protection

While restricting urban expansion to non flood-prone areas may greatly reduce the increasing trend in flood risk, it will not prevent floods from happening and it will also not reduce the risk in areas that already have an urban land use. Therefore, we assessed the potential flood risk reduction that could be achieved by implementing flood protections measures designed to protect against floods up to given return periods (for example dikes and retention areas). These flood protection measures are incorporated in the model routine by truncating the risk curve at a given exceedance probability, which corresponds to an assumed protection standard, and estimating annual expected damage as the integral under the remaining part of the risk curve. We explored the effects of three different protection standards, 10, 50, and 100 years.

Table 5.4: The effect of different levels of flood protection on expected annual damages (EAD). The results shown are for the year 2030 under the scenario of medium SLR.

Protection level	**EAD (%GDP)**	**Reduction in EAD relative to no flood protection (%)**
No protection	0.0177 (± 0.0021)	N/A
1/10	0.0066 (± 0.0008)	63 (±0.10)
1/50	0.0015 (± 0.0002)	91 (±0.07)
1/100	*0.0008* (± 0.0001)	95 (±0.06)

The results are shown in Table 5.4. Clearly, raising the protection levels along the coasts of urban areas greatly reduces the risk. Floods with a relatively low return period are responsible for a large proportion of EAD, since they occur frequently. Even for a relatively low protection standard against 10 year floods, risk could be reduced by ca. 63%. A protection level corresponding to a 100 year flood could lead to a reduction in EAD of 95%. It is important to note that this flood protection analysis is highly dependent on the water level data of the

DIVA database. This is a global database, which has not been validated for Indonesia.

5.3.2 Key results

Based on these preliminary results, both spatial planning and flood protection seem highly effective strategies for reducing flood risk in Indonesia. Under the scenario of mean SLR, a full restriction of new urban land in flood prone areas could lead to an average risk reduction of 80%, relative to a scenario with no urban planning. Also, flood protection can greatly reduce risk. Even a low protection standard, i.e. flood protection against a 10 year flood, could reduce risk by 63% compared to a scenario with no protection.

6 Flood risk governance in Jakarta

The development of methods and tools for assessing flood risk is a very important step in developing flood risk management and adaptation strategies and measures. However, the actual implementation of adaptation strategies and measures is strongly dependent on an effective governance structure. As part of JCAT, we therefore carried out an extensive literature review to derive several key required characteristics of good climate change adaptation governance. Then, we assessed whether these characteristics are reflected in the flood risk management of Jakarta. The results of this study are described in detail in Ward et al. [2013b]. Secondly, we examined how a specific flood risk management plan in Jakarta can cope with an uncertain future, and how elements of adaptive planning are applied (or not applied) to flood risk management in practice? The results of this study are described in detail in Jeuken et al. [2014].

In this section, we provide a brief overview of the main findings of the above mentioned study of Ward et al. [2013b].

6.1 Flood risk management and governance characteristics

The findings in this section are taken from the paper by Ward et al. [2013b]. In that paper, we derived four characteristics identified in the literature as being important for governance related to climate change adaptation. We then examined whether these are reflected in the flood risk management activities in the cities of Jakarta and Rotterdam. In this section, we summarise the findings for Jakarta only.

An extensive review of recent literature on the governance of climate change adaptation was carried out [see Ward et al., 2013b]. From it, we distilled four characteristics that are commonly mentioned as being important for climate change adaptation:

- Its structure is multi-level, multi-domain, and multi-actor [Cash et al., 2006; Olsson et al., 2007];
- its orientation is flexible and robust [Raadgever et al., 2008; Van Buuren et al. 2010a];
- its content accommodates a plurality of societal, economic and other values in combination with flood risk management [Pahl-Wostl, 2006];
- its timeframe is focused on the long-term, but looks for opportunities to integrate urgent matters in the short-term [Folke et al., 2005, Haug et al., 2009].

In the following sub-sections, we examine whether these characteristics are reflected in the flood risk management of Jakarta.

6.1.1 Structure of adaptation governance

Institutions involved in climate change governance need to deal with large uncertainties, for example both global projections of climate change, and their translation into physical and socioeconomic impacts at the local scale [Van Buuren et al., 2010a. As a result, climate change governance needs to be multi-level, multi-scale, and multi-actor.

Multi-level governance

As floods and their impacts cross sectors and geographical scales, adaptation to them can benefit from a capacity to function in multi-level government structures. In Jakarta, an example of multi-level governance can be seen in the responsibility for the city's drainage system, which is based on a three-tier government structure. Nevertheless, at the metropolitan level, political and administrative fragmentation also exists [Laquian, 2005; Firman et al., 2011]. For example, Firman [2011] states that no particular institution is assigned to accounting for managing climate change data; risk and vulnerability assessments; or disseminating climate-related information to the public.

Multi-scale governance: catchment scale approach

To manage water resources and flooding successfully, river catchments need to be assessed and managed in an integrated manner [Rahaman and Varis, 2005]. For cities, this means that flood risk management efforts need to cooperate with activities in upstream areas. In Jakarta, flood risks are related to upstream activities, including land-use change. To regulate the flows of the Ciliwung, upstream rehabilitation projects and reforestation programmes have been established. Jakarta Spatial Plan 2030 also specifically mentions the need to integrate upstream and downstream activities related to water management. In Section 5.1, we demonstrated that a theoretical full implementation of the spatial planning decree 54/2008 could have a significant influence on the discharge and sediment delivery of rivers flowing through Jakarta. It should be noted, though, that this is a national document that provides a framework for future developments, but that its ultimate success clearly depends on its actual implementation.

Transparency and openness regarding responsibilities and tasks

Successful collaboration in multi-actor settings requires good agreement on the allocation or division of responsibilities and tasks, and transparency on these agreements [Van Buuren et al., 2010a]. In Jakarta, an example of unclear responsibilities is the Coordinating Body for Jakarta Metropolitan Region Development (BKSP). BKSP has the task of coordinating, planning, and monitoring development in the Jakarta Metropolitan Region, but lacks authority for implementation [Firman, 2009, Firman et al., 2011].

6.1.2 The orientation of adaptation governance

Due to the large uncertainties involved, adaptation governance needs to be both flexible and robust. Such robustness and flexibility is exemplified in the concept of programme management [Van Buuren et al., 2010b]. Working from a programme, rather than an individual sector, means that robust aims can be set whilst at the same time allowing different organisations to cooperate on a project basis. To date, programme management has been limited in Jakarta, at least in terms of climate change adaptation. For example, Firman et al. [2011] state that Jakarta lacks an agency or institution to manage climate change data and activities.

Increasing decentralisation and the clearly expressed willingness of local government to engage in adaptation provides a window of opportunity for such programmes, and indeed recent years have seen large advances. The National Capital Integrated Coastal Development (NCICD) programme (formerly Jakarta Coastal Defence Strategy) is a clear example of this programmatic approach. As stated in documents related to NCICD (during the JCDS stage), the overall aim is to protect Jakarta against coastal flooding [JCDS, 2011]. To do this, a strategic plan was created that “integrates effective technical solutions to prevent flooding (dikes, retention ponds, pumps) with additional measures to make the technical solutions sustainable (piped water supply, sewerage and sanitation, resettlement), and with investment opportunities to make the overall plan financially feasible based on internal cross-subsidies and public-private partnership (land reclamation, toll roads, and deep seaport)”. An important aspect of the plan is integration. It therefore also aims to solve drinking water shortages, river pollution, and traffic jams, and to turn Jakarta into an “attractive place to live, work and invest” [JCDS, 2011]. Clearly, this programmatic approach is oriented towards robustness and flexibility. Also, the Spatial Plan 2030 can be seen as an explicit attempt to integrate spatial planning with several other values. For example, it explicitly mentions climate change adaptation (e.g. Articles 5 and 13), conservation (e.g. Articles 5, 10, 39, 43, 54, 64, 65, 75 and 95), and flood control and hazard zoning (e.g. 70 and 77).

6.1.3 The content of adaptation governance

The content of climate change adaptation must accommodate a plurality of societal, economic and other values. In Jakarta, several past reports have suggested that a lack of planning or integration across policy sectors has hampering flood impact reduction (Caljouw et al., 2005).

The flood risk management approach can be key to this integration, as it considers both the causes and the consequences of flooding. Two key facets of a risk approach are the development of methods and tools to assess the variables of importance in terms of flood risk, and the mapping of flood risk. These two facets have been at the core of JCAT. Also, the Spatial Plan 2030 and the NCICD are recent examples in Jakarta of where good integration across sectors is taking place.

6.1.4 The timeframe of adaptation governance

Due to the long-term character of climate change, adaptive measures should not be taken in the light of climate change alone. Adaptation should be integrated into other (long and short-term) societal aims and interests [Van Buuren et al., 2010a]. This can be seen in the concept of ‘mainstreaming’. Mainstreaming is the integration of current and future climate change vulnerabilities (or adaptation) within broader government policy aims and implementation programmes [Agrawala and Van Aalst, 2005].

The Jakarta Spatial Plan 2030 is a good example of such mainstreaming, assuming that its concepts and visions can be successfully implemented. It outlines a long-term vision for Jakarta, but explicitly tries to integrate in the short term between different scales, policy fields and institutions.

7 Societal relevance

An important component of JCAT was to ensure societal relevance of the project. This has been achieved by: several stakeholder workshops; developing and using the methods and tools with stakeholders; broad dissemination of the results outside the scientific community, and through higher education. An overview of some of the activities in these aspects is described below.

7.1 Stakeholder workshops

Kick off workshop

On 18 January 2011, the JCAT kick-off workshop was held in Jakarta, hosted by Prof. dr. Sopaheluwakan of the Indonesian Institute of Sciences (LIPI) and Delta Alliance Indonesia Wing. In the workshop, the JCAT team worked together with representatives from a large range of Indonesia organisations active in the fields of water and flood management, to refine and focus the main goals of the project. These organisations included LIPI-ICIAR, Jakarta DKI-PU, Jakarta DKI-Bappenas, ITB Bandung, BPPT, BMKG, Pusair, and many others. The workshop was highly interactive, which provided an opportunity for participants to share their insights on the problems, and to develop visions on focussing the research and linking it to the policy and decision making context. This helped to focus JCAT on elements of relevance to stakeholders in the policy and decision making fields.

International research workshop at World Delta Summit

On 23 November 2011, JCAT organised a session at the World Delta Summit in Jakarta. The session, which took the form of a half-day interactive workshop, was organised by the JCAT consortium and Royal Haskoning within the series '*Towards Adaptive Flood Risk Management of a Delta City*', and was highly praised by delegates and organisation. The main aim of the workshop was to ensure that the work being carried out in JCAT was useful for on the ground problems and activities in Jakarta. It was attended by approximately 40 representatives from international government and research institutes, NGOs, and consultants.

Session on Local Level Risk Assessment at the 5th Asian Ministerial Conference on Disaster Risk Reduction

On 22 October 2012, the JCAT team co-organised a session at the 5th Asian Ministerial Conference on Disaster Risk Reduction. The session was called '*Lo-*

cal Level Risk Assessment for Disaster and Climate Change: How risk assessment can assist local risk reduction and adaptation, governance and risk financing', and was co-organised by JCAT, the Pujiono Center (Indonesia), ActionAid (Bangladesh), Hankuk Academy of Foreign Studies (South Korea), the Agency for Assessment and Application of Technology (Indonesia), and the International Centre for Climate Change and Development (Bangladesh).

The session was important, in that it specifically provided substantive inputs to 5th AMCDRR Sub-theme 2 '*Local Risk Assessment and Financing*', and the '*High Level Roundtable Session*'. The session focused on how disaster risk reduction proponents in Asia could initiate efforts to drive a global change in the field of disaster risk assessment. It also showcased local practices in risk assessments for disaster and climate change and looked for common grounds that could be used as a starting point in developing a robust and integrated risk assessment methodology for disaster and climate change that combines community's perspective and state-of-the art science and technology in the field of risk assessment.

Final workshop

On 21st August 2014, JCAT consortium held its final workshop in Jakarta. The title and main theme was: '*Jakarta Climate Adaptation Tools: The Pathway to City Resiliency*'. The workshop was jointly organised by JCAT, the Jakarta Research Council (Dewan Riset Daerah DKI Jakarta; DRD) and the Indonesia International Institute for Urban Resilience and Infrastructure (i3URI). Several other partners and key institutions also supported the workshop, including the Delta Alliance Indonesia Wing.

The workshop served several purposes. The results and tools of JCAT were presented, and their possible uses discussed with delegates. Also, the concept of flood risk management in Jakarta as a Delta City was discussed in the wider framework of a Green Metropolis Jakarta 2050 Concept. Both JCAT and the Green Metropolis Jakarta 2050 Concept were discussed in the light of several over ongoing activities in Jakarta, including the Garuda Project.

The opening speech was delivered by His Excellency Ir. Basuki Tjahja Purnama, Vice Governor of Jakarta. In it, he empasised the importance of urban planning to achieve the goals of projects and programmes such as JCAT and the Green Metropolis Jakarta 2050 Concept. Presentations and speeches were given by a large range of stakeholders across many different levels and disciplines. The workshop was also attended by a wide spectrum of stakeholders, including representatives from different levels of government, NGOs, businesses, and scientific institutes.

7.2 Embedding of JCAT in local research and policy

Throughout the JCAT project, efforts were undertaken to ensure the embedding of the research and findings in the local research and policy spheres.

In terms of the local research agenda, JCAT has been closely linked to the activities of the Indonesian Institute of Sciences (LIPI). This is demonstrated by the fact that LIPI hosted both the JCAT kick-off workshop, as well a JCAT workshop within the series "*Towards Adaptive Flood Risk Management of a Delta City*" at the World Delta Summit in Jakarta. Moreover, both the Jakarta Research Council of DKI Jakarta and i3URI organised the final JCAT workshop.

In practical terms, several research collaborations have been undertaken with institutes in both Jakarta and Java. For example, the JCAT consortium worked with the Institut Teknologi Bandung (ITB) to develop both the STREAM and SDAS tools. The development of the Damagescanner-Jakarta tool has been undertaken as a joint activity with both the Indonesian Agency for the Assessment and Application of Technology (BPPT) as well as Deltares. In JCAT, we also developed flood hazard maps for future scenarios of climate change, in collaboration with both Deltares and Pusair. The collaborations involved using the SOBEK hydrology suite in both Jakarta and Delft.

Also, JCAT has successfully combined its own research objectives with those of local research programmes. For example, the development of the new vulnerability curves developed for use in Damagescanner-Jakarta was carried out in collaboration with BPPT. This activity involved a series of meetings and a workshop with experts in Jakarta, which was funded by the Ministry of Research and Technology (Ristek) through fund F1.129. This project also contributes to the developing an SMS based flood early warning system. This activity is ongoing, and has clear on the ground implications in terms of flood risk reduction.

JCAT has also worked closely with stakeholders from the decision-making and policy spheres. A main achievement of JCAT has been to help in raising the concept of the integrated flood risk management approach on the agenda. This has been achieved by the high-level workshops organised as part of the project. For example, the final workshop was co-hosted by the Jakarta Research Council of DKI Jakarta, and the welcome speech to this event delivered by His Excellency Ir. Basuki Tjahja Purnama, Vice Governor of Jakarta. The final report of the workshop (in preparation) will be delivered to the Governor's Office. The event was hailed as a success by participants, particularly in that it brought together delegates from a very wide range of disciplines; types of organisation (scientific, business, consultancies, NGOs, governmental); and levels, thus allowing for a timely and unique discussion of the important cross-cutting issues required for city resiliency and flood risk reduction.

The importance of JCAT for DKI Jakarta can be seen through the co-authorship of chapters in Jakarta in both the 2nd and 3rd volumes of the Connecting Delta Cities book series (Marfai et al., 2013; Ward et al., 2010). In these chapters, the findings of JCAT play a key role in demonstrating the approach of Jakarta in terms of flood risk and adaptation. Moreover, based on our most recent findings, PhD candidate Pini Wijayanti has been invited to give a special presentation on the economics of water management for the leading staff of DKI in Jakarta.

To develop the economic tools, several activities were conducted in close collaboration with agencies in DKI Jakarta. The flood damage survey was conducted under coordination with Bappeda, BPBD, and West Jakarta as well as South Jakarta municipalities. In the final phase of JCAT, the benefit and cost analysis of several flood adaptation measures will be estimated. This study will be conducted with data provided by PU, Bappeda, BPN, BPBD (DKI Jakarta) and Ministry of Public Works. The involvement of these institutions in the research and its application, demonstrates the relevance for policy-making.

The assessment of the influence of the spatial planning measures described in Perpres 54/2008 were carried out using the STREAM-Jakarta and SDAS-Jakarta tools, following a request from Director General of Spatial Planning of the Ministry of Public Works. The study therefore gives direct results of relevance for policy-making.

7.3 Dissemination outside scientific community

Next to the workshops described in Section 7.1, JCAT has disseminated its results outside the scientific community by contributing to several high-level reports and books. A number of examples are listed below:

- Marfai, M.A., P.J. Ward, A. Tobing & A. Triyanti, 2013. Jakarta. In: Molenaar, A., J. Aerts, P. Dircke & M. Ikert, (eds.), Connecting Delta Cities. Resilient cities and climate adaptation strategies. Rotterdam, Connecting Delta Cities.
- Ward, P.J., Y. Budiyono, M.A. Marfai, 2013. Flood risk in Jakarta. In: Munich Re (ed.), Severe weather in Eastern Asia. Perils, risks, insurance. Munich Re Knowledge Series Natural Hazards. Munich, Munich Re.
- PBL, 2014. Towards a world of cities in 2050 – an outlook on water-related challenges. PBL background report for UN Habitat Global Report. PBL Netherlands Environmental Assessment Agency, The Hague.
- Marfai, M.A. 2013. Bencana banjir rob. Studi pendahuluan banjir pesisir Jakarta. Yogyakarta, Graha Ilmu.

  - Ward, P.J., M.A. Marfai, A. Tobing. & C. Elings, 2010. Jakarta. In: Dircke, P., J.C.J.H. Aerts & A. Molenaar. (eds.), Connecting Delta Cities. Sharing knowledge and working on adaptation to climate change. Rotterdam, Connecting Delta Cities.

Also, the work of PhD candidate Yus Budiyono was featured in the Jakarta media, namely in the Koran Jakarta during the flood seasons of 2013 and 2014 (e.g. Kalkulasi Kerugian Banjir Jakarta (Koran Jakarta interview with Yus Budiyono), http://koran-jakarta.com/?4767-kalkulasi+kerugian+banjir+jakarta). In this newspaper, three articles were written describing adaptation options to the flood problem in Jakarta..

7.4 Education

- Two Indonesian PhD candidates are working towards the completion and defence of their PhD theses. Through JCAT, these candidates have developed strong networks with the Indonesian policy and scientific community, which will lead to the longevity of the knowledge developed once the project ends.
- In the Netherlands, another PhD candidate, Sanne Muis, has carried out the national scale flood risk assessment for Indonesia, carried out as part of JCAT.
- At Gadjah Mada University, flood risk in Jakarta and the methods developed in the JCAT problem, have been integrated into the MSc teaching program on Planning and Management of Coastal Area and Watershed (MPPDAS).
- At Gadjah Mada University, a text book on Jakarta Tidal Flood Hazard by Muh Aris Marfai has been developed for use the bachelor course on Disaster Management (Marfai, 2013).
- At the Institut Teknologi Bandung, STREAM-Jakarta and SDAS-Jakarta are used in the teaching syllabus of BSc and MSc students, and students from ITB were involved with developing the models.
  - The project leader, Philip Ward, has given a lecture on JCAT as part of a Bachelor’s level course on climate change and adaptation at The Hague University of Applied Sciences.
  - At Wageningen University, two students have been involved in JCAT through their B.Sc. and M.Sc. theses. First, in 2012, Jasmijn Appels wrote her B.Sc. thesis entitled, ‘Adaptation to Flooding in Jakarta: A Cost-Benefit Analysis of the Giant Sea Wall Project’. Second, in 2014 (currently), Nyima Zoutenbier is writing her MSc thesis about ‘Reducing Riverine Flooding in Jakarta: A model-Based Assessment of Different Mitigation Measures.

8 Main conclusions and recommendations

In this section we summarise our main findings with regards to the original aims of JCAT, before suggesting a number of avenues for future research. The conclusions are intended to provide a broad overview of how JCAT addressed the main research aims. For detailed conclusions pertaining to each individual section of the work, the reader is referred to the concluding remarks in each section.

8.1 Contribution to knowledge and capacity building, and dissemination of results

JCAT has contributed to knowledge and capacity building in three main ways, namely through education, workshops and joint research with stakeholders, and scientific research.

In terms of education, the core of JCAT has been the training of two Indonesian PhD candidates (Yus Budiyono and Pini Wijayanti). Both candidates have made good progress, and are now working towards the completion and defence of their PhD theses. Importantly, the JCAT project has allowed these candidates to develop very strong networks with the Indonesian policy and scientific community, which will lead to the longevity of the knowledge developed once the project ends. Moreover, a Dutch PhD candidate has also been involved in the JCAT research, developing a tool for national scale flood risk assessment. Furthermore, JCAT has been used in the teaching of both MSc and BSc students at Wageningen University, Gadjah Mada Univeristy, and ITB Bandung, as well as students at The Hague University of Applied Sciences.

As described in Section 7.1, JCAT has organised several successful and well-attended workshops in Jakarta and Yogyakarta, aimed at learning from local and international scientists and stakeholders, ensuring that the research of JCAT is embedded in the research needs of Jakarta, and the dissemination of the scientific results. These workshops have ensured that the flood risk approach, rather than only focusing on managing flood hazard, have become important aspects in discussions on flood risk in Jakarta.

JCAT has placed a large emphasis on the dissemination of results within and outside the scientific arena, both in Jakarta as well as internationally. An overview of all JCAT publications to date can be found in Annex 1. In summary, 6 scientific papers have already been published or are in press, with another currently in review. By the end of 2014, current expectations are that another 3 papers will have been submitted. Also, 4 books or book chapters have been published, both scientific and policy oriented, including contributions to the third *Connecting Delta Cities* book, and Munich Re's flagship publication on *Sever Weather in Eastern Asia*. Next to this, JCAT has published results in 7 reports or conference proceedings, and 23 presentations have been given.

8.2 Development and improvement of methods and tools

A large number of methods have been developed or improved, which can be used by scientists and decision-makers in assessing issues related to flood risk in Jakarta.

The STREAM-Jakarta model has been developed, and can be used to assess the water-balance and river discharge of river catchments flowing into the Bay of Jakarta. The SDAS-Jakarta model has also been developed, which can be used to assess changes in erosion and sediment delivery in the same catchments. These two models can be used for rapid assessments of the water balance and sediment delivery, either under past, current, of future conditions. The models are housed at ITB-Bandung.

A model has been developed to assess current and future economic exposure to coastal flooding in northern Jakarta. This simple model can give estimates of economic exposure to coastal flooding under different scenarios of sea level rise, land subsidence, and land use change. The model is housed at Gadjah Mada University Yogyakarta.

A river flood risk model, Damagescanner-Jakarta, has been developed to assess flood risk under current and future conditions. It can be used with scenarios of climate change, land subsidence, land use change, and economic growth, to estimate changes in annual expected damage between current conditions and future conditions. The model is housed at BPPT. Building on from this development, a national scale probabilistic flood risk assessment model has been developed for Indonesia. This model incorporates both river and coastal flooding, and can simulate flood risk under current conditions as well as under future scenarios of climate and land use change. The model is housed at IVM-VU University Amsterdam.

Complementary to the city scale flood risk assessment method mentioned above, a survey has been carried out to examine the relationship between flood damages and actual past flood events in flood prone areas along the Pesanggrahan River. This has resulted in a regression model that can be used to rapidly assess local actual damages, both direct and indirect, for a specific flood event. The data and model are housed at Wageningen University.

Two methods have been developed for modelling economic aspects related to flood protection measures. The first is an economic modelling tool that can be used for the selection of potential flood protection measures, and the second is a Cost-Benefit Analysis tool for assessing the feasibility of various flood protection measures. These are housed at Wageningen University.

8.3 Improved flood risk information by incorporating scenarios of future changes in physical and socioeconomic conditions

Prior to JCAT, quantitative assessments of the impacts of future changes in physical and socioeconomic conditions on factors related to flood risk were few. In part, this may be due to the lack of officially mandated scenarios of climate and environmental change. Since no such uniform scenarios are available specifically for Jakarta, in JCAT we used several scenarios on an *ad hoc* basis. This allows us to give first assessments of the influence of changes in physical and socioeconomic conditions, using the methods developed. Once more detailed scenarios of these changes for Jakarta become available, their impacts on factors related to flood risk can be assessed using the JCAT methods in future projects.

River flood risk in Jakarta
As a basis, Damagescanner-Jakarta uses inundation maps previously developed by Deltares and Pusair to represent flood hazard. These high-quality flood inundation maps are well known and used in Jakarta. We combined them with maps of exposure, and vulnerability functions to assess flood risk.

One of the challenging aspects of this assessment was the representation of vulnerability. In Damagescanner, vulnerability is represented by depth-damage functions, or vulnerability curves. In the scientific literature, it is common practice to transfer curves from other cities to carry out risk assessments. However, we assessed the sensitivity of flood risk estimates to this approach, and found that the use of vulnerability curves from different Southeast Asian cities led to large differences in risk estimates. Hence, we held a series of meetings and a workshop to develop new synthetic vulnerability curves. This led to improved estimates of flood damages when compared to the adoption of vulnerability curves from other cities. Hence, flood risk assessments need to pay close attention to the selection, development, and testing of case-specific vulnerability curves.

We used the model to estimate current flood risk in Jakarta, obtaining an estimate of US$ 321 million/year. Under future scenarios of climate change, land subsidence, land use change, and economic development, we projected an increase in risk by a factor of 2.2-5.7 between present and 2030, assuming current asset values. If we also projected increases in asset values, this rises to a factor of 7.5-19.5. The driving factor with the largest influence on this increase in risk is land subsidence (factor 2.7). The importance and severity of land subsidence in Jakarta is already well-known and high on the political agenda, but this study provides the first quantitative estimate of its potential impact on flood risk.

The impact of future climate change alone on river flood risk is highly uncertain. We modelled the change in flood risk between present and 2030 under 42 simulations of future climate (5 climate models x 4 precipitation scenarios x 2 sea level rise scenarios). Out of these 42 simulations, 21 showed an increase in future risk whilst 21 showed a decrease. However, potentially the contribution of climate change to increased future flood risk could be large, with a factor increase >3 in some of the simulations. Moreover, even under the climate change simulations with the largest decrease in risk, this decrease is not enough to cause an overall decrease in projected future flood risk when the other driving factors are included. This highlights the clear need for urgent adaptation, regardless of the driving factor of change.

Coastal economic exposure in Jakarta

We developed a GIS-based tool for rapid inundation mapping and economic exposure estimation for extreme coastal flood events in Jakarta. This approach does not include vulnerability, and hence the estimates refer to potentially exposed values rather than actual damages or risk.

Under current conditions, the potential economic exposure to extreme flood events is high: ca. €4.0 billion for 1:100 year events and €5.2 billion for 1:1000 year events. Under the future scenario of sea level rise and subsidence until 2100, the economic exposure estimate increases to ca. €17 billion. The dominant driver of this increase in economic exposure is land subsidence. Despite large uncertainties in the land subsidence projection, the findings again highlight the need for urgent attention to the land subsidence problem.

Flood risk in Indonesia

We also carried out a quickscan of national scale flood risk in Indonesia. In this report, the results of this analysis are expressed in terms of annual expected damage as a percentage of GDP. We found that between 2000 and 2030, urban expansion will cause these values to increase by 76% (river flooding) and 121% (coastal flooding). These are average values, but the probabilistic method also allows for assessing changes in risk across a probability distribution. The most rapid increases in risk are projected in West Java. Until 2030, the influence of climate change alone on national scale river flood risk is highly uncertain, either resulting in increases or decreases, depending on the combination of scenario and climate model. For coastal flooding, projected increases in sea level rise could cause annual expected damage to increase to 0.023% of GDP, which is more than double the risk in 2000. It should be stressed that the analyses carried out so far for the national scale flood risk assessment do not include land subsidence: future research should also attempt to include this factor at the national scale.

River discharge and sediment yield
We investigated trends and changes in river discharge and sediment yield . Over the entire time-period 1901-2005, there were no significant trends in discharge in any of the basins. For sediment yield, there has been a significant upward trend in the Ciliwung and Cisadane basins over the entire time-period 1901-2005, with particularly strong trends in the last 25 years.

For both discharge and sediment yield, we found that the impact of land use change has been greater than the impact of changes in climate over the last century. Land use change alone led to an increase in discharge over the period 1901-2005, whilst the influence of climate change was small. For sediment yield, both land use change and climate change have contributed to increasing amounts between 1901-1920 and 1981-2005. The relative influence of land use change on sediment yield was approximately factor 9 larger than the influence of climate change in the Ciliwung, and factor 4 large in the Cisadane. Increasing erosion and sediment yield can contribute to increasing loads of sediment in Jakarta’s waterways, and hence reduced drainage capacity.

Finally, we assessed the influence of projected future climate change on annual and monthly river discharge. The results show that the influence of climate change on discharge is highly uncertain. Out of 5 GCMs used, the change is relatively small (increase or decrease) for 3 GCMs, whilst 2 GCMs project large decreases in discharge throughout the year. If this were to occur, this would have a large influence on water resource management of the basin. Only a few GCM-RCP combinations project an increase in discharge, and the projected increases are relatively small (compared to the simulated decreases in other GCM-RCP combinations).

8.4 Assessing the impacts of several adaptation strategies

Whilst the main aim of JCAT was to develop methods and tools to assess flood risk related parameters, we also aim to demonstrate the potential use of some of those tools by applying them to assess a number of adaptation strategies or measures. The majority of these applications will be carried out in the final stage of JCAT, and are therefore not included in this report. These applications will become available in subsequent papers and reports.

We carried out a modelling exercise using STREAM-Jakarta and SDAS-Jakarta to estimate the potential impacts that a full implementation of the spatial planning decree Perpres 54/2008 would have on river discharge and sediment yield. A full implementation could lead to modest decreases in mean annual river discharge (5.6% in the Cisadane; 2.2% in the Ciliwung), but very large reductions in sediment yield (22% in the Cisadane; 61% in the Ciliwung). These findings are very important for water and flood management in the city of Jakarta and its surroundings. Sedimentation of Jakarta's waterways has greatly exacerbated the flood problem in recent years. Here we have shown that good spatial planning practices have the potential to reduce the amount of sediment delivered to the city, thus reducing the flood hazard, and consequently the risk. Moreover, this reduced sediment delivery could reduce to some extent the need for (and cost of) expensive dredging activities.

Our river flood risk modelling results also show the potential impact that well implemented spatial planning could have on flood risk. In our simulations for the future, we only used one land use change scenario, namely the land use maps of the Spatial Plan 2030. This scenario represents an idealised situation, in the case that the land use planning envisioned for the coming decades is successfully implemented, rather than a scenario of unplanned development. Under this scenario, flood risk would increase by a factor of ca. 1.1 between present and 2030. Given that changes in exposure through urban development are seen as one of the main drivers of risk in cities in most developing countries, such a small increase could be interpreted as positive. However, it should be noted that achieving this would entail very strong governance structures, strong spatial planning laws, and thorough implementation.

By carrying out a large number of surveys with households and businesses in flood prone areas along the Pesanggrahan River, and in-depth interviews with inhabitants and stakeholders in northern Jakarta, we have also inventorised a number of household-level and community-level adaptation measures that are already being employed to reduce flood risk. Measures that are already frequently being taken at the household-level include those designed to reduce vulnerability to flooding by moving upwards. Examples include: heightening the first floor of houses; building second floors of buildings; and having attics. Moreover, a large number of inhabitants reduce their own vulnerability by building concrete/board constructions outside the door, to prevent water from entering buildings. A number of measures are also already taken at the community level. For example communal works are undertaken to clean rivers and drainage channels, and to building small dikes around settlements.

A useful next step would be to try to assess how much flood risk is already avoided by the adoption of such measures, and how much more flood risk could be avoided if their adoption was increased. For example, how effective are small scale adaption measures in comparison to larger scale measures such as major dikes, flood canals and so forth.

At the national scale, JCAT is currently examining the potential reduction in flood risk that can be achieved by the implementation of two risk reduction strategies: strategic urban planning and enhanced flood protection. The results presented in this report are preliminary, and so far refer to coastal flooding only. However, they already give an indication of the magnitude of risk reduction that such large scale adaptation strategies could potentially achieve. Under the scenario of mean SLR, a full restriction of new urban land in flood prone areas (i.e. those potentially exposed to a 100 year flood) could lead to an average risk reduction of 80%, relative to a scenario with no urban planning. Also, flood protection can greatly reduce risk. Even a low protection standard, i.e. flood protection against a 10 year flood, could reduce risk by 63% compared to a scenario with no protection. Given these encouraging numbers, future research should examine both the benefits and costs of such strategies in more detail.

8.5 Future research directions

The JCAT project has played an important role in developing new methods for the assessment of flood risk and flood risk related parameters; and in placing flood risk on the agenda in Jakarta. Nevertheless, the project is only able to provide a starting point for further developments in this field. Evidently, a large number of research needs remain. Hereunder a few key research needs and directions are briefly listed, although the list is clearly not exhaustive:

- We have developed a large range of methods and tools, and where possible used these to assess changes in flood risk related parameters due to past and future changes in physical and socioeconomic conditions. However, one of the main hindrances in this process is the lack of mandated scenarios of climate, environmental, and socioeconomic change, specifically designed for impact studies in Jakarta. Hence, we have necessarily used available scenarios on an *ad-hoc* basis. The development of official scenarios, tailored to the situation of Jakarta, should be a research priority. For example, in this project we used climate change scenarios derived from GCMs. The uncertainty of these models at the global scale is large, let alone for Jakarta. Tailored climate scenarios for Jakarta based on a suite of regional climate models would allow for more consistent modelling of climate impacts. The same is true for the scenarios used for the other driving factors. The methods and tools are now available so that the analyses could be carried out once such scenarios become available.

- In JCAT, we have only investigated model uncertainty in some small parts of the work (e.g. the use of different vulnerability curves, the probabilistic projections of land use change at the national scale). Future studies would benefit from an assessment and quantification of uncertainty.
- To date, the JCAT methods have only been used to assess the potential impact of a few adaptation measures and/or strategies to decrease flood risk. Further applications are planned during the final phase of JCAT, especially using Damagescanner-Jakarta, and the economic and cost-benefit analysis tools.
- Further research is needed on the integrated socio-economic and hydrological analysis of measures to reduce flooding in Jakarta and more profound insight in the costs and benefits of the various options to reduce the risks and impacts of flooding need to be obtained.
- Even if flood risk measures and strategies are shown to be effective, research is needed to assess barriers to their successful implementation. A start to this is the work described in Section 6, where we assessed the governance structure of adaptation in Jakarta related to four key characteristics required for adaptation, namely: structure, orientation, content, and timeframe. We have identified several aspects in which the governance structure in Jakarta appears to be well aligned to these characteristics, and given suggestions of aspects where further attention may be required. However, this analysis only provides a start, and more in-depth research and analyses are required.

More broadly, JCAT has developed knowledge on possible changes in flood risk in the future, and methods and tools to assess the benefits, and/or the costs, of a range of adaptation measures. Also, the knowledge base on flood risk management in Jakarta has been increased by the training of the two PhD candidates, and the collaboration with stakeholders. Of course, an important next step would be to actually use these methods and tools to help in developing a strategic vision for flood risk reduction in Jakarta. This could be done by using the developed methods, and expertise, in the context of the many activities or already ongoing in Jakarta, such as the National Capital Integrated Coastal Development program (NCICD) or the activities of the Jakarta Research Council.

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10 Annexes

Annex 1: Publications of this project

Scientific papers (published, in press, or in review)

- Budiyono, B., J.C.J.H. Aerts, J. Brinkman, M.A. Marfai, P.J. Ward, 2014. Flood risk assessment for delta mega-cities: a case study of Jakarta. Natural Hazards, online first, doi:10.1007/s11069-014-1327-9.
- Poerbandono, M. Julian & P.J. Ward, 2014. Assessment of the effects of climate and land cover changes on river discharge and sediment yield, and adaptive spatial planning in the Jakarta region. Natural Hazards, 73, 507-530, doi:10.1007/s11069-014-1083-x.
- Marfai M.A., A.B. Sekaranom & P.J. Ward. Community Response and Adaptation Strategies towards Flood Hazards in Jakarta-Indonesia. Natural Hazards, online first, doi:10.1007/s11069-014-1365-3.
- Wijayanti, P., X. Zhu., P. Hellegers, Y. Budiyono & E.C. van Ierland, 2014. River flood damage estimation in Jakarta, Indonesia. In review.
- Jeuken, A., M. Haasnoot, T. Reeder, T. & P.J. Ward. Lessons learnt from adaptation planning in four deltas and coastal cities. Accepted for publication in Journal of Water and Climate Change.
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- Ward, P.J., M.A. Marfai, F. Yulianto, D.R. Hizbaron & J.C.J.H. Aerts, 2011. Coastal inundation and damage exposure estimation: a case study for Jakarta. Natural Hazards, 56, 899-916, doi:10.1007/s11069-010-9599-1.

Books and book chapters

- Marfai, M.A., P.J. Ward, A. Tobing & A. Triyanti, 2013. Jakarta. In: Molenaar, A., J. Aerts, P. Dircke & M. Ikert, (eds.), Connecting Delta Cities. Resilient cities and climate adaptation strategies. Rotterdam, Connecting Delta Cities.
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- Marfai, M.A., 2013. Bencana banjir rob. Studi pendahuluan banjir pesisir Jakarta. Yogyakarta, Graha Ilmu.
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- Ward, P.J., M.A. Marfai, A. Tobing. & C. Elings, 2010. Jakarta. In: Dircke, P., J.C.J.H. Aerts & A. Molenaar. (eds.), Connecting Delta Cities. Sharing knowledge and working on adaptation to climate change. Rotterdam, Connecting Delta Cities.

Reports and proceedings

- PBL, 2014. Towards a world of cities in 2050 – an outlook on water-related challenges. PBL background report for UN Habitat Global Report. PBL Netherlands Environmental Assessment Agency, The Hague.
- Marfai, M.A, A. Triyanti, 2013. Community based flood disaster management (Comparative study of Jakarta and Surakarta). Proceedings of the Joint Scientific

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