Connecting Delta Cities

COASTAL CITIES, FLOOD RISK MANAGEMENT AND ADAPTATION TO CLIMATE CHANGE

Connecting Delta Cities

Jeroen Aerts, VU University Amsterdam
David C. Major, Columbia University
Malcolm J. Bowman, State University of New York, Stony Brook
Piet Dircke, Rotterdam University of Applied Sciences
Muh Aris Marfai, Gadjah Mada University, Yogyakarta

COASTAL CITIES, FLOOD RISK MANAGEMENT AND ADAPTATION TO CLIMATE CHANGE

Colophon

Authors
Jeroen Aerts, David C. Major, Malcolm J. Bowman, Piet Dircke, Muh Aris Marfai

Contributing authors
Abidin, H.Z., Ward, P., Botzen, W., Bannink, B.A., Nickson, A., Reeder, T.

Sponsors
This book is sponsored by the City of Rotterdam, and Rotterdam Climate Proof and the Dutch research program for Climate (KvK). The Connecting Delta Cities network has been addressed as a joint action under the Clinton C40 initiative. For more information on these initiatives and their relation to Connecting Delta Cities, please see: *www.deltacities.com.*

Supporting Organizations
This book summarizes the outcome of the Connecting Delta Cities Workshop, June 9-10th 2009 in New York City. This workshop was a joint effort of the following organizations:

Columbia University Earth Institute Center for Climate Systems Research

Acknowledgements
We gratefully acknowledge the generous support and participation of Adam Freed (City of New York), Aisa Tobing (Jakarta Governor's Office), Raymund Kemur (Ministry of Spatial Planning, Indonesia) and Arnoud Molenaar (City of Rotterdam). We thank the City of London, Alex Nickson, Tim Reeder of the UK Environment Agency, Robert Muir-Wood and Hans Peter Plag for their participation and support. We furthermore thank Florrie de Pater of the Knowledge for Climate program for her support on communication aspects, Mr Scott Sullivan and his staff of Stony Brook University for providing facilities and assistance at the Manhattan campus, Cynthia Rosenzweig and colleagues at Columbia and NASA GISS for information and participation, Klaus Jacobs of Columbia University, William Solecki of Hunter College and Dennis Kamber of Arcadis for special assistance, and all the participants and agencies who contributed in so many ways to make the Connecting Delta Cities International Workshop a success. We also thank Laurens Bouwer, Susan van 't Klooster, Chantal Oudkerk Pool, Coline Lugassy, Jan Jaap Brinkman, Jan Oegema, John Jacobs, Marco van Bodegom (Beau-design.nl), Marijn Kuitert and Ronald Mijnders for their support. For reviewing the manuscript, we thank Vivien Gornitz, Daniel Bader and Radley Horton. Finally, Raymond Hafkenscheid and the CPWC (Co-operative Programme on Water and Climate) are acknowledged for their support in the production of the "Connecting Delta Cities" documentary movie.

ISBN 978 90 86593 63 7

Contents

Preface

The Netherlands has a long history with water. In the olden days, while merchants sailed the seven seas, engineers on shore were busy reclaiming land in a process called impoldering. This struggle with and war against water has brought the Netherlands and the delta city of Rotterdam to where we stand now: Today, Rotterdam takes up a leading position in the area of water management. Rotterdam is the Gateway to Europe, a port city of international stature.

Currently, a new challenge awaits the world. Climate change will have a severe and inevitable impact, even if we do succeed in substantially reducing its causes and mitigating its effects. Water levels will rise, both in the sea and in the rivers that run through the cities. Precipitation levels will increase, and groundwater levels will change. Preventing or limiting ensuing damage will require a great deal of effort.

Rotterdam, like the other delta cities described in this book, is thoroughly aware of the necessity to expand this effort. Courage is required on the part of the administration to take decisions now that will fill our children with pride in the future, and to take measures to provide safety to our residents and to preserve the economic appeal of our cities.

Of at least equal importance as decisive management is the availability of scientific knowledge. For the measures that are needed fall outside the scope of our current technological ingenuity. Sharing and exchanging insights and experiences with projects in the area of water management will contribute to the development of the necessary new expertise. It gives me great satisfaction to observe that more and more cities are willing and prepared to share knowledge and opportunities for improvement.

Rather than copying the insights that are gained, other delta cities subsequently apply adapted versions according to their own situation. This allows individual cities to define ambitious goals and actually realize them. It is for this reason that I can state with confidence: By 2025, Rotterdam will be fully climate proof.

This book builds a bridge between three delta cities of global stature: New York, Jakarta, and Rotterdam. These are three of the dozens of cities that are confronted with a new approach to water management on an international scale.

Each of these cities grapples with its own problems and devises its own solutions. What binds these cities, however – what they can identify with and helps them to encourage one another – is their common determination to win this fight.

Ing. A. Aboutaleb
Mayor of Rotterdam

Introduction

Several decades of climate change and sea level rise may exacerbate flood risks from storm surges as well as peak river discharges in large coastal cities. As a consequence, the vulnerability of infrastructure, people, nature and other economic sectors is expected to increase in the decades to come [22, 37].

At present, more than 50% of the entire world population lives in cities. According to the United Nations, more than two thirds of the world's large cities are vulnerable to rising sea levels, exposing millions of people to the risk of extreme floods and storms. Within the next 30 years, the United Nations predicts that the number of people living in cities will increase to 60% of the world's population, resulting in even more people living in highly exposed areas. Hence, socioeconomic trends further amplify the possible consequences of future floods as more people move towards urban coastal areas and capital is continuously invested in ports, industrial centers and financial businesses in flood-prone areas.

Both scientists and policy makers have addressed the issue of adapting to the challenge of climate change, and both call for embedding long-term scenarios in city planning and investments in all sectors. The Stern Review[1] presented a global estimate of the costs of adaptation to climate change, suggesting that for most countries, protection costs are likely to be below 0.1% of the gross domestic product (GDP), at least for protection measures that anticipate a 0.5-meter sea level rise. However, for the most vulnerable countries or regions, costs could reach almost 1% of GDP, and for a rise in sea level of one meter, the costs could even exceed several percent of GDP. Based on these estimates of adaptation costs, it appears that investing in adaptation *now* would save money in the long term. Developing and implementing adaptation measures is a complex process, and it is important that policy makers and investors do not inappropriately postpone taking decisions with long-term consequences.

Since the choices made today will influence vulnerability to climate risks in the future, it is important to link adaptation measures to ongoing investments in infrastructure and spatial planning, and to draw up detailed estimates of the benefits of adaptation. In this way, adaptation becomes a challenge rather than a threat, and climate adaptation may initiate opportunities and innovations for investors and spatial planners. Challenges include, for example: are current city plans climate proof or do we need to fine-tune our ongoing investments?; can we develop a flood proof subway system?; and can we develop new infrastructure in such a way that it serves flood protection, housing and natural values?

This book explores the different aspects of climate adaptation; it is an independent investigation of comparative adaptation problems and progress in the cities of Rotterdam, New York and Jakarta. It focuses on the three cities as delta (or coastal) cities. In this regard, each city faces different challenges; one of the lessons of the Connecting Delta Cities initiative is that while cities will follow adaptation paths that may differ, sometimes substantially, each city can learn from the others. Moreover, while this book focuses in large part on coastal flooding, it is important to note that each of the three cities is also affected by climate change in other ways, including impacts that occur away from the coast. The New York City Water Supply System, for example, stretches as far as 120 miles upstate, and the New York City Department of Environmental Protection has undertaken extensive climate assessment not only for its coastal facilities, but also for its upstate facilities, which will be affected by rising temperatures, droughts, inland flooding, and water quality changes.

Socioeconomic developments

2

Being harbor cities, Rotterdam, New York and Jakarta have always been centers of immigration, and melting pots of people with different cultural backgrounds. Immigration plays a crucial role in the development of the populations of Rotterdam, Jakarta and New York. There are, however, differences in how each of the cities' populations have developed.

2 1

Rotterdam: Historical ties

Rotterdam is considered the marine gateway to western Europe and is situated on the banks of the "New Meuse" River ("Nieuwe Maas"), one of the channels in the delta formed by the rivers Rhine and Meuse. Rotterdam has a long history as a port and is currently the second largest port in the world in terms of tonnage. It is, however, also a vulnerable location to floods as most of the city's neighborhoods are located below sea level. The harbor areas lie several meters above sea level and are all human-made dwelling lands which were developed over the last centuries. An important date in the history of Rotterdam is May 1940, when large parts of the city were completely destroyed during a bombardment by the Luftwaffe (German Air Force). The center of Rotterdam, therefore, was completely rebuilt after the Second World War except for a few buildings such as the Town Hall and the Laurens Church (Figure 2.4).

Giovanni Da Verrazzano (also spelled Verrazano), an Italian, is believed to be the first European to have explored, in 1524, the area now known as the New York Harbor. Although Da Verrazzano was the first explorer to visit the location of present-day New York City, it is Henry Hudson who claimed Manhattan for the Dutch VOC in 1609, sailing as far as Albany in his ship the Halve Maen (Half Moon) up the river that bears his name. Over the next 20 years, many Dutch, Walloons, Huguenots, Africans and others settled in New Amsterdam, the principal city and port of New Netherlands. Peter Minuit, a Dutch political director, is credited with making the "deal of the century" when he bought Manhattan Island from the Canarsee Indians for only $24, according to some publications. The Dutch continued to control New Amsterdam until 1664 when the British navy took control of the city from the then Dutch Governor, Peter Stuyvesant. England renamed the city and the colony, New York, after James, Duke of York. Thereafter, except for a brief interlude of Dutch control (1673-1674, when the city was called New Orange), New York remained a colony until the American Revolution was won in 1783. It was the first capital of the newly independent United States.

The history of Jakarta dates back to at least the 14th century, with the development of a small port of the Hindu Pajajaran Kingdom at the mouth of the Ciliwung River. Searching for the fabled "Spice Island", the Portuguese were the first Europeans to arrive and to establish a fortress on the site in the early 16th century. Dutch spice merchants arrived in the late 16th century and began a trading association with Europe. This event was decisive for the story of Jakarta. The Dutch proceeded to rule the town of Jakarta, and the Indonesian archipelago, for nearly 350 years until Indonesia gained independence in 1945.

1. Jakarta 1652 [2]
2. Jakarta 2009
3. New York, Manhattan 1660
4. New York, Manhattan 2009
5. Rotterdam 1652 [3]
6. Rotterdam 2009

Figure 2.1. Jakarta, New York, and Rotterdam in the 17th century, and today.

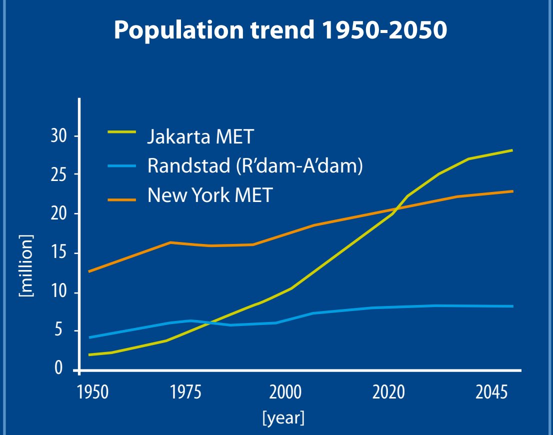


Figure 2.2. Historical and future population trends in the Metropolitan areas of New York, Jakarta and Rotterdam ("Randstad").

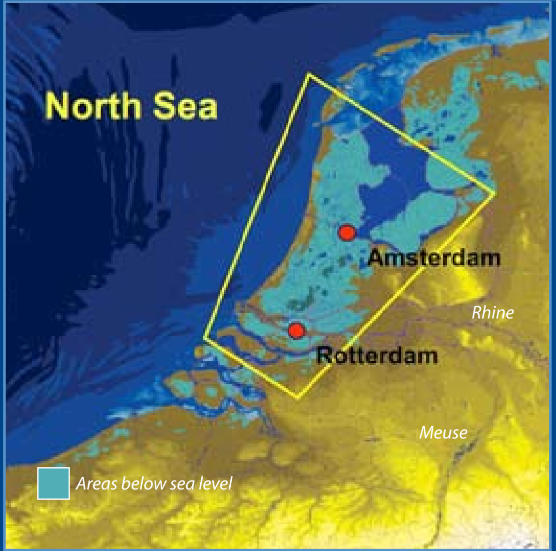


Figure 2.3. The area between Rotterdam and Amsterdam is called the "Randstad", and is one of the largest European metropolitan areas. Most of the Randstad conurbation lies below sea level, which is depicted in light blue.

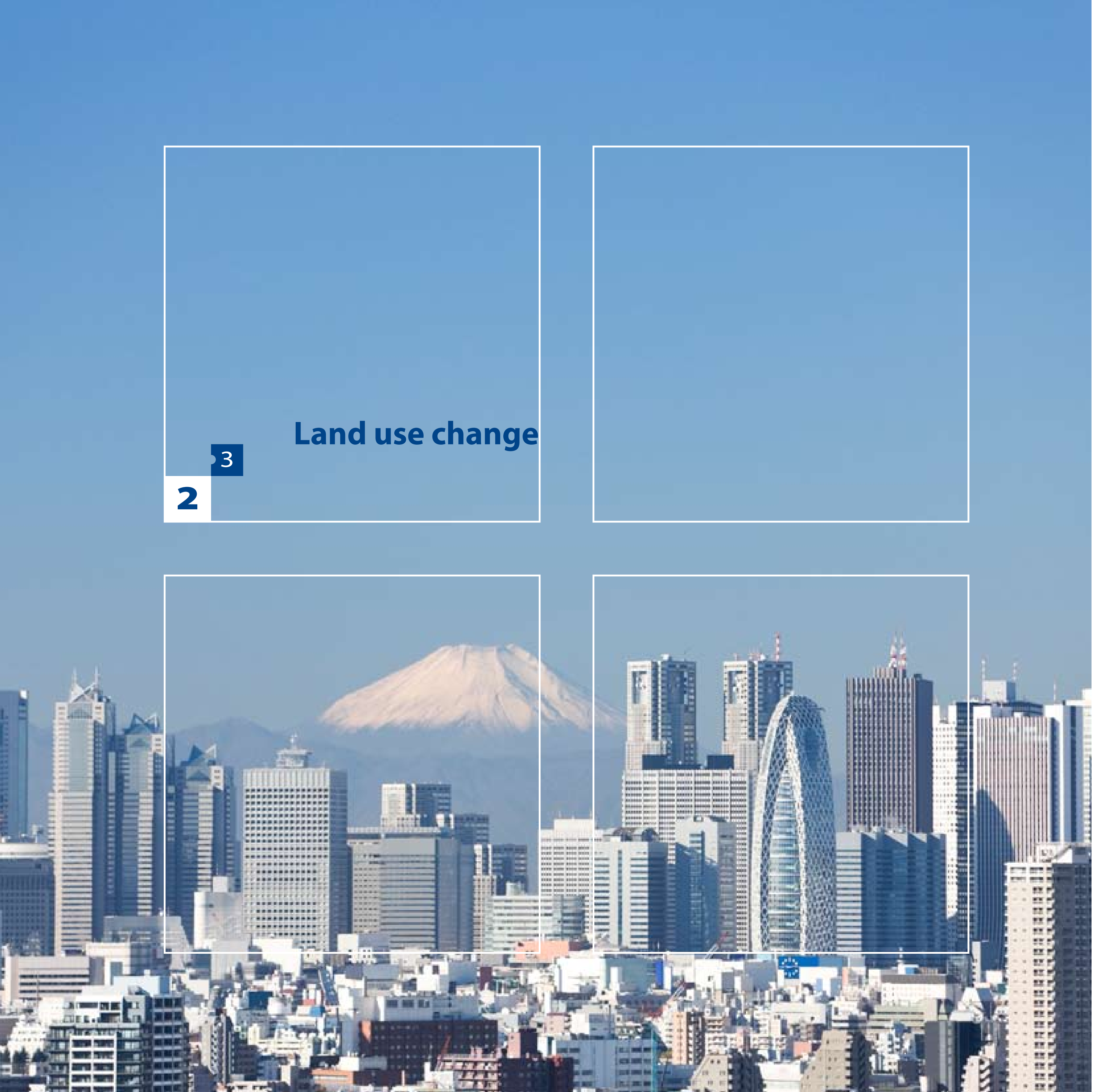
2

2 Trends in population

Soon after the end of World War II, and persisting throughout the 1960s, many industrialized cities, such as Rotterdam and New York, experienced a significant peak in birth rates that produced the generation known as the Baby Boomers. In Rotterdam, labor supply growth increased over the 1970s, as the Baby Boom generation entered the labor force, and continued to grow throughout the 1990s. This was also partly the result of an unprecedented number of women entering the workforce, as well as positive net migration rates over the same period. By 2000, the Netherlands' birth rate fell to 1.5 from 3.06 in 1950; over the same period, life expectancy rose by 5 and 8 years for men and women respectively. Currently, the population of Rotterdam is aging rapidly.
For the Randstad conurbation (the urban area from Rotterdam to Amsterdam), population growth is expected to continue to increase (although at a lower rate than in New York and Jakarta), mainly due to the expected net immigration.

New York City experienced an exceptional period of growth during the 19th century. In 1800, when the city still consisted primarily of Manhattan, the population was 60,515; by 1890 (the last census prior to the consolidation of the present city in 1898) it was 1,515,301, including the West Bronx. The opening of the Erie Canal (the first year of full operation was 1826) provided an efficient transportation network for midwestern grain and other commodities for use both domestically and for export through New York Harbor. Railways and steamboats were important elements of economic development from the first part of the 19th century, and the opening of the Croton water system (1842) for the first time brought clean water, and much improved public health, to the city's population. The consolidation of the city within its present boundaries occurred in 1898.

Except during the 1980s, New York's population has grown from the 1950s onwards to more than 8 million inhabitants. The projected population in Metropolitan New York (MET) in 2050 could be as high as 23 million residents. The growth rate depends on the extent to which immigration from other countries continues at high rates. A well-known example of the influence of immigration could be seen in the 1990s. After a decline in the population of New York in the 1980s, nearly 1.2 million immigrants settled in New York City in the 1990s. This high level of immigration has, to a large extent, countered a net outflow of residents to other parts of the nation.
For Jakarta, the projected growth rates are even higher than for New York. Jakarta is a magnet for migrants from other areas of Indonesia. During the late 1980s, an estimated 250 migrants arrived daily. There are also a significant number of commuters and seasonal migrants who work in government, manufacturing, and services. In addition, many of these temporary residents are engaged in informal employment as drivers, vendors, street sweepers, or in other similar occupations. Population growth in Jakarta is high, and reducing this growth rate is a national priority.
In the 1970s, efforts to control growth by prohibiting the entry of unemployed migrants failed. The current strategy emphasizes family planning, dispersing the population throughout the greater Jabotabek region, and promoting transmigration (the voluntary movement of families to Indonesia's less populated islands).



2.3 Land use change

Population growth, and as a consequence urban development, has a huge impact on land use. Studies carried out to assess the effects of population growth and land use change in the Randstad conurbation show that flood risks have increased over the last 50 years by a factor of 7 due to urbanization. Thus, even without climate change, flood risk will increase simply because residents and businesses continue to settle in vulnerable locations.

Furthermore, research shows that by 2025, loss potentials among the world's 10 largest cities (most of which are in developing countries) are projected to increase by between 22% (Tokyo) and 88% (Shanghai & Jakarta). A repetition in the year 2015 of the floods experienced in Jakarta in 2007 could cause 60% higher losses and affect 20% more people because of population and economic growth, independent of climate change. Since economic and urban development in these areas is inevitable, and the economic impacts of climate change may not only be limited to the city boundaries, rising sea levels could have devastating effects on the worldwide population and economic activity in the future.

1. New York, Manhattan -1664
2. New York, Manhattan -1880
3. New York, Manhattan -2009
4. Rotterdam, Laurens Church -1684
5. Rotterdam Laurens Church -1940
6. Rotterdam Laurens Church -2009

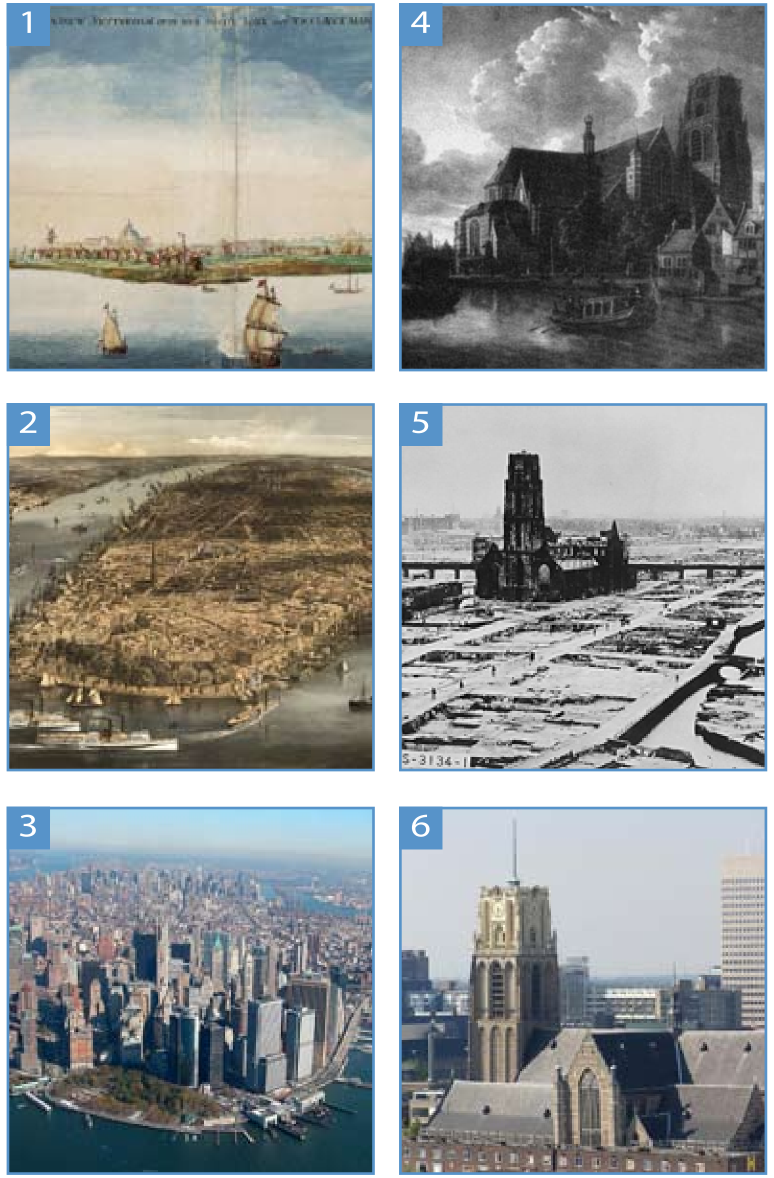
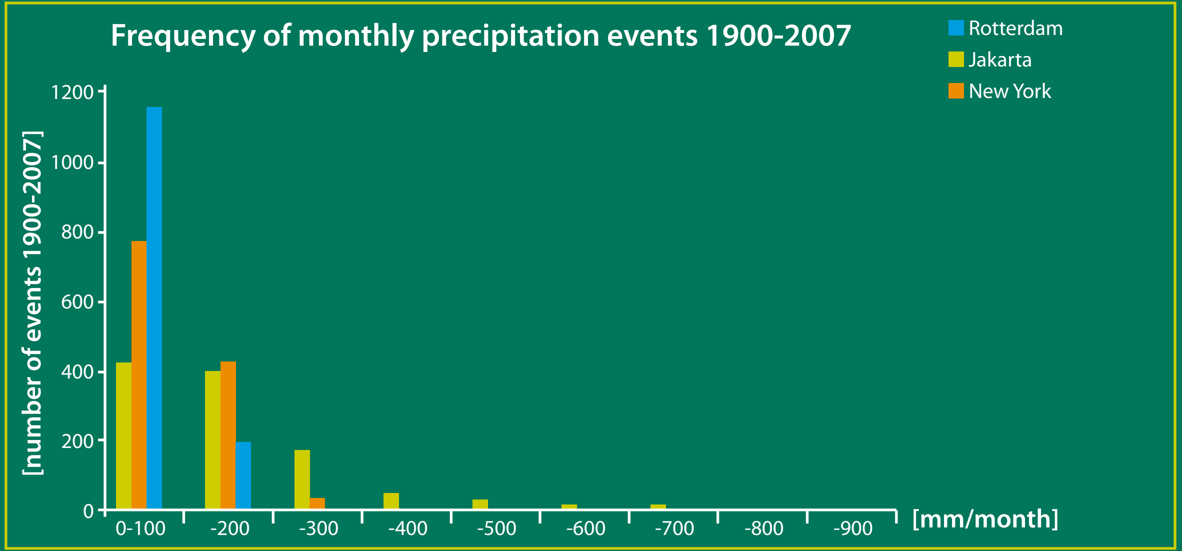


Figure 2.4. Images of New York and Rotterdam over the last several centuries.

Rotterdam has a temperate climate influenced by the North Sea, which maintains moderate temperatures throughout the year. Heatwaves, though, with temperatures above 30°C do occur, and will occur more frequently in the future. Summers are moderately hot with short wet periods, especially at the coast due to the warm seawater temperatures. Rainfall is almost equally distributed over the year, with an average annual rainfall of around 790 mm. A new precipitation record was set in August 2006, when almost 200 mm of precipitation fell in one month, causing large floods and damage in the Rotterdam city area. Winters are relatively wet with persistent rainfall periods. These periods of excessive rainfall can cause floods in the rivers Rhine and Meuse, which partly drain into the unprotected areas of Rotterdam[53].

New York City, Rotterdam and Jakarta are situated in different climate zones. New York City has a temperate, continental climate, with hot and humid summers and cold winters. Records show an annual average temperature between 1971 and 2000 of approximately 12.8°C. The annual mean temperature in New York City has risen by 1.4°C since 1900, although the trend has varied substantially. For example, the first and last 30-year periods were characterized by warming, while the middle segment, from 1930 to the late 1970s, was not. The temperature trends for the New York City region are broadly similar to trends for the Northeast United States. Specifically, most of the Northeast has experienced a trend towards higher temperatures, especially in recent decades. Between 1971 and 2000, New York City averaged 13 days per year with 1 inch (25.4 mm) or more of rain, 3 days per year with 2 or more inches (50.8 mm) of rain, and 0.3 days per year with more than 4 inches (101.6 mm) of rain.

Jakarta's tropical climate is characterized by year-round high temperatures of 24-33°C. The average annual rainfall in Jakarta over the period 1978-2007 was about 1640 mm. Most of the rain falls in the wet season from November to May (on average 1300 mm), with just 340 mm of rain falling on average during the dry season from May till October. This seasonal difference is determined by the monsoonal climate of the region. Climate data for Jakarta show the frequent occurrence of high intensity, short duration storms, especially in the afternoons and evenings. The highest observed precipitation total for a single month in Jakarta is more than 800 mm. There are also large differences in the quantity of precipitation in Jakarta and in the mountainous areas in the river catchments upstream from Jakarta which eventually drain through the city, where annual rainfall can be as high as 4500 mm.



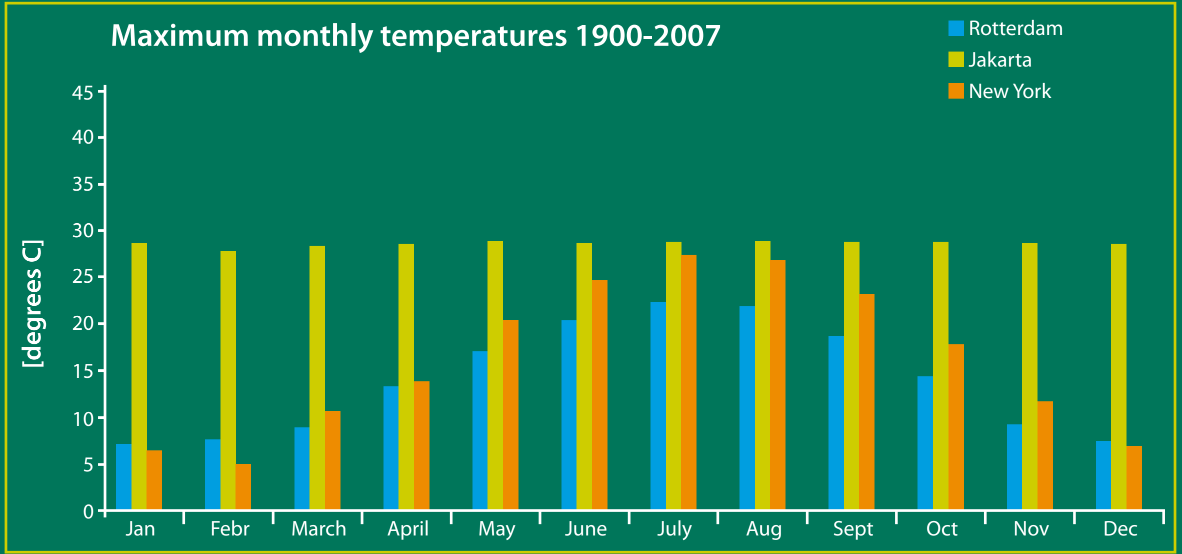


Figure 3.1. Indication of monthly temperature and precipitation extremes for each city: Monthly precipitation frequencies measured over the period 1900-2007 (top). Maximum measured monthly temperatures over the same period 1900-2007 (bottom) [4].

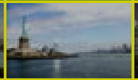
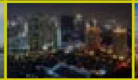
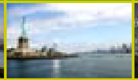
		CURRENT SITUATION			CLIMATE CHANGE: CURRENT SITUATION TO 2080 - 2100		
Average global temperature			15˚C			+1.1 - +6.4˚C	
							
		Current climate Rotterdam	**Current climate New York**	**Current climate Jakarta**	**Climate Rotterdam 2100**	**Climate New York 2080s**	**Climate Jakarta 2100**
Annual temp. (˚C)		9.9	12.3	26.6	+1.8 – +5.6	+2.2 – +4.2	+1 – +2
Average monthly precipitation (mm/year)		65.7	95.71	137.00	+7% – +12%	+5% – +10%	n.a.
Winter/ wet season	**Average temp. (˚C)**	6.6	5.1	26.1	+1.8 – +4.6	n.a.	n.a.
	Average prec. (mm)	67.2	90.07	217.33	+7 – +28%	n.a.	n.a.
	Max. monthly prec. (mm)	193.4	424.9	850		n.a.	n.a.
Summer/ dry season	**Average temp. (˚C)**	13.4	17.5	27.1	+1.7 – +5.6	n.a.	n.a.
	Average prec. (mm)	64.5	100.30	56.00	-28% up to +12%	n.a.	n.a.
	Max. monthly prec. (mm)	220.5	355.9	453	n.a.	n.a.	n.a.
Storm surge	**Max. surge (m) 1/100**	2.5	2.62	1.60[9]	+2.8	+3 – +4.2	n.a.
	Max. surge (m) 1/500	3.0	3.26	n.a.	+3.7	+3.6 – +3.8	n.a.
Sea level rise	**Planning policy scenario**	18-21 cm	22 cm	n.a.	0.85 m	0.3–0.75 m (2100)	0.5 m
	Max. low probability (m)	n.a.	n.a.	n.a.	1.2 m	1.08 m	140 cm (80cm subsid.)

Table 3.1.
Climate characteristics for the cities of Jakarta, Rotterdam, and New York. (n.a. means data is not available)
The table shows the average values for the current situation, and the projected values for the period 2080-2100 [5,7,9].

3 1 Climate change and sea level rise

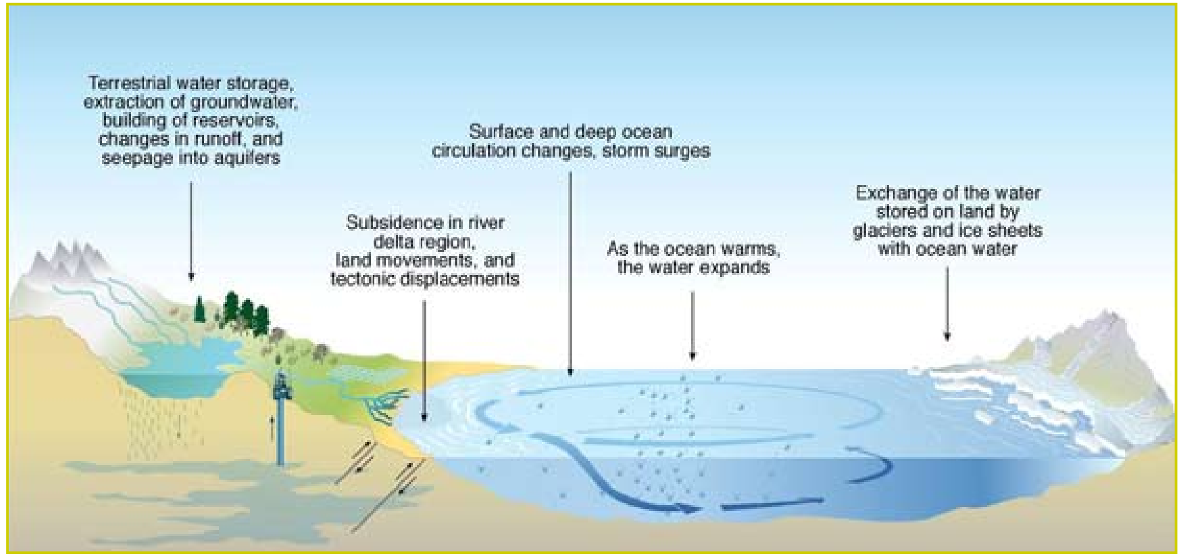
Sea level rise is a natural phenomenon, and historical measurements in New York and Rotterdam show an increase in mean sea level rise of 17-22 cm over the last 100 years [8]. Prior to the industrial revolution, sea level rise in New York and Rotterdam could mainly be attributed to regional subsidence of the earth's crust, which is still slowly readjusting to the melting of ice sheets since the end of the last ice age [9,30]. For New York and Rotterdam, land subsidence accounts for 3-4 mm per year, mainly due to post-glacial geological processes. For Jakarta, land subsidence is seen as the main factor for the observed sea level rise, and parts of the city are sinking at rates of 3.8 cm/year, mainly due to groundwater extraction.

Climate change, however, will accelerate natural sea level rise through the thermal expansion of the oceans, melting of glaciers and ice sheets, changes in the accumulation of snow and melting of the ice sheets in Antarctica and Greenland. It may also change the paths and speeds of major ocean current systems. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change [8] projects an increase of global temperature of between 1.1 and 6.40°C over the next century. As a result, average sea levels could rise by up to 59 cm by 2100.

There are, however, regional differences in projected sea level rise, and it is expected that sea levels in the northeast of the Atlantic Ocean will rise 15 cm more than the world average by 2100. This can be explained through the weakening of the Warm Gulf Stream, gravitational effects and the extra warming of seawater at greater depths. The projected sea level rise for Rotterdam and New York, as shown in Table 3.1, is therefore estimated at around 50-85 cm by 2100. The maximum, low-probability, scenarios indicate a sea level rise from 1.08 m to 1.4 m.

Large uncertainty exists on the future behavior of the large ice sheets in Greenland and Antarctica. Although it is not well understood how quickly the ice sheets will melt, a theoretical collapse of the Greenland and West and East Antarctica ice sheets through accelerated glacier flow would lead to a rise in sea level of several meters over the next centuries.

Figure 3.2. Causes of sea level rise due to climate change[8].



3 2 Climate change and extreme precipitation

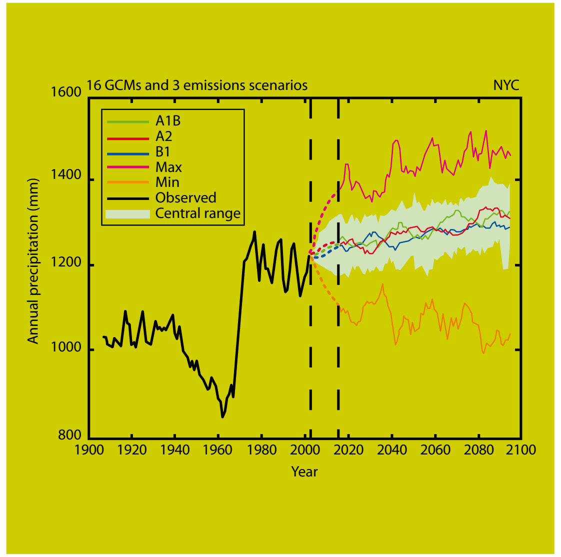
For Jakarta, rainfall patterns are also expected to change due to climate change. In most parts of Java, Bali and South Sulawesi, the amount of rainfall in the rainy season is expected to increase, while the dry season is expected to become drier. The connection between global warming and the change in inter-annual precipitation variability is not clear yet, but there is strong historical evidence showing that El Niño events have become more frequent and stronger. This means that the extreme regional precipitation and climate anomalies associated with El Niño are being exacerbated by increasingly higher temperatures.

Regional precipitation In New York may increase by approximately 5 to 10 percent by the 2080s. Climate models tend to distribute much of this additional precipitation to the winter months. Because of the effects of higher temperatures, New York also faces increased risks of drought.

Although the percentage change in regional precipitation is expected to be relatively small, larger percentage increases are expected in the frequency, intensity, and duration of extreme precipitation events at daily timescales. Moreover, by the end of the 21^{st} century, increases in temperature are expected to outweigh increases in precipitation, resulting in more droughts.

For the Rotterdam region, climate change will alter precipitation trends resulting in more prolonged periods of drought and more heavy showers, both in the summer and winter periods. Precipitation is expected to increase by 7-28% in winter. With the present-day spatial arrangement of land use, and the current sewage system in Rotterdam, it is unlikely that surplus stormwater can be adequately coped with, without causing high economic damage. Water managers are currently developing several adaptation strategies which aim to rearrange the spatial design of the landscape to enhance its flexibility to retain and store water surpluses at times of high precipitation and/or peak river discharges. At the same time, adaptation measures are being undertaken to increase the conveyance capacities of the river systems to ensure their ability to cope with higher peak discharges. In urban areas, the capacity of the sewage system needs to be re-evaluated using the latest climate scenarios, and the question is whether updating the sewage system is the most adequate adaptation option.

Figure 3.3. Inland flooding in New York in 2007 after intense precipitation (left). Projections for average annual precipitation until 2100 for Metropolitan New York [9] (right).



Jakarta: The sinking city[5]

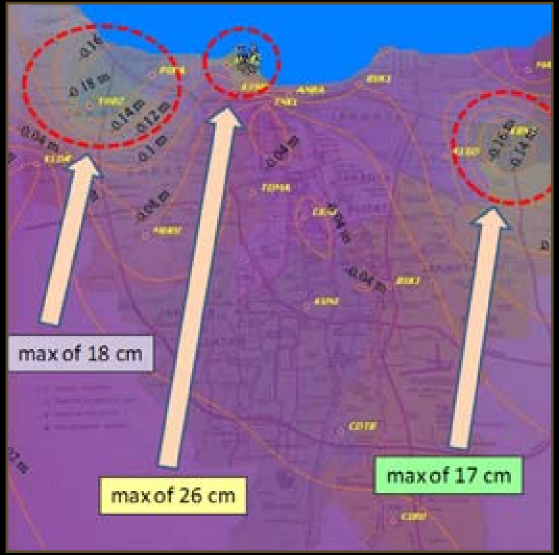


Figure: GPS-derived subsidence in Jakarta basin during the period of September 2007 to August 2008.

Land subsidence is not a new phenomenon for Jakarta. It was first recognized in 1926, based on repeated leveling measurements conducted in the northern part of Jakarta. The results of leveling surveys conducted between the 1980s and 2007 show that land subsidence in Jakarta has both spatial and temporal variations[5]. Average subsidence rates range between 1 and 15 cm/year, but can be as high as 20-25 cm/year at certain locations and for certain time periods. These spatial and temporal variations indicate that the causes of land subsidence in Jakarta may also differ spatially. There is strong evidence to suggest that land subsidence in the Jakarta area is related to the high volume of groundwater extraction from the middle and lower aquifers, with secondary contributions by building/construction loading and natural consolidation of sedimentary layers. In general, the rate of land subsidence in the northern part of Jakarta, which is close to the sea, is larger than in the southern part of Jakarta. The trend in land subsidence already influences the safety of Jakarta and is one of the main causes of coastal flooding. Development and population in Jakarta are both growing rapidly and therefore coastal land reclamation has been carried out for residential, recreational, and industrial purposes on low-lying and coastal areas. These new developments have initiated the exploitation of groundwater resources in these low-lying areas, which has led to accelerated land subsidence. The combined effects of land subsidence and sea level rise in the coastal areas of Jakarta will introduce other collateral hazards, namely the tidal flooding. Several areas along the coast of Jakarta already experience tidal flooding during high tides. The adaptation measures to reduce the impacts of this phenomenon need to be developed as soon as possible.

3

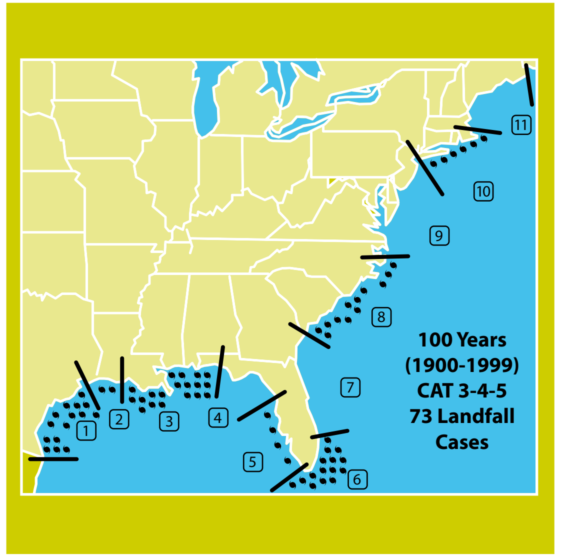
Storm surges, winter storms and hurricanes

New York and Rotterdam are vulnerable to coastal storm surges, which can cause surge levels of several meters. Storm surges along the eastern seaboard of the United States are associated with either late summer-autumn hurricanes or extra tropical cyclones in the winter period: nor'easters in New York and northwesterly storms over the North Sea in Rotterdam. The effects of extra-tropical cyclones can be large, in part because their relatively long durations (compared to hurricanes) lead to extended periods of high winds and high water. In the past, both New York and Rotterdam have been hit by winter storms coinciding with high tides.

New York is also vulnerable to hurricanes in the summer and autumn. Hurricanes are major tropical cyclones or low-pressure systems whose destructiveness derives from very high winds (minimum wind speeds of 120 km/h), flooding due to high storm surges and waves, and heavy rainfall. The height of the surge is amplified if it coincides with the astronomical high tide; when waves breaking on the shoreline add to the flooding. A period characterized by many severe hurricanes (Saffir-Simpson categories 3-5) in the 1940s to 1960s was followed by relative quiescence during the 1970s up to the early 1990s. Again, greater activity has occurred since the late 1990s. Hurricanes strike New York City infrequently. When they do strike, generally between July and October, they can produce large storm surges as well as wind and rain damage inland. Atlantic hurricanes are affected by the El Niño-Southern Oscillation (ENSO, a warming of the ocean surface off the western coast of South America that occurs every 4 to 12 years). During the El Niño phase, tropical vertical shear increases due to stronger upper-atmosphere westerly winds, inhibiting the development and growth of tropical Atlantic hurricanes. Therefore, Atlantic cyclones are 36% more frequent and 6% more intense during the La Niña phase of ENSO than during the El Niño phase[10]. Figure 3.4 shows all category 3 hurricanes (or higher) that made landfall on the US coast in the period 1900-1999. It shows that hurricanes have struck the coastal New York area six times in that period[11].

For Jakarta and the island of Java, ENSO is one of the natural phenomena that have increased the frequency and severity of natural disasters. In Indonesia, El Niño is often related to drought, and La Niña to flooding. Of 43 drought events that occurred in the period 1844-1998, only six were not associated with El Niño[12,13,14]. Moreover, ENSO is considered to be one of the main control factors in major forest/land fire and haze occurrence and frequency. Climate-related hazards in Indonesia are also caused by the location and movement of the tropical cyclones in the eastern South Indian Ocean (January to April) and the Pacific Ocean (May to December). Prerequisites for cyclone genesis are ocean surface temperatures above 26.5°C, at a latitude higher than 5 degrees north or south of the equator, and small vertical wind shear. Since tropical cyclones have sustained surface wind speeds in excess of 32 m/s, their impacts on the Indonesian region are commonly in the form of strong local winds and heavy rainfall lasting in the order of hours to days. Strong winds often also occur during the transition between the northeast to the southwest monsoon, and vice versa.

Figure 3.4. Hurricanes rated category 3 or higher that made landfall on the US East and Gulf coasts in the period 1900-1999 [15].



There are many definitions of flood vulnerability in the scientific literature. Important elements of flood vulnerability are: (1) what is the probability of a flood occurring?; and (2) what are the possible consequences of a flood in terms of casualties, direct economic damage (such as destruction of houses), and intangible damage (such as production loss and loss of natural values)? Furthermore, flood vulnerability is also determined by the adaptive capacity of a city or system following the event through evacuation and insurance relief options. Estimates of flood risk and flood vulnerability can be further disaggregated into vulnerability to coastal floods, vulnerability to river floods, and vulnerability to extreme rainfall. In the case of coastal floods and the flooding of large rivers, the impact can be very high with numerous casualties and much damage to property.

These events are relatively rare, with typical return periods of 1/100 years and lower. Extreme precipitation events in the non-tropical cities of New York and Rotterdam rarely cause casualties, but do frequently cause damage to property and infrastructure. In Jakarta, however, there are a number of historic events where extreme rainfall has caused flash flooding, leading to casualties and flood damage in large parts of the city. It should be noted that vulnerability is not a static concept. If evacuation plans are well developed, vulnerabilities can be reduced; and, with expected advances in scientific modeling and prediction of storms and storm surges, facilitated by increased computational power, much improved warnings can be brought to bear in alerting communities at risk and in managing evacuations.

"Because of its geographical condition as a delta and low lying region, Jakarta is very vulnerable to climate change. The solutions should be based on integrated Spatial Planning to accommodate climate adaptation, and should introduce various sustainable actions with participation and consistent communication so that more people will understand the impact of climate change".

Fauzi Bowo, Governor of Jakarta, Indonesia

4.1

History of flood events

Extreme flood events			
City	**Year of flood**	**Impacts**	**Economic damage [2009 US$]**
New York/ Long Island - CT	1938	- 600 fatalities - 14,000 houses destroyed	US$ 6 billion
Rotterdam/ SW Netherlands	1953	- 50,000 buildings destroyed - 300,000 people left homeless - about 1800 fatalities	US$ 70 billion
Jakarta	2007	- about 80 fatalities - 70,000 houses flooded - 450,000 people displaced	US$ 1 billion

Table 4.1. Examples of the impacts and economic damage of extreme flood events in New York, Rotterdam and Jakarta [25,39,40,41,42].

Jakarta, New York and Rotterdam each have long histories of fighting deluges of water and coping with flooding events. Figure 4.1 shows the main historical flood events for each city between 1850 and 2007. Many of those floods have had an enormous impact on the cities and the region. The storm surge of 1953 in the Netherlands, for example, caused 1800 casualties and led to the initiation of one of the largest infrastructure works in the world, called the "Delta Works". The same storm sparked the development of the Thames Barrier in the United Kingdom. The 1938 hurricane storm surge (the so-called "Long Island Express"), experienced along the south coast of Long Island, also caused extensive damage, with many houses washed into the sea, a new inlet created in the barrier beach (Shinnecock Inlet) and many casualties. The consequences of this devastating storm led to the construction of storm surge barriers in the small coastal cities of Stamford CT, Providence RI and New Bedford MA, an example of how extreme events may create an unanticipated urgency to develop new mitigation and adaptation measures.

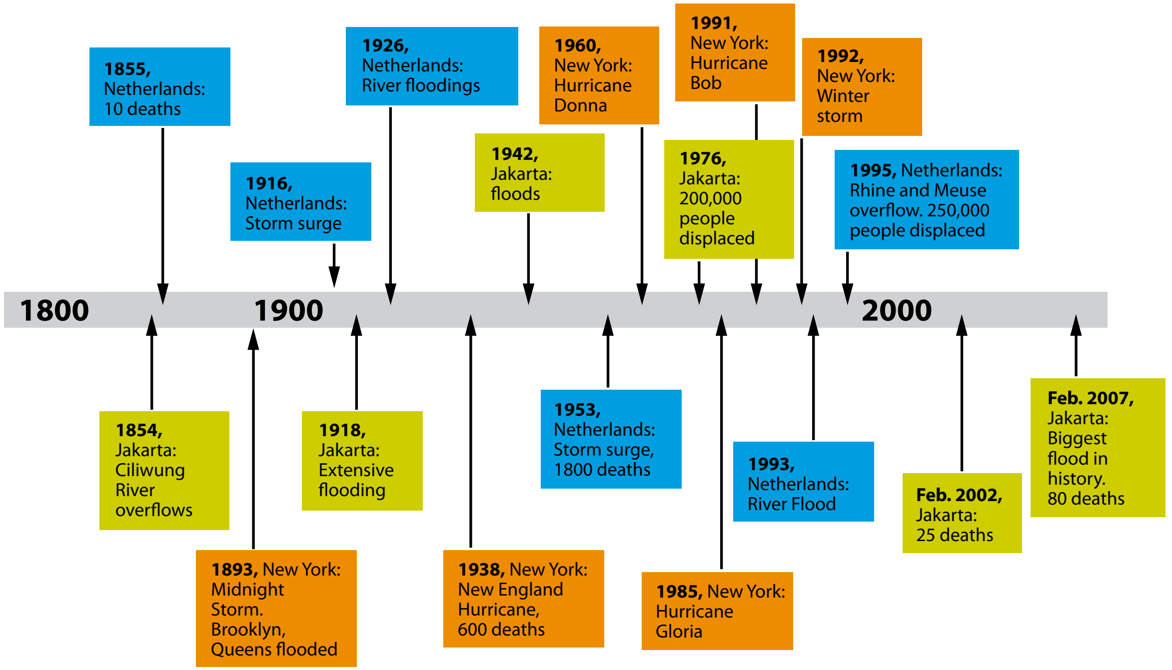


Figure 4.1. Main historical flood events for the cities of Jakarta, Rotterdam and New York from 1850 to the year 2007 [25,27,43,44,45].

Jakarta

The city of Jakarta suffers from both coastal and river flooding. River floods occur mainly during the rainy season, as extreme rainfalls in the city or in the mountainous upstream regions lead to the overflowing of drainage systems, causing large-scale inundations in many parts of the city, including public facilities and roads. Furthermore, Jakarta suffers from daily tidal floods near the coast. Their severity depends on the biweekly cycle of spring tides, determined by the alignment of the sun, earth and moon. People and infrastructure at low elevations are subject to chronic inundation, although coastal protection measures have been constructed in a number of vulnerable areas. These include drainage and pump systems. Existing infrastructure has also been improved to reduce inundation damage, such as the protection of highways along the coastal area. However, the risk to coastal communities from coastal inundation continues to present major challenges to the government.

Recent floods, such as the flood of 2007 can partly be explained by the inadequate drainage design capacity of the sewage system. Furthermore, the capacity of many rivers, canals and drainage channels in the city of Jakarta are greatly reduced due to waste disposal in watercourses. This occurs in part due to a lack of waste collection and management in Jakarta and its upstream areas, and partly due to cultural traditions which regard rivers as waste repositories. Moreover, the increase and magnitude of flooding in Jakarta is also strongly influenced by land use changes in the river basins upstream of the city. In the last few decades, deforestation in these basins has taken place rapidly, especially in the areas of Bogor and Depok. Forests have been replaced successively by agricultural production and urbanization. This leads to an increase in average river flows because less water is absorbed by the soil and/or lost to evapotranspiration. Also, the magnitude of peak river flows increases because during heavy rainfall events, rainwater reaches the river systems more quickly as the buffering effects of the forest are lost. Moreover, the rates of soil erosion have increased due to the reduction of forest cover, which means that more sediments make their way to the river channels, and eventually to the watercourses of Jakarta, thus reducing the capacity of the city's rivers, canals and drainage channels even further.

A study conducted by the Indonesian Ministry of Environment[16] indicated that if the sea level were to rise by about 0.5 meter, and land subsidence continues at its present rate, parts of six sub-districts of North Jakarta and Bekasi will be permanently inundated.

2007 flood in Jakarta

The floods of February 2007 were the worst in the recorded history of Jakarta. Intense rainfall started in January and the beginning of February; 50 mm/day on average with a peak of 317 mm/day on February 2nd in West Jakarta. The two main rivers in the capital, Ciliwung and Pesanggrahan, flooded. Furthermore, the river floods coincided with high sea levels in Tanjung Priok (North Jakarta). This added an additional meter of inundation to the river floods. Research showed that, apart from the exceptional climate conditions, the lack of maintenance and urban planning contributed to worsen the already poor drainage conditions, and caused the flood to extend to even more areas.

The flood of 2007 affected 80 separate regions in and around Jakarta. Over 70,000 houses were flooded, thousands destroyed or heavily damaged, and many houses built on the riverbanks by informal settlers were washed out by floods, resulting in the displacement of over 400,000 people. About 60-70% of the urban area was affected. In some areas, the water level reached as high as 7 meters, with an average depth of 2-3 meters. The flood resulted in power failures, leaving over 670,000 people without electricity for days. Telephone lines were cut off, and several roads, including the main highway to the international airport, ended up under water. About 80 people died due to hypothermia, drowning or electrocution. In February and March 2007, the Ministry of Health recorded outbreaks of water-related diseases like dengue fever, leptospirosis and diarrhea. The losses due to the 2007 flood are estimated at approximately US$ 830 million.

Figure: Floods in Jakarta, February 2007.

Rotterdam
Rotterdam and the Netherlands as a whole have a long history of managing flood risks. The low-lying parts of the country, including Rotterdam, have been flooded many times throughout history. In the Netherlands as a whole, approximately 9 million people live below sea level; some areas lie at 7 meters below mean sea level, making them the lowest areas in Europe. Many low-lying parts have been reclaimed from former lakes (usually referred to as "polders") and are protected by so-called "levee rings" along the main rivers and coastal areas. Being a delta system formed by several of Europe's major rivers, it is a highly developed agricultural area, of significant human and economic activity. Two thirds of Dutch GDP is earned in these low-lying polders, and most Dutch urban development is concentrated here. For these reasons, the Dutch have continued to invest heavily in flood protection, even though the area represents one of the most vulnerable locations to flood risk in the world. Currently, the Dutch flood protection standards are by far the highest in the world. For example, the protection system (levees and barriers) around Rotterdam is designed to withstand a storm that is estimated to occur once in every 10,000 years. However, most parts of the Netherlands are not protected to this highest level.

While most of the residential areas of Rotterdam are protected by levees and lie either at or below sea level, the newest port area of Rotterdam lies outside the protection of the levee Ring System. As ships must have free access to the port, the City of Rotterdam and the Port Authority have chosen to develop an area outside the levee protection system, but at such an elevation that most of the port area remains "dry" during floods. Hence, over the last 100 years, more than 10,000 hectares of land have been elevated using fill materials to several meters above sea level. Along with the Palm Islands in Dubai, this is the largest area of human-made land in the world to be largely surrounded by water.

Several historic events led to the initiation of new flood protection paradigms in the Netherlands, and in Rotterdam in particular. For example, the storm surge of 1953 led to the formation of a large flood protection plan ("Delta Works"), with new levees and storm surge barriers. One of the main aspects of this plan was to improve the protection of Rotterdam during an extreme storm surge, and it was decided to develop the Maeslant Storm Surge Barrier, which seals off the port area in the case of an extreme event, but stays open during normal conditions to allow free access to the older port areas as well as the inland shipping canals behind the barrier.

Storm surge 1953: The initiation of the Delta Plan in the Netherlands

During the night of January 31, 1953, a northwesterly windstorm pounded the coast of Zeeland, North Brabant and South Holland. The levee system failed to prevent the flooding of the islands of Goeree-Overflakkee, Tholen and Schouwen-Duiveland, and many other parts of the southwestern delta of the Netherlands; large stretches of the east coast of the United Kingdom were also inundated. The consequences were disastrous, with 1,835 fatalities, 100,000 evacuees, 200,000 hectares of land being inundated, and large economic losses of about € 50 billion (US$ 70 billion, 2009 values).

After the catastrophic event of 1953, a committee was established to design a plan to study the causes of the flood and to develop measures to prevent similar disasters in the future. Plans were made to connect the islands of South Holland and Zeeland with dams. The combination of these plans and dams was called the Delta Plan. The plan led to the implementation of the Delta Works, which is a series of dams, sluices, levees, and storm surge barriers constructed between 1958 and 1997 in the southwest of the Netherlands. The aim of the Delta Works was to improve flood protection by shortening the Dutch coastline, thus reducing the number of levees that had to be raised. With over 10,550 miles of levees (1,800 miles designated as primary levees and 8,750 miles as secondary levees) and 300 structures such as sluices and bridges, Dutch flood protection is one of the most extensive engineering undertakings in the world. The Delta Works reduced the length of the levees exposed to the sea by approximately 400 to 450 miles (640 to 700 km). In most cases, building a barrier or a dam was much faster and cheaper than reinforcing existing levees. The Dutch government stated that a major storm surge flood must never happen again, and therefore the Delta Plan consisted of the reconstruction of the levees that failed during the 1953 event as well as developing the storm surge barriers, resulting in very high coastal protection levels.

Figure: Levee breach near Papendrecht in 1953 (left page). Locations of the storm surge barriers and dams of the Delta Plan that were constructed in the period between 1958 and 1997 (bottom).

New York
A large proportion of New York City and the surrounding region lies less than 3 m (10 ft) above mean sea level, and infrastructure in these areas is vulnerable to coastal flooding from either nor'easter storms in winter or North Atlantic hurricanes in the summer period.

Significant nor'easters of the last 40 years include the "Ash Wednesday" storm (March 6-7, 1962), the Halloween storm (October 31, 1991), and two other powerful coastal storms on December 11-12, 1992 and March 13-14, 1993. The "Ash Wednesday" storm had a particularly destructive impact on the mid-Atlantic States because it lasted for five consecutive tidal cycles. The accompanying storm surge peaked at over 2.1 m at the Battery, lower Manhattan.

However, the December 1992 storm produced some of the worst flooding seen in Metropolitan New York in over 40 years. The water level at the Battery in Lower Manhattan peaked at 2.4 m above mean sea level; spring tides were already higher than normal due to the full moon. Flooding of lower Manhattan, together with near hurricane force wind gusts, led to the almost complete shutdown of the New York City transportation system, as well as evacuation of many seaside communities in New Jersey, Connecticut, and Long Island.

While hurricanes are much less frequent than nor'easters on the eastern seaboard of the United States, they can be even more destructive. At least nine hurricanes have struck the Metropolitan New York City region in the last 200 years, including major strikes in 1821, 1893, 1938, and 1960[15]. Impacts include severe coastal flooding, damage and destruction of beachfront property, severe beach erosion, downed power lines, power outages, and disruption of normal transportation.

The December 11-12 1992 storm revealed the vulnerability of the Metropolitan New York – New Jersey – Connecticut transportation systems to major nor'easters and hurricanes. Most of the area's rail and tunnel points of entry, as well as airports, lie at elevations of 3 m or less[18]. This elevation represents a critical threshold. Flood levels of only 0.30-0.61 m above those of the December 1992 storm could have resulted in massive inundation and potential loss of life. The vulnerability of the regional transportation system to flooding was demonstrated again on August 26, 1999, after 6.4-10.2 cm of rain fell on the New York metropolitan area, nearly paralyzing the transport system[19]. With future sea level rise, even less powerful storms could inflict considerable damage.

Hurricanes: The New York Metropolitan area
The worst natural disaster to strike the northeastern US was the hurricane of September 21, 1938, which claimed some 600 lives and injured several thousands. This storm struck with little warning. A wall of water 7.6-10.7 m high (surge plus breaking waves) swept away protective barrier dunes and buildings on the shores of eastern Long Island, eastern Connecticut, and Rhode Island.

The August, 1893 hurricane completely destroyed Hog Island, a barrier island and popular resort area on the south coast of Long Island that once existed seaward of Rockaway Beach. The right angle bend between the New Jersey and Long Island coasts tends to funnel offshore surge waters toward the New York Bight apex, and into New York Harbor. Nor'easter winds also drive significant surges down the axis of the Long Island Sound, which then propagate through the East River into New York Harbor, adding to the oceanic surge.

One estimate, perhaps too high, for maximum surge levels for a category 3 hurricane (179-209 km/h winds) moving along a worst case storm track west of New York City suggests that surges could reach 7.4 m above mean sea level at JFK Airport. Other locations in the New York metropolitan area could experience surge levels of up to 4.75 -7.3 m on the same worst case basis. These estimates are based on projections of the SLOSH model, a commonly-used computerized model for estimating storm surge heights resulting from historical or predicted storms. However, recent calculations based on high-resolution surge models suggest these estimates are likely to be too high, a finding that reinforces the importance of continuing to improve the modeling basis of adaptation planning. Notwithstanding, historical storms have demonstrated that dangerously high surge levels can occur in the New York area.


Hitler Says Army Will March Against Czechs
SOUTHBRIDGE EVENING NEWS
DEATH TOLL NEAR 600; WARN AUTOS
Half Billion Loss In N. E. States
Appeal to Keep All Cars Off Streets
List of Dead

Figure: 1938 Hurricane Long Island, NY, CT.

4.2

Storm surge heights and frequency

A 1 in 100 year flood could produce a 3 m (8.6 ft) surge in New York Harbor and along the south coast of Long Island. Such a surge is more likely to be caused by a hurricane than a winter nor'easter. On the other hand, hurricanes occur much less frequently than nor'easters. Nor'easters are dangerous and can cause considerable damage, even though their wind speeds are lower than those in fast-moving hurricanes, as nor'easters cover a much greater area, and tend to last several days. This means that sequential high tides will carry the storm surges further inland at a particular location.

Storm return frequencies along the US East Coast over the last 50 years peaked in the late 1960s, diminished in the 1970s, and picked up again in the early 1990s. However, there has been no appreciable increase in either the number or severity of storms over this period. The increase in coastal flooding is largely a consequence of the regional sea level rise during this period, and illustrates how rising ocean levels are likely to exacerbate storm impacts in the future as sea level rise accelerates [9].

For Rotterdam, the design surge level that is generated by a 1/10,000 storm is determined at 4 m (the 1953 storm caused a surge height of 3 m)'.
To protect against such a storm, taking both surge levels and breaking wave heights into account, the average levee along the Rotterdam coast is over 10 m in height above Dutch ordnance datum (NAP).

By the end of the 21st century, the effects of sea level rise alone may cause coastal flood levels that currently occur on average once per decade, to occur once every one to three years in both Rotterdam and New York.

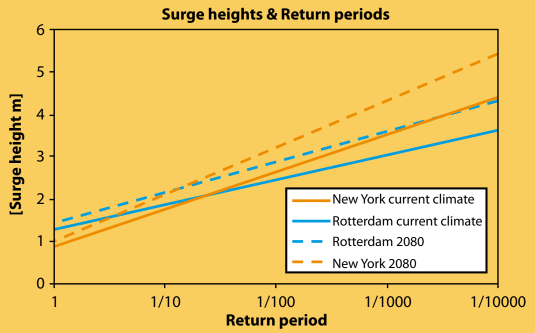


Figure 4.2. Extrapolated storm surge heights and their recurrence times for New York and Rotterdam [20].

Stated another way, sea level rise alone may cause the current 1 in 100 year flood to occur approximately four times more often by the end of the century. Moreover, by the end of the 21st century, the current 1 in 500 year flood event may occur approximately once every 200 years [9].

The projected flood heights of extreme storms shown in Figure 4.2 correspond to the Battery in lower Manhattan (New York) and Hoek van Holland (Rotterdam). Note, however, that storm surges vary over the coastal areas surrounding each city due to both geographical and morphological characteristics. Moreover, large uncertainty exists with regard to the characteristics of the most extreme storms as by definition they occur very rarely and hence are usually non-existent in the historical record. Documenting and extrapolating their occurrence is challenging, but it is a critical first step in understanding future storms and their impacts, especially because rising sea levels will result in more severe coastal flooding.

Figure 4.3 shows the potential extent of coastal and river surges around the cities of New York, Rotterdam and Jakarta for 2009 and 2080 for various storm return periods. Note that each map highlights different contributors to flood risks. The amount of damage from a flood is dependent on, among other things, the size of the flooded area and the water depth. Other factors also play an important role, for example the duration of the flood and the flow velocities in swollen rivers. Furthermore, the rate at which the water rises and the available time for evacuation largely determines the number of casualties[21].

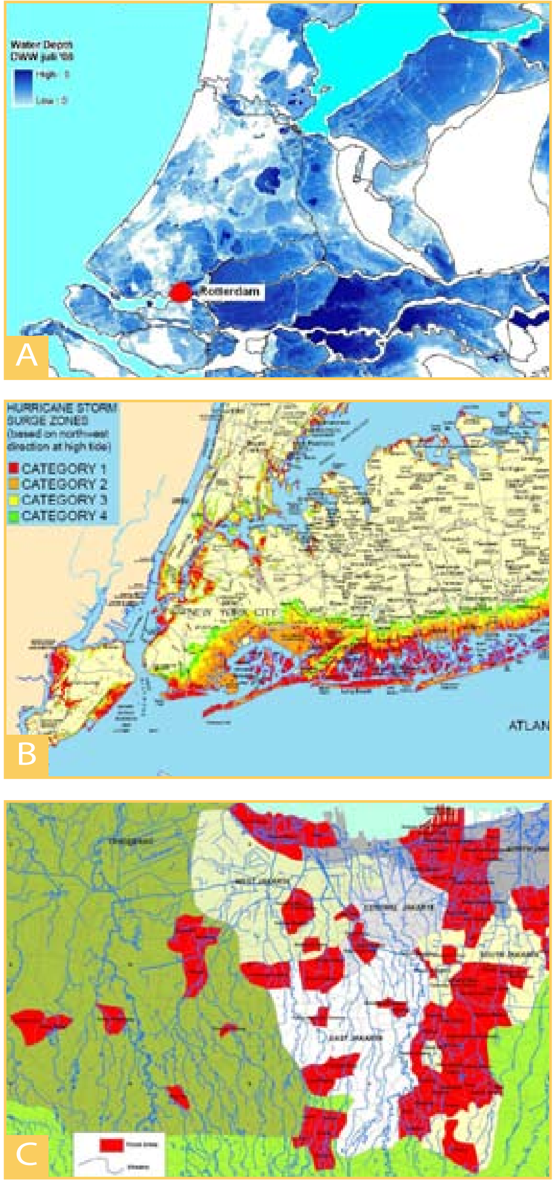


Figure 4.3. Flood extent maps for Rotterdam (a), New York SLOSH maps (b) and Jakarta (c)[30].

Socioeconomic effects of flooding

5

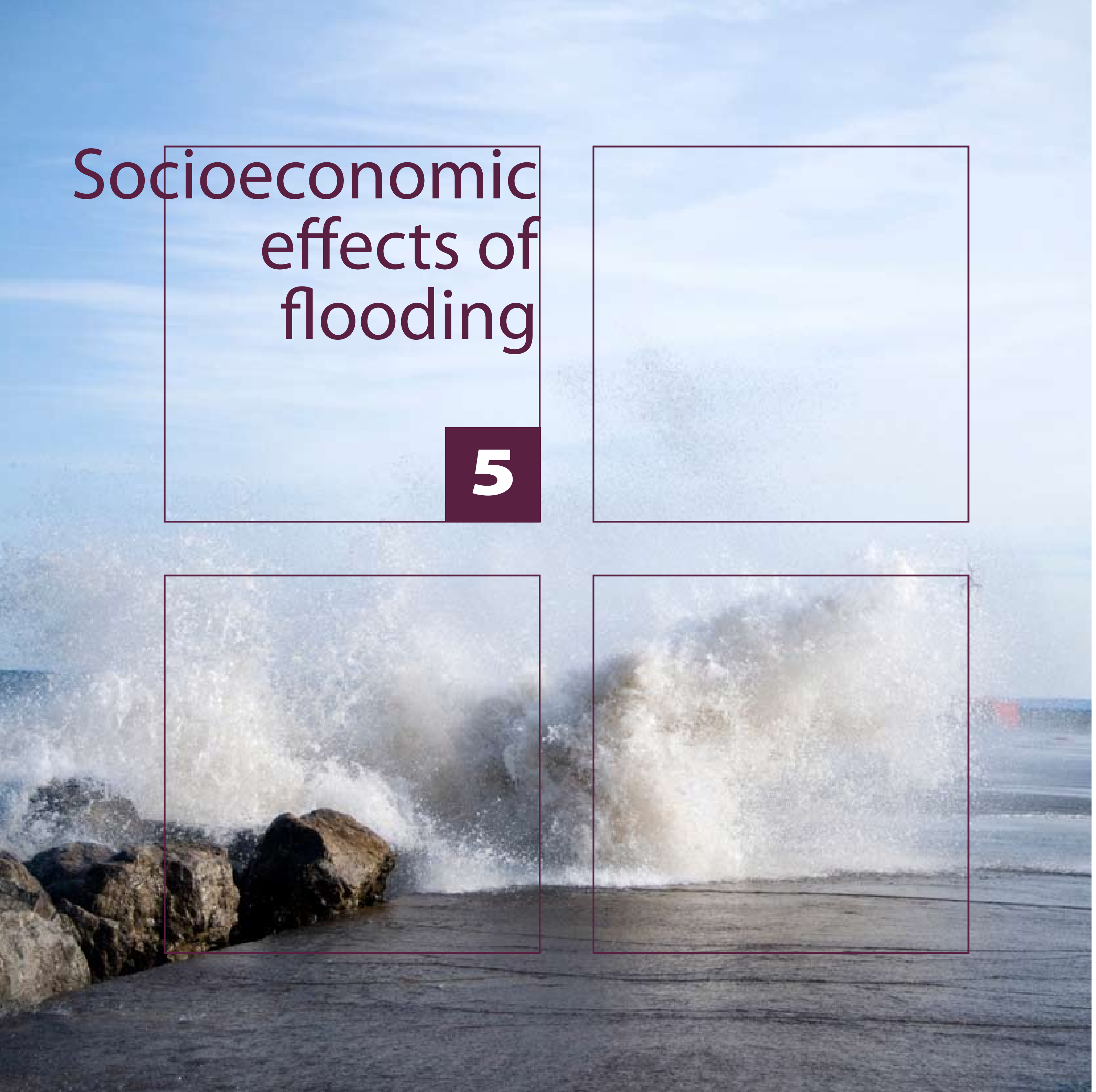


Table 5.1 summarizes the most important consequences of a flood for different economic sectors. It appears that all of the three cities are subject to similar threats from flooding, both from oceanic storm surges and from inland sources. For example, for all three ports of New York, Jakarta and Rotterdam, both land-based transportation and the use of inland waterways are of importance to connect the port areas with surrounding regions. These connections may be threatened as the clearance levels of bridges decrease during a flood, train and subway stations may be flooded, coastal highways inundated, emergency and hospital services curtailed and communications disrupted. Furthermore, floods cause direct economic damage to infrastructure and property, with the magnitude of the damage depending on the depth and duration of the flood. Most estimates of flood damage rely on studies that quantify the direct economic damages only. However, other, non-flooded areas may also be affected, as the supply of goods and services to the flooded area may be hindered. Production loss due to floods, however, is difficult to quantify, and is not well understood. At the same time, indirect flood damages may be twice as high as the direct economic damage. Finally, each extreme flood event could potentially claim a significant number of lives.

	NEW YORK	JAKARTA	ROTTERDAM
Infrastructure/ transportation	Increased damage to, and shutdown of rail and subway systems	Permanent inundation of low-lying areas and business district	Port facilities and railroads compromised
	Temporary inundation of low-lying business district (e.g., Wall Street) and transportation hubs	Decreased clearance levels under bridges	(Petro)chemical industry and increase of hazardous waste
	Decreased clearance levels under bridges	Structural damage due to coastal flooding	Decreased clearance levels under bridges
	Structural damage to infrastructure due to storm surge and wave setup	Temporary flooding of roads and airport	Structural damage to infrastructure due to storm surge and wave setup
	Increase in delays on public transportation and low-lying highways	Saltwater intrusion into freshwater resources. Increased damage to infrastructure not designed to withstand saltwater exposure	Delays in shipping due to closure of storm surge barrier
	Increased saltwater encroachment into local freshwater aquifers. Increased damage to infrastructure not designed to withstand saltwater exposure		
Waste/water infrastructure	Wastewater treatment plant, street, basement, subway and sewer backups and flooding	Street, basement and sewer flooding	Saltwater intrusion, loss of drinking water quality
	Increased pollution runoff from brownfields and waste storage facilities. Alterations to the flushing characteristics of the harbor and surrounding waterways	Increased pollution runoff	Diminished sewer system capacity
Nature/ environment	Intensification of the rate and extent of coastal erosion (damage to beach and salt marshes). Destruction of barrier islands; creation of new inlets	Beach erosion through degradation and coral reefs	Beach erosion
	Inundation of wetlands (loss of coastal wetlands and their associated ecological resources)	Increase in number of endangered species	
	Submergence and burial of shellfish beds by large volumes of sediment transport	Increase of frequency and intensity of flash floods and landslides	
		Increased rate of sedimentation	
Agriculture/ fisheries	Disruption of commercial and recreational fishing activities. Destruction of fishery/shellfishery habitats, migratory patterns	Polluted water may enter economically important fish ponds	Saltwater intrusion may impact agricultural production, in particular the very salt-sensitive and very high-intensity production in greenhouses
	Damage to aquaculture facilities and loss of captive fish populations	Continued decrease of paddy production and decrease in maize production due to floods	

Table 5.1. Summary of the most important consequences of flooding in New York, Jakarta and Rotterdam [9,26,27,28,29,30].

With almost 2400 km of shoreline, Metropolitan New York's historical development has been intimately tied to the sea. Four out of five of New York City's boroughs are located on islands. Many bridges and tunnels connect these islands to the New York State and New Jersey mainland. Many of the area's rail and tunnel entrance points, as well as some elements of major airports, lie at elevations of 3 m above sea level or less. As noted earlier, flooding levels of only 0.30-0.61 m above the level which occurred during the December 1992 winter nor'easter could have led to massive inundation and potential loss of life Climate change-induced rising sea levels will make such flooding events more commonplace in the decades and centuries ahead.

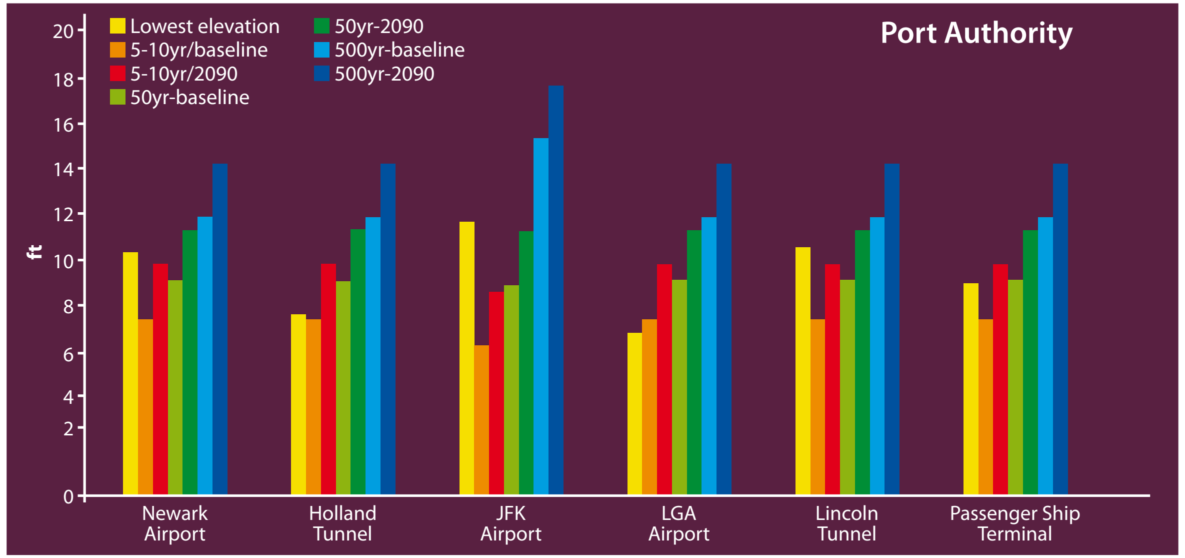


Figure 5.1. Comparison of lowest critical facility elevation with surge height for storms with return period of 5-10, 50 and 500 years (from left to right) and at the beginning (baseline) and end (2090) of the 21st century[27].

Infrastructure/transportation
Over time, sea level rise associated with climate change will place the area's low-lying transportation infrastructure at increased risk of flooding. This includes bridge and tunnel access roads, subway stations, rail and road tunnels, coastal highways and airports, including all three of the major New York metropolitan regional hubs (La Guardia, JFK, and Newark-Liberty). Many of the above elements of the transportation system are located at elevations of 2 to 6 ft (~ 0.6 to 2 m) above current sea level. Extreme storms have produced storm surges, wave setup and coastal flooding in excess of 6 ft (2 m), and will do so more frequently as the sea level rises [27].

Beach erosion
Over 70% of the world's sandy beaches are retreating[23]. In the Metropolitan East Coast (MEC) region, beaches and barrier islands are narrowing or shifting landward, partly as a result of ongoing sea level rise as well as land subsidence. Accelerated sea level rise will intensify the rate and extent of coastal erosion. While sea level rise is obviously an important factor, beach erosion is frequently intensified by ill-advised human activities, such as trapping of silt and sand in upstream reservoirs, disruption of longshore drift by poorly designed groins and breakwaters, and sand mining in inappropriate areas.

Water supply
The upland sources of New York City's water supply system will be impacted by higher temperatures and forecast increased precipitation. It is expected that the combination of these two factors over time will result in both increased flooding and increased droughts, with the resulting need to adjust system operating rules and drought regulations in order to maintain supply levels [29].

Water quality
Climate change is expected to have many possible impacts on water quality. In the upland systems that serve many coastal cities, the results of increasing temperatures and changing precipitation patterns may bring changes in runoff patterns and consequent impacts on changes in turbidity, eutrophication and other quality parameters. For cities that depend on groundwater, rising sea levels may bring increased saltwater intrusion into aquifers, and higher sea levels and storm surges will also affect the operation of existing wastewater treatment plans and outfalls, with consequent water quality impacts to receiving water bodies.

Maintenance of acceptable water quality standards in New York Harbor, western Long Island Sound, the lower Hudson, Passaic and Hackensack Rivers depends on an adequate flushing rate driven by the twice daily flood and ebb circulation of the tides. All treated and untreated sewage emanating from the communities of northern New Jersey, New York City, the Hudson River valley and western Long Island Sound, is eventually discharged into the harbor and waterways surrounding Metropolitan New York. There are ocean outfalls in sections of Nassau and Suffolk Counties along the south shore of Long Island.

Much of New York City relies on a combined sewer system, which means that heavy precipitation events often result in sewage flows being routed around treatment facilities and stored in temporary holding tanks or released directly into the receiving water bodies. New York City has had over 770 combined sewer overflows, some of which are blocked by storm surges, preventing discharge. Intense precipitation events can lead to occasional overflowing of the combined sewers into city streets and subway systems.

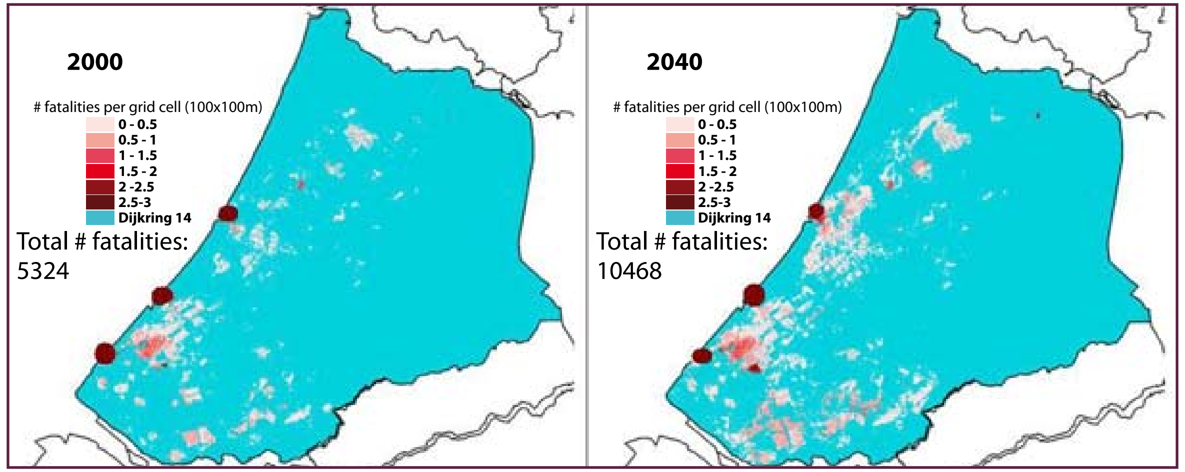
5.2 Rotterdam

Figure 5.3. The potential number of fatalities caused by simultaneous levee breaches at Katwijk, Ter Heijde and The Hague with current land use (left) and possible future land use according to the GE scenario (right) [30].

The Port of Rotterdam is one of the largest harbors in the world, and is of vital economic importance for Rotterdam itself and the Netherlands as a whole. Most of the 12,000 ha of port area has been developed on elevated land at an average height of about 3-4 m above mean sea level, and a new area ("Maasvlakte 2") is being developed at 5 m above mean sea level. Large parts of the port area are protected by the Maeslant surge barrier. This barrier, however, was designed for a maximum sea level rise of 60 cm. Both the Port Authority and the City of Rotterdam are considering options to cope with increasing flood risks due to climate change. At risk are port facilities, railroads, tunnels and container terminals.

A large proportion of the Netherlands' economic assets are clustered in the port area of Rotterdam, where the estimated potential damage in case of flooding is in the order of tens of billions of euros (see Figure 5.2 for a flood risk map of the port area). In addition, a large section of Rotterdam's working population works in the port area, and many businesses strongly depend on activities in the port. For example, the 1995 flood of the River Rhine, which connects Rotterdam with Germany's industrial area in the Ruhr Valley, with 15 million inhabitants, caused more than 200 million euros of commercial loss due to the temporary closure of shipping routes.

Moreover, the port area of Rotterdam contains one of the largest petrochemical industries in Europe. Although little research has been conducted into the effects of floods on water quality, research in Germany shows that 50% of the damage caused by floods is a result of water pollution. Leakages from chemical plants and



old underground oil tanks can cause considerable damage and are difficult to clean after the flood event.

The expected number of casualties as a result of flooding in the Rotterdam region is regarded as an important indicator of vulnerability. Figure 5.3 shows the projected effects of growth in urban development in low-lying polders north of Rotterdam by 2040, on the potential number of casualties in the province of South Holland in case of levee breaches. The expected growth in population in vulnerable areas of South Holland is expected to be much higher than the average population growth in South Holland as a whole (+50% in the areas that could be hit by flooding, compared to +33% for the area as a whole). This is one of the most important factors explaining why the estimated number of fatalities grows at a faster pace than the nation's average population growth.

The increase in the potential number of fatalities is primarily caused by the growth of the population in low-lying polders; the limited rise in sea level has a relatively small effect in the low-lying polders. For example, a sea level rise of 30 cm could cause an increase in the fatality rate by as much as 20%, while an 87% growth in the population of Wateringse Veld by 2040 is projected to cause a 156% increase in potential fatalities in the area. The influence of the population growth on the fatality rate is therefore considerably greater than the effect of a 30 cm sea level rise.

Figure 5.2. Example of a flood risk map of the port area of Rotterdam. The colors indicate the potential flood losses in euro/m^2 [24].

In Indonesia, about 42 million people live in areas less than 10 meters above mean sea level, so flood vulnerability in Jakarta is already very high. Tidal surges cause frequent damages in low-lying coastal areas, and little protection is available. The 2007 floods showed that the threat to Jakarta comes from both the rivers and the sea, and when an extreme river surge coincides with an extreme tidal surge, the flood damage can be disastrous.

Coastal flood modeling results suggest that a 60 cm sea level rise would lead to the permanent inundation of 28 ha of land in northern Jakarta, causing an estimated damage of 50 million euros. If the sea level were to rise by 120 cm, a total area of 3,084 ha in northern Jakarta would be permanently inundated, with an associated cost of 3.7 billion euros (see Table 5.2).

Type of land use	Cost damage estimate (billion euros)			
	Permanent inundation		Temporary flood	
	60 cm	120 cm	1/100 year flood Current	1/100 year flood Year 2100
Uniform settlement	0.02	0.67	0.80	3.20
Non-uniform settlement	0.00	0.32	0.38	2.60
Business area	0.05	2.7	2.90	10.80
Agriculture area	0.00	0.00	0.00	0.10
Bare land, beach, and yard area	0.00	0.01	0.01	0.01
Fish pond area	0.00	0.04	0.03	0.05
Total (billion euros)	0.07	3.7	4.0	16.8

Table 5.2. Cost damage estimates for Jakarta following different inundation and flood scenarios [25]. Shown are the estimated cost damages per land use type (in billion euros) associated with a permanent sea level rise of 60 cm and 120 cm, and associated with a coastal flood event with a recurrence time of 100 years under current conditions, and a coastal flood event with a recurrence time of 100 years in the year 2100 assuming a sea level rise of 60 cm, land subsidence of 370 cm, and an increase in storm surge intensity of 10%.

A coastal flood event with a return period of 100 years (1/100) at present, would lead to the temporary flooding of about 3,400 ha, including 1150 ha of business area, and over 980 ha of residential areas. The value of assets that would be exposed to such a flood is estimated at 4 billion euros (see Table 5.2), not to mention the potential loss of life.

However, as a result of future climate and environmental change, the scale of the problem is expected to become much more serious. Assuming a sea level rise of 60 cm by 2100 (low by recent estimates), land subsidence of 370 cm, and an increase in the intensity of storm activity by 10%, the value of assets in northern Jakarta that would be exposed to a 1/100 year coastal flood in 2100 would be greater than 17 billion euros. This estimate does not include the effects of changes in GDP and population, which will make the potential economic damage even higher. The extent of the 1/100 year coastal flood in 2100 is shown in Figure 5.4.

The flood of 2007 has already shown that vital infrastructure is at high risk. Main highways and railroads were blocked, causing large traffic jams. Furthermore, floods in Jakarta have negative impacts on fisheries. In the Krawang and Subang districts, the losses associated with extreme flooding in fish and prawn production are estimated at over 7,000 tons and 4,000 tons respectively. In the lower Citarum Basin, sea level rise could result in the permanent inundation of about 26,000 ha of ponds and 10,000 ha of cropland. This could result in the loss of 15,000 tons of fish, shrimp and prawn production, and about 940,000 tons of rice production.

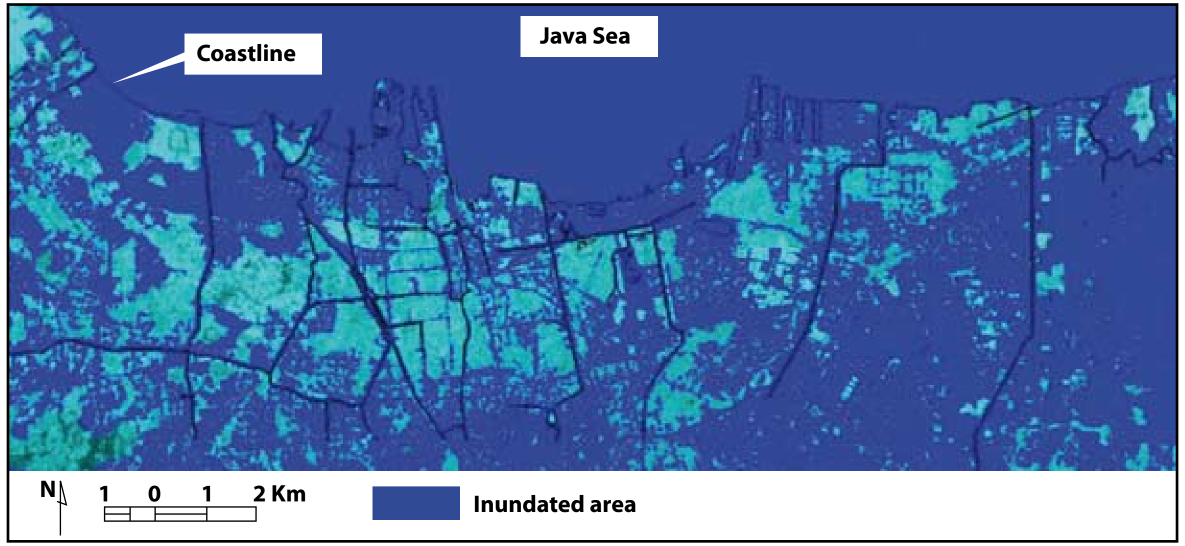
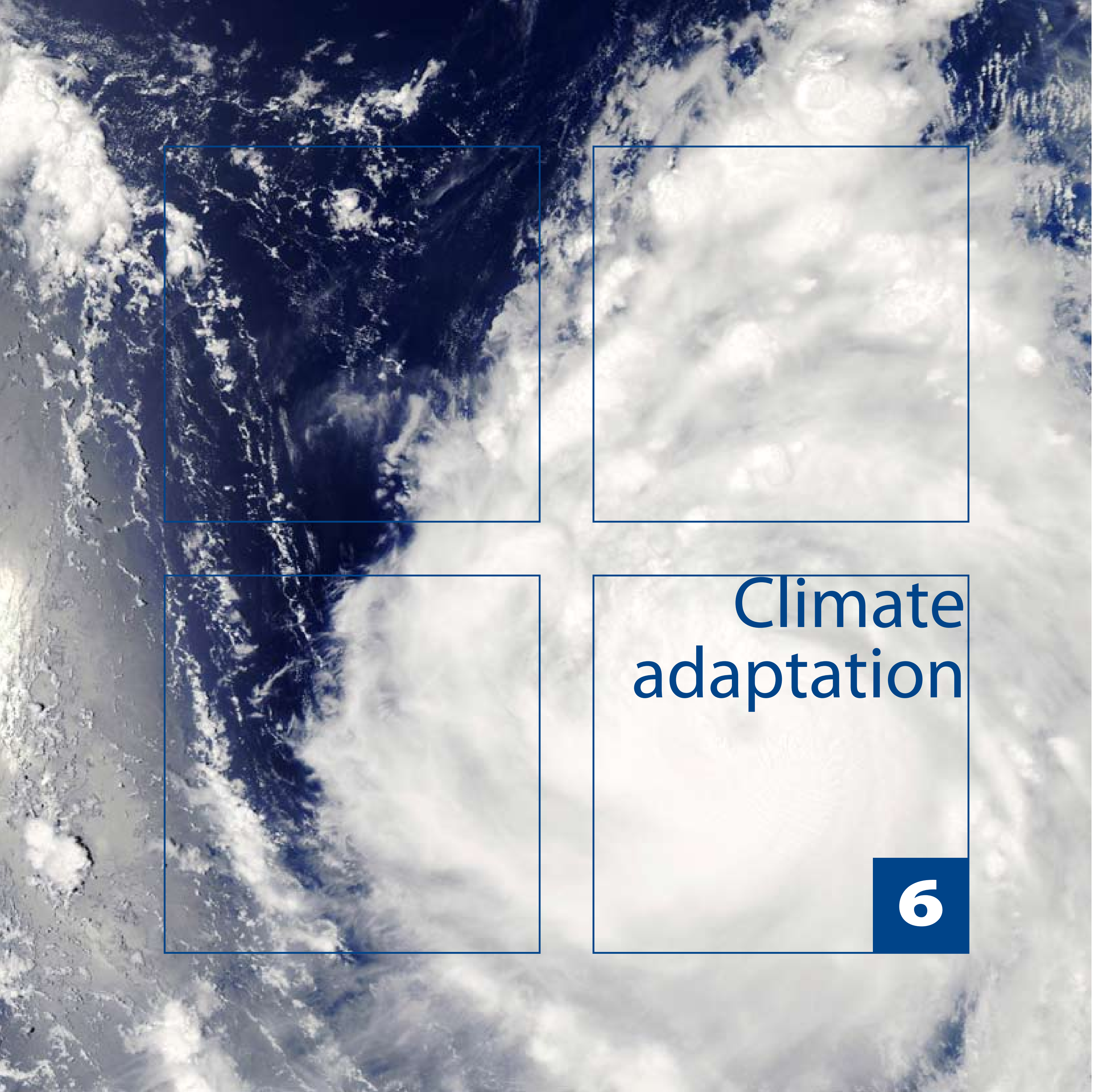


Figure 5.4. The extent of a 1/100 year coastal flood event in northern Jakarta in the year 2100, assuming a sea level rise of 60 cm, land subsidence of 370 cm, and an increase in storm surge intensity of 10%[25].



6 Climate adaptation

The IPCC 4th Assessment Report states that since emissions of CO_2 can last for 100 years in the atmosphere, sea level rise will continue into the future, even if the global community rapidly achieves a massive reduction in its carbon emissions down to the levels of the 1990s. Therefore, even with such a strong reduction of greenhouse gas emissions, global warming will have a serious impact on coastal cities and their residents. Hence, it is inevitable that flood risks and other climate change impacts will continue to increase, and that adaptation measures and policies need to be developed parallel to mitigation efforts[38]. The question is not if, but how quickly will societies need to adapt?

Adaptation to changing climatic and socioeconomic conditions is not new; cities have been adapting to societal and environmental changes for centuries. However, the world of today is much more complex than it was in the past, and interventions taken to adapt to climate change in one sector have significant impacts on other economic sectors. In today's world, societal activities are more connected and interdependent. Adaptation to climate change, therefore, requires a holistic approach, where all sectors and stakeholders participate in order to include long-term adaptation planning in their daily operations.

The cities of Rotterdam and New York have anticipated the climate adaptation challenge and have initiated both scientific and policy processes that have led to overall adaptation plans. For example, the Rotterdam Climate Initiative 2030 provides a planning horizon, outlook and goals for the year 2030 and have defined objectives and tracks that are geared towards achieving a sustainable and climate-neutral City of Rotterdam by that year. Rotterdam has also developed the "Rotterdam Climate Proof – RCP" plan, which focuses on water management and climate adaptation measures to make Rotterdam climate proof in 2030. New York is developing its adaptation strategy in a series of PlaNYC and other reports to counter the impacts of climate change and to increase the City's climate resiliency. While differences in climate, geography, and socioeconomic factors and thus in adaptation plans exist, both cities are following robust strategies for managing the risks of climate change.

Existing climate policy documents for both Rotterdam and New York, and recently also for Jakarta, state that long-term planning is the key to successful adaptation. Effective land use planning is crucial for enhancing the cities' adaptive capacities to climate change.
The role of stakeholders in the development and implementation of adaptation measures is a key ingredient, recognized by both New York and Rotterdam. Also, the city government of Jakarta clearly sees that effective adaptation will eventually require the local implementation of measures, and is collaborating with NGOs to improve its interrelationships with local institutions. A participative approach ensures that stakeholders can express their objectives, concerns and visions, and stimulates the formulation of innovative ideas in the adaptation process. An adaptation process also enlarges the commitment of stakeholders to ensure that new measures are accepted and implemented.

Rotterdam Climate Proof, Rotterdam Water Plan 2030

6 1

The City of Rotterdam started the "Rotterdam Climate Initiative" to develop Rotterdam into a climate-neutral city[36]. The focus of this plan is on mitigating the emission of greenhouse gases and on strengthening the city's economy through innovative solutions to save energy and store CO_2. The goal is to achieve a 50% reduction in CO_2 emissions by 2025 (compared to the level of emissions in 1990), in conjunction with economic growth. The founders of the Rotterdam Climate Initiative are the Port of Rotterdam, the companies in the industrial port district, the municipality, and the environmental protection agency Rijnmond. A 50% reduction in CO_2 emissions by 2025 implies an annual reduction of 30 megatons of CO_2 emissions.

The Rotterdam Climate Proof (RCP) plan focuses on adaptation, and is complementary to the Rotterdam Climate Initiative. Within the RCP initiative, water is an important aspect, but it is not only seen as a threat. Water is seen as an asset, an element for developing an attractive and economically strong city, and hence it plays a crucial role in the adaptation strategy of Rotterdam.

There are three main challenges in the RCP plan related to water and climate change:

(1) Flood protection

Sea level rise will increase flood risk. According to Dutch law, flood defenses will have to be reinforced. All quays and levees that are not yet high enough will be reinforced in the coming years. However, in the long term additional reinforcement may be needed. For this reason, space needs to be reserved now for the possible upgrading of flood defenses in the future.

(2) Architecture and spatial planning

One of the challenges is to find alternative options that both enhance flood protection and add value to the attractiveness of the city. To achieve this, spatial planning, architecture and flood protection should join forces in looking for alternative adaptation options. Traditional solutions are inadequate in this respect. In the city center and the old neighborhoods, for example, it is not possible to tackle the problems of water storage by constructing extra facilities. The costs are exorbitant and existing buildings cannot simply be demolished. Innovations such as green roofs, "water plazas", alternative forms of water storage and the like, are therefore essential for the further development of the city.

The city also plans to develop new suburban centers outside the levee system. The challenge for spatial planners and architects is to find areas that are able to absorb high flood levels. The Rotterdam harbor area lies several meters above sea level and parts of this area are no longer in use. These areas are suitable for urban development, as long as architectural planning accommodates the possibility of flood risks in the future.

(3) Rainwater storage, updating sewage system

The severity and frequency of extreme rainfall events will increase in the future; there is a risk that the current sewage system may not be able to treat and drain the surplus of water. In practice, rainwater usually drains away via the sewers; increasing amounts of rainfall already lead to problems with the existing sewage system. One possible way to avoid these problems is to collect the rainwater and allow it to drain away in a system other than the sewers, separating the dirty "black" wastewater from the relatively clean "brown" wastewater. However, this system must not

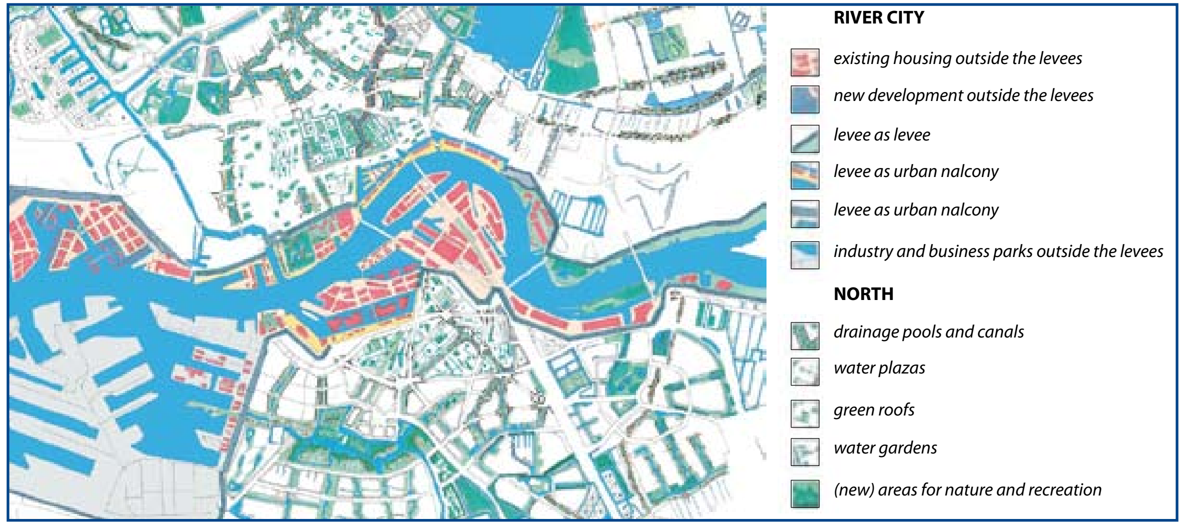


Figure 6.1. A map from the Rotterdam Water Plan 2030 as part of the adaptation initiative "Rotterdam Climate Proof" (RCP) showing new possibilities for water management.

be allowed to affect public health, the quality of the groundwater or groundwater levels. Sewage pipes generally last for about fifty years; the reconstruction would take several decades.

One option is to look for locations for the (temporary) storage of rainwater. The Rotterdam Water Plan 2030 is looking for an additional 600,000 m^3 of water storage space. At least 80 hectares of extra lakes and canals would be needed to provide this storage in open water. Additionally, water could be stored on green roofs or in water plazas.

Another important aspect of adaptation planning in Rotterdam is to understand how the regional and national government plans for adaptation intersect, and hence the requirements and boundary conditions that they set for the City of Rotterdam. In 2008, for example, the "Veerman Committee", a special national committee set up to study the challenges that the Netherlands face as a result of future climate changes, presented new recommendations on flood management and adaptation to climate change for the whole of the Netherlands[26,54]. The recommendations follow the current Dutch water management approach, which focuses on reducing the probability of flooding through the use of flood defenses such as levees, beach nourishment and storm surge barriers. The plan has implications for adaptation planning in Rotterdam: should the city invest in additional storm surge barriers?; or should the city invest in adaptive architecture and become a more open city where water can move around freely?

New York: PlaNYC 2030

6 2

In December 2006, Mayor Michael R. Bloomberg challenged New Yorkers to generate ideas for achieving 10 key goals for the city's sustainable future[6]. New Yorkers in all five boroughs responded positively. The result is the most sweeping plan to enhance New York's urban environment in the city's modern history. On Earth Day 2007, the Mayor released PlaNYC 2030, a comprehensive sustainability plan for the city's future. PlaNYC puts forth a strategy to reduce the city's carbon footprint, while at the same time accommodating population growth of nearly one million, and improving its infrastructure and environment. Recognizing the importance of reducing global greenhouse gas emissions, and the value of leading by example, New York has set the goal of reducing its citywide carbon emissions by 30% compared to 2005 levels.

Focusing on the five key dimensions of the city's environment – land, air, water, energy, and transportation – PlaNYC 2030 could serve as a model for other cities in the 21st century. The combined impact of this plan will not only help ensure a higher quality of life for generations of New Yorkers to come, but will also contribute to a 30% reduction in greenhouse gas emissions.

An interesting aspect of PlaNYC 2030 is the participation of stakeholders in the development of the plan. After PlaNYC was announced, over 100 organizations were invited and meetings were held throughout the five boroughs. Additionally, during a four-month public outreach process, PlaNYC received over 3,000 email messages through its website with ideas and visions from New Yorkers in all five boroughs. These citizen suggestions helped to form a plan to address the critical challenges that lie ahead to create a sustainable city.

In recent decades, New York City has acquired a substantial history of efforts to assess adaptation strategies to address climate change. The Metro East Coast Report, a report for the National Assessment of Climate Variability and Change [27], reviewed climate change with many regional stakeholders. The New York City Department of Environmental Protection's Climate Change Task Force, initiated in 2004, surveyed the entire range of vulnerabilities to climate change of the water system. Its most recent report, the Assessment and Action Plan[29], was published in 2008.

Mayor Michael Bloomberg, in partnership with the Rockefeller Foundation, convened the New York City Panel on Climate Change (NPCC) in August 2008.

The NPCC, which consists of climate change and climate impact scientists, as well as legal, insurance and risk management experts, serves as the technical advisory body for the Mayor and the New York City Climate Change Adaptation Task Force (the "Task Force") on issues related to climate change, impacts and adaptation. The Task Force has focused its work on critical infrastructure in the city, and the NPCC has developed three workbooks to guide adaptation planning; a full report from the NPCC is forthcoming [38].

The City has developed a robust, durable framework for effective, flexible and cost-efficient adaptation planning designed to meet the challenges of climate change in the city [17]. This framework is based on IPCC GCM model outputs for climate scenarios, and carefully developed adaptation assessment procedures in the context of climate protection levels. On a State-wide level, the ClimAID study sponsored by the New York Energy Research and Development Authority (NYSERDA) includes an assessment of coastal impacts, as does the New York Commission on Sea Level Rise and several other studies.

There is a growing awareness that all these recommendations will have to be monitored and adjusted as new research and observations become available as to the projected rate of sea level rise. It is worth noting that global emissions of CO_2 now exceed the upper limit envisaged by the IPCC for the worst-case "business as usual" scenario, in spite of the Kyoto Accord which specified that the signatories reduce their carbon footprints to 1990 levels.

"Climate change is real and could have serious consequences for New York if we don't take action," said Mayor Michael Bloomberg. "Planning for climate change today is less expensive than rebuilding an entire network after a catastrophe. We cannot wait until after our infrastructure has been compromised to begin to plan for the effects of climate change."

Michael Bloomberg,
Mayor, City of New York

planYC

Adaptation planning in Jakarta

6.3

At the national level, both mitigation and adaptation strategies on flooding are addressed in Act Nr 24/2007 on Disaster Management and Act Nr 27/2007 on Coastal Management and Small Island Protection. The Disaster Management Act focuses on the mobilization of aid and relief services during and after floods. This has led to the creation of organizations to be better prepared and to manage potential disasters.

The former "Task Forces" were transformed into standing organizations like the Badan Nasional Penanggulangan Bencana (PNPB), with branch offices at lower administrative levels (Badan Daerah Penanggulangan Bencana, or BDPB). Greater Jakarta has prepared a policy for disaster management, which includes an implementation strategy. It is also conducting regular disaster drills, and focusing on early intervention to reduce the loss of life and financial and economic damage. They recognize the need for preventive measures, both upstream and downstream, and acknowledge that reducing flood risk is a government responsibility.

Another important development was the introduction of a presidential decree in 2008 (Peraturan Presiden Nomor 54 Tahun 2008 – Perpres 54/2008) which aims to regulate land use for various purposes across Jakarta and its upstream areas, including Bogor and Depok. The decree sets out ambitious targets for ensuring the integrity of spatial planning, sustainability of the environmental carrying capacity in providing water supply, flood protection, and local economic development. For example, it is required to reduce surface runoff and increase water residence times in river basins, in order to reduce flood risk. Hence, flood management and spatial planning are making great advances in the city and region, yet the various acts and decrees do not specifically set out an overall action plan on how to move towards the implementation of adaptation measures at the local level.

Adaptation to flood risk in London: The Thames Estuary 2100 study

London is a city that, like the three cities primarily discussed in this volume, has been concerned with the effects of climate change on the urban area, and experts from London participated in the conference on which this book is based. The Thames Estuary 2100 project (TE2100), commissioned by the UK Environment Agency, provides a plan to manage flood risk in the Thames Estuary for the next 100 years. Central to this is adapting to the uncertain effects of climate change. This has the potential to drive changes in sea level, storm surge height and frequency, and river flows. The River Thames Estuary area covers about 500,000 homes and 40,000 nonresidential properties, including key governmental and financial centers in London. The estuary is also important from an environmental perspective, and is one of the five most important estuaries in Europe for bird habitats.

TE2100 has devised an approach to evaluate different flood management options or packages of measures relevant to each reach of the estuary. These options are progressively iterated and tested against a decision framework, which addresses the uncertainties in projections of future climate and development along the Thames.

This framework has tested the suitability of the options against differing futures driven by a range of socioeconomic and climate change scenarios. Using this method it has been possible to detect thresholds, which will be critical to various options. For example, modifying the existing barrier and defenses will only cope with a certain level of sea level rise and increase in storm surge.

Resulting from this work and using the threshold or scenario neutral approach, TE2100 produced its High Level Options in 2007, which have been the subject of extensive online stakeholder engagement. These are a set of adaptation response options (HLO1, 2, 3a, 3b, and 4). Each option consists of a pathway or route through the century that can be adapted to the rate of change that is experienced. They are described in the figure below, which essentially shows how the four different options perform against the range of new TE2100 climate change scenarios. It can be seen that not only are the options flexible, but it is possible to move from one adaptation option to another depending on the actual rate of change that occurs in reality. This illustrates the benefits of looking at higher scenarios in terms of a robust analysis.

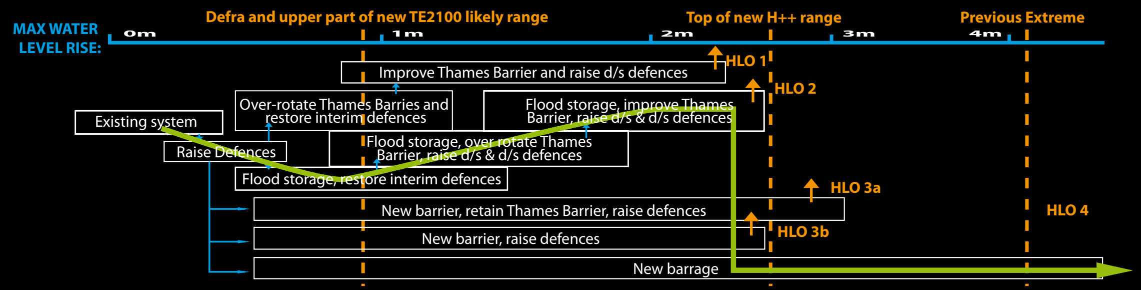


Figure: Different adaptation strategies for London. The green path shows a possible future adaptation route (or pathway) in the event of extreme change. The vertical dashed lines show the new TE2100 scenarios[46].

4

6

Adaptation cost

The cities of Rotterdam, Jakarta and New York are still in the planning phase of adaptation and moving towards the evaluation and implementation of concrete measures. Hence, an estimate of the total cost for flood management adaptation in the three cities is not yet available. However, recent studies exist that provide estimates of the cost of flood management adaptation. The Attention for Safety Study[30] estimates adaptation costs for the whole low-lying part of the Netherlands. For comparison, we here specifically mention another detailed study in the UK and the Thames 2100 study[31] provides adaptation cost. This study's estimates are for the Thames Estuary area around London.

Table 6.1 shows the costs of adaptation for the low-lying areas of the Netherlands with additional flood protection measures under different climate change scenarios. These are costs for 3500 km of levees, the nourishment of 450 km of beaches and the widening of the main rivers. Each climate change scenario consists of a combination of projected sea level rise and maximum discharges from the rivers Rhine and Meuse. Different sea level rise scenarios (even up to 500 cm) have been used to calculate the effects on flood probabilities. Note, however, that the maximum sea level rise scenario provided by the Royal Netherlands Meteorological Institute (KNMI) projects a rise of 85 cm by the year 2100. The total costs of adaptation vary from 9 to more than 80 billion euros. These are estimated values without upgrading the current Delta Works barrier system[26]. When expressed as a percentage of GDP, the costs are expected to be limited to the range of 0.1-0.2%, assuming a sea level rise scenario of 85 cm by 2100.

SCENARIOS					
	2040	**2100**	**2100**	**2100**	**Far future**
Sea level rise (cm)	24 cm	60 cm	85 cm	150 cm	500 cm
Max. discharge River Rhine (m^3/s)	16,700	18,000	18,000	18,000	18,000
Max. discharge River Meuse (m^3/s)	4,200	4,600	4,600	4,600	4,600
COSTS IN BILLION EUROS					
River works					
River widening Rhine	2.7	5.5	5.5	5.5	5.5
River widening Meuse	1.3	4.2	4.2	4.2	4.2
Levee reinforcement	0.2	1.8	2.6	6.1	36
Coast					
Beach nourishment Holland	1.9	6.4	9.1	16.0	25
Beach nourishment Wadden Sea	1.1	3.8	5.4	9.6	?
Beach nourishment Western Scheldt	0.1	0.4	0.6	1.1	?
Coastal levee reinforcement	1.9	2.3	2.6	3.4	8
Total	**9**	**24**	**30**	**46**	**>80**

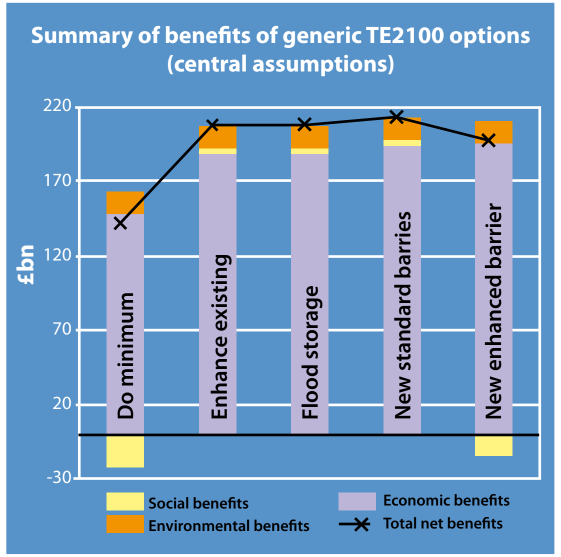
Table 6.1. Costs of flood management investments under different climate change scenarios (billion euros). These are the costs without upgrading the existing large barriers such as the Maeslant storm surge barrier in Rotterdam[30].

Adaptation cost for the Thames Estuary (UK)
The adaptation costs for the Thames Estuary are lower than those for the Netherlands as the area is smaller. The discounted whole-life capital and maintenance costs for TE2100's estuary-wide options under a "central" climate change outcome (involving 1 m of sea level rise) range between £1.6 billion for the "do minimum" option (purely maintaining the existing system), through to £5.3 billion for a new flood barrier to the most protective design. These costs include the greenhouse gas impacts of construction and maintenance work, valued at the UK government's Shadow Price of Carbon, which typically make up around 5% of the overall cost.

A comprehensive assessment of economic, environmental and social benefits of the options was conducted, and the figure below summarizes the benefits estimates for the four generic flood risk management approaches under a central scenario. This highlights the fact that a key differentiating factor in the performance of options is their environmental performance (impacts on physical habitats, biodiversity, natural processes, water quality, landscape and the historic environment). All options have very significant economic and social benefits.

The study has revealed that under a "central" outcome, two "front runners" emerge: either enhancing the existing system; or maintaining the existing system and then building a new "standard" flood barrier further downstream (around 2070). Under more extreme climate and socioeconomic scenarios, new barrier options emerge more strongly as preferences. While this might suggest that a new barrier would be the best overall solution, the difficulty is that such an approach may cause infringement of key environmental legislation if climate change variables such as water level rise turn out to be near or below "central" estimates. If, however, sea level rise accelerates but a new barrier is not put in place, there could be increased risk to the Thames Estuary[46].

Figure: Cost of climate adaptation: example for the greater Thames Estuary area in the UK. The figure summarizes the benefits of adaptation options presented in the Thames Estuary 2100 study using a future scenario of 1 m sea level rise.



The issue of climate adaptation is very complex, and there is no single readily available adaptation solution applicable to all coastal cities. Adaptation is partly a matter of allowing experiments and innovation. On the other hand, there is the need to keep all options open because of the uncertainty of future scenarios – one can never predict exactly how the future will develop and what measures are needed. Hence, climate-robust and flexible measures should be considered. In addition, there are the issues of policy making, stakeholder involvement and financing new measures, which may hinder the quick implementation of adaptation measures, and may cut ambitious plans to more modest levels.

Therefore, it is important to consider a variety of possible measures in the planning process of climate adaptation, and to learn from experiences from other areas and coastal cities. Table 7.1 provides a number of examples of existing adaptation measures, although the list is by no means exhaustive.

	NEW YORK	JAKARTA	ROTTERDAM
Measures			
Nature restoration/ augmentation	Beach nourishment, wetland and estuary restoration, salt marsh restoration	Improving the shoreline by mangrove conservation	Beach nourishment, water retention areas
Engineering protective measures	Sea walls, flood walls, groins, jetties, breakwaters, storm surge barriers	Levees, drainage systems, pumping stations, temporary dams	Levees, storm surge barriers
Freshwater storage	Staten Island Bluebelt Program, green roofs	Increasing greenery in the city, increase capacity of existing watercourses through dredging and waste management	Green roofs, water plazas
Architecture	Flood-proofing basements and ground level dwellings/buildings	Raised highways	Floating houses, adaptable water-front development in old harbor area
Insurance	Available through NFIP (National Flood Insurance Program)	Available but market penetration is low	Not available
Better fore-casting and evacuation	Evacuation plans developed. Extensive work to improve forecasting and warnings	Evacuation not an option	Evacuation not an option

Table 7.1. List of existing adaptation measures to reduce impacts from coastal flooding due to climate change.

7.1 Nature restoration/ augmentation

Sand nourishment projects represent one temporary solution to coastal erosion and protection against storm surges considered in parts of New York City, the south shore of Long Island and Rotterdam. Sand is mined from offshore bars, usually located within several kilometers of the beach at depths of around 10-20 m below mean sea level. If possible, the texture and grain size of the mined sand is closely matched with the original beach sand. Sand nourishment is relatively cheap compared to other measures but has only a temporary effect and therefore has to be repeated on a regular (annual) basis.

Table 7.2 displays estimates of the volumes of sand mined for beach nourishment at present for the Netherlands and greater New York ocean coastlines.

Currently, about 25 million m^3 of sand is introduced onto Dutch beaches every year. For the New York/Long Island south coasts, a modest 4 million m^3 of sand is pumped and sprayed onto certain vulnerable sections. To protect the respective coastlines adequately against a future sea level rise of 80 cm, the annual volumes of sand required to maintain present policies rise to 60 and 17 million m^3 respectively.

In Jakarta, mangrove conservation is considered one of the best ways to protect the coastal area, not only in terms of flood protection, but also from a sustainability point of view. The Ministry of Forestry has developed a program to increase the area of mangroves on the coastal area near Jakarta; in some areas these had almost disappeared due to deforestation.

Volumes of sand necessary for beach nourishment

	Current climate 20 cm "natural" SLR (mil. m^3)	Climate change 80 cm SLR (mil. m^3)
The Netherlands	25	~60
New York - south coast of Long Island	4	~17

Table 7.2. Volumes of sand necessary for beach nourishment for the current sea level rise and climate change [27,30].

Engineering measures

7.2

Figure 7.1. Drainage channel in the City of Jakarta.

Levees & flood walls

The low-lying part of the Netherlands is divided into 53 levee rings. A levee ring is a separate administrative unit under the Water Embankment Act of 1995. The latter aims to guarantee a certain level of protection against flood risks within each levee-ring area.
For example, the levee ring in the northern part of Rotterdam has a safety norm of 1/10,000, meaning that the levees have been designed to withstand a flood with an estimated probability of occurring ("return period") once in every 10,000 years. Safety norms reflect both the number of inhabitants and the economic value of assets within a levee ring; the more people and economic value to be protected by levee infrastructure, the higher the safety standard. The safety norms of levee rings vary considerably in the Netherlands, between 1/1,250 and 1/10,000. These norms are substantially above protective standards that may be appropriate for Metropolitan New York, which is not, like much of the Netherlands, located below sea level. However, as climate change is expected to increase the frequency and severity of flooding events, these flood probabilities will accordingly increase rapidly with sea level rise. At a certain point in time the normative circumstances will be manifest at frequencies higher than the law permits for certain levees, rendering such levees substandard. Therefore, reinforcing levees is an ongoing business in the Netherlands. Yet even though the Dutch safety standards are very high, current norms still do not take further growth of socioeconomic values into account, as the norms themselves have remained unchanged for the past 50 years.

Jakarta is improving its levees along the drainage system and shorelines (Figure 7.1). Currently under discussion is the possibility of building a levee along the north coast area to protect the lowland regions. The Public Works Agency of Jakarta has also introduced a project to upgrade the drainage system of the city including removing sediments and waste from the channel system in the city's rivers and canals. In the coastal residential areas, additional pumping stations have been established along with improved drainage systems. The drains are pumped directly into the main watercourses, which then flow to the sea or towards pumping stations further downstream. Additional pumping stations may help to avoid inundations and hence reduce flooding and serious traffic jams along the major highways, including to key transportation facilities such as the Soekarno-Hatta International Airport. On a less technical level, people living in informal settlements and in the city outskirts have installed simple structural devices such as small dams to protect their houses from tidal floods.

Storm surge barriers

Storm surge barriers and large shipping locks and sluices are part of the protective constructions built along the Dutch coast and inland to provide sufficient protection as demanded by Dutch law, while maintaining accessibility, both for economic activities and ecological processes. Large constructions, such as the Eastern Scheldt and Maeslant barriers, were designed to function for at least 100 years, taking the observed sea level rise of 30 cm per century into account.
A faster rise of the sea level would shorten the functional period in which the barriers remain within set norms. Renewal costs would, as a consequence, occur sooner than expected.

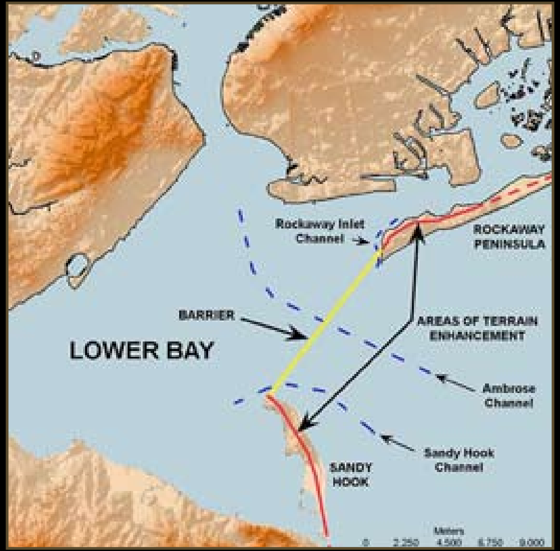
One possible long-term infrastructure adaptation measure that might be considered to protect New York City and northern New Jersey is storm surge barriers spanning the major navigation channels connecting New York Harbor to the sea. As New York is generally located on higher ground than Rotterdam, London and other threatened European cities, New York City planners enjoy the benefit of more time to consider options. Much can be learned from the British, Russian, Italian and Dutch experiences in storm surge barrier design, construction and operation. The problems of climate change impacts to be faced in New York 50 and 100 years from now may be in some respects similar to those of some European cities today.

Similar to the Delta Works and the Thames River Barrier, New York barrier design and emplacement would require comprehensive cost/benefit analyses, desired protection level and efficacy studies[47]. Many New York communities are built on relatively high ground in each of the five boroughs. Protection against modest levels of surge could be provided with a combination of local measures (such as flood walls and raised subway entrances) coupled with evacuation plans. However, many locations in the outer boroughs of Brooklyn, Queens, southern Staten Island, areas in New Jersey, Jamaica Bay and JFK Airport are at risk of flooding from a direct hit from a major hurricane or winter nor'easter. Many subway station entrances are located less than 3.5 m above high tide sea level; flooding of even one station with corrosive seawater could result in a system-wide shutdown. An example is the flooding of the Hoboken PATH trans-Hudson tube station during the December 1992 storm, which resulted in the interruption of service on one PATH line for 10 days. Such a sudden shutdown would disrupt important rail elements of city evacuation plans for several million directly affected residents, although surface evacuation routes would still be available.

Barriers are designed to protect against oceanic storm surge. As elsewhere, barriers do not protect against the substantial inland damages arising from wind and rain that often accompany extreme weather events. Some conceptual engineering barrier design work has recently been undertaken by the professional engineering community. Possible locations include the Verrazano Narrows, which is the main shipping channel connecting Upper New York Bay and Port Elizabeth NJ with the Atlantic Ocean. Other possible connections include the upper East River to eliminate surges originating in western Long Island Sound, the Arthur Kill behind Staten Island and a more ambitious outer barrier system stretching across from Sandy Hook, NJ to Far Rockaway, Long Island. This latter approach follows the Delta Works design by shortening the length of coastline that needs to be protected as well as safeguarding JFK Airport and communities in northern NJ and Jamaica Bay.

Figure 7.2. The Eastern Scheldt storm surge barrier in the Netherlands.

One possible long-term infrastructure adaptation: storm surge barriers in New York

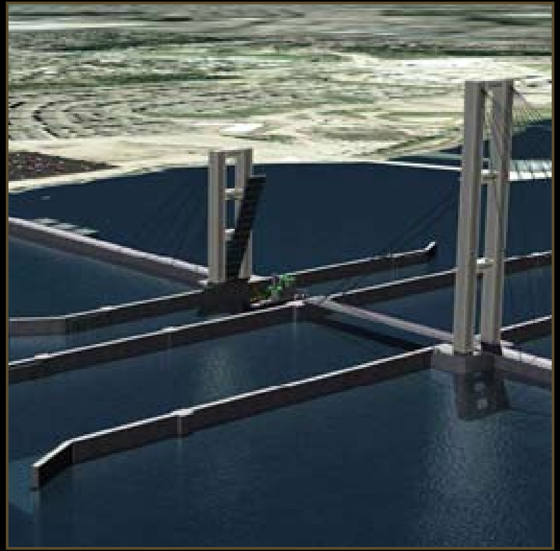


Endnote 50

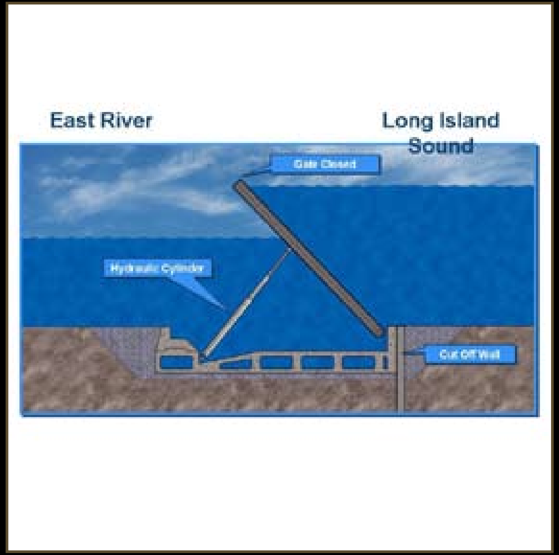
Endnote 49

One possible long-term infrastructure adaptation measure for New York would be storm surge barriers. After extensive storm surge modeling by Stony Brook University oceanographers and following a 2009 international conference sponsored by the Metropolitan Chapter of American Society of Civil Engineers, scientists and engineers concluded that the risk of future casualties and damage might be significantly reduced by storm surge barriers placed across vulnerable openings to the sea including the Verrazano Narrows, upper East River and Arthur Kill. Another more ambitious approach is the construction of an outer barrier system, which would link northern New Jersey to Long Island. This would eliminate the need for the Verrazano and the Arthur Kill barriers, provide protection to the outer boroughs of Brooklyn and Queens, additional northern NJ communities, Jamaica Bay and JFK Airport.

For each barrier, requirements regarding passage of ships and maintenance of water quality would require large open navigation channels for ships to pass through in normal conditions and a porous cross section allowing sufficient tidal exchange and river discharge from New York Harbor. A possible design is based on experience with storm surge barriers in The Netherlands. The location for the storm surge barrier would lie half a mile north of the Verrazano Bridge. The Arthur Kill barrier would be a system of two shipping locks, sluice gates and a lifting bridge. The upper East River design would consist of a row of hydraulically operated, hinged lifting flat gates, similar to those being built in Venice. The outer barrier design would be of similar design to the Verrazano barrier, providing storm surge protection, but would also carry rail and road traffic as a New York City bypass and connection to JFK Airport.



Endnote 52



Endnote 51

These possible designs of storm surge barriers in the Verrazano Narrows, upper East River, Arthur Kill and the Outer Harbor are presented as contributions to the debate on how to deal with the increasing risks of a storm surge in Metropolitan New York in the era of climate change. These options are at present only conceptual, and would require very extensive study of feasibility, costs, and environmental and social impacts before being regarded as appropriate for implementation. New York City has high ground in all of the boroughs and could protect against some levels of surge with a combination of local measures (such as flood walls) and evacuation plans; and barriers would not protect against the substantial inland damages from wind and rain that often accompany hurricanes in the New York City region.

7.3

Wetland restoration

The city of New York initiated the "Staten Island Bluebelt Program" to reduce the risks of flooding on Staten Island from stormwater, by providing and constructing stormwater detention ponds and enhancing or creating streams, ponds and wetlands. New, separate, storm and sanitary sewer infrastructure networks are also included in the program. The 10,000-acre Bluebelt investment has saved the municipality tens of millions of dollars, providing stormwater drainage for about a third of the island. The implementation of the Bluebelt program, at an estimated cost of 37 million dollars, cost some 39 million dollar less than a conventional underground network of storm sewers [29].

In the more rural areas around Rotterdam, agricultural land is used for the temporary storage of water during floods (mainly grassland and nature areas) and farmers and/or nature conservation institutions are being involved in jointly identifying the most suitable areas for additional storage. The costs of converting agricultural land into storage areas may be up to ca. 250,000 €/ha. Enhancing the storage capacity of polder areas by enhancing the number of ditches and disconnecting these from the main receiving reservoirs will cost between € 0.3 and 0.7 billion in total for the entire Randstad conurbation (Amsterdam – Rotterdam).

7.4

Peak water storage in urban areas

In Rotterdam, sufficient peak water storage is one of the main goals of the city's newly formulated adaptation plan. The city has estimated that 300,000 m^3 of extra water storage facilities must be developed in order to accommodate the additional volume of rainwater that is expected due to climate change. Several options exist. For example, water retention areas are being allocated temporarily to store the surplus of freshwater originating from either excessive rainfall or peak river discharges. In the city center, open water areas are used for storing extra water by retrofitting ponds in city parks or adjusting canals to store more water, so that in the case of an extreme precipitation event their water levels may rise without inundating surrounding areas. An artist's impression of creating more open water is presented in Figure 7.3. Intensive (garden-like) green roofs range from $15 to $70 per square foot (~$50 to $375 per square meter). Costs also depend on whether the roof requires structural support or other repairs [32].

The provision of extra storage capacity for water is not always dependent on building or creating new areas of open water spaces. In Jakarta, one of the main causes of flooding is the reduced capacity of many of the city's rivers, canals and drainage channels. In many parts of the city these are clogged with solid waste and with sediments derived from upstream. Removing this waste and sediment would lead to an enormous increase in the storage capacity of the urban water system, and would have a significant effect on flood risk in Jakarta. In the Jakarta Flood Management Pilot Dredging Project, which was carried out in 2008 and 2009, the Netherlands provided assistance to the local government in the form of two heavy dredging machines and training, in order to dredge between 20,000 and 30,000 m^3 of sediments from the Mati and Pademangan canals. The local authorities will continue and elaborate on such schemes in the future, to dredge other parts of the city, and to ensure that the water system is well maintained.

Figure 7.3. Artist's impression of creating more open water in the city for storing excess rainwater in the Rotterdam area [36].

7 5

Architecture and water storage

In densely populated urban areas where space is lacking to create open water storage, other measures have to be developed to decrease peak water load on the combined sewer and stormwater systems. Even today, extreme precipitation events can overload the wastewater systems and cause them to flood, dumping raw sewage into local waterways. Examples of such events and their consequent damages can be found in each of the cities of Jakarta, New York and Rotterdam.

Innovations in climate adaptation can come from architecture and the multifunctional use of space, where properties are used for both residential purposes and the storage of water. One adaptation option is to use public areas such as playgrounds, or sealed parts of underground parking lots, to store excess water temporarily during peak events. An example is presented showing a water plaza in Rotterdam that can store water in times of peak events but is used as a playground in normal conditions (Figure 7.4). Another example is presented in Figure 7.5, showing the development of a new underground parking garage; the design of the garage is such that underneath the slope of the entrance a storage basin is created that is connected to the stormwater and sewage system. In case of an extreme event, the stormwater pipeline drains into the sealed garage reservoir and the capacity of the reservoir is large enough to store 50% of the expected volume of water that falls in one storm on the central city of Rotterdam (10,000 m^3 of water).

Figure 7.5. Reservoir connected to the sewage and stormwater system being developed as part of a newly built underground parking garage in Rotterdam [36].

Another adaptation option is to develop green roofs to decrease the total amount of runoff. Green roofs have been proven to slow the rate of runoff from the roof, and they can retain 10-20 mm of rainwater, which equals an average of 100-200 m^3 of water per roof in Rotterdam. After an extreme precipitation event, green roofs gradually release water back into the atmosphere via evapotranspiration. A similar example is found in the project called "Elevation 314", a new development in Washington DC, which uses green roofs to filter and store some of its stormwater on site, avoiding the need for expensive underground sand filters to meet DC Department of Health stormwater regulations. Green roof costs vary widely. In New York City, green roof costs range from $5 to $35 per square foot (~$50 to $375 per square meter). Intensive green roofs range from $15 to $70 per square foot (~$160 to $750 per square meter). Costs also depend on whether the roof requires structural support or other repairs[32]. An essential aspect of stimulating climate adaptation in city architectural planning is that of finance. Rotterdam has a large government support program in place for the partial subsidizing of the development of green roofs.

Figure 7.4. Example of a water plaza that is used as a playground during normal conditions and as a reservoir in case of extreme precipitation.

Waterfront development

6

7

In most cities, future population is expected to increase, and finding suitable properties with minimal vulnerability to climate change will be difficult. In Rotterdam, for example, most of the higher regions behind the levees are already occupied, and what is left are the deepest polders. Furthermore, cities increasingly plan to create attractive neighborhoods with lots of greenery and water. So, the challenge is to find top locations that offer both opportunities for climate proof development and a high quality living environment. Adaptive waterfront development is seen as a solution to address these different issues and requirements.

Rotterdam plans to develop 1600 ha of waterfront locations in the old harbor area in the center of the city, called Stadshavens (Figure 7.6). The properties are built on elevated land that has been raised during the last 100 years. Through adaptive architecture, this new neighborhood can be made climate proof and serve as a high quality waterfront living area. This requires new ways of developing buildings that, for example, allow water to move through the neighborhood in the event of a flood without causing casualties or damage to assets. Such a concept exists in the city of Hamburg, Germany, in the HafenCity project. The HafenCity is located in an old harbor area outside the protection of flood walls and is thus within the flood plain of the Elbe estuary. The existing elevation of the HafenCity is between 4.4 m and 7.2 m above sea level, and it is not adequately protected against flood. Therefore, every public road and bridge, as well as all buildings, will be elevated to a minimum height of 7.5 m above sea level (Figure 7.7). The buildings' foundations will serve as ground-floor garages, which can be protected with moving flood gates that seal off the ground floors. Roads and paths will be constructed above the flood line to ensure unrestricted access for the fire and emergency services in the event of an extreme storm tide[33]. Total costs for this project are estimated at about 600 million euros.

Figure 7.6. Plan: 1600 ha of waterfront development in an old harbor area in the city center of Rotterdam.

Figure 7.7. Waterfront development in Hamburg (Germany), 7.5 m (24 ft) above mean sea level.

7 Building codes & insurance

A well-diversified climate change adaptation strategy comprises both measures aimed at reducing the probability of a natural disaster occurring, for example by strengthening flood protection infrastructure, and measures that limit damage once a disaster happens. Damage caused by natural disasters can be limited by land use planning, such as preventing development in hazard-prone areas, and by building structures that are better able to withstand natural hazard impacts. For example, damage may be limited by constructing elevated houses and building with water resistant materials in flood plains or by strengthening roofs in order to prevent hurricane damage.

Adaptation measures undertaken at the household level can reduce natural hazard risks considerably. A study of The Wharton School estimates the potential hurricane damage that can be prevented in New York if all existing building code standards would be implemented. The results indicate that potential losses caused by a hurricane that occurs on average once in 100 years could be reduced by 39%[34].
Also, a study for the Netherlands indicates that several billion euros of damage can be prevented during a flood if households undertake (low-cost) adaptation measures, such as installing temporary water barriers and adapting buildings to flooding. In Jakarta, flooding is more common and to a certain extent households have already adapted their homes to prevent flood damage, by building on poles, for example (see Figure 7.8). However, the projected rise in sea level and land subsidence requires further adaptation measures in Jakarta to prevent future flood losses.

Figure 7.8. A 'flood proof' house constructed on poles in Indonesia.

In the future, the combination of societal and climate change is expected to accelerate upward trends in economic losses due to extreme weather events. The projected rise in damage challenges the insurance industry in providing affordable insurance against natural disasters. Insurers need to incorporate changes in natural disaster risk caused by climate change in the assessment and management of their risk exposure. Governments can promote affordability of insurance in the face of climate change by investing in risk reduction. In addition, public-private partnerships to insure natural hazard risk may be established, for example, with a role for the government as an insurer of last resort.

Climate change is, however, not only a threat for insurers but also provides new business opportunities. The experience of the insurance sector with assessing, managing, and spreading risks may be useful in fostering adaptation of societies to climate change. Insurance could provide tools to assess natural hazard risk, which can be useful to guide adaptation policies, such as spatial planning. Well-designed financial compensation arrangements can speed up the recovery process after natural disasters have struck and provide financial security to the insured. Moreover, insurance with risk-based premiums can provide economic incentives to limit damage by acting as a price signal of risks. For example, insurance can provide higher coverage or reductions in insurance premiums to homeowners who invest in measures that limit potential damage due to natural disasters. Indeed, a survey conducted in the Netherlands indicates that many homeowners would be willing to invest in adaptation measures in exchange for discounts on their insurance premium[35]. Insurance could play an important role in requiring or promoting the adoption of stricter building codes and other adaptation measures.

Existing flood damage compensation arrangements in New York, Rotterdam and Jakarta can be improved to promote adaptation to climate change. Insurance against flood damage in the USA is mainly covered through the NFIP program, which has failed to encourage homeowners to take adaptation measures. Many premiums are not based on actual risks, so that no premium discounts are offered to homeowners who invest in flood-proofing their homes. However, substantial efforts have gone into considering insurance in the context of climate change in the United States, and in the New York region in particular[17]. In the Netherlands, no flood insurance is available and households depend on (uncertain) ad hoc compensation of damage by the government. Recently, academics, insurers and policy makers have started to examine possibilities for a (partly) private insurance against flood risk. In Jakarta, flood insurance is available but market penetration is very low. Micro-insurance schemes may be promising financial arrangements to foster development of insurance markets in Jakarta. Such schemes could be facilitated by the involvement of international organizations, such as the World Bank.

8

Recommendations

On 9-10 of June, 2009, a group of 75 scientists, engineers, social scientists, architects, insurance experts, policy makers and planners gathered in New York City to discuss the issue of climate change adaptation in coastal cities: the Connecting Delta Cities Workshop. Representatives from the cities of Rotterdam, New York, Jakarta and London shared their experiences in adaptation planning. Innovations and bottlenecks in adaptation policies were addressed, and areas were explored with potential for further extended exchange of experience and expertise.

The roles that urban planners have in the implementation of adaptation policies and management are important to the successful construction, operation and maintenance of essential infrastructure and services in major coastal cities impacted by the challenges of climate change. These challenges include changing weather patterns, rising temperatures and sea levels, worsening threats of floods and storm surges, aging infrastructure and demographic shifts, all within an environment of ever growing populations and a scarcity of suitable land for adaptation practices.
For example, careful planning based on the best scientific understanding of the changing physical and natural environments, creative engineering solutions and effective emergency management systems to address ever increasing flood risks, both from upstream rivers and from the ocean, can substantially reduce the consequences of a flood. This requires, however, embedding climate change and adaptation considerations and long-term policy making into the daily operations of urban planners and policy makers. It also requires carefully considered legislation and new urban building codes to ensure that plans are effectively implemented to meet new climate-proofing standards.

The adaptation planning process also requires a systems approach with full participation of stakeholders. If stakeholders are aware of climate risks, and the understandings and perceptions of the climate scientists, social scientists, and engineers whose responsibility it is to plan, design and build resilient infrastructure, it will be much more feasible to jointly develop a workable adaptation plan for a city. The issue of climate adaptation and the role of spatial planners, water managers and other key stakeholders is too complex to tackle with a single disciplinary or sectoral approach.

Coastal cities continue to grow and continue to develop new urban areas in exposed locations near and at the coast. Waterfront development appeals to the desires of people who can afford to live in vibrant large cities with easy coastal access, high environmental quality and convenient transportation and health services. For many others, less fortunate, there is simply no other option than to live in a vulnerable location. To meet these demands of living near the waterfront, both of the wealthy and the poor, new forms of adaptive architecture, revised building codes and effective risk management policies are needed to maintain public safety, to limit the impact of floods and to facilitate large-scale evacuation if needed.

Another important issue raised during the workshop was how to mainstream adaptation policies into current and planned investments. For example, the infrastructure sector in all three cities spends billions of dollars on updating and expanding their various networks. Choices made today will influence the vulnerability to climate risks of assets and people far into the future. Therefore, it is important to study impacts and adaptation options under long-term trends in climate and socioeconomic change. Note that many large-scale infrastructure works take 10 to 20 years or more to design, plan and implement. Postponing adaptation planning and policy development to future generations will only exacerbate the problems of vulnerable city communities and expose them to unacceptable threats to life and property.

On the positive side, creative adaptation will stimulate new business and environmental opportunities and innovations in economic activities. Thus, there are many challenges and opportunities for both business interests and researchers to feed policy makers with new ideas and solutions. Green roofs as a way of storing excess precipitation is just one good example of such innovation, already being implemented in some cities.

While New York City, Rotterdam, and Jakarta are all in different situations with respect to adaptation to the coastal impacts of climate change, there is much that can be learned and shared among these and other cities. The common elements include the need for continued contact with climate science, in order that the best future scenarios can be used for planning, the need for a thoughtful planning process, and the need to ensure that planning for climate change is mainstreamed into all of the relevant agencies' planning and review procedures. In terms of timing, Rotterdam (and much of the rest of the Netherlands) has for a long period of time been faced with the urgent necessity of forestalling catastrophic damage; New York City has the time to work through a well-thought-out adaptation program that, if well done, can result in adaptations to climate change that are flexible yet cost-efficient. Jakarta, on the other hand, faces substantial problems from climate change but as of now has few resources to deal with them in the context of the other resource demands that it faces.

During the Connecting Delta Cities Workshop, it became clear that the challenges of climate adaptation pose fundamental and difficult questions and hard choices for research, policy and industry. There is a clear need for unprecedented cooperation and knowledge exchange across all sectors.
Much learning and skill development and many innovative practices, are starting to take place around climate issues in many coastal cities. These must be channeled in such a way that all stakeholders benefit across all socioeconomic classes from coordinated knowledge exchange networks. It is hoped that this Connecting Delta Cities initiative will provide a forum for those with important responsibilities in coastal cities.

References

1. Stern, N. (2006). The economics of climate change: the Stern Review. Cabinet Office – HM Treasury. Cambridge University Press, Cambridge University Press.
2. voc-kenniscentrum.nl/. Kaart van Batavia, circa 1652, gravure van Mattheus du Chesne, KITLV.
3. www.engelfriet.net/Alie/Hans/draaisteeg.htm.
4. KNMI Climate explorer. http://climexp.knmi.nl/.
5. Abidin, H.Z., Andreas, H., Djaja, R., Darmawa, D., Gamal, M. (2008). Land subsidence characteristics of Jakarta between 1997 and 2005, as estimated using GPS surveys. GPS Solutions, 12(1), 23-32.
6. City of New York (2007) PlaNYC 2030. http://www.nyc.gov/html/planyc2030/html/plan/climate.shtml.
7. Hurk, B.J.J.M. van den, et al. (2006). De KNMI'06 klimaatscenario's. http://www.knmi.nl/klimaatscenarios/knmi06/.
8. IPCC (2007). Climate Change 2007. The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.
9. NPCC (2009). Climate Risk Information. New York City Panel on Climate Change (NPCC). http://www.nyc.gov/html/om/pdf/2009/NPCC_CRI.pdf.
10. Landsea, C. W., Pielke Jr., R. A., Mestas-Nuñez, A.M., Knaff, J.A. (1999). Atlantic basin hurricanes: Indices of climatic changes. Climatic Change, 42, 89–129.
11. Neumann, C.J., Jarvinen, B.R., McAdie, C.J., Hammer, G.R. (1999). Tropical Cyclones of the North Atlantic Ocean, 1871-1998. Historical Climatology Series 6-2. National Climatic Data Center, pp. 206.
12. Boer R., Subbiah, A.R. (2005). Agriculture drought in Indonesia. In Boken, V.S., Cracknell, A.P., Heathcote, R.L. (eds.), Monitoring and Predicting Agricultural Drought: A Global Study Oxford University Press, Oxford, pp. 330–344.
13. ADB & Bappenas (1999). Causes, extent, impact and costs of 1997/98 fires and drought. Final report, Annex 1 and 2. Planning for fire prevention and drought management project. Asian Development Bank TA 2999-INO. Fortech, Pusat Pengembangan Agribisnis, Margules Pöyry, Jakarta, Indonesia.
14. Quinn W.H., Zopf, D.O., Short, K.S., Kuo Yang, R.T.W. (1978), Historical trends and statistics of the Southern Oscillation, El Niño, and Indonesian droughts, Fisheries Bulletin, 76, 663-678.
15. Coch, N.K. (1994). Hurricane hazards in the Northeast U.S. Journal of Coastal Research, 12, 115-147.
16. Ministry of Environment of Indonesia (2007). Indonesia country report. Climate variability and climate changes and their implication, pp. 79.
17. New York City Panel on Climate Change, Adapting to Climate Change: The New York City Experience, William Solecki and Cynthia Rosenzweig, eds., forthcoming.
18. U.S. ACOE/FEMA/NWS (1995). Metro New York Hurricane Transportation Study. Interim Technical Data Report.
19. New York Times, August 27, 1999.
20. KNMI (2008) http://www.knmi.nl/klimaatscenarios/documents/AVV_maart_2008.pdf.
21. Jonkman, S.N., Bočkarjova, M., Kok, M., Bernardini, P. (2008). Integrated hydrodynamic and economic modelling of flood damage in the Netherlands. Ecological economics, 66(1), 77-90.
22. Rosenzweig, C., Solecki, W. and Hammer S. First UCCRN Assessment Report on Climate Change in Cities (ARC3), forthcoming.
23. Bird, E.C.F. (1985). Coastline Changes: a Global Review. Wiley-Interscience, Chichester.
24. Developed by the Flood Resilience Group, Unesco-IHE/TU-Delft.
25. Marfai, M.A., Yulianto, F., Hizbaron, D.R., Ward, P.J., Aerts, J.C.J.H. (2009). Preliminary assessment and modeling of the effects of climate change on potential coastal flood damage in Jakarta. Joint research report of Gadjah Mada University, Yogyakarta and IVM, VU University Amsterdam.
26. Deltacommissie 2008 (2008). Samen werken met water (in Dutch). ISBN/EAN 978-90-9023484-7.
27. Rosenzweig, C., Solecki, W. (2001). Climate Change and a Global City: The Potential Consequences of Climate Variability and Change, Metro East Coast. Report for the U.S. Global Change Research Program, Columbia Earth Institute.
28. Rosenzweig, C., Major, D.C., Demong, K., Stanton, C., Horton, R., Stults, M. (2007). Managing Climate Change Risks in New York City's Water System: Assessment and Adaptation Planning, Mitigation and Adaptation Strategies for Global Change, doi:1007/s11027-006-9070-5.
29. New York City Department of Environmental Protection Climate Change Program (2008). Assessment and Action Plan, May, 2008.
30. Aerts, J., Sprong, T., Bannink, B. (2008). Attention for Safety. www.adaptation.nl. Report for the Dutch Delta committee pp. 258.
31. EA (2008). Thames Estuary 2100 Flood Risk Management Plan. http://www.environment-agency.gov.uk/homeandleisure/floods/104695.aspx.
32. PlaNYC 2008. Sustainable Stormwater Management Plan 2008.
33. http://www.hafencity.com
34. Kunreuther, H.C., Michel-Kerjan, E.O., Doherty, N.A., Grace, M.F., Klein, R.W., Pauly, M.V. (2008). Managing Large-Scale Risks in a New Era of Catastrophes: Insuring, Mitigating and Financing Recovery from Natural Disasters in the United States. Wharton Risk Management and Decision Processes Center, Georgia State University, and the Insurance Information Institute, Philadelphia.
35. Botzen, W.J.W., Aerts, J.C.J.H., Bergh, van den, J.C.J.M. (2009). Willingness of homeowners to mitigate climate risk through insurance. Ecological Economics, 68 (8-9), 2265-2277.
36. Rotterdam Climate Initiative. www.rotterdamclimateinitiative.nl
37. Nicholls, R.J., S. Hanson, C. Herweijer, N. Patmore, S. Hallegatte, J. Corfee-Morlot, Jean Château and R. Muir-Wood (2008). "Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes Exposure Estimates." OECD Environment Working Papers No. 1, 19/11/2008, November
38. Intergovernmental Panel on Climate Change, 2007, Climate Change 2007: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the IPCC, Cambridge, UK: Cambridge University Press.
39. http://www2.sunysuffolk.edu/mandias/38hurricane/
40. Pielke, Roger A., Jr.; et al. (2008). "Normalized Hurricane Damage in the United States: 1900-2005" (PDF). Natural Hazards Review 9 (1): 29-42. doi:10.1061/(ASCE)1527-6988(2008)9:1(29). http://forecast.mssl.ucl.ac.uk/shadow/docs/Pielkeetal2006a.pdf.
41. http://en.wikipedia.org/wiki/North_Sea_flood_of_1953
42. Instituut voor Sociaal Onderzoek van het Nederlandse Volk, National Research Council (U.S.). Committee on Disaster Studies (1955). Studies in Holland flood disaster 1953. Four volumes.
43. http://www.platformoverstromingen.nl/overstromingen/watersnood-historie
44. FEMA, New York Disaster history. http://www.fema.gov/news/disasters_state.fema?id=36
45. Naparstek, A (2005) A history of hurricanes in New York-including the day in 1893 that Hog Island disappeared for good. http://nymag.com/nymetro/news/people/columns/intelligencer/12908/
46. EA (2008) Thames Estuary 2100 plan. http://www.environment-agency.gov.uk/research/library/consultations/106100.aspx
47. Colle, B.A., Buonaiuto, F., Bowman, M.J., Wilson, R.E., Flood, R., Hunter, R., Mintz, A., Hill, D., 2008. New York City's vulnerability to coastal flooding. Bull. Amer. Met. Soc. 89, 829-841.
48. FEMA, NFIP. The National Flood Insurance program http://www.fema.gov/business/nfip/
49. Jansen, P en Dircke, P. Conceptual design of a Barrier across the Narrows. Conference Against the Deluge: Storm Surge Barriers to Protect New York, March 2009
50. Forsyth, G. Conceptual design of a New York - New Jersey Outer Harbor Gateway Barrier. Conference Against the Deluge: Storm Surge Barriers to Protect New York, March 2009
51. Abrahams, M. Conceptual design of an East River Storm Surge Barrier. Conference Against the Deluge: Storm Surge Barriers to Protect New York, March 2009
52. Schoettle, Th. Conceptual designs of an Arthur Kill Storm Surge Barrier. Conference Against the Deluge: Storm Surge Barriers to Protect New York, March 2009
53. Aerts, J.C.J.H., Renssen, H., Ward, Ph., Moel de H., Odada, E., Goose, H. (2006) Sensitivity of Global River discharges to Long Term Climate Change and Future Climate Variability. Geophysical Research Letters, 33 L19401
54. Kabat, P., Fresco, L.O., Stive, M., Veerman, C., Alphen, J. van, Parmet, B. , Hazeleger, W. & Katsman, C. Nature Geoscience 2, 450 - 452 (2009) doi:10.1038/ngeo572

ANNEX 1.

Participant list

Connecting Delta Cities Workshop, June 9-10, New York City

Aarts, Martin	DSV Rotterdam
Abidin, Hasan	Jakarta
Abrahams, Michael	Parsons Brinkerhof NYC
Aerts, Jeroen	VU University Amsterdam
Aguschandra, Beny	Regional Planning Board, Jakarta
Albrecht, Jochen	Hunter College CUNY
Alfaro, Marvin	Univ. Miami
Barita, Palty Saur	Governor's Office, Jakarta
Bass, Peter	NY Metropolitan Transportation Authority
Bigio, Tony	World Bank
Blake, Reggie	NASA GISS
Blumberg, Alan	Stevens Institute of Technology, Hoboken NJ
Botzen, Wouter	VU University Amsterdam
Bouwer, Laurens	VU University Amsterdam
Bowman, Malcolm	Stony Brook University
Brinkman, Jan Jaap	Deltares
Buonaiuto, Frank	Hunter College CUNY
Caradonna, Peter	Peter Caradonna Architecture and Planning
Colle, Brian	Stony Brook University
De Vries, Tineke	NL Consultant NYC
Deodatis, George	CU civil engineering
Dircke, Piet	Arcadis
Dutta, Projjal	NY Metropolitan Transportation Authority
Emanuel, Kerry	
Faris, Craig	Oliver Wyman
Flagg, Charles	Stony Brook University
Flood, Roger	Stony Brook University
Forsyth, Graeme	Halcrow UK
Freed, Adam	City of New York
Friedman, Joshua	NYC Office of Emergency Management
Garrell, Martin	Adelphi
Gennaro, Jim	NYC Council
Gilbride, Joe	Columbia University
Gornitz, Vivien	Columbia/NASA GISS
Hafkenscheid, Raymond	CPWC
Hamanaka, Akihiko	Tokyo
Hartemink, Sander	Dutch Embassy, Washington
Heath, Gary	NYC-DEP
Herrington, Tom	Stevens Institute of Technology, Hoboken NJ
Hill, Douglas	Stony Brook University
Hill, Kristina	University of Virginia
Hoekstra, Jandirk	HNS
Horton, Radley	Columbia University
Jacob, Klaus	Columbia University
Jacobs, John	City of Rotterdam
Janssen, Peter	Replaced by Al Lopez
Kamber, Dennis	ARCADIS
Kemur, Raymond	DG Spatial Planning Jakarta
Kim, Nicholas	HydroQual Inc.
Koenig, Stephanie	SBU
Kurtz, Warren	DEP (retired)
Lacy, Hugh	Mueser Rutledge Consulting Engineers
Lawitts, Steve	DEP
Le Blanc, Alice	Environmental and Economic Consulting
Leighton, Isabelle	Hudson 400
Leo, William	HydroQual Inc.
Lin, Brian	McGill Univ.
Linkin, Megan	Swiss Re
Lombardi, Frank	Port Authority NY/NJ
Lopez, Al	ARCADIS
Lutterbie, John	Humanities Institute
Major, David	Columbia University
Marfai, Muh Aris	Gadjah Mada University, Yogyakarta
McLaughlin, Brian	PANYNJ
Miejer, Siet	World Bank
Miller, Jon	Stevens Institute of Technology, Hoboken NJ
Molenaar, Arnoud	City of Rotterdam
Muir Wood, Robert	RMS
Muller, Jim	DEP
Newkirk, Sarah	TNC
Nickson, Alex	City of London, UK
O'Grady, Megan	Columbia University
Pirani, Robert	RPA
Plag, Hans Peter	University of Nevada
Pol, Peter	Ontwikkelingsbedrijf Rotterdam
Ratnaningsih Setiawati, Endang	Governor's Office, Jakarta
Ravela, Sai	MIT
Reeder, Timothy	Environment Agency
Roiter, Heather	NYC Office of Emergency Management
Ronan, Anne	
Rosborough, Brian	Earth Watch Institute
Rosenzweig, Cynthia	NASA GISS
Roth, Lawrence	
Sarrinikolaou, George	PANYNJ
Savio, Thomas	MTA NY
Scarano, Michael	
Schiff, Arthur	NYC Council
Schlaff, Robin	NYS DEC
Schoettle, Thomas	
Seebode, Joseph	USACE
Shioda, Tsutomu	Tokyo
Sijmons, Dirck	HNS
Solecki, William	Hunter College
Surminski, Swenja	ABI
Swanson, Larry	Stony Brook University
Tanski, Jay	NY Sea Grant
Tetteroo, Gert	Hudson 400 Coordinator
Tobing, Aisa	Governor's Office, Jakarta
Tollerson, Ernest	NY Metropolitan Transportation Au.
Tortora, Aniello L. (Col)	USACE
Tweedy, David	PANYNJ
Van der Meer, Rinsk	Port Authority, Rotterdam
Van Nieuwenhuijze, Lodewijk	HNS
Van 't Klooster, Susan	VU University Amsterdam
Ward, Chris	PANYNJ
Ward, Philip	VU University Amsterdam
Webb, Anna	Stony Brook University
Weber, Elke	Columbia University
Weisberg, Robert	University of South Florida
Westerink, Johanes	Notre Dame University
Wilson, Robert	Stony Brook University
Woolston, Helen	Sustainability Unit, HSE, London
Yaro, Robert	RPA
Yohe, Gary	Wesleyan Univ.
Zeppie, Chris	PANYNJ
Zevenbergen, Chris	Dura Vermeer
Zimmerman, Rae	New York Univ.

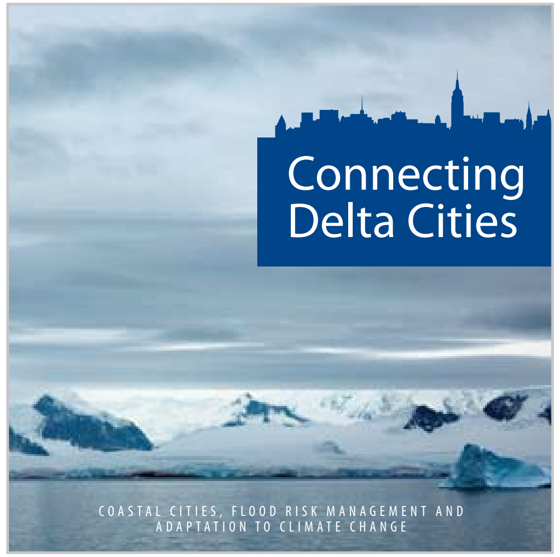
Connecting Delta Cities

At present, more than 50% of the entire world population lives in cities. According to the United Nations, more than two thirds of the world's large cities are vulnerable to rising sea levels, exposing millions of people to the risk of extreme floods and storms. Within the next 30 years, the number of people living in cities will increase to 60% of the world's population, resulting in even more people living in highly exposed areas.

Both scientists and policy makers have addressed the issue of adapting to the challenge of climate change, and both call for embedding long-term scenarios in city planning and investments in all sectors. Based on estimates of the cost of adaptation, it appears that investing in adaptation *now* will save money in the long term. However, developing and implementing adaptation measures is a complex process, and policy makers and investors may postpone taking long-term decisions into the future.

Since the choices made today will influence vulnerability to climate risks in the future, it is important to link adaptation measures to ongoing investments in infrastructure and spatial planning, and to draw up detailed estimates of the benefits of adaptation.
In this way, adaptation becomes a challenge rather than a threat, and climate adaptation may initiate opportunities and innovations for investors and spatial planners. Challenges include, for example: are current city plans climate proof or do we need to fine-tune our ongoing investments?; can we develop a flood proof subway system?; and can we develop new infrastructure in such a way that it serves flood protection, housing and natural values? Furthermore, adaptation policies may address evacuation schemes, improved communication to both citizens and companies as well as post-event measures, such as insurance and emergency relief.

This book shows the different aspects of climate adaptation and is a joint initiative of the Cities of Rotterdam, New York and Jakarta. In this regard, each city faces different challenges; one of the lessons of the Connecting Delta Cities initiative is that while cities will follow adaptation paths that may differ, sometimes substantially, each city can learn from the others.



At present, more than 50% of the entire world population lives in cities. According to the United Nations, more than two thirds of the world's large cities are vulnerable to rising sea levels, exposing millions of people to the risk of extreme floods and storms. Within the next 30 years, the number of people living in cities will increase to 60% of the world's population, resulting in even more people living in highly exposed areas.

Both scientists and policy makers have addressed the issue of adapting to the challenge of climate change, and both call for embedding long-term scenarios in city planning and investments in all sectors. Based on estimates of the cost of adaptation, it appears that investing in adaptation now will save money in the long term.

This book explores the different aspects of climate adaptation; it is an independent investigation of comparative adaptation problems and progress in the cities of Rotterdam, New York and Jakarta. In this regard, each city faces different challenges; one of the lessons of the Connecting Delta Cities initiative is that while cities will follow adaptation paths that may differ, sometimes substantially, each city can learn from the others.

Connecting Delta Cities

VU University press