Climate Risks and Adaptation in Asian Coastal Megacities

A
SYNTHESIS
REPORT

Climate Risks and Adaptation in Asian Coastal Megacities

A Synthesis Report

THE WORLD BANK

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Table of Contents

Annexes

Figures

Boxes

Tables

Acknowledgments

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Abbreviations and Acronyms

ADB	Asian Development Bank
AOGCM	Atmosphere-ocean general circulation models
BMR	Bangkok Metropolitan Region
BAU	Business as usual
CCA	Climate change adaptation
CoP	Conferences of Parties
DIVA	Dynamic interactive vulnerability assessment
DRR	Disaster risk reduction
ECLAC	Economic Commission for Latin America and the Caribbean
GCMs	Global climate models
GDP	Gross domestic product
GEF	Global Environment Facility
GHG	Greenhouse gas
GPCP	Global Precipitation Climatology Project
GRDP	Gross regional domestic product
HCMC	Ho Chi Minh City
1DD	One-degree daily
IPCC	Intergovernmental Panel for Climate Change
IRS3	Integrated research system for sustainability science
IZ	Industrial zones
JICA	Japan International Cooperation Agency
LGUs	Local government units
MONRE	Ministry of Natural Resources and Environment
MP	Master plan
NESDB	National Economic and Social Development Board
PC	People's Committee
PCMDI	Program for Climate Model Diagnosis and Intercomparison
SRES	Special Report on Emissions Scenarios
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Convention on Climate Change
VOC	Vehicle operations cost
WCRP	World Climate Research Program
WGCM	Working Group on Coupled Modeling

Note: Unless otherwise noted, all dollars are U.S. dollars.

Executive Summary

INTRODUCTION AND RATIONALE

Coastal areas in both developing and more industrialized economies face a range of risks related to climate change and variability (IPCC 2007a). Potential risks include accelerated sea level rise, increase in sea surface temperatures, intensification of tropical and extra tropical cyclones, extreme waves and storm surges, altered precipitation and runoff, and ocean acidification (Nicholls et al. 2007). The Intergovernmental Panel for Climate Change Fourth Assessment Report (IPCC 2007a) points to a range of outcomes under different scenarios. It identifies a number of hotspots—including heavily urbanized areas situated in the low-lying deltas of Asia and Africa—as especially vulnerable to climate-related impacts.

The number of major cities located near coastlines, rivers, and deltas provides an indication of the population and assets at risk. Thirteen of the world's 20 largest cities are located on the coast, and more than a third of the world's people live within 100 miles of a shoreline. Low-lying coastal areas represent 2 percent of the world's land area, but contain 13 percent of the urban population (McGranahan et al. 2007). A recent study of 136 port cities showed that much of the increase in exposure of population and assets to coastal flooding is likely to be in cities in developing countries, especially in East and South Asia (Nicholls et al. 2008).

In terms of population exposed to coastal flooding, for example, in 2005 five of the ten most populous cities included Mumbai, Guangzhou, Shanghai, Ho Chi Minh City, and Kolkata (formerly Calcutta). By 2070, nine of the top ten cities in terms of population exposure are expected to be in Asian developing countries (Nicholls et al. 2008). The vulnerability of the East Asia region is also highlighted by the global study on the economics of adaptation to climate change, which estimates that the cost of adaptation to climate change is likely to be the highest in this region (World Bank 2010). In flood-prone cities such as Ho Chi Minh City, Kolkata, Dhaka, and Manila, potential sea level rise and increased frequency and intensity of extreme weather events poses enormous adaptation challenges. The urban poor—often living in riskier urban environments such as floodplains or unstable slopes, working in the informal economy, and with fewer assets—are most at risk from exposure to hazards (Satterthwaite et al. 2007).

Despite its importance, few developing country cities have attempted to address climate change systematically as part of their decision-making process. Given the risks faced by coastal cities and the importance of cities more broadly as drivers of regional economic growth, adaptation must become a core element of long-term urban planning. The Mayor's Summit in Copenhagen in December 2009—and follow-on efforts to institutionalize a Mayor's Task Force on Urban Poverty and Climate Change—signify much-needed attention to this issue.

In response to client demand and recognizing the importance of addressing urban adaptation and major vulnerabilities of Asian coastal cities, the Asian Development Bank (ADB), the Japan International Cooperation Agency (JICA), and the World Bank agreed to undertake an analysis in several coastal megacities to address climate adaptation and prepare a synthesis report based on the city-level findings. The selected cities included Manila (led by JICA), Ho Chi Minh City (led by ADB), and Bangkok (led by the World Bank).[1]

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[1] Kolkata is also one of the selected cities but is not included in the synthesis report as it was ongoing at the time of the preparation of this report. A brief overview is included in Annex A.

Why these three cities? The three developing country cities selected for this study are all coastal megacities with populations (official and unofficial) ranging from 8 to 15 million people. Two are capital cities and all three are centers of national and regional economic growth contributing substantially to the GDP of the respective countries. However, being low-lying coastal cities situated in the deltas of major river systems in the East Asia region, all three are highly vulnerable to climate-related risks and rank high in recent rankings of exposure and vulnerability. Ho Chi Minh City and Bangkok are among the top 10 cities in terms of population likely to be exposed to coastal flooding due to climate-related risks in 2070, according to the first global assessment of port cities (Nicholls et al. 2008). Further, Manila has been identified as particularly vulnerable to typhoon damage, and HCMC ranks fifth by population exposed to the effects of climate change (Nicholls et al. 2008). A recent study also identifies Manila, Ho Chi Minh City, and Bangkok among the top eleven Asian megacities that are most vulnerable to climate change (Yusuf and Francisco 2009).[2] Devastating floods in Manila in 2009 only confirm the vulnerability of this city to extreme weather events. For instance, flooding in Manila from tropical storm Ketsana in September was the heaviest in almost 40 years, with flood waters reaching nearly 7 meters. More than 80 percent of the city was underwater, causing immense damage to housing and infrastructure and displacing around 280,000–300,000 people.[3] All of this highlights the need to better understand and prepare for such climate risks and incorporate appropriate adaptation measures into urban planning.

While there is a growing literature on cities and climate change, as yet there is limited research on systematically assessing climate-related risks at the city level. This report aims to fill this gap. Further, it aims to provide evidence-based information to support urban policy and planning as these issues are debated at the local, national, and global levels.

OBJECTIVE

The main objective of this report is to strengthen our understanding of climate-related risks and impacts in coastal megacities in developing countries using case studies of three cities that are different in their climate, hydrological, and socioeconomic characteristics. Specifically, it draws on an in-depth analysis of climate risks and impacts in Bangkok, Manila, and Ho Chi Minh City to highlight to national and municipal decision makers (a) the scale of climate-related impacts and vulnerabilities at the city level, (b) estimates of associated damage costs, and (c) potential adaptation options. While the report focuses on three cities in East Asia, the policy implications resulting from the comparative analysis of these cities has broader relevance for assessing climate risks and identifying adaptation options in other coastal areas.

APPROACH AND METHODOLOGY

The approach to assessing climate risks and impacts consists of the following sequential steps: (1) determining climate variables at the level of the city/watershed through downscaling techniques; (2) estimating impacts and vulnerability through hydrometeorological modeling, scenario analysis, and GIS mapping; and (3) preparing a damage/loss assessment and identification/prioritization of adaptation options.

As a first step, each of the city-level studies considered two IPCC scenarios, a high- and a low-emissions scenario,[4] and estimated climate risks to 2050. The 2050 time horizon for the study is appropriate given city-level planning horizons and the typical time frame for major flood protection measures. The downscaling analysis allowed estimation of changes in temperature and precipitation in 2050. These parameters were used as inputs to the hydrological modeling. In addition to this, assumptions and estimates were also made about changes in sea level rise and storm surge in 2050 based on past historical data and available estimates.

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[2] Vulnerability in the scorecard was understood in terms of exposure, sensitivity, and adaptive capacity of the cities. See also http://www.idrc.ca/uploads/user-S/12324196651Mapping_Report.pdf.

[3] http://edition.cnn.com/2009/WORLD/asiapcf/09/27/philippines.floods/index.html.

[4] Different scenarios were considered to assess impact due to the uncertainties in projecting future climate conditions.

For each city, complex hydrometeorological models were then developed using a whole host of local information. These included (a) climate variables such as changes in temperature, precipitation, sea level rise, and storm surge; (b) socioeconomic and developmental factors such as land subsidence, land use, and population increases; and (c) local topographical and hydrological information. Flooding in the metropolitan areas was chosen as the key variable to assess impact. The hydrological analysis allowed determination of the area, depth, and duration of flooding under different scenarios. This information was used to identify the scale of risks and vulnerability of sectors, local populations, and districts (represented in GIS maps), as well as estimate damage costs. Two of the three studies undertook cost-benefit analysis to prioritize adaptation options, while the third approached the issue of adaptation more qualitatively. To understand the impact of climate change in 2050 in each city, an important assumption made by all teams was that without climate change, the climate in 2050 would be similar to the 2008/ base-year climate. Various climate scenarios are overlaid on this assumption.

PROCESS OF PREPARATION

The analysis was carried out over a period of one-and-a-half years. The synthesis team and the city-level teams met periodically and worked closely to develop common terms of reference to guide the city-level studies, as well as share methodological issues and ongoing findings. These discussions and the analysis undertaken for each city have formed the basis of this report. Further, each city-level team worked with their respective country/urban counterparts to build ownership and capacity for the analysis. For instance, the main counterparts in HCMC were the HCMC People's Committee and the Department of Natural Resources and Environment (DoNRE). The study sought to inform the preparation of HCMC's citywide adaptation plan. In Bangkok, the main counterpart was the Bangkok Municipal Authority. In Metro Manila, the main counterpart was Metro Manila Development Authority (MMDA). At the global level, a preliminary version of the study has been presented at several international forums.

UNCERTAINTIES, LIMITATIONS, AND INTERPRETING THE FINDINGS OF THIS STUDY

Any study forecasting conditions four decades hence will be faced with large uncertainties and these need to be borne in mind in interpreting the results of this study. One uncertainty concerns the pathway of GHG emissions. To address that issue, the city case studies examined both a high and a low GHG emissions scenario to bracket the likely future conditions. In the climate change downscaling methodologies, there are uncertainties in forecasting the increase in extreme and seasonal precipitation under the different scenarios. The techniques applied in the statistical downscaling examined the results from sixteen atmosphere-ocean general circulation models (AOGCM). Robust relationships were identified for temperature (with a ~ 10 percent internal error) and precipitable water increases (with a ~ 10–20 percent error) (Sugiyama 2008). Hydrologic models can simulate flood events with relatively small errors (<10 percent) if sufficient data are available for good calibration. For future forecasts, however, land use changes in the watersheds and drainage areas can dramatically affect flood patterns and can be further examined in future sensitivity analyses.

Further, cities in 2050 are likely to be vastly different from today's cities. Understanding how different is a huge task and there was no attempt to model economic growth and link it to urban development. Instead, assumptions about cities in 2050 were based on best available data, government plans and projections which also introduced uncertainties and errors. Despite these limitations, the results presented in this report highlight the scale of the likely risks and impacts facing coastal cities that appear to be robust to the assumptions about the climatic, spatial, and socioeconomic development of the cities by 2050. Key findings and lessons are summarized below.

KEY FINDINGS

Frequency of extreme events likely to increase

All three cities are likely to witness increases in temperature and precipitation linked with climate change and variability. In Bangkok, temperature increases of 1.9° C and 1.2°C for the high and low emissions scenarios respectively are estimated for 2050 and are linked with a 3 percent and 2 percent increase in mean seasonal precipitation respectively. In Manila, the mean seasonal precipitation is expected to increase by 4 percent and 2.6 percent for the high and low emissions scenarios. In HCMC, future projections suggest greater seasonal variability in rainfall and increasing frequency of extreme rainfall related to storms.

Increase in flood-prone area due to climate change in all three cities

In all three megacities, in 2050, there is an increase in the area likely to be flooded under different climate scenarios compared to a situation without climate change. In Bangkok, for instance, under the conditions that currently generate a 1-in-30-year flood, but with the added precipitation projected for a high emissions scenario, there will be approximately a 30 percent increase in the flood-prone area. In Manila, even if current flood infrastructure plans are implemented, the area flooded in 2050 will increase by 42 percent in the event of a 1-in-100-year flood under the high emission scenario compared to a situation without climate change. In HCMC, for regular events in 2050, the area inundated increases from 54 percent in a situation without climate change to 61 percent with climate risks considered under the high emission scenario. For extreme (1-in-30 year) events, in 2050, the area inundated increases from 68 percent (without climate change) to 71 percent (with climate risks considered) under the high emission scenario. Further, there is a significant increase in both depth and duration for both regular and extreme floods over current levels in 2050 in HCMC. The analysis also highlights areas that will be at greater risk of flooding in each metropolitan area. In Metro Manila, for instance, areas of high population density such as Manila City, Quezon City, Pasig City, Marikina City, and San Juan Mandaluyong City are likely to face serious risks of flooding.

Increase in population exposed to flooding

In all three cities, there is likely to be an increase in the number of persons exposed to flooding in 2050 under different climate scenarios compared to a situation without climate change. For instance, in Bangkok in 2050, the number of persons affected (flooded for more than 30 days) by a 1-in-30-year event will rise sharply for both the low and high emission scenarios—by 47 percent and 75 percent respectively—compared to those affected by floods in a situation without climate change. In Manila, for a 1-in-100-year flood in 2050, under the high emission scenario more than 2.5 million people are likely to be affected (assuming that the infrastructure in 2050 is the same as in the base year), and about 1.3 million people if the 1990 master plan is implemented. In HCMC, currently, about 26 percent of the population would be affected by a 1-in-30-year event. However, by 2050, it is estimated that approximately 62 percent of the population will be affected under the high emission scenario without implementation of the proposed flood control measures. Even with the implementation of these flood control measures, more than half of the projected 2050 population is still likely to be at risk from flooding during extreme events. How to plan for such large percentages of population being exposed to future flooding needs to be seriously considered.

Costs of damage likely to be substantial and can range from 2 to 6 percent of regional GDP

In Bangkok, the increased costs associated with climate change (in a high emission scenario) from a 1-in-30-year flood is THB 49 billion ($1.5 billion), or approximately 2 percent of GRDP. These are the additional costs associated with climate change. The actual costs of a 1-in-30-year flood—including costs resulting from both climate change and land subsidence—are close to $4.6 billion in 2050. In Manila, a similar 1-in-30-year flood can lead to costs of flooding ranging from PHP 40 billion ($0.9 billion)—given current flood control infrastructure and climate conditions—to PHP 70 billion ($1.5 billion) with similar infrastructure but a high emission climate scenario. Thus, the additional costs of climate change from a 1-in-30-year flood would be approximately PHP 30 billion ($0.65 billion) or 6 percent of GRDP. The HCMC study adopts a different methodology to analyze costs and its results cannot directly be compared to the costs of Manila and Bangkok. The HCMC study uses a macro approach and estimates a series of annual costs up to 2050. The flood costs to HCMC, in present value terms, range from $6.5 to $50 billion.[5] The "annualized" costs of flooding would likely be comparable to the costs of Bangkok and Manila.

Damage to buildings is an important component of flood-related costs

Damage to buildings is a dominant component of flood-related costs, at least in Bangkok and Manila. In these cities, over 70 percent of flood-related costs in all scenarios are a result of damages to buildings. Cities are, almost by definition, built-up areas full of concrete structures, so it is not surprising that the main impact of floods is on these structures and the assets they carry. In HCMC, 61 percent of urban land use and 67 percent of industrial land use are expected to be flooded in 2050 in an extreme event if the proposed flood control measures are not implemented. Potential flooding in HCMC also has major implications for planning in key sectors such as transportation and waste management. For instance, the city's existing and planned transportation network, wastewater treatment plants and landfill sites are likely to be exposed to increased flooding under the high emission scenario even with the implementation of the proposed flood protection system, raising important issues for planners such as managing the environmental consequences of flooding. Thus, as cities develop over the next 40 years, it will be important to consider climate risks in designing their commercial, residential, and industrial assets and zones.

Impact on the poor and vulnerable will be substantial, but even better-off communities will be affected by flooding

In Bangkok, the study estimates that about 1 million inhabitants will be affected by flooding under a high emission scenario in 2050. One out of eight of the affected inhabitants will be those living in condensed housing areas where the population primarily lives below the poverty line. Of the total affected population, approximately one-third may have to encounter inundation of more than a half-meter for at least one week, marking a two-fold increase in the vulnerable population. People living in the Bang Khun Thian district of Bangkok and the Phra Samut Chedi district of Samut Prakarn will be especially affected. In HCMC, in some of the areas, both the poor and non-poor are at risk. However, in general, poorer areas are more vulnerable to flooding. Thus city planners need to devise strategies that focus on the poorer sections of the city through improved access to housing, infrastructure and drainage, devising appropriate land use policies and improving the level of preparedness among the more disadvantaged social groups.

Land subsidence is a major problem and can account for a greater share of the damage cost from flooding compared to climate-related factors

One of the main findings of this study is that non-climate-related factors such as land subsidence are important and in some cases even more important than climate risks in contributing to urban flooding. In Bangkok for instance, there is nearly a two-fold increase in damage costs between 2008 and 2050 due to land subsidence. Further, almost 70 percent of the increase in flooding costs in 2050 in the city is due to land subsidence. While data for land subsidence were not available for Manila and HCMC and this issue was not considered in the hydrological modeling for these two cities, available literature suggests that it is an important factor in all three cities and should be considered in follow-up studies. Even though the megacities have already undertaken a number of measures to slow down land subsidence, further regulatory and market incentives are clearly required to stem groundwater losses. City governments need to better assess factors contributing to land subsidence and consider options to reduce it.

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[5] The exchange rates used were the average exchange rates in 2008: 1 USD = THB 33.31, PHP 44.47 and VND 16,302.25.

RECOMMENDATIONS

Coastal cities in developing countries face enormous challenges linked with current patterns of population and economic growth, associated environmental externalities, urban expansion and existing climate variability. Climate change will pose additional risks beyond those currently facing coastal megacities. As the study shows, these risks will also be associated with significant costs to local populations and infrastructure. Strong political will is thus needed to strengthen the capacity to address both existing climate variability and additional risks posed by climate change. Three main lessons stand out from the study.

Better management of urban environment and infrastructure will help manage potential climate-related impacts

Analysis carried out in the city case studies show that sound urban environmental management is also good for climate adaptation. As the Bangkok study shows, land subsidence, if not arrested, would contribute a greater share of damage costs from floods than a projected change in climate conditions. Thus, addressing land subsidence and factors contributing to it is important from the perspective of urban adaptation. While the HCMC study has not estimated the damage costs due to other environment-development factors—such as the presence of solid waste in the city's drains and waterways, poor dredging of canals, siltation of drains, deforestation in the upper watershed—it provides extensive qualitative evidence to demonstrate the role these factors play in contributing to urban flooding. Collectively, the studies highlight the importance of addressing existing environment-development factors as a critical part of urban adaptation. They also show that given the high risks of continuing to urbanize according to current patterns, much more effort should be given to considering the environmental implications of urban growth and expansion in the context of managing current and future climate risks.

Climate-related risks should be considered as an integral part of city and regional planning

While improved urban environmental management is important, the studies also show that given the additional costs linked with climate change, cities need to make a proactive effort to consider climate-related risks as an integral part of urban planning and to do so now. First, city planners need to develop strategic urban adaptation frameworks for managing climate risks involving a range of tools such as policy and regulatory reforms, investments, and capacity building. Such a strategy can provide an overarching framework for actions taken within each sector at the regional, delta, and city levels. Second, much more emphasis needs to be given to improving the knowledge base regarding climate risks and related socioeconomic and development factors. Developing and updating scenarios and planning for a range of potential outcomes will be critical for urban planners. This can be accomplished by strengthening the collaboration between planning and sector agencies and research institutions, thus giving municipal agencies the tools to make decisions regarding risk management over the long term (Rosenzweig et al. 2007) Third, it is important to strengthen the capacity of local urban governmental institutions to adapt to climate change. Among other things, this involves strengthening the capacity to prioritize different adaptation options, improving coordination between various urban sector agencies and sector plans, and incorporating climate change considerations into the earliest stages of decision making.

Targeted, city-specific solutions combining infrastructure investments, zoning, and ecosystem-based strategies are required

Given that cities are characterized by distinct climatic, hydrological, and socioeconomic features—but also that the urban poor in general are more vulnerable to increased flooding due to climate change—targeted, city-specific, and cutting edge approaches to urban adaptation are needed. First, these include strategies that focus on the more vulnerable areas of the city and the urban poor. Second, as the studies show, hard infrastructure interventions can also be usefully combined with ecosystem-based solutions. For instance, construction of dykes can be matched with management and rehabilitation of mangrove systems, reforestation of upper watersheds, river and canal bank protection, and implementation of basin-wide flow management strategies. Urban wetlands provide a range of services, including flood resilience, allowing groundwater recharge and infiltration, and providing a buffer against fluctuations in sea level and storm surges. Thus, rehabilitation of urban wetlands is critical. Third, as the city case studies show, while a combination of climate-related factors can contribute to urban flooding, some factors are much more important than others in different cities depending on location, elevation, and topography of the city. For instance, in HCMC, storm surges and sea level rise are important factors contributing to flooding. However, in Bangkok these factors are relatively less important. The policy implication is that adaptation measures need to be designed based on the specific hydrological and climate characteristics of each city. Fourth, damages to buildings emerge as a dominant component of flood-related costs, at least in Bangkok and Manila. Vulnerability mapping, land use planning and zoning could be used to restrict future development in hazardous locations, ultimately retiring key infrastructure and vulnerable buildings in these areas. Similarly, building codes aimed at flood-proofing buildings (including the lowest habitable elevation in vulnerable areas) could dramatically reduce damage costs. Such targeted measures could go a long way in helping coastal megacities to adapt to current and future climate risks.

1 Introduction

BACKGROUND AND RATIONALE

As recent weather events have illustrated, coastal areas in both developing and more industrialized economies face a range of risks related to climate change (IPCC 2007a). Anticipated risks include an accelerated rise in sea level of up to 0.6 meters or more by 2100, a further rise in sea surface temperatures by up to 3° C, an intensification of tropical and extra tropical cyclones, larger extreme waves and storm surges, altered precipitation and runoff, and ocean acidification (Nicholls et al. 2007). The Intergovernmental Panel for Climate Change Fourth Assessment Report (IPCC 2007a) points to a range of outcomes under different scenarios and identifies a number of hotspots—including heavily urbanized areas situated in the large low-lying deltas of Asia and Africa—as especially vulnerable to climate-related impacts. For instance, by 2080, the report points out, many millions more people may experience floods annually due to sea level rise (IPCC 2007a). More frequent flooding and inundation of coastal areas can also result in various indirect effects, such as water resource constraints due to increased salinization of groundwater supplies. Human-induced pressures on coastal regions can further compound these effects.

The location of many of the world's major cities—such as Mumbai, Shanghai, Jakarta, Lagos, and Kolkata—around coastlines, rivers, and deltas provides an indication of the population and assets at risk. Thirteen of the world's 20 largest cities are located on the coast and more than a third of the world's population lives within 100 miles of a shoreline. Low-lying coastal areas—defined as areas along the coast that are less than 10 meters above sea level—represent 2 percent of the world's land area, but contain 13 percent of the urban population (McGranahan et al. 2007). A recent study of 136 port cities showed that the population exposed to flooding linked with a 1-in-100-year event is likely to rise dramatically, from 40 million currently to 150 million by 2070 (Nicholls et al. 2008). Similarly, the value of assets exposed to flooding is estimated to rise to $35 trillion, up from $3 trillion today. The study also shows that significant, increasing exposure is expected for the populations and economic assets in Asia's coastal cities.

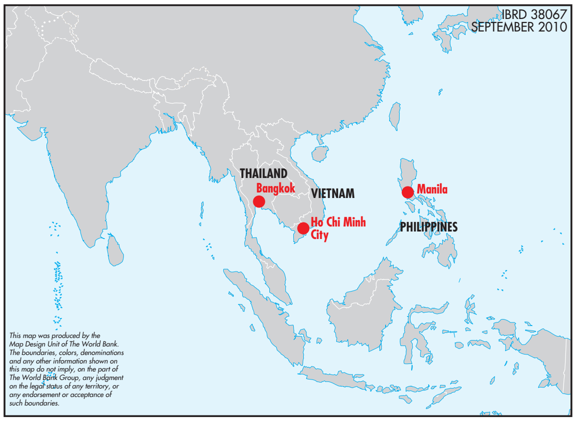
In flood-prone cities such as Manila, potential sea level rise and increased frequency and intensity of extreme weather events poses enormous challenges on urban local bodies' ability to adapt. Apart from their location, the scale of risk is also influenced by the quality of housing and infrastructure, institutional capacity with respect to emergency services, and the city's preparedness to respond. The urban poor are most at risk from exposure to hazards in coastal cities, as they tend to live in riskier urban environments (such as floodplains, unstable slopes), tend to work in the informal economy, have fewer assets, and receive relatively less protection from government institutions (Satterthwaite et al. 2007).

Despite its importance, few developing country cities have initiated efforts to integrate climate change issues as part of their decision-making process. Given the risks faced by coastal cities and the importance of cities more broadly as drivers of regional economic growth, adaptation must become a core element of long-term urban planning.

Recognizing the importance of this issue, the World Bank, Asian Development Bank (ADB) and the Japan International Cooperation Agency (JICA) agreed to undertake an analysis in several coastal cities to address climate change adaptation and prepare a synthesis report based on the city-level findings. The selected cities include Manila (led by JICA), Ho Chi Minh City (led by the ADB), Bangkok (led by the World Bank's East Asia and Pacific Region), and Kolkata (led by the World Bank's South Asia Region). This synthesis report builds on the analysis undertaken in three of these cities—Manila, Bangkok, and Ho Chi Minh City (Figure 1.1).[6]

The different cities were selected given the threats they face from increasing hydrometeorological variability driven by climate change. Bangkok, located in the Chao Phraya delta, was identified as a hotspot in a background report to the IPCC's AR4 (IPCC 2007b). Manila was identified in OECD's vulnerable port cities report (Nicholls et al. 2008), particularly regarding typhoon damage. HCMC ranked fifth by population exposed to the effects of climate change (Nicholls et al. 2008). A recent study also identified Manila, Ho Chi Minh City, and Bangkok among the top eleven Asian megacities that are most vulnerable to climate change (Yusuf and Francisco 2009).[7] Devastating floods in Manila in September and October 2009 only confirm the vulnerability of this city to extreme weather events. For instance, flooding in Manila caused by tropical storm Ketsana in September was the heaviest in almost 40 years, with flood waters reaching nearly 7 meters. More than 80 percent of the city was underwater, causing immense damage to housing and infrastructure and displacing around 280,000–300,000 people.[8] All of this highlights the need to better understand and prepare for such climate risks and incorporate appropriate adaptation measures into urban planning. While there is a growing literature on cities and climate change, as yet there is limited research on systematically assessing climate-related risks at the city/local level and assessing damage costs, particularly in cities in developing countries. This report aims to fill this gap. Further, it aims to provide science-based information to support urban policy and planning as these issues are being debated at the local, national, and global levels.

FIGURE 1.1 ■ Asian Megacity Hotspots



IBRD 38067
SEPTEMBER 2010

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Source: Asia map IBRD 38067

OBJECTIVE

The main objective of this report is to strengthen our understanding of climate-related risks and impacts in coastal megacities in developing countries using case studies of three cities that are different in their climate, hydrological, and socioeconomic characteristics. Specifically, it draws on in-depth analysis of climate risks and impacts in three cities—Bangkok, Manila, and Ho Chi Minh City—to highlight to national and municipal decision makers (a) the scale of climate-related impacts and vulnerabilities at the city level, (b) estimates of associated damage costs, and (c) potential adaptation options. The comparative analysis carried out in this report shows the increasing climate risks faced by coastal megacities and the need to consider adaptation as part of long-term strategic planning. Even though the study is based on analysis in three cities, the

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[6] The Kolkata study was not completed at the time of the preparation of the synthesis report and thus was not included in main report. Annex A provides a brief overview of the study.

[7] Vulnerability in the scorecard was understood in terms of exposure, sensitivity, and adaptive capacity of the cities. See also http://www.idrc.ca/uploads/user-S/12324196651Mapping_Report.pdf

[8] http://edition.cnn.com/2009/WORLD/asiapcf/09/27/philippines.floods/index.html

policy implications have broader relevance for assessing climate risks and identifying adaptation options in other coastal areas.

PROCESS OF PREPARATION

The analysis was carried out over a period of one-and-a-half years. The synthesis team and the city-level teams worked closely to develop common terms of reference to guide the city-level studies. Further, while the synthesis team helped coordinate the process, each city-level team worked independently with their respective country counterparts to build ownership and capacity for the analysis. The city teams were comprised of members with a range of skills, including climate modeling, hydrological analysis, GIS mapping, economic analysis, and urban planning. The city teams and the synthesis team preparing this report also met periodically to share methodological issues and ongoing findings and research. These discussions and the analysis undertaken for each city have formed the basis of the preparation of this synthesis report. At the level of each city, the teams have undertaken stakeholder consultations with city officials and government agencies at different levels, nongovernmental organizations, the private sector, and other constituencies. For instance, the main counterparts in HCMC were the HCMC People's Committee and the Ministry of Natural Resources and Environment (MONRE); the study sought to inform preparation of HCMC's city-wide adaptation plan. In Bangkok, the main counterpart was the Bangkok Municipal authority. In Metro Manila, it was the Metro Manila Development Authority (MMDA). At the global level, preliminary findings have already been presented at several international forums to reach urban planners, municipal decision makers, and researchers.

OVERVIEW OF METHODOLOGY/ APPROACH AND CLIMATE PARAMETERS SELECTED

The city-level studies considered two IPCC emissions scenarios,[9] A1FI and B1 (with the exception of HCMC, which considered the A2 and B2 scenarios), and estimated climate risks to 2050. The 2050 time horizon for the study is appropriate, given planning horizons in most cities and given that the typical time frame for major flood protection planning is about 30 years. Moreover, the uncertainty in climate projections expands rapidly past roughly the mid-21st century, providing additional justification for limiting the time horizon to 2050. Climate variables considered included changes in temperature, changes in precipitation, estimated sea level rise, and estimated storm surge. In addition, non-climate factors—such as land subsidence, land use changes, salinity intrusion, and population increases—were also considered. Flooding in the metropolitan areas was chosen as the key climate variable to be examined. The approach consisted of the following sequential steps: (1) downscaling climate variables to the level of the city/watershed; (2) hydrometeorological modeling and scenario analysis, presented in GIS maps; and (3) damage/loss assessment and identification/prioritization of adaptation options. These steps are discussed in more detail in chapter 2.

To support this analysis, each city team collected extensive historical and city-specific data related to past climate events such as storms and flooding, socioeconomic data, information about local topography and hydrology, information on land use, and so forth. Data limitations were a major challenge, but each team worked with existing data from public sources, as well as data made available by city governments and institutions. There are numerous uncertainties at each step of the analysis.

While the main focus of this report is on assessing future climate risks at the city level, it builds on the recognition of strong links between climate adaptation and ongoing efforts toward disaster risk management. Despite the institutional differences in terms of how these efforts have emerged, and differences in how climate change/variability and disasters manifest themselves, they both share common ground in striving toward strengthening adaptive capacity of vulnerable communities, building resilience, and reducing the impact of extreme

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[9] Different scenarios were considered to assess impact due to the uncertainties in projecting future climate conditions.

events. The analysis undertaken in this report uses several methodologies that have long been used in the context of disaster risk management—such as damage cost assessment and probabilistic risk analysis—illustrating the opportunities for cross-fertilization in both areas.

STRUCTURE OF THE REPORT

Chapter 2 presents methodologies used to determine climate change risks at the city/river-basin level through downscaling techniques, flood risk assessment through hydrometeorological models, and damage cost analysis. Chapter 3 presents the main findings from climate downscaling, hydrological modeling analyses, and use of GIS mapping.[10] Chapter 4 presents the analysis and findings relating to damage cost assessment, as well as an analysis of adaptation options. Finally, Chapter 5 draws broad policy lessons and presents conclusions.

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[10] For a broader set of GIS maps, please refer to city-specific reports.

2

Methodologies for Downscaling, Hydrological Mapping, and Assessing Damage Costs

In order to assess the impact of climate change in terms of increased flooding in 2050 in each of the coastal cities, three main methodological steps were taken. These include (1) determining climate-related impacts at the city/river-basin level through downscaling; (2) developing flood risk assessment hydrometeorological models for each city to estimate flooding in 2050 under different scenarios; and (3) assessing damage costs. This chapter provides a summary of these methodologies. It highlights the climate change scenarios selected, approaches to downscaling, assumptions underlying hydrological analysis, and the approach to damage cost assessment. Some of the methodologies used here—such as damage cost analysis and probabilistic risk assessment—are also used in disaster risk management.[11] Uncertainties and errors involved in different steps of the analysis are also discussed.

SELECTION OF EMISSIONS SCENARIOS, DOWNSCALING, AND UNCERTAINTIES

To measure the impact of climate change on the cities in 2050, it was necessary to assume emissions scenarios and as a first step, "downscale" climate change forecasts to local levels so that the meteorological parameters—such as changes in temperature and precipitation—could be applied as inputs to the hydrometeorological models.

Range of emissions scenarios considered

The potential impact of climate change can vary greatly depending on the development pathway that is assumed. Beginning in 1992, the IPCC has provided various scenarios for the emissions of greenhouse gases based on assumptions of different development pathways—namely, complex and dynamic interactions among future demographic changes, economic growth, and technological and environmental changes. These emissions scenarios are projections of what the future may look like and are a tool to model climate change impacts and related uncertainties. As described in the IPCC *Special Report*

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[11] A probabilistic risk assessment provides an estimate of the probability of loss due to hazards. It is commonly used in disaster risk management planning and provides a quantitative baseline for measuring the benefits (or losses avoided) of disaster management alternatives. In climate change impact and adaptation studies, it also provides a baseline for assessing the change in risks due to the increasing hydrometeorological hazards associated with climate change. See, for instance, *Earthquake Vulnerability Reduction Program in Colombia, A Probabilistic Cost-benefit Analysis* (World Bank Policy Research Working Paper 3939, June 2006) for an example of a probabilistic risk assessment used in disaster risk management planning. The process involves the development of several interconnected modules, which calculate in turn the hazard probability, exposure, vulnerability (or sensitivity to damage), damages, and losses. While the approaches used in the development of the modules and the calculation of the losses varied, each city case study did, however, follow a similar analytical process.

on Emissions Scenarios (IPCC 2000), four storylines yield four different scenario families—A1, A2, B1, and B2—that have allowed development of 40 different scenarios, organized in six different groups (IPCC 2007a). Each of these scenarios is equally valid, with no probabilities of occurrence being assigned. Thus, the A1 storyline refers to assumptions of a future world of rapid economic growth, global population that peaks in mid-century and declines afterwards, and the introduction of efficient technologies. The A1 storyline is disaggregated into three groups—based on alternative directions for technological changes in the energy system—where A1FI refers to fossil intensive sources. The B1 scenario family also assumes a global population that peaks in mid-century but is based on an assumption of a shift toward a service and information economy and the introduction of clean technologies.[12] Together, these scenarios "capture the range of uncertainties" linked with different driving forces (Jones et al. 2004).

For this study, the A1FI and B1 scenarios were chosen because they represent the high and low brackets, respectively, of the estimated global temperature increases under the SRES storylines. In contrast to the Bangkok and Manila studies, HCMC used the A2 and B2 scenarios. The main reason for this is that the A2 and B2 scenarios have been adopted as the official climate scenarios for Vietnam by the government of Vietnam under the national target program to respond to climate change.[13] There are numerous uncertainties associated with projecting future climate; selecting different scenarios allows the case studies to account for some of these uncertainties.

Downscaling from global climate models

Projections of future climate change are usually derived from global climate models (GCMs). A GCM is a mathematical representation of the climate system based on the physical attributes of its components, their relation, and various feedback processes. Various emissions and concentration scenarios (discussed above) are used as input into climate models to estimate global climate projections. GCMs—including atmosphere-ocean general circulation models (AOGCMs)[14] —are run at a course spatial resolution (a few hundred kilometers) and cannot capture the local detail needed for hydrological modeling and impact assessments at national or regional level (Jones et al. 2004). Further, GCMs are not designed to study hydrological phenomena, and GCM outputs and hydrological inputs are not at the same temporal and spatial scales.[15] Another related but important consideration is to perform bias corrections on the GCM results. To overcome some of these problems, downscaling techniques have been developed to obtain local-scale surface weather (at resolutions of 10–50 kilometers), from regional scale atmospheric variables that are provided by GCMs. Downscaling is the process of making the predictions from global climate models (GCMs/AOGCMs) relevant to a specific region so as to generate appropriate inputs for other tasks (in our case to feed hydrological models). There are several methods, each with its own degree of challenges based on the quality/quantity of detailed local/regional meteorological data required and computational complexity (Box 2.1).

Cascading set of uncertainties in using climate models for assessing impacts at local level

There are a number of caveats about the use of climate models. First, there is a cascading set of uncertainties, starting with the emission scenario chosen, uncertainties in future concentrations and CO_2 feedback cycles, uncertainties in the response of the climate, the AOGCMs used, the downscaling technique utilized, and the manner in which the im-

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[12] For more details, see http://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf.

[13] They were also chosen because they were the scenarios available for the ECHAM model used in the study. See HCMC study, Annex C.

[14] AOGCMs are global climate models that couple together the interactions between atmosphere and ocean. For a nested RCM, there is generally no feedback process of the changes in the RCM cells into the parent AOGCM, leading to disparities in boundary conditions between the RCM and the parent AOGCM.

[15] Empirically, it has also been observed that only poor quality hydrological models can be derived when using the GCM outputs directly, and that even simple downscaling methods improve the quality of hydrological models. For hydrological impact studies of climate change, the important climatic variables are temperature and precipitation, which are downscaled to provide inputs of precipitation and evapotranspiration to hydrological models while maintaining the correlation between the downscaled variables.

BOX 2.1 ■ Strengths and Limitations of Different Downscaling Techniques Selected for this Study

The city studies utilized two different downscaling techniques—pattern scaling which is a kind of statistical downscaling, and dynamic downscaling techniques. The first was undertaken for all the studies. The HCMC study also used dynamic downscaling. Briefly, statistical downscaling techniques are "based on the construction of relationships between large scale and local variables calibrated from historical data" (Jones et al. 2004). These statistical relationships are then applied to large-scale climate variables from AOGCM simulations to estimate corresponding local/regional characteristics (like temperature and precipitation). Pattern scaling, one of the techniques used in this work, is a form of statistical downscaling that requires minimal regional meteorological data and is computationally not very complicated. In pattern scaling the change in the local variable of interest—like temperature or precipitation—is represented in terms of the GCM's change for the variable per unit change in global temperature (this is the scaling factor). This factor is then multiplied by the global change in temperature associated with a specific IPCC scenario (A1FI and B1). In this specific case, the scaling factor was obtained by performing a linear regression on a number of GCM models available (see Sugiyama 2008 for details). The main advantage of statistical downscaling is that it is computationally not very expensive and can provide information at point locations. However, among several limitations, one issue is that the statistical relationships may not remain the same in a future climate world and the method does not provide information on temporal and location linkages.

In contrast, dynamical modeling techniques use physical models of the climate system allowing direct modeling of the dynamics of the physical systems that influence the climate of a region. They are rapidly becoming the most widely applied downscaling technique. New systems like PRECIS—used by the HCMC study—can be utilized from a PC platform, but they can still generate a broad range of daily, site-specific (i.e., 25 kms resolution grids) hydrometeorological data for time periods spanning a century. This allows examination of time slices like 2030 to 2070 to establish frequency relations for events in 2050 that can include both floods and droughts. Boundary conditions need to be derived from coupled GCMs. Nevertheless, RCMs also have a number of potential pitfalls that need to be understood. They require large amounts of boundary data linked with the parent GCM, acquire the errors of the parent GCM, and (as is the case with PRECIS) may take several months to run. An additional limitation is their potential exclusive reliance on only one AOGCM. Before applying the RCM, the user needs to understand whether it can model the types of events (e.g., typhoons) that are of particular interest in the study. Typically, for studies that involve downscaling analysis such as disaster risk assessments, when trying to incorporate climate change risk factors into the analysis, statistical downscaling or regional climate models are likely to be the methods of choice.

Source: Authors' compilation.

pact parameters (e.g., precipitation and temperature increase) that are generated are applied in estimating flood impacts at the city level. Trying to quantify these uncertainties—and given a confidence interval for the outcomes—is extremely difficult, and some uncertainties—like future emission scenarios—cannot be assessed. However, despite these uncertainties, the IPCC AR4 recognizes that the AOGCM climate change models do allow global forecasts, and that increasingly the downscaling techniques are providing information on the likely scale of different climate impacts at local levels (Giorgi 2008).

Estimates for changes in temperature and precipitation in 2050 based on statistical downscaling approach

The statistical downscaling technique used in the study (see Sugiyama 2008)[16] provided estimates of (a) the expected temperature increases, (b) extreme 24-hour precipitation increase factors, and (c) seasonal mean precipitation increases for 2050 for the two climate change scenarios A1FI and B1. These factors were derived from16 AOGCMs models for all four cities and are shown in Table 2.1.

The robustness of the relationships was examined statistically by the IR3S team by examining the scatter among the data points generated by the downscaling of the 16 AOGCMs. They found robust relations for global and local temperature and precipitable water (used as a proxy for extreme precipitation) relationships, and viable but less strong relationships for the temperature/mean seasonal precipitation increases. How this was handled is explained in Box 2.2.

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[16] This part of the analysis was carried out by Integrated Research System for Sustainability Science (IR3S) at the University of Tokyo. The results are presented in Sugiyama (2008).

TABLE 2.1 ■ Climate Change Forecasts for 2050

City	Manila	Bangkok	Ho Chi Minh City	Kolkata
Approx. longitude	121° E	100° E	106° E	88° E
Approx. latitude	14° N	13° N	10° N	23° N
$\Delta T_{local} / \Delta T_{global}$ [unit less]	0.88	0.94	0.89	0.90
ΔT_{local} (A1FI) [K]	1.8	1.9	1.8	1.8
ΔT_{local} (B1) [K]	1.1	1.2	1.2	1.2
$\Delta P_{mean} / P^{present}_{mean} / \Delta T_{global}$ [% / K]	2.0	1.5	2.2	5.1
$\Delta P_{mean} / P^{present}_{mean}$ (A1FI) [%] (June-July-August)	4.0	3.0	4.4	10
$\Delta P_{mean} / P^{present}_{mean}$ (B1) [%] (June-July-August)	2.6	2.0	2.9	6.6
$\Delta P_{extreme} / P^{present}_{extreme} / \Delta T_{global}$ [% / K]	8	8	8	9
$\Delta P_{extreme} / P^{present}_{extreme}$ (A1FI) [%]	14	15	14	16
$\Delta P_{extreme} / P^{present}_{extreme}$ (B1) [%]	9.2	9.8	9.3	11

Source: Sugiyama (2008).

BOX 2.2 ■ Downscaling from 16 GCMs

To develop the estimates, the study first downscaled global mean temperature and precipitation. The pattern scaling technique adopted ignores the differences between locations within the grid used in the GCM. The downscaled relationships were robust and the inter-model variation was small. To examine the increases in extreme and mean precipitation, the study examined the forecasts made by the models for 24-hr extreme and mean precipitation increases. They found significant variability among them in the simulation. For example, the factor increase for extreme precipitation in the tropics as drawn from the models ranged from 3 percent/°C to 28 percent/°C. For storms with a 1-in-30-year return period, the mean increase among the models was 10 percent/°C, but the standard deviation was 6.9 percent/°C , making the statistical relationships unusable.

To overcome this problem, the study used the increase in precipitable water (i.e., the amount of water in a column of air that could fall as precipitation), for which there was a more robust relationship within the models, which researchers have indicated would serve as a good scaling factor for extreme precipitation (Allen and Ingram 2002) as a proxy for the increases in extreme precipitation. Such relationships have been established in the literature (see the report for the references). For mean precipitation, the team found a stronger correlation in monthly mean precipitation estimates and used these data sets to make the mean increase estimates.

Source: Sugiyama, 2008

Use of regional climate modeling in HCMC study

In addition to the above, the HCMC study also utilized the PRECIS model nested in the low resolution (~2o) ECHAM Version 4 AOGCM model (European Centre for Medium Range Weather Forecasts, University of Hamburg) to generate daily hydrometeorological data for the study.[17] For this modeling, A2 and B2 scenarios were used, which for the year 2050 do not deviate dramatically from the A1FI and B1 scenarios respectively. For the parent AOGCM used, the A1FI and B1 forecast simulations were not available. Although HCMC utilized a dynamic downscaling technique, they also compared their precipitation forecasts with those derived from the statistical method and found the results broadly consistent with their forecasts.

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[17] The Southeast Asia (SEA) Regional Center (RC) for the Systems for Analysis, Research and Training (START) undertook the work.

Uncertainties in the assignment of future probabilities

Hydrometeorological probability assessments (as used in this study) are based on the analysis of historical data of extreme events and assume that the underlying population's statistics (e.g., mean, standard deviation, skew, etc.) do not change over time. In this regard, the discussion of probabilities associated with future extreme events presents a conundrum, which is approached differently depending on whether a statistical or nested RCM downscaling technique has been used. For the statistical methodology used in this study, a factor increase has been computed for extreme 24-hour and mean seasonal precipitation events. These factors were applied to current events with the comparable probability. For the RCM methodology, simulations over a 40-year time slice around the study date (2050) allowed calculation of the probability of the extreme events. These approaches have some inherent limitations. For the statistical methodology, it assumes that the parent population's inherent variability remains the same, which could easily be wrong. For the RCM, decadal variations, which also affect the population sets' characteristics, may not be reflected. The statistical downscaling "factor increase" or RCM forecasts can have significant errors even though they both reflect best practices in climate science. The specific question of the influence of these errors on downstream impact assessments has not been studied in any detail. In addition to estimating changes in temperature and precipitation under different scenarios in 2050, each city team also made estimates for changes in storm surge and sea level rise. Further, where data was available, estimates for land subsidence were also considered in estimating flooding under different scenarios. How each city study approached these issues is discussed in more detail in chapter 3.

HYDROLOGICAL MODELING FOR DEVELOPING SCENARIOS OF FLOOD RISK

The second sequential step of the analysis involved hydrological analysis to estimate the extent of flooding in each coastal city under different scenarios in 2050. Outputs from the downscaling analysis—including estimates and assumptions for a range of climate variables (such as sea level rise, storm surge) and non-climate variables (such as land subsidence, land use, population changes, economic growth, existing and planned infrastructure)—were used as inputs into the hydrological analysis and GIS mapping. This part of the analysis is discussed below.

Estimating flooding in urban areas under different scenarios

The risk of loss from a hazard such as flooding is based on exposure and, consequently, is site specific. Thus, to estimate the extent of flood risk in each city, hydrometeorologic models specific to each city (Box 2.3) were developed. These models were based on a host of historical and city-specific information—such as existing drainage and sewerage systems, soil characteristics, river flow, canals, dams, land subsidence, siltation, existing flood protection infrastructure, and so forth—to estimate future flooding under different scenarios. Floods can occur from a combination of factors, including upstream storm runoff, storm rainfall on the city, or sea level rise and storm surge acting alone or in conjunction with other storm events. These factors were incorporated into the scenario analysis.

The extent of flooding was estimated in terms of the depth, duration and area flooded and overlaid on GIS maps with land-use mapping of the population (disaggregated by poverty levels and other vulnerability criteria), assets, infrastructure, utilities, and environmental and cultural resources. This was done both for the base case and for the year 2050 under different climate scenarios. For the purposes of this study, the city studies assumed that without climate change, the climate in 2050 would be similar to the climate in 2008/base year. This helped assess the scale of physical damage that can be caused to infrastructure, income, land, populations, etc, in the cities with and without climate change.

Return periods considered [18]

In this study, for each of the cities, flood risk was estimated for events of different intensities or return periods, namely a 1-in-10-year, 1-in-30-year, and 1-in-100-year floods in the base year and in 2050.[19] This was based on a statistical evaluation of historic storm events that allowed the assignment of probabilities to extreme precipitation events[20] associated with the floods.

Hydrological modeling undertaken to estimate flooding under different scenarios

The hydrological models simulate the movement of water on land after it falls as precipitation.[21] A key initiating input parameter for such modeling is precipitation (derived for each city from the downscaling analysis). The manner and timing of the precipitation's arrival in the rivers is driven by the precipitation intensity and duration, the terrain slopes and land use cover (which can drive infiltration and evapotranspiration), and the channel characteristics. Computer models, in which the relevant information is digitized, allow the otherwise daunting calculation of the movement of water through the watershed and channel. In addition to the input parameter of precipitation and spatial data affecting the flow of the runoff, the boundary (or tail-water) conditions where the flood exits a system into the sea can create a backwater effect, raising the water level profile of the river upstream from the sea and increasing the overbank spillage and flood inundation levels. Storm surge can also cause the movement of the water upstream from the sea into the coastal cities. The hydrometeorological models were designed to model these interactions and are based on general principles outlined below (Box 2.3).

Manila and Bangkok applied commercially available software to develop the hydrologic models and HCMC utilized hydrologic models that had already been developed and calibrated by the government for their catchment area. Outputs from the HCMC hydrologic models can also be linked to commercial or open-sourced software models to refine inundation information. Typically a combination of models was used in the city studies (Table 2.2).

Large watersheds with many sub-basins, reservoirs, diversions, etc. have necessarily complex models describing the water transfer within the basin. For the Chao Phraya River Basin, for example, a complex combination of models needed to be interlinked to accurately simulate flooding in Bangkok. The schematic shown in Figure 2.1 below shows the interconnectedness of rainfall-runoff (on the upper watersheds), reservoir and river routing, and flood routing (2D). The complexity has an impact on the time and depth of analysis. For example, a simulation run for Bangkok with one set of input parameters took 24 hours of computer time, and the study required over 30 simulation runs not counting the runs required for calibration. HCMC used a simulation model that had been previously developed and calibrated by the government. Manila's hydrologic models were far simpler and the period of flooding modeled was only a few days, so the length of the simulation runs in terms of computer time was far shorter than for Bangkok.

Calibration of hydrometeorological models

As noted above, to ensure the accuracy of the models, rigorous calibration is necessary. The process requires significant trial and error in getting the model to accurately reflect historic movements of floods as runoff, through river channels and overland flood events. In Figure 2.2 below for Manila, the dotted line shows the observed discharge and the blue line

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[18] This refers to the recurrence interval or the return period of a flood and is an estimate of the time interval between two flood events of certain intensity. It is a statistical measure of the average recurrence interval over a long period of time and is the inverse of the probability that the event will be exceeded in any one year. For example, a 10-year flood has a 1 / 10 = 0.1 or 10 percent chance of being exceeded in any one year and a 50-year flood has a 0.02 or 2 percent chance of being exceeded in any one year. Thus, a 100-year flood has a 1 percent chance of occurring in any given year. However, as more data becomes available, the level of the 1/100 year flood will change.

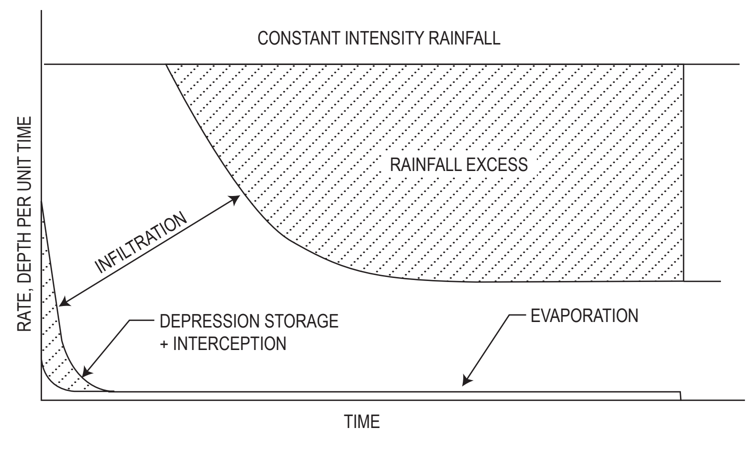
[19] HCMC restricted its analyses to 1-in-100 and 1-in-30-year floods.

[20] An extreme event that causes flooding could be from extreme 24-hour rainfall on a small watershed, a high seasonal rainfall on a large watershed, or a typhoon or cyclone and associated storm surge.

[21] Storm surge and SLR have been incorporated into the models as boundary tailwater conditions for the hydrologic models.

shows the simulated discharge using the model and the actual input precipitation data, indicating the robustness of the model. This type of "ground-truthing" was done for the hydrological modeling in the Bangkok and HCMC studies as well.

BOX 2.3 ■ Some Basic Principles for Hydrological Mapping



Hydrologic models use a mass balance approach in developing the empirical relationships, wherein the volume of inflow (or precipitation) minus the losses equals the volume of outflow. For the rainfall-runoff relationship, the rainfall excess, which appears as runoff in the river channels, is equal to the precipitation minus the evaporation, infiltration, depression storage, and interception as depicted in the figure below. The empirical models must be calibrated against observed events in order to provide useful estimates.

The empirical relationships generally capture physical information (e.g., land use information, soil types, antecedent rainfall, area, and gradients for rainfall-runoff models, or river gradient, cross-sections, and roughness estimates for river-channel routing models) that are used with parameters to generate the input-output relationships. The parameters are adjusted in an iterative approach to obtain the best fit to the actual data as part of the calibration process.

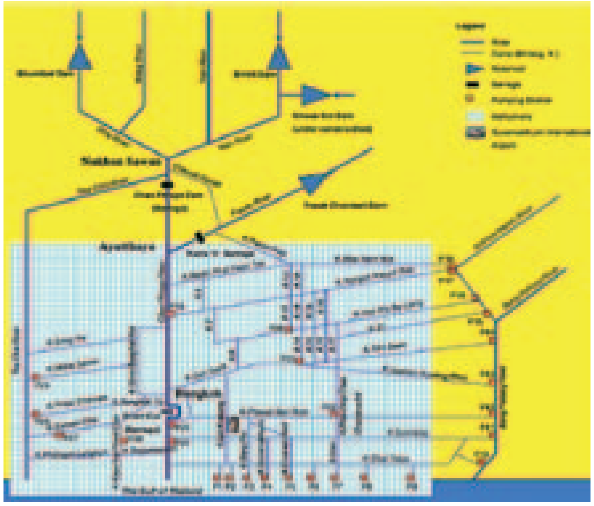
Source: American Society of Civil Engineers, Hydrology Handbook (1996).

TABLE 2.2 ■ Summary of City Case Study Hydrologic Modeling

City Study	Hydrologic models used
Bangkok	Rainfall-runoff modeling of the upper Chao Phraya watershed entailed dividing the basin into 15 sub-basins and using NAM model; the MIKE FLOOD software model was used for the lower Chao Phraya coupling the MIKE 11 and MIKE 21 for 1D and 2D flows.*
HCMC	Rainfall in the upper watershed of the Saigon and Dong Nai rivers are captured by the Dau Tieng and Tri An reservoirs; outflows from these were modeled by the Southern Institute of Water Resource and Planning based on historical (2000) flooding. The HYDROGIS model was used for the modeling of HCMC. It has been specifically designed and calibrated by Vietnam's Ministry of Natural Resources and Environment's Institute of Meteorology, Hydrology and Environment and models both 1D and 2D flows.
Manila	The NAM software was used to model the rainfall-runoff relations linked to the MIKE FLOOD; MIKE 11 and 21 were used to model floods in Manila.

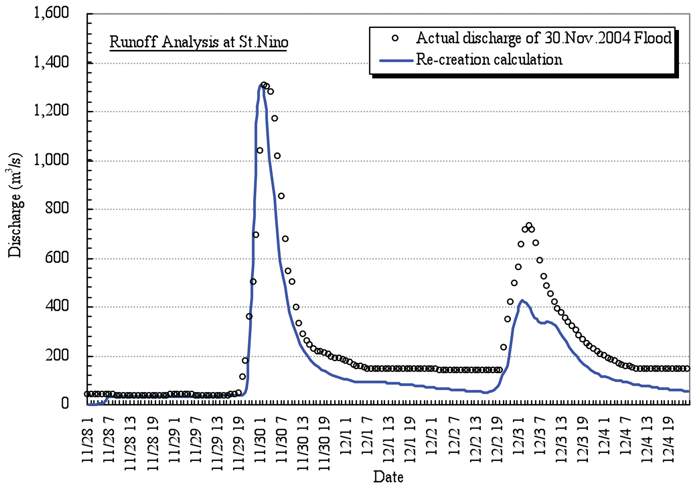
Note: * When the water is flowing in a channel, the model is frequently referred to as one-dimensional (1-D) and overland flow models are referred to as two-dimensional (2-D) models.

FIGURE 2.1 ■ Hydrometeorological Model Schematic for Chao Phraya Watershed



Source: Panya Consultants.

FIGURE 2.2 ■ Manila Rainfall-Runoff Calibration Hydrographs



Source: Muto et al. (2010).

Infrastructure scenarios and additional climate inputs into hydrological modeling

Since the extent and impact of flooding in 2050 in different cities will depend not only on climate and weather variables but also on the infrastructure available in the cities to drain water and prevent flooding, the hydrological models also assumed certain infrastructure and flood protection scenarios to estimate flood occurrences. Further, the studies also made estimates and made assumptions regarding storm surge and sea level rise as inputs to the hydrological modeling. These assumptions and estimates are discussed in more detail in chapter 3.

APPROACH TO ASSESSING DAMAGE COSTS

The main impact of climate change on the four cities in 2050 is assumed to be in the form of increased flooding. Flooding has direct and indirect effects. The direct impacts have to do with immediate physical harm caused to "humans, property and the environment" (Messner et al. 2007) and involve costs from loss in the stock of infrastructure, tangible assets and inventory, agricultural and environmental goods, and injuries and life loss.[22] The indirect impacts of flooding are a result of a loss in the flow of goods and services to the economy (ECLAC 2003; Messner et al. 2007).[23] These costs are in terms of traffic delays, production losses, or emergency expenditures. Some delays may be immediate, while others may be more medium term because of the secondary effects of flood-related transportation bottlenecks and re-directed traffic, for example. Table 2.3 summarizes the different direct and indirect and tangible and in-tangible costs associated with flooding.

The Bangkok and Manila case studies follow the approach outlined above and estimate direct and indirect costs for four areas: (1) buildings, industry, and commerce; (2) transportation and related infrastructure; (3) public utilities such as energy and water supply and sanitation services; and (4) people, income, and health. The HCMC study also discusses the impacts of extreme events on natural ecosystems. However, the HCMC study does not provide any detailed monetization of impacts. The more macro approach it takes to damage cost assessment is discussed in detail later in this chapter. The

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[22] One of most difficult of the direct costs to value is loss of life. Manila and HCMC have both witnessed loss of lives during major storms in the past but do not attempt to value such losses from future storms.

[23] It is important to be careful not to double count damages since the value of the sum for flows from an asset would equal the value of the asset.

TABLE 2.3 ■ Direct and Indirect Costs from Flooding

	Tangible	Intangible
Direct Costs	Repair, replacement, and cleaning costs associated with physical damage to assets Public infrastructure Commercial and residential buildings Inventory Vehicles Loss of productive land and livestock Crop loss[1]	Loss of human life Loss of ecological goods Loss of archaeological resources
Indirect Costs	Loss of industrial production or revenues Increased operational costs for commercial entities Lost earnings or wages Time costs from traffic disruptions Post-flood flood proofing investments by the private sector Emergency flood management costs to the public sector	Long-term health costs from pollution or flood injuries Post-flood recovery inconvenience and vulnerability

[1] Income loss from crop destruction is conventionally treated as a direct cost. If land is salinized or there is permanent inundation, then the loss in the asset value of land is the cost to include. Care needs to be taken to distinguish between one-time crop loss and land value losses that are of longer duration.

Source: Modified from Messner et al. (2007).

methods used by the Manila and Bangkok study to develop cost estimates are discussed below. Figure 2.3 summarizes the main steps taken in estimating costs and then estimating the net benefits from investments to reduce flooding.

Damages to buildings, industry, commerce, and residents in Bangkok and Manila

A key impact of floods is on existing buildings. Floods are assumed to cause damage but not destroy

FIGURE 2.3 ■ Estimating Impacts—A Flow Chart

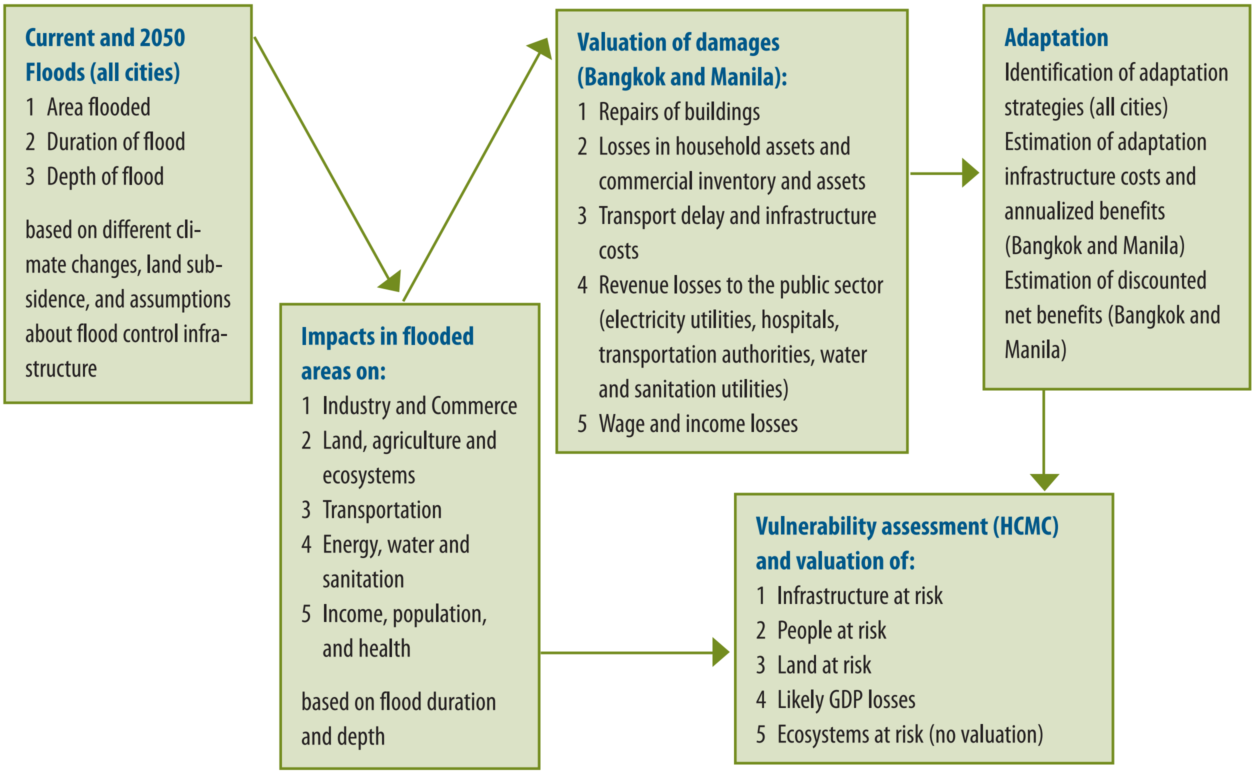

FIGURE 2.3 ■ Estimation of Damage to Buildings, Assets, and Inventories in the Bangkok and Manila Cases

1. Identify buildings in flooded areas using building /infrastructure surveys.
2. Classify buildings into commercial, industrial, residential or other sub-classifications.
3. Identify assets and inventories in buildings based on surveys or on the type of building.
4. Establish average values of buildings and assets/inventories based on tax information, industrial surveys, household durable wealth data etc.
5. Apply a damage rate to different buildings and assets/inventories to establish actual damage at different levels of flooding. The damage rate is obtained from previous flood information or from secondary sources and varies with the level of floods.

buildings. The steps used in estimating damage costs in the case of Bangkok and Manila are identified in Figure 2.4.

Identifying, classifying, and valuing damage to buildings

The Bangkok and Manila case studies used information from building censuses and other infrastructure-related studies to classify buildings first into residential, commercial, and industrial buildings. Based on national statistical organization classifications, these categories of buildings were further subdivided. For example, commercial buildings alone were subcategorized into nine groups in the case of Bangkok.

Once buildings were classified into different subgroups, they were valued based on available government data. The Bangkok case study identified the book values of buildings of different types based on construction costs when the buildings were legally registered. These values were then depreciated to reflect aging. In Manila, the base unit construction cost of residential and commercial buildings was obtained from the government assessor's office and the median value of different types of buildings estimated. Then, based on the estimated depth of floods (output from the hydrological analysis), the value of floor areas of flood-affected buildings was identified.

In order to estimate the actual cost of damage to buildings, the case studies used different damage rates depending on the level of the flood.[24] The damage rate or the percent of the value lost from floods is dependent on the depth of inundation. A different rate is applied to assess damage to buildings and damage to assets. The Bangkok study used a 1997 survey to establish damage rates; the rate was used for all types of buildings and housing (residential, commercial, and industrial). The Manila study used damage rates, which vary across buildings and assets.

Assets such as machinery, office furniture, and inventory damaged by floods also need to be valued. The loss of assets from damaged buildings was evaluated based on "representative assets" in different types of buildings. For example, in the case of the Bangkok case study, average asset values obtained from census data for buildings are THB 328889 ($9,873) for Bangkok and THB 220180 ($6,609) for Samut Prakarn. In the Manila study, the value of stocks, assets, and inventories of commercial and industrial enterprises was obtained from the National Statistical Organizations' data of

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[24] The flood damage rates used in the case studies were obtained from either local surveys or from secondary sources.

establishments. A damage rate (Table 2.4) was applied to assets and inventories to determine losses. The Bangkok study used a similar approach.

To estimate losses to residential assets, the value of household goods first needs to be established. In the Manila case, the value of household effects was estimated to be 35 percent of the value of residential construction costs of flooded buildings. Similarly, finishings were estimated to be 25 percent of construction costs. In the Bangkok study, average household assets or durables were obtained from the Population and Housing Census of 2000. The value of these assets was based on market prices. Once the asset values were obtained, damage rates were used to estimate the losses from different levels of flooding.

Assessing impacts on roads and transportation networks

Flooding affects road and train networks in all the cities. There are direct and indirect costs associated with loss of transportation infrastructure. Direct costs are (a) construction or repair costs; and (b) any losses of vehicles or damaged trains and so on. These costs are estimated where applicable, based on average repair costs. Indirect costs associated with damage to transportation infrastructure include increased vehicle operations costs (VOC) resulting from damages to roads from flooding or because of changes in traffic pattern (increased petrol costs), or time costs from losses in productivity (ECLAC 2003).

More than 90 percent of inhabitants of Bangkok and Samut Prakarn travel by roads and highways. However, the road network in Bangkok, Samut Prakarn, and the BMR are set at an elevation of 1.5–2.0 meters above ground, and most of them are covered with reinforced concrete pavement or 7–10 cm of asphaltic pavement. Therefore, they are not expected to incur flood damages. Rail lines are generally set at about 1 meter above the surrounding ground level. The Bangkok rapid transit system, both elevated and underground, has been designed to be protected from overflow flood water. Thus, the costs associated with transport networks from flooding in Bangkok are expected to be minimal.

The Manila study undertook a detailed analysis of damages to the transport sector. First, based on the transport master plan, future road construction was identified. The length of major and minor current and future roads likely to be affected by floods was then established. Based on unit maintenance cost data from the Department of Public Works and Highways, the cost of maintaining these flood-affected roads was estimated. The Manila study also estimated indirect costs from flooding related to time delays from traffic disruptions and problems with vehicle operations. In the Manila case, the vehicle operations cost (VOC) is obtained from the Department of Public Works and Highways and includes fixed costs of operating vehicles and running costs. The costs of floods or the change in VOC per km was estimated as the difference between VOC on flooded roads and on roads in good condition. This difference in VOC is multiplied by the number of affected roads in 2008 and 2050 to obtain damage costs in these two periods. To estimate time-delay costs, data on flood related transport delays and the number of road commuters were obtained from secondary sources and transportation surveys.[25] The number of commuters delayed by flooding was then multiplied by average hourly income as a proxy for time costs.

Table 2.4 ■ Flood Damage Rate by Type of Building in Manila

		Flood Level	
Type of Building	Affected Assets	100–200 cm	200–300 cm
Residential	Finishings	0.119	0.58
	Household Effects	0.326	0.928
Business Entities	Assets	0.453	0.966
	Stocks	0.267	0.897

Source: Adapted from Manual on Economic Study of Floods, Japan
Note: Damage rates are available for less than 50cm and more than 300 cm as well

Assessing direct and indirect costs in energy, water supply and sanitation

Energy, like the transportation sector, may sustain direct and indirect damages from floods. Direct damages to electricity generation plants, transmis-

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[25] The Manila study draws heavily on the government's Transport Master Plan, which lays out potential transportation changes up to 2015, and on the Metro Manila Urban Transportation Integration Study (MMUTIS).

sion and distribution lines, and energy distribution centers depends on whether these facilities are in the flood-affected area of each city. If they are, then the extent of damage is estimated and replacement and repair costs are used to value these damages based on cost information available with government departments. In most cases, electric utilities have strict rules for cutting electricity during certain types of floods. This leads to revenue losses, which were estimated in the Bangkok case study. In terms of direct costs, future power generation plants for Bangkok and Samut Prakarn are planned outside the cities and there will be no direct impact. The Manila study did not estimate energy-related costs.

As with the case of the energy sector, costs to water and sanitation systems are evaluated only if it is established that there is a likelihood of flood damage to specific subcomponents such as water intake facilities, pumping stations, water treatment plants, main lines to storage tanks, storage tanks, distribution networks, and so on. In the case of Bangkok, it is assumed that water supply will become dysfunctional if water floods reach 2 meters above the ground surface. This will disrupt water services to the area and result in revenue losses to the utilities as well as other costs, including health costs. The calculation of sales loss for the water supply system due to flood damages in Bangkok was estimated as follows:

Water supply sales loss = No. affected users x water demand per user x water sales rate x flood duration

The data for this estimation came from the five-year record of the Metropolitan Waterworks Authority, which indicates water sales for a residential unit are 0.48 m^3 per day per household and water revenue is 2.06 baht per m^3. Water sales for a nonresidential unit are 3.71 m^3 per day per customer and water revenue is 2.83 baht per m^3. In the Bangkok study, direct damage to the water supply and sanitary infrastructure is not assessed since they are protected from the worst possible flood in the future. The calculation of income losses to sanitation service providers because of the shutdown of sanitation services was similarly undertaken. The Manila study did not find major costs associated with the water delivery sector because of the position of the pipes and extent of pressure in them.

Estimating income losses

As previously noted, each city estimates the population likely to be affected by 2050 floods. Where possible, survey data and other secondary sources were used to identify the characteristics of the affected population, particularly to examine whether floods will affect the poorest communities.

Income losses to the commercial sector

In order to estimate income losses from floods, the Manila and Bangkok case studies examined losses to firms and individuals. During the duration of the flood, income losses are borne by the private commercial sector because of a halt in their activities. Since it is difficult to directly estimate these costs without detailed production information, where available, national statistics on income per day associated with different kinds of commercial structures were used.

The Bangkok study identified the number of buildings in flood-affected areas and then, based on the duration of the flood, estimated the rate of damage to these buildings. To obtain business losses, the Bangkok case study then identified the average income per day from commercial establishments based on business surveys. The loss in value added per day (net income) was adjusted due to savings in business expenditure when an operation is closed down. The net commercial income was estimated to be THB 4930 ($149) per establishment per day. A similar accounting was used to estimate average income to industrial establishments. These average values are multiplied by the number of days of flooding and the number of buildings affected by floods to estimate income losses from commerce and industry.

The Manila case study took a similar approach. The analysis was based on a 2008 survey on business income losses to flood-affected firms. The study used data on sales losses as a substitute for income or profit data, which were unavailable. Buildings that were affected by floods were categorized according to different commercial activities; each floor was assumed to host one firm. By multiplying the sales loss data (categorized by type of economic activity) by the number of affected buildings in each economic category, the study established the value of income losses to the commercial sector.

Estimation of income losses for poor and non-poor households

Households who work in flood-affected areas may lose income during the duration of the flood. A general assumption made in the Bangkok case is that salaried workers will not see income losses from floods. However, the informal sector needs further accounting. In Bangkok, the low-income housing developments, called condensed housing, in flooded areas are identified and—based on estimates of household size—the number of daily wage earners in this area is estimated. Then based on the daily wage rate, the income loss to poor and non-poor households is calculated.

The Manila case study examines income losses to workers in the formal and informal sectors. Because of lack of data on number of households, the case study, like Bangkok, relied on the number of buildings affected by floods. Non-poor residents were assumed to occupy residential buildings at the rate of 1.5 households per building. This allowed the Manila study to estimate the total number of non-poor resident households in flood-affected "formal" residential buildings. The total number of affected households was multiplied by the average income per household (based on government statistics) to obtain income losses to the formal sector.

To establish losses to the poor, the Manila study first estimated the number of informal structures affected by floods. It was assumed that at least two households live in each structure. Thus, the total number of affected households was estimated. Again, using government statistics on the poverty level per day of PHP 266 per household, the total losses to the informal sector was then established.

Limited analysis of health impacts in the city studies

An important question concerns the impact of floods on public health. Each city is different and has health impact data based on previous experience with floods and expert advice. The main diseases associated with floods are diarrhea, conjunctivitis, athlete's foot, malaria, cholera, and typhoid. Ideally, we would require information on different outbreaks and cost per episode per person for specific diseases in order to value health impacts. However, this is difficult to obtain and some approximations are made. The Bangkok study makes an attempt to examine health costs associated with floods. In this case study, the number of individuals affected by floods is estimated and multiplied by the average per person health costs associated with hospital admissions. This is clearly a first approximation for what might be the real costs on health from flooding. However, lack of data, and difficulties in establishing dose-response information related to different flood-related diseases, lead to this more simplistic analyses. The Manila study does not estimate the health costs from floods even though it makes an attempt to estimate some of the health impacts of flooding. A more detailed analysis of health impacts needs to be carried out as a follow-up to this study.

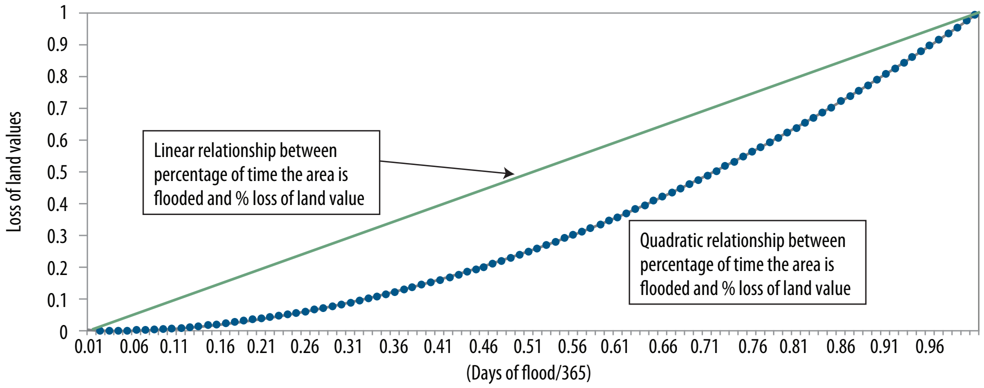
ASSESSMENT OF DAMAGE COSTS IN THE HCMC STUDY

The HCMC study used a macro-approach to assess damage costs. Two different methods were used to calculate the cost of climate change at an aggregate macro-level: (1) cost estimates using land values; and (2) cost estimates based on aggregate GDP loss. The methodology applied in each of these approaches and the results obtained are described below.

The land value approach

Economically speaking, the value of any asset is the sum of the value it is expected to generate over time, discounted to reflect people's preferences for consumption in the present. The same is true for land. In principle, the current value of the land stock in HCMC is the value of future production that can be expected to be generated with this asset. Land value can be a particularly good guide to the cost of climate change as land values capitalize most values that need to be captured in any assessment of cost (such as roads, railways, water supply systems,

FIGURE 2.5 ■ Possible Relationships between Flood Duration and Land Value Loss



Source: ADB (2010).

drainage systems, energy infrastructure, hospital and schools). An estimation of how the impacts of climate change may affect the value of the land stock in HCMC thus provides a first-order approximation of the economic costs of climate change for the city.

The first step in the analysis was to determine land prices. Land price data was aggregated by district and an average land price determined for each district. The administratively determined price for land is published by HCMC People's Committee annually, as required under the 2004 Land Law. These prices are used to determine the level of compensation for state appropriations of land and for taxation purposes. In principle, these administrative prices are based upon the potential productive value of the land, rather than market prices (although following the 2004 Land Law, the administrative price for land has moved closer to land market values). These are current land prices, not 2050. These are also not market prices.

The area subject to flooding both in extreme events and regular flooding was then determined under future scenarios using the HydroGIS modeling. Once the average land price and flooding extent and duration were estimated, the relationship between the flooding and the decline in the economic value of the flooded land was determined to allow the calculation of the cost of flooding due to climate change. The study assumes that there is some positive relationship between the duration of the flooding and the loss in land value: that is, the longer the period of flooding, the greater the loss in land value. However, the precise nature of that relationship between the economic value of land and the number of days in any given year that an area is flooded is not known, and must be assumed.

In the HCMC report, two types of relationship have been assumed: The loss of land value is directly proportional to the proportion of time the land is inundated; this is the linear relationship in Figure 2.5. For example, if the land is flooded for 182 days per year, (about half of the time), this assumption yields an estimated loss of 50 percent of the land value. A proportional relationship would overestimate the loss in land value. Indeed, if land is flooded only a few days a year, we might suppose that this would have a limited impact on the value of the land, if any. On the other hand, the proportion of the loss of land value may increase at an increasing rate as the length of time the land is flooded increases, reaching 100 percent of land value lost when the land is flooded for 100 percent of the time (the quadratic relationship is shown in Figure 2.5). The quadratic relationship is considered to represent a more realistic relationship between flood duration and land value loss as small periods of flooding (e.g. for one or two days) are unlikely to influence land value much, whereas longer term flooding (e.g. for 300 days a year) is likely to reduce the value to near zero.

The GDP approach

The second approach to estimating the costs of climate change is to calculate costs on the basis of expected losses in production (proxied by GDP) due to climate-change-induced flooding. Like land, GDP measures capture a number of important values (level of economic development, extent of industrial activities, transportation system, water supply, drainage, etc). To calculate costs using this method, a number of important assumptions were integrated into the analysis: Areas subject to flooding lose all their productivity for the duration of the flood. The GDP produced in a particular area is directly proportionate to population (i.e. if an area accounts for 1 percent of the population it will also account for 1 percent of the GDP). GDP is produced evenly over time (i.e. with 1/365th of annual GDP being produced everyday). Based on GSO statistics, GDP growth will average 11.5 percent between 2006–10; 8.7 percent between 2011–25; and 8 percent between 2026–50. Population growth will take place in line with the high estimate discussed in chapter 4. Future values are discounted at an annual rate of 10 percent.[26]

Given these assumptions and the information on flooding derived from the HydroGIS models, an estimation of the costs due to flooding is relatively straightforward. For each district and for each year until 2050, the following calculation was performed:

Annual cost of flooding = Number of days the district is flooded x number of people affected x GDP/capita/day

The annual cost of flooding was calculated for each year between 2006 and 2050, and the discounted costs summed for the whole period. The HCMC study presents results from both the land values and GDP measures. The differences in the results and approaches are discussed in chapter 4.

ASSUMPTIONS ABOUT THE FUTURE OF CITIES IN ESTIMATING DAMAGE COSTS

Cities in 2050 are likely to be vastly different from today's cities. Understanding how different is a huge task and there is no attempt to model economic growth and link it to urban development. Instead, existing data and official plans and projections are used to understand and develop GIS-based maps. Further, in assessing damage costs, each city study made assumptions about population size and distribution, poverty, economic growth and city-specific gross domestic product, urbanization, flood and transportation infrastructure, and spontaneous adaptation and migration. Where possible, they built on existing plans and studies undertaken by city governments related to urban growth, public utilities and transportation networks, and so forth. Population in 2050 is estimated based on the best available local projections for each city. The population distribution within each city in 2050 builds on available estimates of population density and distribution and some understanding of future population dynamics. Economic growth and poverty projected in 2050 varies across the case studies. These assumptions are made explicit in the following chapters with respect to each city.

Human spontaneous adaptation to the possibility of increased flooding is considered but is not fully incorporated into the studies. This is partly because of the difficulties in predicting adaptation behavior and partly because populations, while likely to respond to incremental change, may not have a measured response to the type of extreme events considered in this study.[27] The case studies do take into account human migration in identifying population distribution in 2050. In general, populations exposed to flooding are likely to continue to be exposed to flooding except in cases where there is improved flood infrastructure put into place.

Assumptions about prices

Given difficulties in estimating future prices, all the three case studies largely keep the real value of goods and services unchanged. The Bangkok study estimates the costs of damage in 2008 using current

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[26] Because in the case of land, the land value already represents the discounted future income stream capitalized in land value, so there is no need for discounting when using land values to estimate the cost of climate change in the previous analysis.

[27] Yohe et al. (1995), for example, argue that if permanent inundation is expected due to SLR, it might be appropriate in cost-benefit analyses to treat the value of inundated buildings as zero or very low. If there is full information and efficient adaptation, economic agents can be expected to let these buildings fully depreciate before they are inundated. In our study, we do not assume full information. Nonetheless, rational households who can afford to move are likely to move away from flood-prone areas, which may be then populated by poorer communities.

prices and the same prices are applied to 2050 damages. The Manila study assumes a 5 percent annual growth in the value of goods and services lost from floods; that is, damages grow annually at 5 percent up to 2050. However, for comparison, the Manila study deflates its 2050 values and presents the 2008 values of all damages whether they occur in 2008 or 2050. The HCMC study uses a macro approach to estimating costs and examines current land values as well as annual income loss based on annually projected GDP.[28]

The interest rate is an important price variable for assessing adaption investments. The case studies use discount rates that are normally used to discount public investments in each city. The Bangkok study presents results using 8 percent, 10 percent, and 12 percent rates. The Manila study uses a 15 percent discount rate and the HCMC study uses a 10 percent rate.

CONCLUSION: METHODOLOGICAL LIMITATIONS AND UNCERTAINTIES IN INTERPRETING RESULTS OF THE STUDY

Difficulties with 2050 projections

While the studies attempt to establish some understanding of how the cities may look in 40 or so years from now as is discussed in the following chapters, this is really very difficult to do. Hydrological models in all three studies incorporate flood control infrastructure and the type of land use that may exist in the future. Future transportation networks are incorporated into damage assessments undertaken by Manila and Bangkok, and official population projections are used. Yet there are numerous assumptions underlying each of these projections and the future may look different from what is assumed. The road networks may not be built, new land use plans may be put in place, and exogenous shocks could change the population distribution. We can imagine a situation where flood-prone areas are made into wetlands or parks and set aside for some form of recreation. In these circumstances, the costs of flooding may be very different.

Impacts on populations working in flooded areas are another area of concern. It is hard to establish what categories of people may actually inhabit flood-prone areas in 2050. While the studies incorporate trends in population distribution, it is not clear that these trends will remain unchanged in the next forty years. It is rational to consider a scenario where increased flooding will lead to commercial establishments moving away from flood-prone areas. Thus, these areas could become recreational areas as previously discussed, or they could become a refuge for the poor and vulnerable because of low land values. These complex issues cannot be teased out in the damage costs framework that is used.

There are two confounding issues to consider in examining health impacts: (a) climate change is likely to change the incidence and geographic range of different diseases such as dengue or malaria, for example, and it is difficult to predict changes in the general prevalence of these diseases in the three cities in 2050; and (b) economic growth and increased education will potentially reduce the prevalence of certain diseases such as diarrhea. Each city has made its own assumptions about health impacts and provides qualitative and some quantitative information on costs, but this information is subject to significant uncertainty.

Estimating physical damages requires a variety of assumptions

Establishing exactly how and what will be affected by natural disasters is not easy. The Bangkok and Manila studies examine a variety of impacts on buildings and income, but a series of assumptions underlie this analysis. In order to estimate income losses, for example, both case studies have to make assumptions about the number of households and firms residing in flood-affected buildings. Without a careful survey of each flood-affected area, it would

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[28] In order to examine adaptation-related investments, some additional assumptions are made. The Bangkok study estimates net benefits under two scenarios: (a) prices stay the same, and (b) net benefits grow at an annual rate of 3 percent . The Manila study uses a 5 percent annual rate of growth.

be very difficult to know how accurate these assumptions are.

Valuation considerations

There are numerous challenges to valuing flood impacts that have to do with current and future data availability. Flooding damages to building stocks and machinery, for instance, are best valued at their depreciated replacement cost. In practical terms, the valuation exercise was carried out in different ways in each study depending on data availability. For example, in Bangkok the value of an entire asset or building was assessed and a percentage of the value was treated as the damage cost. Further, in Manila and Bangkok, buildings are evaluated at book-values, or the cost of the buildings when they were initially established. In HCMC, land is evaluated at government-established prices, but in some cases the market value of this land may be higher. Also, the cost of repairing flooded components of a building may be very different from the value obtained by applying a damage rate to the entire value of the building. Another issue is how losses related to electricity and water supply have been evaluated because of lack of appropriate information. The costs of supply disruptions should be assessed by estimating the economic value of public water/electricity supply, or, for example, by estimating the costs to water consumers of securing alternative water when service is interrupted. In Bangkok, water and energy-related flood costs, however, are estimated by examining revenue losses to the government.

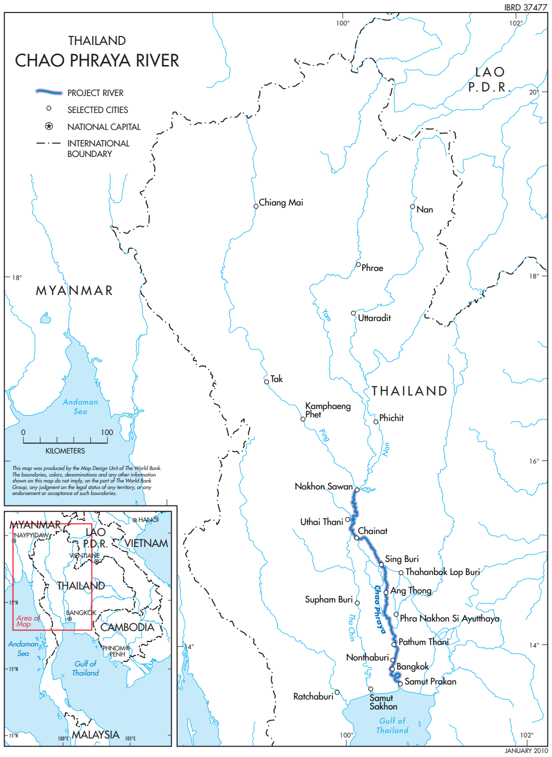
Another important issue is the role of prices. It is very difficult to estimate the value of assets and incomes damaged by flooding in 2050. Given difficulties in predicting prices, most prices are held constant or in some cases some reasonable growth rates are assumed. However, urban real estate prices and the prices of a variety of goods and services damaged by floods can change significantly and this would affect the evaluation in 2050. There are also difficulties in estimating income or productivity losses as a result of floods. The Manila study and Bangkok (for low income households) estimate the number of households affected by floods and multiply this by an average value of household income based on the type of houses these families live in. However, average values used may not apply for flood-prone areas. Further, the families may have a way of earning income even under flood circumstances if they can leave the area for work. In the HCMC study, a macro approach is applied and GDP per capita is used as the value of productivity lost in flooded areas. However, if these areas may not be producing the "average GDP per capita," this could lead to an overestimation of impacts. These uncertainties and limitations need to be borne in mind in interpreting the results of this study.

3

Estimating Flood Impacts and Vulnerabilities in Coastal Cities

In this chapter, the main findings of the hydrological analysis—in terms of potential increase in flooding in 2050 under different scenarios—are presented. For each city, the analysis presents the main drivers of flooding, how climate change is likely to influence flooding, and the potential physical consequences on the city and its residents in 2050. The findings from the hydrological modeling were overlaid on GIS maps, thus relating flood depth/duration and area flooded (estimated from the hydrologic modeling) with maps of future land use; location of residential, commercial, and industrial areas; and essential infrastructure and environmental resources. Use of GIS enables a visual mapping of the area inundated and districts and sectors likely to be at risk from flooding under different scenarios in 2050.[29] For the purposes of this report, only a selection of GIS maps is included; a more extensive set of maps can be obtained from the city-level studies.

FIGURE 3.1 ■ Location of Bangkok in the Chao Phraya River Basin



Source: Thailand map IBRD 37477.

ESTIMATING FUTURE CLIMATE-RELATED IMPACTS IN BANGKOK

The Bangkok Municipal Region covers an area of about 1,569 sq kms and is located in the delta of the Chao Phraya River basin—the largest river basin in Thailand, covering an area of 159,000 sq kms, or 35 percent of the total land area of the country (Figure 3.1). The basin area is flat at an average elevation of 1–2m from mean sea level. Some areas are at sea level due to land subsidence. Bangkok straddles the Chao Phraya River approximately 33 kilometers above the Gulf of Thailand.

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[29] For 2050, projected land use changes—where available—were incorporated into the GIS to assess the future impacts.

Importance of BMR to the regional economy

The Bangkok Metropolitan Region (BMR) is the economic center of Thailand. It is the headquarters for all of Thailand's large commercial banks and financial institutions. The area to the east of Bangkok and Samut Prakarn is also an important industrial zone. In 2006, the gross domestic product (GDP) of the Bangkok Municipal Region was 3,352 billion baht, or 43 percent of the country's GDP (7,830 billion baht). The annual average growth rate was 7.04 percent, and per capita GDP was 311,225 baht (Bangkok case study report). The current official population of Bangkok is estimated to be about 10 million people (based on 2007 estimates) with an estimated growth rate of .64 percent between 2003–07.[30]

Nature of urban poverty

As stated in the Bangkok study, in 2007, 0.6 percent or 88,361 people in the BMR were poor (Table 3.1). The poverty line for the Bangkok municipal region was 1,638 baht ($49) per person per month in 2007.[31] The number of poor is an official estimate and does not include unregistered people. Most of the poor live in condensed housing and are unregistered. Statistics from the Office of National Economic and Social Development Board (NESDB 2007) show 768,220 people living in 133,317 housing units of the condensed housing area. Therefore in the assessment of flood impacts on the poor, this housing unit and population was used as a base for the assessment of income loss of the poor.

Climate and precipitation in the Chao Phraya River Basin

Bangkok has a tropical monsoon climate. The average annual rainfall over the basin is 1,130 mm, and is higher in the northeastern region of the basin (Table 3.2). About 85 percent of the average annual rainfall occurs between May and October (Panya Consultants 2009). Tropical cyclones occur between September and October. In this case, rainfall continues for a long period of time in a relatively wide area. The peak river discharge is registered in October at the end of the rainy season. Severe flood damage may arise with high tide in this period (ibid.). BMA's maximum temperature is in April and its minimum temperature is in December. The mean temperature ranges from 26°C to 31°C.

Main climate-related drivers of flooding

Severe flooding in Bangkok is associated with heavier than normal rainfall occurring over several

TABLE 3.1 ■ Poverty Line and the Poor in the BMR[1]

	Poverty Line (Baht/person/month)		Proportion of the Poor (%)		No. of the Poor (person)	
Province	2006	2007	2006	2007	2006	2007
BMA	2,020	2,065	0.51	1.14	28,692	64,422
Samut Prakarn	1,647	1,712	—	0.78	—	9,961
Samut Sakhon	1,511	1,564	0.76	0.42	4,313	2,436
Nonthaburi	1,529	1,561	0.30	0.06	4,124	845
Pathum Thani	1,409	1,458	0.56	0.20	5,376	1,939
Nakhon Pathom	1,434	1,466	0.45	0.98	3,918	8,758
BMR	1,592	1,638	0.43	0.60	46,422	88,361

Source: The Office of National Economic and Social Development Board (NESDB), 2007 as cited in the Bangkok city study.

[1] Most of the poor live in condensed housing and are unregistered. So the figure of 768,220 does not align with the number of poor in the table.

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[30] This figure does not include unregistered migrants.

[31] Poverty incidence is measured at the household level by comparing per capita household income against the poverty line, which is the income level that is sufficient for an individual to enjoy society's minimum standards of living. If an individual's income falls below the poverty line, he or she is classified as poor.

TABLE 3.2 ■ Bangkok Monthly Average Temperature and Precipitation

Month	Temperature Average Low (°C)	Temperature Average High (°C)	Average precipitation (mm)
January	23°	32°	7.2
February	24°	33°	13.7
March	26°	34°	32.5
April	27°	35°	58.3
May	27°	34°	170.8
June	26°	33°	112.5
July	26°	33°	118.1
August	26°	33°	160.0
September	25°	33°	262.5
October	25°	32°	207.3
November	24°	32°	32.4
December	22°	32°	3.3
Total			**1,171.4**

Source: http://weather.uk.msn.com/monthly_averages.aspx?wealocations=wc:THXX0002

months during the monsoon period over the Chao Phraya watershed. The flooding can last several weeks to over a month. Intense short-duration rainfall over the city can cause localized flooding that normally lasts for less than 24 hours. Bangkok is not subject to direct hits from tropical typhoons or cyclones. Large floods have occurred in 1942, 1978, 1980, 1983, 1995, 1996, 2002, and 2006. A number of dams in the upper watershed—including the Bhumibol Dam (1964) and Sirikit Dam (1971)—have helped reduce flooding in Bangkok. In 1995 a serious flood occurred due to a series of tropical storms reaching the upper watershed from the end of July to September. The resultant runoff exceeded the storage capacity of the Sirikit Dam, which had to release 2,900 million m^3 of storm runoff. Despite efforts to attenuate the flood wave by allowing flooding of agriculture lands upstream of Bangkok, the flood wave crest reached Bangkok at the same time as the high spring tide, flooding 65 percent of BMA with inundation depths up to 2 meters and left some areas flooded into December. The flood event of 1995 is estimated to have a return frequency of 1-in-30 years.

Non-climate drivers of flooding

In addition to climate-related drivers, non-climate drivers such as land subsidence, deforestation, urbanization, and removal of natural attenuation basins (like wetlands) also contribute to flooding. Land subsidence is a critical factor in flooding and is discussed later in the section.

Existing flood protection in Bangkok—diversion canals and flood dikes with pumped drainage

In response to the flooding, Bangkok has implemented a large-scale flood protection system that includes a flood embankment surrounding the city and a pumped drainage system. In 2006 there was another significant flood event in the upper Chao Phraya watershed. Flood peaks were again attenuated by allowing the agricultural lands north of Bangkok to flood, and flood flows were also diverted to channels to the east of Bangkok. The flood embankment system and pumped drainage system protected the city. Nevertheless, areas surrounding Bangkok continue to experience inundation during peak flood flow. The city and national planners have plans to add further flood protection, which has been planned and budgeted through 2014. The long-term land use plan until 2057 for the greater Bangkok region provides for development areas and environmental zones that will be used to allow flood flows and drainage. Most of the flood control activities that are being considered in the Royal Irrigation Department master plan are infrastructure activities (such as construction and improvement of canals, dikes, pumping stations, etc.). Flooding of agricultural lands upstream of Bangkok is utilized during major floods to help attenuate the flood peak, lowering the flood profile in Bangkok.

Current and planned land use and urban planning in Bangkok—Bangkok in the future

The Bangkok study projected what the city would look like in the future based on a wide range of available data about population and growth and a number of sectoral and urban development plans (Box 3.1). Modern urban land use planning in Bangkok started in the 1950s. Bangkok's inner city contains the Grand Palace, government offices, major universities and educational establishments, and 2-to-4-story row houses that are used as commercial and residential units. The inner city is a national historic conservation area where construction of high-rise buildings is prohibited. Urban growth in Bangkok, however, has progressed in a sometimes ad hoc manner and without a unified plan linking it to the surrounding areas. To remedy this problem, the government has developed a 50-year regional spatial plan (finished in 2007) that foresees growth of the surrounding areas. This plan also provides for significant environmental protection and wetland areas.

Climate change parameters—statistical downscaling

For the 2050 simulations, the Bangkok City case study applied the statistical downscaling factors estimated by the University of Tokyo's Integrated Research System for Sustainability Science (IRS3) discussed in chapter 2. Given the size of the Chao Phraya watershed and the long time it takes upper watershed rainfall to reach Bangkok as stream flow, the team applied the mean increase in seasonal precipitation (3 percent and 2 percent for A1FI and B1 respectively) to the three-month rainfall events for the corresponding 1-in-10, 1-in-30 and 1-in-100-year precipitation events for the watershed. These total precipitation levels were distributed over the watershed using spatial and temporal patterns from historic flood years. The forecasted temperature increases of 1.9°C and 1.2°C for the A1FI and B1 scenarios respectively for 2050 were used in the hydrological modeling. The SLR estimates used were 0.29 m and 0.19 m for the A1FI and B1 scenarios respectively. This was based on IPCC AR4 (Working Group 1, Chapter 10, Table 10.7) estimates. It was decided to use half of the 2099 increase for the 2050 estimates; namely, 0.29 m and 0.19 m for the A1FI and B1 scenarios respectively.

BOX 3.1 ■ The Bangkok Metropolitan Region (BMR): Some Assumptions about the Future

Bangkok is changing rapidly and some of these changes have been taken into account in modeling the future. Bangkok is increasingly "suburbanizing." Between 1998 and 2003, BMR saw a 74 percent increase in urban development. The city's housing stock has doubled in the last decade. This trend is expected to continue. The Government's Land Use Plan for 2057 is used to project the number of commercial, residential, and industrial buildings in Bangkok in 2050. Available government plans are taken into account in establishing future road and transportation networks. Plans suggest tightened urban areas within a network of expressways bounded by large environmental protection areas to divert any floods from the centers.

Based on existing trends, the city of Bangkok is not expected to grow a lot, while neighboring suburbs will continue to grow. For instance, suburban Nonthaburi increased its population by 47 percent during 2002–07. Bangkok City is expected to have a population of 10.55 million (4.65 million households) and BMR a population of nearly 16 million by 2050. To forecast the population in 2050 for BMR, information on population projections for Thailand 2003–30 prepared by the government (NESDB) was used as a base. The NESDB report projects population to the year 2030 for the whole kingdom and to 2025 and 2020 for Bangkok and other provinces respectively. In projecting the population to 2050, a regression function was applied.

In terms of the BMR economy, regional GDP is projected for two areas (Bangkok and Samut Prakarn) of BMR most likely to be affected by flooding. GDP for Bangkok and Samut Prakarn in 2050 is expected to be six-fold higher than the current GDP. In terms of poverty in the cities, in Bangkok in 2007 only 88,361 people (0.6 percent of the total) in the BMR were officially considered poor. However, this number excludes some 768,220 people living in 133,317 condensed housing units. In the flood impact assessment, the higher, more accurate number was used.

Source: Adapted from Panya Consultants (2009).

Estimation of storm surge in the case of Bangkok

For storm surge, the team examined historic storm surges in the Gulf of Thailand. There have been three events since 1962 along the coast of southern Thailand. No recorded typhoon or cyclone has had a track that approached the mouth of the Chao Phraya at the north of the Gulf of Thailand. Nevertheless, one typhoon created wind patterns that drove 2 to 3 meter waves near the mouth and drove up sea levels. As a result, the team used a storm surge of 0.61 m for the study. It needs to be noted that the time frame for the storm surge would be on the order of 24 hours, and only one event has been recorded in 30 years. The hydrometeorological processes driving these events have little or no correlation. To have a joint impact, the storm surge effect would have to occur near the peak storm discharge for the Chao Phraya watershed. The joint probability of occurrence, although not calculated in detail, is less than 1/1000. Table 3.3 summarizes the climate change parameters used to model the 2050 impacts in Bangkok.

Land subsidence – a significant contributor to future flooding

Although land subsidence is not driven by climate change, its impact on flooding in Bangkok needs to be considered for the 2050 simulations. The team undertook a comprehensive assessment of historic and forecasted land subsidence for Bangkok, and held technical consultations with the concerned agencies. Historic land subsidence in Bangkok has reduced from highs of 10 cm/year to 1 to 2 cm/year over the period of 1978 to 2007, and from 2002 to 2007 the rate had declined to 0.97 cm/year. The team predicted that due to government efforts to control groundwater pumping, the average subsidence rate would continue to decline by 10 percent/year, assuming that current efforts to reduce groundwater extraction continue. As a consequence, the team's estimate of land subsidence by 2050 varied from 5 to 30 cm depending on the location. Figure 3.2 shows land elevations in 2002 versus projected land elevations in 2050 as a consequence of land subsidence.

Simulation events modeled

The study ran simulations for 1-in-10, 1-in-30, and 1-in-100-year flood events for 2008 as the baseline for the inundation hazard. The study then ran simulations applying only the land subsidence expected by 2050 without applying the climate change factors for precipitation or SLR. This was done to allow differentiation of the contribution of land subsidence to the flood hazards and risks. Then simulation runs were made for 1-in-10, 1-in-30, and 1-in-100-year flood events in 2050, applying either the A1FI or B1 forecasted variables (precipitation and SLR). Finally, simulation runs were made for the impact of storm surge on the 1-in-30-year A1FI and 1-in-100 A1FI and B1 simulations.

Infrastructure scenarios were assumed as follows. For the 2008 base year calculations, it was assumed that the existing and nearly completed flood protection infrastructure was in place. For the future 2050 calculations, it was assumed that the planned flood protection infrastructure will have been implemented (Panya Consultants 2009).

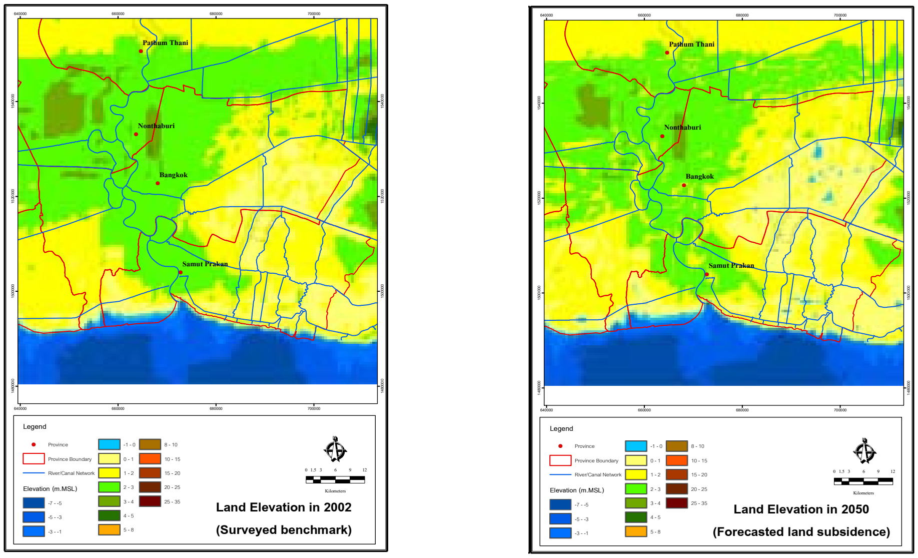
Conservative values were used in forecasts

The use of the mean increase in seasonal precipitation for the Chao Phraya watershed is appropriate, as it matches the time to concentration for the flooding in Bangkok. Mean seasonal increases were applied to the 1-in-10-year, 1-in-30-year, and 1-in-100-year precipitation events and distributed across the watershed spatially and temporally using historical rainfall

TABLE 3.3 ■ Climate Change and Land Subsidence Parameter Summary for Bangkok

IPCC Scenario	Temperature increase (ºC)	Mean Seasonal Precipitation Increase (%)	Sea Level Rise (m)	Storm Surge (m)	Land subsidence (m)
B1	1.2	2	0.19	0.61	0.05 to 0.3
A1FI	1.9	3	0.29	0.61	0.05 to 0.3

FIGURE 3.2 ■ Land Elevations, 2002 versus 2050 Land Subsidence



Source: Panya Consultants (2009).

distribution patterns (1995). There is an implicit assumption that the underlying variability (timing and location) will remain the same in 2050. This is conservative in the sense that increased variability (worse floods and droughts) around the mean would generate greater losses than estimated in the study.

MAIN FINDINGS FROM HYDROLOGICAL ANALYSIS AND GIS MAPPING FOR BANGKOK

Flood-prone area likely to increase in Bangkok in the future

The hydrological analysis shows that for events of different return periods, the area inundated will increase in 2050 for both the B1 and the A1FI scenarios (Table 3.4).

For instance, the current (2008) estimated annual inundated area in Bangkok and Samut Prakarn is about 550 km^2, which will increase to 734 km^2 in 2050 under the A1FI scenario for a 1-in-30-year flood. That is an increase of 184 kms, or approximately a 30 percent increase in the area inundated. The inundation could be for varying depths and varying number of days, but about 7 percent of these provinces could remain under water for over a month. The increase is likely to be in the western areas, where existing flood protection infrastructure is likely to be insufficient. There is also an increase in the maximum water depth between the base year and 2050 for events of different return periods. Figure 3.3 for example, shows a comparison of the maximum depths of flooding for the 1-in-30-year flood under 2008 and the 2050 A1FI scenario. The implication is that the people living in Bangkok will be facing more frequent events that significantly disrupt daily life.

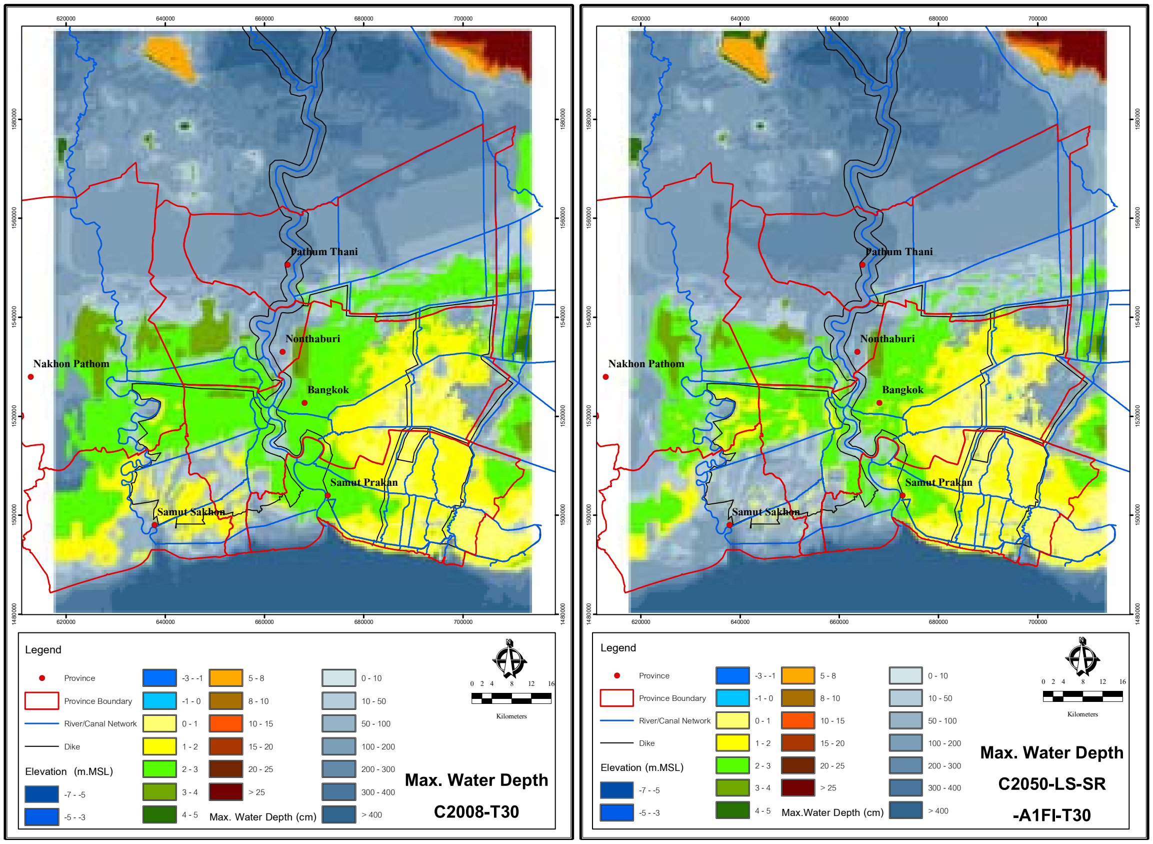
A flood frequency graph obtained by plotting the inundated area versus return frequency for the Bangkok City case study results for the 2008 and 2050

TABLE 3.4 ■ Bangkok Inundated Area under Current Conditions and Future Scenarios

	Scenario		
Frequency	2008 (km^2)	2050 B1 (km^2)	2050 A1FI (km^2)
1/100-year	737	893	927
1-in-30-year	550	719	734
1-in-10-year	359	481	518

Source: Panya Consultants (2009), Appendix k, Table K2.4-1.

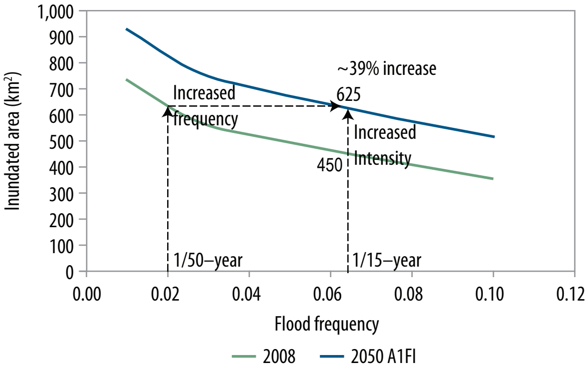
FIGURE 3.3 ■ Maximum Water Depth for 1-in-30-year event, 2008 and 2050, A1FI



Source: Panya Consultants (2009).

A1FI further demonstrates how the flood hazard will increase dramatically in Bangkok. As the graph in Figure 3.4 below illustrates, a flood event in 2008 with an inundated area of 625 km^2 has a frequency of 0.02 or return period of 1-in-50 years. By 2050 under the A1FI scenario, flood events inundating areas of 625 km^2 would be expected to occur with an increased frequency of 1-in-15 years. The corollary of this is that the intensity of flooding for a 1-in-15-year event would increase from about 450 km^2 to 625 km^2.

FIGURE 3.4 ■ Bangkok Flood Hazard Relationship



Source: Panya Consultants (2009).

Population exposed to flooding will increase for 1-in-30-year flood for both A1FI and B1 scenarios

Severe floods inundate the lower Chao Phraya floodplain in which Bangkok is situated. The huge volume of water (over 31,000 million cubic meters for a 1-in-30-year event) associated with these floods can take months to drain as Bangkok acts as a "bottleneck" to the discharge reaching the Gulf of Thailand. This can leave many areas flooded for more than 30 days. The flood protection schemes for Bangkok are generally designed to protect against

1-in-30-year floods. There are steep increases in persons affected as inundation levels exceed the 2008 1-in-30-year design standards. For example, the number of persons who would be affected by 1-in-100-year flood event in 2008 is nearly double the number affected by a 1-in-30-year flood, as shown in Table 3.5. *Similarly, the number of persons affected in 2050 by a 1-in-30-year event will rise sharply for both B1 and A1FI scenarios, with 47.2 percent and 74.6 percent increases, respectively.*

Areas in Bangkok vulnerable to flooding

Although Bangkok's flood embankment and pumped drainage will continue to offer substantial protection for the interior area, land outside the embankment to the north and the southwest is likely to experience significantly worse flooding. These are areas which are undergoing housing, commercial, and industrial development. Within BMR, Bangkok and Samut Prakarn are the two provinces that are most affected by climate change. In a C2050-LS-SR-SS-A1FI-T30 scenario, almost 1 million people in Bangkok and Samut Prakarn would be impacted by floods. The impact will be profound for people living on the lower floors of residential buildings. Nevertheless, people living on higher floors in the Bang Khun Thian district of Bangkok and the Phra Samut Chedi district of Samut Prakarn might also be impacted. District-wise, Don Muang district in north Bangkok has the highest number of people affected by floods (approximately 90,000) owing to its higher population density. In the western part of the Chao Phraya River, about 200,000 people in Bang Khun Thian, Bang Bon, Bang Khae, and Nong Kham districts might be impacted. The maps in Figure 3.5a and 3.5b below show the differences in flooding for the 1-in-30-year event, currently and in 2050.

Table 3.5 ■ Exposure of Bangkok Population to Flooding

	Population affected for >30 days		
Frequency	2008	2050 B1	2050 A1FI
1-in-100 year	1,002,244	1,187,803	1,271,306
1-in-30 year	546,748	805,055	954,389

Source: Panya Consultants (2009).

Impact of the floods on people living in condensed housing

Figures 3.5a and 3.5b show the impact of flooding under the 1-in-30-year A1FI flood in 2050 in comparison to 2008, with an overlay of poor housing in Bangkok. It shows increased flooding in several condensed housing areas where the poor live. As the study points out, " about 1 million inhabitants of Bangkok and Samut Prakarn will be affected by the A1FI climate change condition in 2050. *One in eight of the affected inhabitants will be from the condensed housing areas where most live below the poverty level. One-third of the total affected people may be subjected to more than a half meter inundation for at least one week.* This marks a two-fold increase of that vulnerable population. The impact will be critical for the people living in the Bang Khun Thian district of Bangkok and the Phra Samut Chedi district of Samut Prakarn" (Panya Consultants 2009).

Key sectors likely to be affected by flooding in 2050 but buildings and housing most affected

The most significant impacts will be felt by the residential, commercial, and industrial sectors with more than a million buildings being affected by a 1-in-30-year event in 2050. About 300,000 buildings in areas to the west of Bangkok—like Bang Khun Thian, Bang Bon, Bang Khae, Phra Samut, and Chedi districts—will also be impacted. For the 1-in-30-year event, approximately 1,700 km of roads would be exposed to flooding. The Lat Krabang water supply distribution station and the Nongkhaem solid waste transit station would both be subject to 50–100 cm inundation, although the main water and wastewater treatment facilities are protected. In addition, 127 health care facilities would be subject to flooding, with inundation levels ranging from 10 to 200 cm.

Storm surge and sea level rise have relatively small role in contributing to flooding in Bangkok

Analysis carried out in the Bangkok study found a linear relationship between future precipitation

FIGURE 3.5a ■ Affected Condensed (Poor) Community of Case C2008-T30

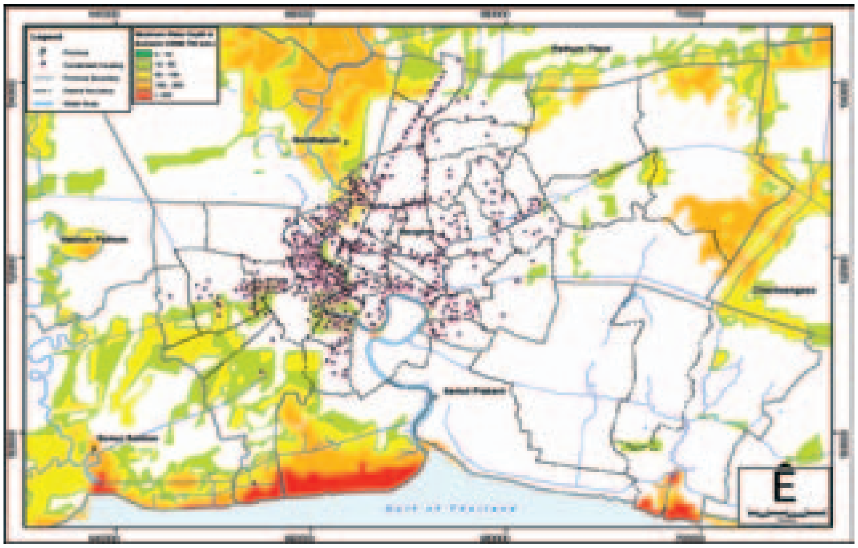
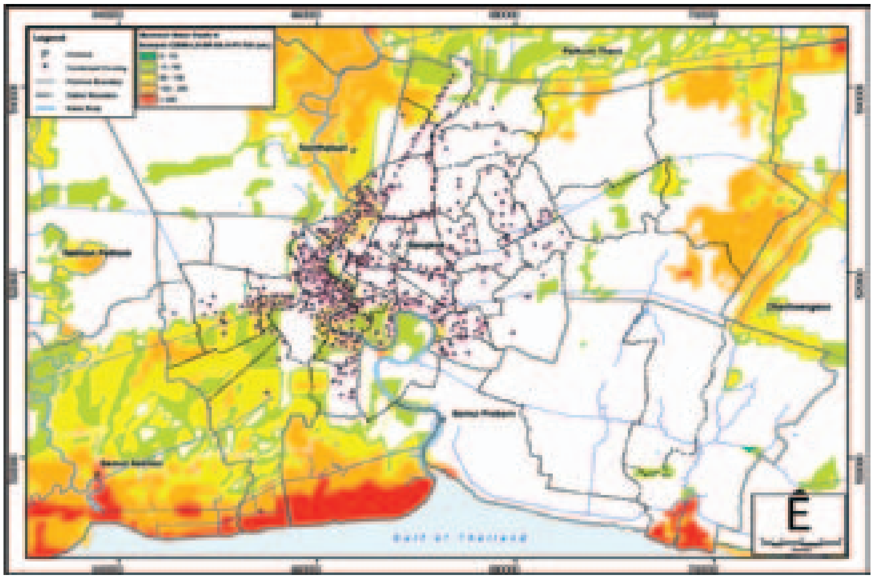


FIGURE 3.5b ■ Affected Condensed (Poor) Community of Case C2050-LS-SR-SS-A1FI-T30



Source: Panya Consultants (2009).

and flood volume in the Chao Phraya River. However, it found that flood peak discharge in the Chao Phraya River will increase by a larger percentage than precipitation, due to unequal travel times of floods from upstream catchments. Further, while storm surges and sea level rise are important, they will have less effect on flooding in Bangkok. While storm surges do occur in the Gulf of Thailand and contribute to flooding the BMR area, it was estimated that the flood-prone area in Bangkok and Samut Prakarn will increase by about 2 percent due to a storm surge striking the western coast of the Gulf of Thailand.

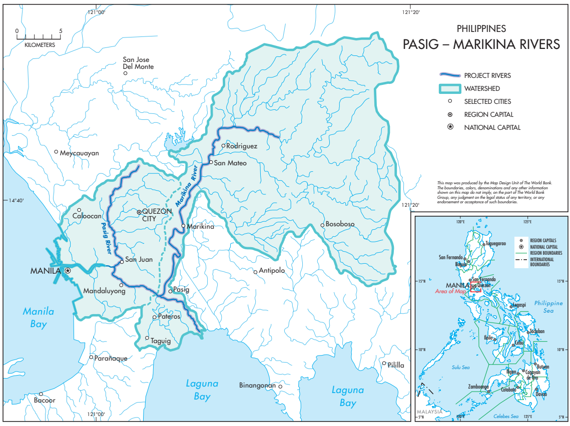
ESTIMATING CLIMATE-RELATED IMPACTS IN MANILA

The Manila study (Muto et al. 2010) focuses on Metro Manila and includes Manila and 16 municipalities. It is a low-lying area crisscrossed by the Pasig River and its tributaries, which flows northwestward from Laguna de Bay, the largest lake in the Philippines, to Manila Bay in the west. Metro Manila lies on a swampy isthmus and is marked by three quite diverse hydrological characteristics. These include the Pasig Mariquina area, Kamanava area, and the west of Managhan area facing the Laguna de Bay (Figure 3.6). The *Pasig Mariquina area* has several river systems and a catchment area of 651 sq kms. It includes 10 cities/municipalities of Metro Manila. The *Kamanava area* along the low-lying coast is flat, prone to typhoons, and has elevations ranging from around sea level to 2–3 meters above sea level. Before the 1960s, it mainly consisted of lagoons, but has been filled up and currently comprises commercial districts, residential areas, and fishponds. The West of Managhan area is 39 square kms and covers five cities. There are a number of drainage channels draining into the Laguna Lake or Napindan River.

Importance of Metro Manila to the regional economy

Like Bangkok, Manila is also a capital city and a major economic center. It is located on the eastern shore of Manila Bay, on the western side of the National Capital Region. It is a central hub of the thriving Metropolitan Manila area. With a population of 11 million, it is ranked as one of the most densely populated cities in the world. The Pasig River bisects the city in the middle before draining into Manila Bay. Metro Manila, the broader urban agglomeration, has the highest per capita GDP in the country. In 2007, its population was estimated to be over 20 million people. In 2008, it was ranked as the 40th richest urban agglomerations in the world, with a GDP of $149 billion, indicating the economic importance of Metro Manila. Manila is also a major tourist destination, with over 1 million tourists visiting the city each year.

FIGURE 3.6 ■ Metro Manila and its Watershed



Source: Philippines map IBRD 37476.

Unregulated expansion into fragile areas and informality

With large in-migration and rapid population growth, the city expanded to the suburbs, surrounding municipalities, and to areas risky for habitation (e.g., swampy areas, near or above esteros or water canals, along the river or earthquake fault lines, etc.). A large part of the developments in informal settlements are unregulated. Many structures are built on dangerous and risky areas, such as near the seashore or flood zone, or on ground prone to landslides. Socioeconomic factors like land use practices, infrastructure development, building standards/codes and practices, and urban development policies and programs have greatly shaped the settlement and building patterns of the city. These forces generate an environment that poses high risks to residents and infrastructure alike, especially in the low-lying flood-prone areas. As in other cities in developing countries, there are significant wealth disparities in Manila that are reflective of the country as a whole, with 97 percent of GDP controlled by 15 percent of the population (WWF 2009). Within Metro Manila, 10.4 percent of the population in lives below the poverty line, according to 2006 official statistics.[32] Approximately 61 percent of the population in Metro Manila does not have access to basic services, according to the 2008 Philippine Asset report report card (cited in Manila study). There is an estimated housing backlog of almost 4 million.

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[32] http://www.nscb.gov.ph/poverty/2006_05mar08/table_2.asp

Manila's current climate—Tropical with distinct wet and dry seasons

Figure 3.7 shows the four main climate regimes in the Philippines and the relative frequency of typhoons making landfall. Manila falls into Type 1, which is defined as having two distinct seasons, with the dry season running from November to April and the wet season occurring in the other months. About 16 percent of the typhoons crossing the Philippines pass in the general vicinity of Manila and its nearby areas. The average temperatures and precipitation in Manila are shown in Table 3.6. Manila has an average annual precipitation of about 1,433 mm, but there is significant variability.

TABLE 3.6 ■ Manila: Monthly Average Temperature and Precipitation

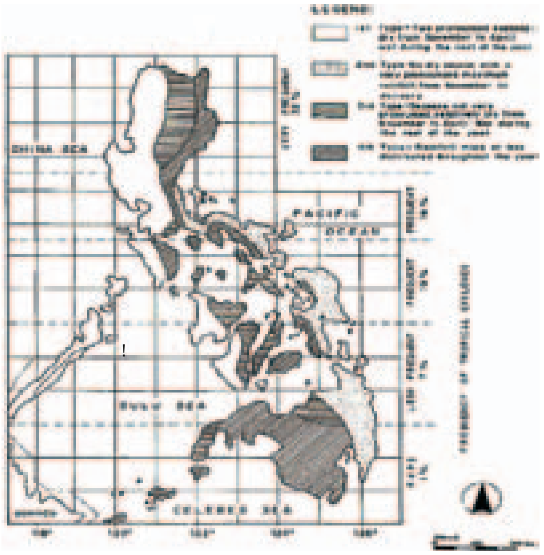
Month	Temperature Average Low (ºC)	Temperature Average High (ºC)	Average precipitation (mm)
January	24°	30°	Negligible
February	24°	30°	12.1
March	25°	32°	9.1
April	27°	33°	15.9
May	27°	33°	133.0
June	26°	32°	150.8
July	26°	31°	292.9
August	26°	31°	305.8
September	26°	31°	237.5
October	26°	31°	137.2
November	25°	31°	81.3
December	24°	30°	58.0
Total			**1433.6**

Source: http://weather.uk.msn.com/monthly_averages.aspx?wealocations=wc:RPXX0017

Main climate-related drivers of flooding—driven by single-storm events, usually related to typhoons

Unlike Bangkok, where floods are generated by heavy seasonal precipitation over 1 to 3 months, extreme flood events in Manila are caused by heavy precipitation events over 1 to 3 days generally associated with typhoons and storm surge. The watershed area for Manila's Pasig-Marikina River System is 651 km^2, which includes the San Juan River catchment. This is relatively small in comparison to the watersheds of other cities in the study. The precipitation pattern causing flooding is often associated with strong winds and flash flooding, which can be devastating for informal housing located along drainage ways. Seeking refuge during such events is extremely difficult and hazardous to the population. Other climate-related factors contributing to flooding include a combination of high tide, excess runoff from rivers, heavy rains, and sea level rise. A schematic of the watersheds around Manila is shown in Figure 3.8.

FIGURE 3.7 ■ Different Climatic Regimes in the Philippines



Source: Muto et al. (2010).

Non-climate related drivers of flooding

Even though land subsidence is an important issue in Metro Manila, it was not possible to consider it for the hydrological simulation for the Manila study because of lack of availability of reliable data.[33] The

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[33] One difficulty in Metro Manila is that the station that is supposed to measure land subsidence of Manila de Bay is located on one of the old piers of Manila Port, which itself is sinking gradually.

severe flooding caused by Typhoon "Ondoy" in September 2009 has raised public awareness of the underlying causes of flooding. Recent analysis points to mostly anthropogenic causes behind the extreme flood event, including (a) a decrease in river channel capacity through encroachment of houses, siltation from deforestation, and garbage; (b) disappearance of 21 km of small river channels; (c) urbanization accelerating runoff concentration and reducing infiltration losses; (d) loss of natural retention areas; and (e) land subsidence. Among these, land subsidence is the least understood but important cause. It is being driven by groundwater pumping and possibly geologic processes associated with the West Marikina Valley Fault (Siringan 2009). Land subsidence continues decades after the groundwater pumping stops, as illustrated by the Bangkok city case study.

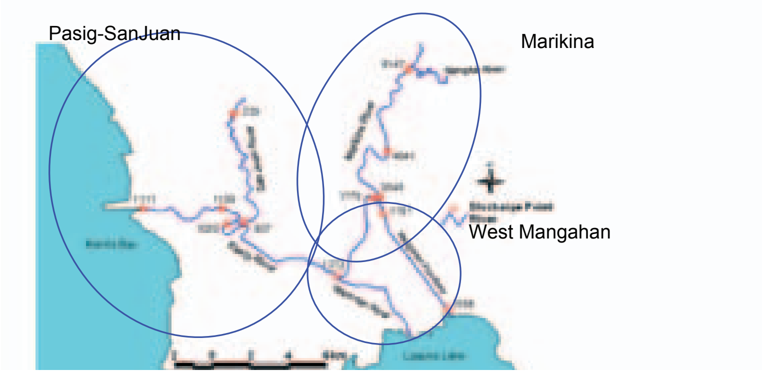
Flood control and mitigation projects—1990 Master Plan

Flood control and mitigation projects have been planned and implemented in Metro Manila over the years.[34] A key feature of flood control in Manila is the Mangahan Floodway, which was constructed in 1985 and diverts flood flows from the Marikina River into Lake Laguna as a method of attenuating peak discharges and protecting Manila's urban areas from excessive inundation. JICA supported the development of a Flood Protection Master Plan in 1990, which still serves as a basis for current and future flood protection planning. The flood protection measures undertaken as part of these projects are primarily infrastructure projects involving attenuating peak flood flows in Laguna de bay, improving conveyance of flood waters through Manila to Manila Bay, and preventing overbank spillage where the flood profile is higher than the adjacent river bank.

Climate change flood simulation parameters

To simulate the future climate-change-induced flooding, the city study applied the statistical downscaled results from the University of Tokyo's Integrated Research System for Sustainability Science (IRS3) for temperature and extreme precipitation increases. For SLR in 2050, the study applied approximately 50 percent of the increase in sea level rise in 2100 projected in the IPCC AR4.[35] Historic storm surge in Manila Bay was calculated at 0.91 m during major typhoons; for 2050, a 10 percent factor increase was applied based on Ibaraki University methodology,[36] bringing the storm surge estimate for 2050 to 1.0 m.

FIGURE 3.8 ■ Major Watershed and Drainage Areas of Manila



Source: Muto et al. (2010)

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[34] See Manila study for a list of planned and ongoing flood control projects and studies.

[35] In terms of boundary conditions for the hydrological model, the SLR values were added to high tidal level; that is, mean spring high water level in Manila Bay was set as the base line water level for the flood simulation, to which was added an SLR increase in accordance with the two IPCC scenarios.

[36] The university provided a detailed technical methodology for calculating the increase in storm surge based on an analysis of historic surges and forecasted increased typhoon intensity.

TABLE 3.6 ■ Manila Climate Change Parameters

	Simulation Case	Temperature Rise (°C) (downscaled)	Sea Level Rise (cm) (global)	Increased Rate of Rainfall 24-hr event (%)	Storm Surge Height (m) at Manila Bay
1	Status quo climate (no change in climate dependant variables)	0.0	0.0	0.0	0.91
2	B1 with no change in storm surge	1.17	19	9.4	0.91
3	B1 with strengthened storm surge level	1.17	19	9.4	1.00
4	A1FI with no change in storm surge	1.80	29	14.4	0.91
5	A1FI with strengthened storm surge level	1.80	29	14.4	1.00

Source: Muto et al. (2010).

The factors applied are summarized in Table 3.7. The 24-hr precipitation factor increase is reasonable as it is close to the time of concentration of flood flows for the Manila watershed. Similarly, SLR is conservative, since it is taken from the IPCC estimates and does not include polar ice cap melt.

Infrastructure scenarios assumed in base year and in 2050

For the simulation runs, the study examined two flood infrastructure alternatives based on the 1990 Master Plan. The first was to assume the implementation of the Master Plan would be halted in 2008, the base year—referred to as "existing" infrastructure and abbreviated as "ex." The other alternative was that the full plan would be implemented by 2050—referred to as "business as usual" and abbreviated as "BAU." To do this and include the climate change factors noted above, the team developed 22 simulation runs (Muto et al. 2010).

BOX 3.2 ■ What does Metro Manila Look Like in the Future?

For the hydrological mapping, the team used 2003 topography data for the structure of the city. It was assumed that in terms of number of buildings and road network, Metro Manila in 2050 would look very similar to what it is today. Further, while the team intended to use future land use in the hydrological and GIS mapping, this was not possible due to logistical reasons. Regarding population growth, Manila uses a linear extrapolation of current trends to project population to the future. The city is expected to be a megacity with a population greater than 19 million by 2050. Commercially growing sections of Manila are expected to see a decline in population, with growth occurring in other parts of the city. Areas such as the Pasig-Marikina river basin are seeing a decline in population, which is expected to continue; growth will likely continue to occur in West Mangahan and Kamanava. Future regional GDP is not projected, but a real growth rate of 5 percent is applied to a variety of economic variables and damage costs.

Source: Muto et al. (2010).

Assumptions made regarding population increase, land use, urbanization in 2050

Numerous assumptions regarding what Metro Manila might look like in 2050 compared to the base year were made in the study (Box 3.2).

FINDINGS FROM THE HYDROLOGICAL ANALYSIS AND GIS MAPPING FOR METRO MANILA

Significant increase in area exposed to flooding by extreme events (1-in-100-year event) in 2050 under B1 and A1FI scenarios

The flood pattern in Manila for 2050 is likely to be significantly affected by the extent to which the 1990 Master Plan is implemented. Table 3.8 shows that the area exposed to flooding from a 1-in-100-year event under current conditions will increase from 82.62 km^2 to 97.63 km^2 under the 2050 A1FI 1-in-100-year event, *an increase of 18.2 percent*. This represents a significant increase in the inundated area. With the

TABLE 3.8 ■ Manila: Comparison of Inundated Area (km²) with 1-in-100-year flood for 2008 and 2050 Climate Change Scenarios with only Existing Infrastructure and with Completion of 1990 Master Plan

	No change to existing infrastructure			All 1990 Master Plan infrastructure implemented		
	2008 (km²)	2050 B1 (km²)	2050 A1FI (km²)	2008 (km²)	2050 B1 (km²)	2050 A1FI (km²)
Pasig-Marikina	53.73	63.19	67.97	29.14	40.09	44.14
West Mangahan	10.65	11.09	11.42	7.79	8.16	8.30
KAMANAVA	18.24	18.24	18.24	—	—	—
Total	**82.62**	**92.53**	**97.63**	**36.93**	**48.25**	**52.44**
Relative increase		12.0%	18.2%		30.7%	42.0%

Source: Muto et al. (2010).

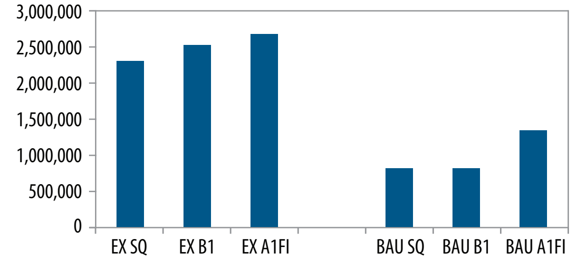
implementation of the 1990 Master Plan, infrastructure in the inundated areas will be reduced considerably for the current flood hazard (i.e., an inundated area of only 36.93 km² from a 1-in-100-year event in 2008), but the infrastructure will not afford the level of protection in 2050 for the return periods on which the designs are based. Climate change impacts under the A1FI 1-in-100-year storm event would increase the inundated area by 42 percent (from 36.93 km² to 52.44 km²) compared to the base year 2008. The main point is that that the master plan will not offer the planned level of protection.

Increase in percentage of population exposed to flooding under high and low emissions scenarios

As would be expected from the significant increase in inundated area under the B1 and A1FI climate change scenarios, the number of people affected by the floods increases significantly as well, as illustrated in Figure 3.9. Thus, for a 1-in-100-year flood in 2050, under the AIFI scenario more than 2.5 million people are likely to be affected, assuming that the infrastructure in 2050 is the same as in the base year. In a scenario where the flood protection infrastructure under the 1990 Master Plan is implemented, the level of protection expected by its implementation will not be achieved under the A1FI 1-in-100-year storm event, where approximately 1.3 million persons would be affected.

An overlay of population density maps with GRID data on inundation shows areas of high population density that are likely to face serious flooding risk (Figure 3.10). These include Manila City, Quezon City, Pasig City, Marikina City, San Juan, and Mandaluyong City.

FIGURE 3.9 ■ Comparison of Population Affected by Flooding under Different Scenarios*



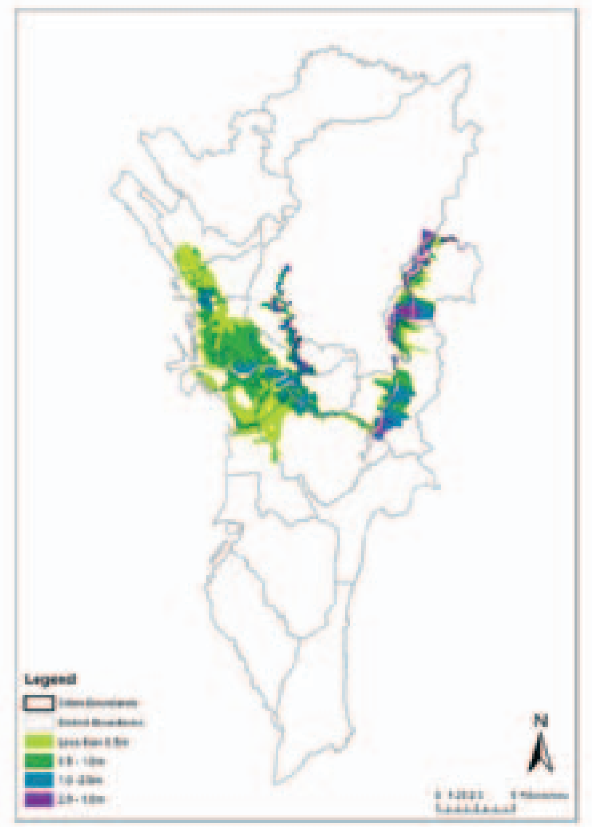
Source: Muto et al. (2010).

* Scenarios include 1-in-100-year event (P100) in 2008 (SQ) with the 2050 B1 and 2050 A1FI scenarios with only the existing infrastructure (EX) and with the full implementation of the 1990 Master Plan (business as usual or BAU).

Areas in Metro Manila likely to be at high risk from flooding due to extreme events in 2050

The hydrological analysis shows that some local government units (LGUs) will be much more affected than others under different scenarios. As Figure 3.11 shows, municipalities in the Pasig Marikina River basin (namely Manila, Mandaluyong, and Marikina) and Kamanava areas (namely Malabon and Navotas) are more likely to be vulnerable to flooding compared to those in the West Managhan area.

FIGURE 3.10 ■ Areas of High Population Density and with High Risk of Inundation under A1FI Scenario



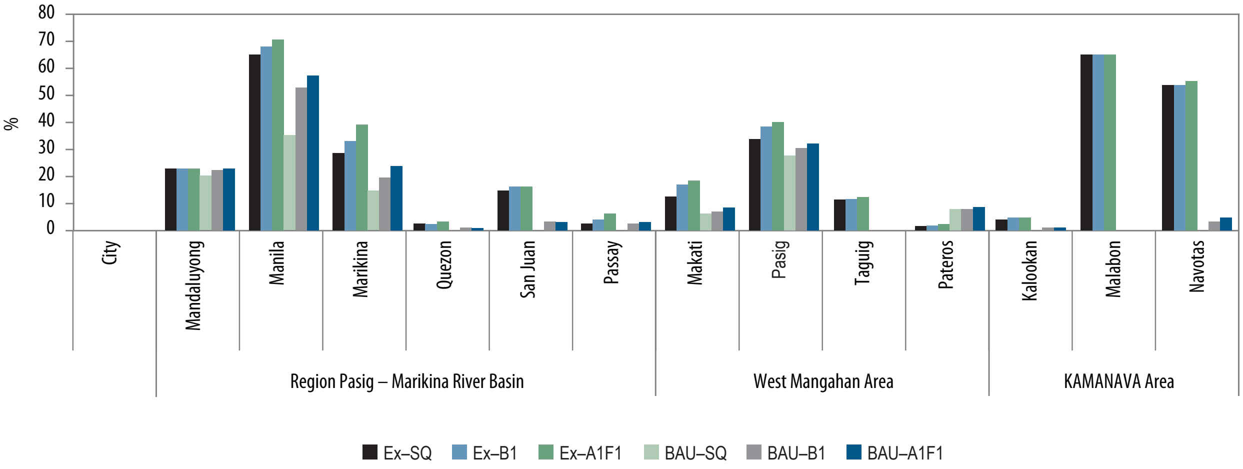
Source: Muto et al. (2010).

Impact on roads, rail network, power and water supply facilities and transportation

The hydrological analysis shows the length of roads that are likely to be flooded (in terms of depth and duration) under different scenarios. Thus for instance, under both emissions scenarios—A1FI and B1, more roads are flooded under "existing infrastructure scenario" where no additional infrastructural improvements are made, compared to a scenario where there is continued implementation of flood protection infrastructure in 2050 (Table 3.9). As a reference, it is useful to note that a depth of more than 26 cms is considered impassable for most vehicles in Manila.

The hydrological analysis also shows specific locations where the power distribution system in Manila is vulnerable. It notes that the elevated rail system in Manila, although above the flood levels, is vulnerable to loss of power from the power utility Merelco, and that a number of the stations would be inaccessible during extreme floods. The impact of high winds in these situations was not detailed. The consultants held discussions with the water supply providers who indicated that their facilities were not vulnerable to floods.

FIGURE 3.11 ■ Areas at High Risk from Flooding under Different Scenarios



Source: Muto et al. (2010).

TABLE 3.9 ■ Affected Length of Road by Inundation Depth

	Road Length by Inundation Depth (kms)						
	8–20 cm		21–50 cm		Above 50 cm		
Flood Scenario (Ex)	Major	Minor	Major	Minor	Major	Minor	Total
Status Quo	4.5	3.9	22.1	23.8	31.9	39.8	125.9
B1	5.4	9.7	13.6	15.1	47.9	55.6	147.3
A1FI	5.3	6.9	14.6	18.2	53.6	60.3	158.9

	Road Length by Inundation Depth (kms)						
	8–20 cm		21–50 cm		Above 50 cm		
Flood Scenario (BAU)	Major	Minor	Major	Minor	Major	Minor	Total
Status Quo	3.78	4.33	6.40	10.45	7.45	13.42	45.82
B1	7.24	8.15	9.54	15.73	12.07	20.82	73.55
A1FI	9.45	9.05	12.62	16.28	14.97	25.63	87.99

Source: Muto et al. (2010).

Impact of existing flood-related events on the poor[37]

In Metro Manila, there is a strong link between where the urban poor reside and their vulnerability to flooding. Interviews with 300 poor households (in 14 communities in three river basins) to assess the impact of floods (conducted as part of the Manila study) show that they primarily live in environmentally fragile, low-lying areas and/or swamps or wetlands that are highly vulnerable to storm and tidal surges. Households interviewed have a median monthly income of about 44 pesos/day (less than $1/day). Further, most of them live in slum or squatter settlements and do not have tenure security or access to basic services such as clean water, electricity, sanitation, and drainage. About two-thirds reported suffering regular losses due to typhoons, floods, and storm surges. Twenty-seven percent of the households interviewed have substandard latrines (dug latrines) or none at all (and use neighbor's latrine or direct to the river/sea). Those who do have toilets complained about toilets overflowing and garbage being carried during floods contributing to waterborne diseases. About 65 percent of the households buy water from neighbors or suppliers. During floods, household expenditures on water and transportation increase. Coping strategies include addition of stilts or additional levels by households to escape rising flood waters, use of styrofoam boats, installation of pumps or "bombastic" to help drain flood water (done in some municipalities by the mayor).

The survey details many of the public health hazards associated with flooding . However, for some of the respondents, the consciousness of health risks posed by flooding is not very high. They say "Hindi ka naman namamatay dahil sa baha!" (You do not die from floods or rising waters here!). For example, the risk of catching an infection like the deadly effects of rat's urine (i.e., leptospirosis) is not high in their consciousness. Following Typhoon "Ondoy" in September 2009, however, there was an epidemic of leptospirosis that infected over 2,000 people, with over 160 people dying and many requiring dialysis.

ESTIMATING CLIMATE-RELATED IMPACTS IN HO CHI MINH CITY, VIETNAM

HCMC is a tropical coastal city located on the estuary of the Saigon–Dong Nai River system of Vietnam. While not a capital city, Ho Chi Minh City

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[37] A detailed analysis of the impact of future flooding on the poor was not undertaken as part of the Manila study and needs to be carried out as a follow-up to this report.

is also a key economic and financial center and a core part of the Southern Economic Focal region in Vietnam. The city's official population is estimated to be about 6.4 million people. The actual current population, which includes temporary and unregistered migrants, is estimated to be 7–8 million. The population of HCMC has been growing at a rate of 2.4 percent per year, which is a faster rate than anywhere else in the country. The city accounted for over 23 percent of the country's GDP in 2006 (ADB 2010). Rapid economic growth—11.3 percent annually between 2000 and 2007—has been the central driver behind the city's expansion, as the increasing number and magnitude of income earning opportunities attract migrants from throughout Vietnam. Key economic growth sectors include industrial and service sectors, which have grown at a rate of 11.9 percent and 11.1 percent annually respectively between 2000 and 2007. During the same period, agriculture and related activities have grown relatively slowly at a rate of 4.8 percent annually (ADB 2010).

TABLE 3.10 ■ HCMC District Poverty Rates, 2003

Urban districts		Rural districts	
District	Poverty Rate (%)	District	Poverty Rate (%)
District 1	2.4	Cu Chi	6.9
District 2	4.5	Hoc Mon	6.9
District 3	2.8	Binh Chanh	4.4
District 4	5.6	Nha Be	12.9
District 5	3.8	Can Gio	23.4
District 6	5.5		
District 7	3.0		
District 8	7.4		
District 9	5.0		
District 10	3.0		
District 11	4.6		
District 12	6.3		
Go Vap	6.9		
Tan Binh	5.5		
Binh Thanh	5.0		
Phu Nhuan	3.7		
Thu Duc	7.8		
HCMC average poverty rate		**5.4**	

Source: Inter-ministerial Poverty Mapping Task Force, 2003, cited in ADB (2010).

Nature of poverty in HCMC

In 2006, HCMC had an overall poverty rate of 0.5 percent (GSO Vietnam 2006).[38] While this rate is the lowest in the country, the absolute number of poor in the city is still high at between 30,000 and 40,000 persons. In addition, the number of households living in inadequate housing and poor environmental conditions is likely to be much higher than the official poverty rate suggests. If unregistered migrants are primarily poor, then the poverty rate would also be higher due to the large numbers of migrants missing from official statistics. Spatially disaggregated data for the city shows that there is significant variation in poverty levels in different parts of HCMC. In general, rural districts have higher poverty levels compared to more urban districts. The highest poverty levels are in the relatively sparsely populated rural districts of Can Gio and Nha Be to the south of the city toward the coast. These are also the two districts that are the most prone to flooding in the city (Table 3.10).

Climate and precipitation in the Dong Nai River Basin

HCMC has a tropical monsoon climate with pronounced wet and dry season variations in precipitation. There is a large variation in monthly precipitation, but relatively constant daily temperatures with an annual average in the range of 26–27°C and a variation between months in the range of 4° to 5°C. As shown in Table 3.11, precipitation is highest in the months from May to November, accounting for 90 percent of the annual rainfall. Typhoon events can pass over HCMC. The dry season runs from December to April and can cause drought conditions regularly. Extreme droughts have occurred in 1993, 1998, and 2002.

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[38] This is calculated on the basis of the expenditure typically required to meet a minimum daily calorific requirement of 1,700 Kcals. A number of qualifications need to be made, as the official figure does not include migrants.

TABLE 3.11 ■ Ho Chi Minh City: Monthly Average Temperature and Precipitation

Month	Temperature Average Low (ºC)	Temperature Average High (ºC)	Average precipitation (mm)
January	22°	32°	5.6
February	23°	33°	4.1
March	25°	34°	14.2
April	26°	35°	42.4
May	26°	34°	138.9
June	25°	33°	209.8
July	25°	32°	204.7
August	25°	32°	186.7
September	25°	32°	178.3
October	24°	31°	222.0
November	23°	32°	88.9
December	22°	31°	23.6
Total			1313.7

Source: http://weather.msn.com/monthly_averages.aspx?&wealocations=wc%3aVMXX0007&q=Ho+Chi+Minh+City%2c+VNM&setunit=C

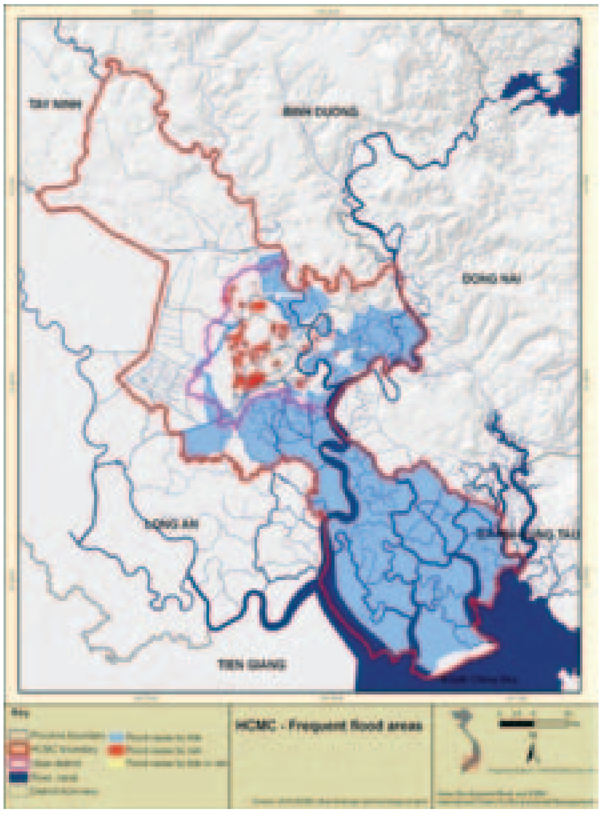
Low elevation topography contributes to flooding

Much of HCMC is located in low-lying lands that are prone to frequent flooding associated with heavy rains or even just high tides. As reported in the HCMC case study (ADB 2010), about 40–45 percent of land cover in HCMC is at an elevation of between 0 and 1 m. The mangrove forests of Can Gio district in HCMC are a key natural resource and provide considerable storm protection. Figure 3.12 shows the areas of HCMC that flood frequently; areas colored in blue and red indicate areas flooded by tides (and hence is salty) and rain (freshwater) respectively.

Main climatic factors contributing to flooding

HCMC is subject to both regular and extreme flooding. Regular floods refer to floods that occur throughout the year on a daily and seasonal basis. Some of the main *climatic* factors that contribute to it include seasonal monsoonal rainfall and tides. Extreme flooding occurs when tropical storms and storm surges combine with tidal influences and monsoon rainfall to create extreme weather conditions. *Storm surge has been identified as a key driver for extreme events in HCMC*. Further, warmer temperatures in the South China Sea are expected to increase the frequency of tropical storms and typhoons that land in southern Vietnam. *SLR is likely to have an important influence on the inland reach of tidal flooding in HCMC*. Currently 154 of the city's 322 communes and wards have a history of regular flooding, affecting some 971,000 people or 12 percent of the HCMC population (ADB 2010). With an extensive area subject to regular flooding, it is not surprising that more extensive flooding can be induced by tides, storm surges, heavy rains on the city directly or in the upper watershed, or a combination of those events associated with a typhoon.

FIGURE 3.12 ■ HCMC: Frequently Flooded Areas under Current Conditions



Source: ADB (2010).

BOX 3.3 ■ HCMC in 2050

Future land use and development projections for HCMC were guided by a number of sectoral and urban development plans and strategies. As per the adjustment plan, the population of HCMC in 2025 is expected to be about 10 million; economic growth in HCMC is expected to increase 8 percent annually in the period from 2026 to 2050 (ADB 2010). Land use for residential purposes is expected to grow by 28 percent and for interior traffic by 215 percent. The vision underlying the adjustment plan includes distributing a population of about 10 million in several satellite cities. It assumes growth in both the industrial and service sectors until 2020. In accordance with this vision, a substantial amount of land in HCMC is being reallocated for industrial purposes. An industrial master plan prepared by the Ministry of Industry estimates this to be around 11,000 ha by 2025. While the adjustment plan recognizes the importance of green space, it also estimates that open areas will decline by about 25 percent. The adjustment plan refers to climate change but does not address measures needed for adaptation.

Population projections for 2050 were developed by the study team based on government data and Master Plan. This resulted in two population estimates, one low estimate of 12 million people, and a high estimate of 20.8 million people by 2050. The high population estimate is likely to be more realistic. Future population distributions were also estimated based on current patterns and trends and are expected to be influenced by the hollowing out of the city center, higher growth and increased population densities in peripheral areas, and the development of satellite cities. In 2006, HCMC had an overall poverty rate of 0.5 percent. While this rate is the lowest in the country, the absolute number of poor in the city is still high, at between 30,000 and 40,000 people. The HCMC poverty rate was projected to remain significant as climate change impacts take hold.

Rapid economic growth (11.3 percent between 2000 and 2007) has been the central driver behind the city's expansion, as the increasing number and magnitude of income earning opportunities attract migrants from throughout Vietnam. The HCMC study bases its GRDP numbers on an "Adjustment Plan" developed by the government. The master plan, which was developed for 2025, contained projections to 2050 for GDP. Accordingly, economic growth in HCMC is expected to be 8.7 percent between 2011 and 2025, and 8 percent between 2026 and 2050. Industrial zones and export promotion zones are expected to increase and the service sector, including financial and tourism services, is expected to grow rapidly.

Source: ADB (2010).

Importance of non-climate-related factors in contributing to flooding

The HCMC study shows that a number of non-climate-related factors also contribute to and exacerbate the impacts of flooding. This includes domestic solid waste that is often dumped in canals and waterways, as well as poor dredging of canals. Canals are often choked with water weeds and garbage, so that in addition to accumulating sediment, their capacity to drain storm waters is severely limited (ADB 2010). Further, land subsidence is also an important problem in HCMC, but was not included in the flood modeling simulations because like Manila, land subsidence data were not reliable. This is an important limitation of this study. The upper watershed of the Saigon River and Dong Nai River, both of which drain HCMC, are well-regulated with dams and reservoirs, including the man-made Dau Tieng Lake and Tri An Lake, which are able to reduce peak flood flows associated with extreme precipitation events. Given the intense management of the HCMC upper watershed, upstream rainfall is not considered to be a major factor affecting flooding in HCMC.[39] However, the watershed of the Dong Nai River basin has been subject to considerable deforestation. Deforestation leads to increased runoff, erosion, and sediment release and exacerbates flooding in HCMC; this needs to be addressed.

Urban planning and assumptions about the city in the future

As with the other studies, analysis carried out for HCMC built its understanding of the future city on the basis of a vast amount of data relating to current conditions and a number of sectoral and urban development plans and strategies developed by the government about the future (Box 3.3). Briefly, the planning system in HCMC is shaped by several strategic plans, including the urban

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[39] The Dong Nai and Saigon rivers are heavily regulated by hydropower and irrigation dams. They are the main source of energy and water supply for HCMC. However, climate change has not been factored into their construction or operation.

BOX 3.4 ■ Overview of Downscaling and Hydrological Analysis Carried out for HCMC Study

Low-resolution outputs (~2o) from ECHAM's (European Centre for Medium Range Weather Forecast-University of Hamburg) atmosphere-ocean-coupled global circulation model (GCM) Version 4 were downscaled by PRECIS (Providing Regional Climates for Impacts Studies, and a dynamic modeling tool developed by the UK Met Office Hadley Centre for Climate Prediction and Research, precis.metoffice.com). Two IPCC SRES greenhouse gas emission scenarios were used as inputs to the GCM. SRES A2 is a high-emission scenario, while B2 represents the low-emission world.

ECHAM is considered a "moderate" GCM in that it does not give any extreme temperature or precipitation projections, but tends to be in the middle ranges. However, other GCM's are also available and need to be included in subsequent studies. PRECIS was used because it is the regional modeling tool that has been most widely used globally, as well as being the tool that the UNDP National Communication Support Unit recommends for countries receiving GEF funding.

PRECIS gridded outputs at resolution 0.22o (~25km) for the Sai Gon-Dong Nai Basin were provided by SEA START RC. Daily outputs for maximum/minimum temperature and rainfall for the baseline decade (1994–2003) and a future decade (2050–59), which represent the year 2050, were taken as a key input for the hydrodynamic model—HydroGIS—to calculate the water and flood regime of Ho Chi Minh City. PRECIS gave the total and seasonal rainfall anomalies that are comparable, though with a slightly wider range than the JBIC/IR3S ensemble, which was used by the other city studies in this collaborative initiative (see table below). By using PRECIS, the daily outputs as well as spatial distribution of climate variables were also obtained to get more in-depth information on temporal and geographic variables for the study area.

The table below provides a comparison of 10 years averaged June-July-August rainfall from PRECIS and the IR3S rainfall ensemble for Ho Chi Minh City for the year 2050 (%change relative to baseline)

GHG Emission Scenarios	PRECIS	IR3S
High	+7.5 (A2)	+4.4 (A1FI)
Low	+1.5 (B2)	+2.9 (B1)

Monsoon-driven seasonal rainfall years with maximum and minimum annual rainfall for each decade were selected to represent "wet" and "dry" years of the baseline and future A2 and B2 decades.

Event-based rainfall extremes for the baseline and future time slices were derived from the 1-, 3-, 5-, and 7-day maximum rainfall from PRECIS over the HCMC urban area. Extreme rainfalls of 30- and 100-year return periods were extrapolated from the log-log (power) regression between the frequency of occurrence (years) and amount of each rainfall extreme. The 30-year and 100-year extremes and 1-, 3-, 5-, and 7-day rainfall data were rescaled to the observed extreme rainfalls at Tan Song Nhat Airport. The scaling factors for each extreme period were used for scaling the respective future extreme rainfall.

Source: Adapted from ADB (2010).

master plan prepared by the Department of Planning and Architecture, the land use plan prepared by DoNRE, and the socioeconomic development plan prepared by the Department of Planning and Investment. These are prepared by different agencies under different time scales with little coordination between them, thus posing a difficult problem in estimating future infrastructure and urbanization scenarios. In terms of a development scenario for 2050, HCMC has an urban master plan that was approved in 1998. In 2007, a study was completed to adjust the HCMC master plan up to 2025 (commonly referred to as the Adjustment Plan).[40] *The city case study used the Adjustment Plan as the basis of the most likely development scenario for 2050* (ADB 2010).

In terms of land use, key trends include a declining population in central HCMC; doughnut-shaped urbanization, with higher population growth within 10 kms from the center of the city; and industries being relocated and established in industrial zones. Agriculture and forest land (primarily made up by the Can Gio biosphere reserve) situated in the rural and suburban areas, has declined from 64 percent in 1997 to 59 percent in 2006. According to DONRE's land use plans, open space is expected to decline by 25 percent by 2020 (ADB 2010). Rivers and canals cover close to 15 percent of the total land use, reflecting the

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[40] Even though it is in the process of being formally approved by the government, in the interim, it is the recognized update for the 1998 Master Plan.

original swamp land on which the city was settled. Roads and other transport facilities occupy around 3 percent; land for industry and commerce is expanding rapidly and now represents about 5 percent of the city's land use. There are 90 parks in HCMC. In addition to the urban master plan and the HCMC land use plans, the department of transportation has prepared a transport master plan for HCMC until 2020, which has been used for modeling impacts of climate change on the transport sector (ADB 2010). HCMC also has a power development plan and a health sector master plan, both to 2020. Similarly, a water supply master plan until 2025 is currently under preparation (ADB 2010) and has been used to model impacts on the water sector in 2050.

Flood protection infrastructures assumed for the hydrological analysis

HCMC has a planned flood protection dyke and sluice system to protect much of the city from flooding with an estimated cost of $650 million. This is to be implemented in phases, which will allow lessons learned during implementation to be applied to the later stages. The 2050 modeling has developed scenarios assuming implementation and no implementation of the proposed flood protection measures.

Dynamic downscaling technique applied to model 2050 climate change

The HCMC study used the SRES A2 and B2 scenarios as the enveloping case for high and low projections. Further, unlike the other cities in the study, which used statistical downscaling, the HCMC case study used both statistical downscaling and also a PRECIS dynamic downscaling technique to model future climate change parameters (Box 3.4). The dynamic downscaling approach allowed the study to address the complex hydrometeorological and oceanographic changes. Specifically, PRECIS allowed simulation of mean (minimum and maximum temperatures) for the base case and A2 and B2 scenarios, simulation of daily rainfall data in the base year (averaged over 1994–2003) and for 2050 (based on average of 2050–59). Based on this, the percent increase in rainfall in terms of average increase and increase for extreme events (1-in-30 year, 1-in-100 year, etc.) was calculated. *Thus, it was estimated that future extreme rainfall under the high emissions scenario will increase by more than 20 percent for a 1-in-30-year flood and by 30 percent for a 1-in-100-year flood*. This information was then used as input into the hydrological modeling.

Inputs and outputs for the hydrological modeling

The main drivers of the water regime in the HCMC include the following: seasonal monsoon-driven rainfall, extreme rainfall due to typhoons and tropical storms in the vicinity of the city, local SLR, storm surge, upstream-downstream inflow as a function of catchment basin hydrology, and various land uses such as water management infrastructure, hydrologic/hydrodynamic conductivity, and water demand by sectors and geographic locations. Some of these are related to regional climate change and are more a function of land use and development. For instance, "over 75 percent of flooding points in HCMC have occurred following rainfall of 40mm even during ebb tide," which indicates that surcharge from storm drains is a major factor contributing to flooding. For the hydrological simulations, it was assumed that the population and land use in 2050 were the same as the base year (see HCMC annex). For the HCMC study, a hydrodynamic modeling tool—Hydro-GIS—was used to integrate information about these drivers and derive output variables (such as flood depth, duration, salinity distribution, etc) for an assessment of risks and impacts in 2050.

Estimates for sea level rise and storm surge

In addition to using dynamic downscaling to estimate precipitation changes, the study used the DIVA (Dynamic Interactive Vulnerability Assessment) tool developed by the DINAS-COAST consortium.[41] The results from that tool yielded SLR of 0.26 m and 0.24 m

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[41] In DINAS-COAST, the DIVA method was applied to produce a software tool that enables its users to produce quantitative information on a range of coastal vulnerability indicators, for user-selected climatic and socioeconomic scenarios and adaptation policies, on national, regional and global scales, covering all coastal nations. http://www.pik-potsdam.de/research/research-domains/transdisciplinary-concepts-and-methods/project-archive/favaia/diva

TABLE 3.12 ■ Climate Change Parameter Summary for HCMC

IPCC Scenario	Temperature increase (ºC)	Precipitation 24-hr event	Precipitation 3–5 days	Sea Level Rise (m)	Storm Surge (m)	Land subsidence (m)
B2	+1.4	–25%	Insignificant change	0.24	1.08 (from 0.53 2008)	Not considered
A2	+1.4	+20%	+20%	0.26	1.08 (from 0.53 2008)	Not considered

for the A2 and B2 scenarios, respectively. The study also notes that the city's low topography creates a situation where a tipping point[42] of around 50 cms would considerably increase the impact of SLR, with significant areas potentially becoming permanently flooded. For storm surge, the study assessed that the historic storm surge lasts about 24 hours and reached about 0.5 m. For storm surge from intensified typhoons in 2050, the study examined adjusted historic tracks that would increase the storm surge and estimated future storm surges associated with extreme events at 1.08 m, which would be associated with a track making landfall at HCMC.

Flood simulations limited to regular and extreme 1-in-30-year flood events for current and the 2050 A2 high emission scenario

In assessing the impact of extreme flooding in HCMC, the study focused mainly on the 1-in-30-year extreme event for 2008 and the 2050 scenario. Also, the study focused mainly on the A2 scenario because the team found that the extreme precipitation events under the B2 scenario were not significantly different than 2008 events. A summary of the simulations conducted is provided in Annex B. A significant advantage of the dynamic downscaling technique is that it gives temporal and spatial information on precipitation patterns on a daily basis, which allows assessment of not only floods, but also drought events. While this was not defined as a focus of the study for the four cities, it is important in the context of HCMC. Drought scenarios also were modeled.

MAIN FINDINGS FROM HYDROLOGICAL ANALYSIS AND GIS MAPPING FOR HCMC

Flood hazard increases, for both regular and extreme events and number of persons exposed to flooding rises dramatically

Large areas of HCMC (1,083 km^2)[43] flood annually; extreme floods (1-in-30-year) inundate 1,335 km^2. Similarly, much of HCMC's population already experiences regular flooding with about 48 percent of the communities affected annually. Table 3.13 shows a comparison of regular (annual) and extreme (1-in-30-year) flooding under the current and the 2050 A2 scenario for inundated areas and communities affected. The analysis shows that the area inundated increases for regular events from 54 percent to 61 percent in 2050, and for extreme events

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[42] A point at which the changes or impacts rapidly increase, possibly irreversibly.

[43] 1 km^2 = 100 ha.

TABLE 3.13 ■ Summary of Flooding at Present and in 2050 with Climate Change

	Present		2050	
	Regular flood	Extreme flood	Regular flood	Extreme flood
Number of communes affected (from a total of 322)	154	235	177	265
Area of HCMC flooded (ha)	108,309	135,526	123,152	141,885
% of HCMC area affected	54	68	61	71

Source: ADB (2010).

from 68 percent to 71 percent; that is, an increase of 7 percent and 3 percent for regular and extreme events respectively in 2050. This is also indicated through GIS maps (Figures 3.13a and 3.13b).

Significant increase in both flood depth and duration for regular and extreme events in 2050

A key finding of the hydrological analysis is that there is a significant increase in both depth and duration for both regular and extreme floods over current levels in 2050. The average maximum flood depth in HCMC is about 35 cm and the average maximum flood duration is 64 days. As a rule of thumb, more than 50 cm of flood water is considered the threshold for safe operation of vehicles and bikes. Flood duration of more than three days at 50 cm depth is considered to cause significant disruption in the city. Results from the hydrological analysis estimate that there will be a 20 percent and 43 percent increase in average maximum depth for regular and extreme events respectively, and a 21 percent and 16 percent increase in average maximum flood duration during regular and extreme events respectively in 2050. That is, the average maximum flood duration increases from 64 to 86 days for regular events, and from 18–22 days for extreme events. Similar to past events, the depth of extreme floods in 2050 throughout the city will be higher (72–100 cm) compared to the depth for regular flooding (35–44 cm).

Increase in populations at risk from flooding by regular and 1-in-30-year event in 2050

Results from the hydrological modeling and GIS mapping show that an increasing number and proportion of the population[44] will be affected by flooding from regular and extreme events in 2050 (Table 3.13). For regular floods, about 15 percent of HCMC's population is affected for the baseline scenario (in 2007). This increases to 49 percent without implementation of proposed flood control measures. With the implementation of the proposed flood control measures, the percentage of affected population is reduced to 32 percent (ADB 2010). Climate change will also impact daily life in HCMC

FIGURE 3.13a ■ **HCMCCity Case Study: Comparison of 1-in-30-year Flood for 2008**

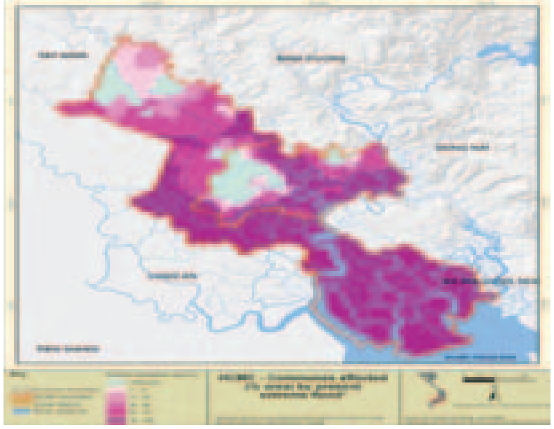
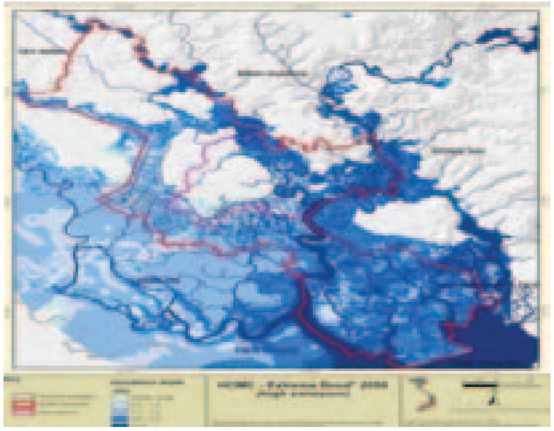


FIGURE 3.13b ■ **HCMCCity Case Study: Comparison of 1-in-30-year Flood for 2050 A2 Scenario**



Source: ADB (2010).

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[44] As mentioned earlier, the official population of HCMC in 2007 was 6.4 million people and about 8 million if unregistered migrants are included. The team considered two (high and a low) population growth scenarios, but assumed a high population growth scenario for the vulnerability analysis. The high case includes unregistered migrants into the baseline; that is, it assumes current population to be about 8 million. This seems more realistic compared to the assumption in the low-growth scenario, which does not assume unregistered migrants currently in the city. Further, the existing rate of 2.4 percent population growth assumed in the low-case scenario is low compared to the experience of other large cities in the region.

by 2050 under the A2 scenario. As Table 3.14 shows, currently about 26 percent of the population would be affected by a 1-in-30-year event. However, this is expected to rise to 62 percent of the population (about 12.9 million people) by 2050 under the A2 scenario without implementation of the proposed flood control measures (ADB 2010). With the construction of the flood control system, it is estimated that under the A2 scenario, for a 1-in-30-year flood, 52 percent of the population—or about 10.8 million people—will be affected. Thus with the implementation of the flood control measures, 2 million fewer people are likely to be affected. However, even with the flood control measures being implemented, more than half of the projected 2050 population is still at risk from flooding during extreme events.

Districts and areas most at risk from flooding due to 1-in-30-year event in 2050

Another important finding from the hydrological analysis is that the spatial distribution of floods is also likely to change in 2050 under extreme conditions, depending on implementation of dif-

TABLE 3.14 ■ District Population Affected by an Extreme Event in 2050

			2007		2050—without flood control measures		2050—with flood control measures	
District	Population 2007 (1,000)	Population 2050 (1,000)	No.	%	No.	%	No.	%
District 1	201	232	88	44	100	43	64	27
District 2	130	1,492	85	66	1,410	95	1,160	78
District 3	199	148	17	9	42	28	35	23
District 4	190	125	99	52	125	100	81	64
District 5	191	128	42	22	83	65	54	42
District 6	249	216	34	14	193	90	26	12
District 7	176	1,071	94	53	1,071	100	691	65
District 8	373	575	88	24	574	100	171	30
District 9	214	3,420	39	18	2,322	68	2,311	68
District 10	239	172	67	28	76	44	76	44
District 11	227	154	46	20	36	24	26	17
District 12	307	1,583	65	21	795	50	788	50
Go Vap	497	592	73	15	149	25	103	17
Tan Binh	388	671	9	2	20	3	20	3
Tan Phu	377	482	0	0	19	4	17	4
Binh Thanh	450	623	64	14	511	82	502	81
Phu Nhuan	176	146	0	0	4	3	0	0
Thu Duc	356	1,433	133	37	756	53	733	51
Binh Tan	447	1,557	64	14	776	50	318	20
Cu Chi	310	1,804	83	27	489	27	502	28
Hoc Mon	255	1,483	77	30	728	49	728	49
Binh Chanh	331	1,926	282	85	1,744	91	1,601	83
Nha Be	75	437	75	100	437	100	369	84
Can Gio	67	393	66	99	393	100	393	100
Total	6,425	20,863	1,690	26	12,851	62	10,766	52

Source: ADB (2010).

TABLE 3.15 ■ Districts Affected by Flooding in Base Year and in 2050

		Present				2050			
		Regular		Extreme (Linda)		Regular		Extreme	
Commune name Dist (means District)	Area (ha)	Flooded area (ha)	% flooded area	Flooded area (ha)	%flooded area	Flooded area (ha)	%flooded area	Flooded area (ha)	%flooded area
Dist.1	762	42	5.56	215	28.24	54	7.13	327	42.94
Dist 2	5,072	3,134	61.80	4,525	89.21	3,691	72.78	4,784	94.32
Dist 3	471	0	0.00	57	12.14	0	0.00	133	28.17
Dist 4	408	61	14.93	397	97.35	110	27.03	408	100.00
Dist 5	432	15	3.46	183	42.28	16	3.68	282	65.17
Dist 6	713	16	2.25	224	31.41	56	7.88	638	89.53
Dist 7	3,554	1,068	30.05	3,178	89.42	2,040	57.39	3,552	99.94
Dist 8	1,969	185	9.42	1,700	86.38	846	42.99	1,964	99.78
Dist 9	11,357	7,165	63.09	7,829	68.93	7,350	64.72	8,103	71.34
Dist 10	584	37	6.25	144	24.57	37	6.25	258	44.08
Dist 11	508	18	3.55	70	13.77	18	3.55	120	23.67
Dist 12	5,463	2,559	46.85	2,621	47.98	2,563	46.92	2,742	50.20
Dist Go Vap	2,010	171	8.50	343	17.05	219	10.92	506	25.19
Dist Tan Binh	2,226	0	0.00	41	1.86	0	0.00	65	2.92
Dist Binh Thanh	2,094	594	28.36	1,619	77.33	942	44.99	1,718	82.02
Dist Phu Nhuan	468	0	0.00	1	0.12	0	0.00	12	2.56
Dist Thu Duc	4,692	1,514	32.27	2,140	45.62	1,813	38.64	2,256	48.08
Dist Cu Chi	43,246	7,313	16.91	10,842	25.07	7,985	18.46	11,735	27.14
Dist Hoc Mon	10,838	3,657	33.74	5,311	49.00	3,855	35.57	5,322	49.10
Dist Binh Chanh	25,422	16,924	66.57	22,340	87.88	20,863	82.07	23,057	90.70
Dist Nha Be	10,005	8,272	82.68	9,984	99.79	9,876	98.71	10,005	100.00
Dist Can Gio	61,284	55,148	89.99	60,413	98.58	59,734	97.47	61,284	100.00
Dist Tan Phu	1,575	0	0.00	0	0.00	0	0.00	63	3.98
Dist Binh Tan	5,192	415	7.98	1,349	25.98	1,082	20.84	2,551	49.12
HCMC TOTAL	200,346	108,309	54.06	135,526	67.65	123,152	61.47	141,885	70.82

Source: ADB (2010).

ferent adaptation options. As Tables 3.14 and 3.15 indicate, the districts are not evenly affected due to flooding. Districts 6 and 8 and Binh Than district, for example, will experience a significant increase in the proportion of population affected, as well as an increase in the area flooded compared to other districts. Some areas—such as Nha Be and Can Gio—will be severely affected by extreme events, with 100 percent of its area flooded. With the flood control system implemented, some districts (District 9, Binh Than) will experience significant increases in flooding, while others (Districts 1, 7, 11) will see a reduction in flooding.

The poor are at greater risk from flooding; in some cases, both the poor and non-poor are at risk

In general, poorer areas in HCMC are more vulnerable to flooding. As Figures 3.14a and 3.14b show, some of the districts that are more vulnerable to flooding (dark purple in Figure 3.14b, are also the

Figure 3.14a ■ HCMC Poverty Rates by District

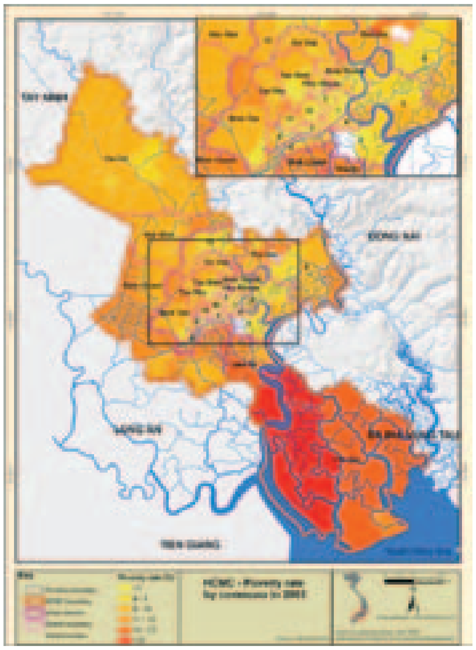
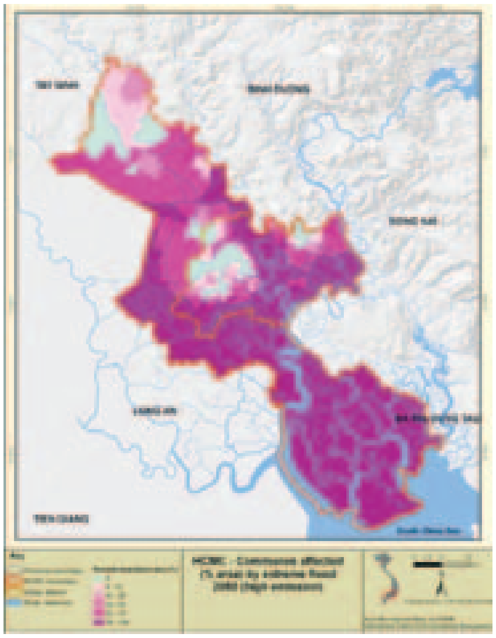


FIGURE 3.14b ■ Districts Vulnerable to Flooding



Source: ADB (2010).

districts with higher poverty rates (indicated by red and orange in Figure 3.14a). However, in some of the areas that are most at risk—such as Can Gio and Nha Be—the poor and non-poor are both at risk. The rural poor living in the south of the city are directly dependent on natural resources for their livelihood. For instance, 60 percent of agricultural land would be affected by saline intrusion during regular floods. Inundation by salt water can damage crops and reduce the productivity of agricultural land, thus impacting the livelihoods of the rural poor. In urban areas of the city, the poor typically live along canals and drainage ditches—for example, Nhieu Loc Thi, Nghe canal, Tan Hoa-Lo Gom canal, Doi-Te canal—or in slum areas near industries. These areas are among those at higher risk from flooding, in part due to underdeveloped infrastructure and poor drainage and sanitation facilities.

Economic activity is highly vulnerable to flooding now and in the future

The industrial sector is an important and growing part of the HCMC economy. Climate change will affect economic activity and industrial production both directly through inundation of production areas, and indirectly through inundation of essential infrastructure linked to strategic economic assets and effects on the availability of key production inputs (e.g. water, primary resources). Fifty percent of industrial zones (IZs) are at risk[45] of flooding from extreme events with the proposed flood control measures in place, and 53 percent without the system in place (ADB 2010). An additional 20 percent of IZs will be located within 1 km of likely inundation if the proposed flood control measures are in place (22 percent if the flood control measures are not in place), meaning that they are likely to suffer indirect impacts. In terms of land area assigned to industrial activities, about 67 percent of the area potentially under industrial use in 2050 is likely to be affected (Table 3.16).

The city's existing and planned transport network is also likely to be exposed to increased

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[45] Risk from impacts due to climate-related impacts—namely, flooding— in the study was determined by calculating the distance of an infrastructure component or facility from the flood zone that is inundated and assigning it a risk factor. Thus a distance of 0km from the flood zone shows it is inundated, <1km = very high risk, <5km = high risk, <10 kms =medium risk, and > 10kms =low risk.

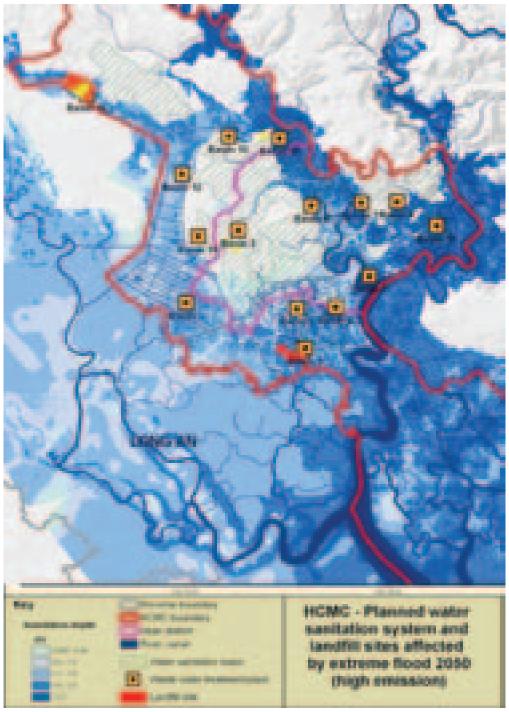
TABLE 3.16 ■ Effects of Flooding on Future Land Use under 2050 A2 Extreme Event

Future land use type	% future land use affected without flood control system	% future land use affected with flood control system
Urban	61	49
Industrial	67	63
Open space	77	76

Source: ADB (2010).

flooding. Under the A2 scenario, a 1-in-30-year event would inundate 76 percent of the axis roads, 58 percent of the ring roads, and nearly half of the city's main intersections, even with the flood dyke protection system. Further, 60 percent of the city's waste water treatment plants and 90 percent of the landfill sites are at risk of flooding (Figure 3.15). The environmental consequences of flood waters inundating landfill sites and carrying pollutants to nearby fish ponds is a potential risk that needs further consideration.

FIGURE 3.15 ■ Impact on Waste Management Sector

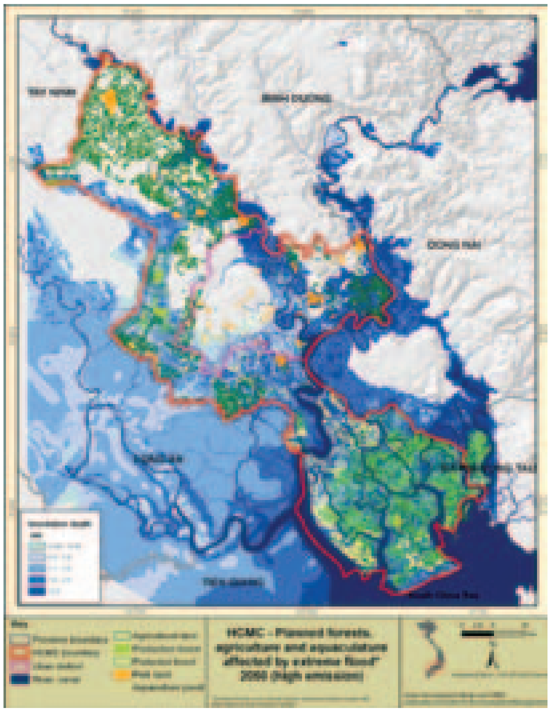


Source: ADB (2010).

Impact of saline intrusion on natural resource dependent sectors

It is estimated that the impact of flooding on agriculture, forestry, and primary industries will be severe. In 2050, it is expected that there will be a significant increase in saline intrusion. Saline intrusion is mainly a problem during regular flooding, which is dominated by tidal influences (ADB 2010). It is estimated that close to 60 percent of agricultural lands are expected to be affected by increased salinity in 2050. Increased storm activity and sea level rise are expected to increase the level of salinity in surface waters and also groundwater resources. However, since agriculture is of declining importance in HCMC, this has a more direct impact on the poor and farmers directly dependent on these resources rather than the economy as a whole. Figure 3.16 shows an overlay of the 2050 A2 1-in-30-year flood on projected land use patterns. It shows that flooding will impact broad areas and sectors, but particularly agricultural and protected areas.

FIGURE 3.16 ■ HCMC 2050 A2 1-in-30-year Flood Inundation Overlaid on Projected Land Use Patterns

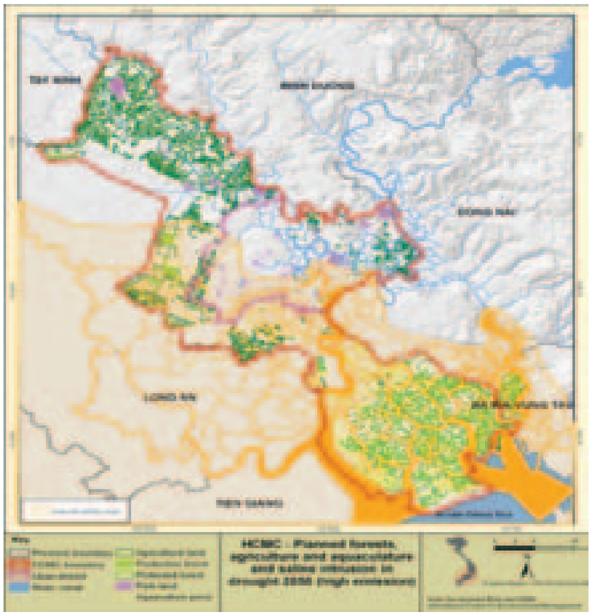


Source: ADB (2010).

Potential increase in drought in 2050 under low emission scenario

An initial analysis of the data collected for the study shows that "the frequency of dry season drought in 2050 is likely to increase by the order of 10 percent under the low-emission scenario with little change under high-emission scenario" (ADB 2010). Further, the incidence of drought is likely to increase under the low-emission scenario in both the dry and the wet season. These assessments require more in-depth analysis. However, they do provide an indication of the order of magnitude of change and illustrate which scenarios are more susceptible to drought.

FIGURE 3.17 ■ HCMC Droughts and Salinity Intrusion in 2050



Source: ADB (2010).

CONCLUSION

To sum up, all three megacities face considerable climate-related risks in terms of changes in temperature and precipitation. These climate risks are compounded by risks posed by non-climate factors (such as land subsidence, poor drainage, and deforestation in upper watersheds), thus increasing the likelihood of urban flooding. Under different scenarios, in all three cities, there is likely to be an increase in the area exposed to flooding and an increase in the percentage of population affected by extreme events. Given that all three cities are megacities with high population growth rates, the results warrant serious consideration. Despite data limitations, it is apparent that both climate and non-climate factors are important and need to be considered in future adaptation efforts. While flood protection infrastructures are either in place or planned, the analysis shows that in all three megacities, while these are likely to reduce the impact of flooding, they are not sufficient to provide the expected level of protection from future climate events.

4

Assessing Damage Costs and Prioritizing Adaptation Options

Chapter 3 described the scale of physical impacts in terms of area, population, and sectors that are likely to be affected under different climate and infrastructure scenarios in the coastal cities. In this chapter, we discuss (a) the nature of the damages and monetary costs borne as a result of these physical changes, and (b) adaptation options considered by the city studies. The overall approach to estimating costs was discussed in chapter 2 and is further elaborated in this chapter.

BANGKOK: ANALYSIS OF DAMAGE COSTS RELATED TO FLOODING IN 2008 AND 2050

In Bangkok, climate-change-induced flooding will likely result in physical damages to buildings and housing, income losses to individuals and firms, revenue losses to public utilities, and might also adversely affect public health. In estimating costs, the Bangkok study examines direct and indirect tangible damages (Table 4.1) associated with potential floods under 16 scenarios. Damage costs are evaluated for the base year of 2008 and for 2050. As previously described, the scenarios include three climate change scenarios (current climate, B1 and A1FI), three levels of flood intensity (1-in-10 year, 1-in-30 year, and 1-in-100 year) and additional scenarios that include land subsidence, sea-level rise, and storm surge. *Estimates for area, depth, and duration of flooding derived from the hydrological analysis were key inputs for the damage cost assessment*. In addition, the damage cost assessment makes numerous assumptions regarding prices, population growth, GDP, and the location of major infrastructure such as roads, electric utilities and so on related to Bangkok in 2050, as discussed in chapter 2. While assessing damage costs, prices are held constant in real terms

TABLE 4.1 ■ Summary of Damages Assessed in the Bangkok Study

Damage Type	Sector	Damage Mechanism
Direct Damages	Residential units	Damage to buildings and assets
	Commercial units	Damage to buildings and assets
	Industrial units	Damage to buildings and assets
	Transportation, public health, energy, water supply and sanitation	No direct damage to these infrastructures expected in the future
Indirect Damages	Population	Loss of income
	Commercial units	Loss of income
	Industrial units	Loss of income
	Transportation	Loss of revenue (negligible)
	Public health	Additional costs of medical care
	Energy	Loss of net revenue
	Water supply and sanitation	Loss of net revenue

Source: Panya Consultants (2009).

over the period of analysis. These assumptions are described in chapter 2. Damages costs are evaluated in Thai Baht and converted to US dollars, using an average exchange rate for 2008 of 1 US$ = 33.31 THB.

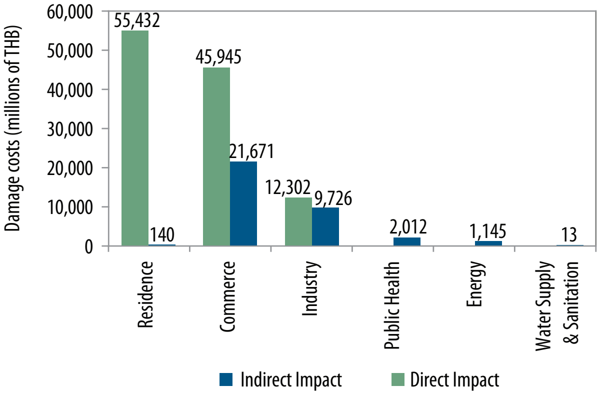
Bangkok likely to witness substantial damage costs from flooding in 2050, ranging from $1.5 billion to $7 billion under a series of climate and land use scenarios

Table 4.2 presents the costs incurred from damages to buildings, income losses, health costs, and revenue losses to public utilities for a range of scenarios. A comparison across scenarios shows that the costs are likely to significantly increase with climate and land use change. In the base case scenario (2050-LS-T10), a 1-in-10-year flood is estimated to result in damages of 52 billion THB ($1.5 billion), but a 1-in-100-year flood with climate change (2050-LS-SS-SR-A1FI) could cost THB 244 billion ($7 billion).

The increase in costs from flooding are best illustrated by looking at the implications of a medium-sized flood. A 1-in-30-year flood in 2008 (2008-T30), for instance, is estimated to result in damage costs of 35 billion THB ($1 billion). In 2050 with climate change (2050-LS-SS-SR-A1FI-T30), a similar 1-in-30-year flood would cost 148 billion ($4.5 billion)[46]. *Thus, in a future climate change (A1FI) scenario, a 1-in-30-year flood in 2050 could lead to a four-fold increase in costs to Bangkok.*

To illustrate the nature of different costs associated with floods, Figure 4.1 breaks down the costs associated with a 1-in-30-year flood in the future (2050-LS-SS-SR-A1FI). As the figure shows, the direct costs to buildings are the highest costs borne as a result of flooding, followed by income losses to commercial establishments.

FIGURE 4.1 ■ Damage Cost Associated with a 1-in-30-year Flood (C2050-LS-SR-SS-A1FI-T30)

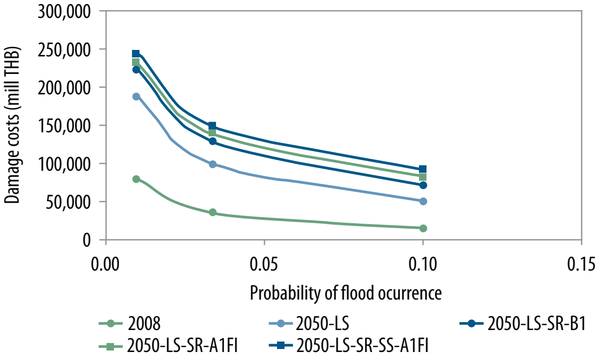


Damage to Residencial Building	55,432 MBaht
Damage to Commercial Building	45,945
Damage to Industrial Building	12,302
Income Loss of Daily Wage Earner	140
Income Loss of Commerce	21,671
Income Loss of Industry	9,726
Health Care Cost	2,012
Income Loss of Energy	1,145
Income Loss of Water Supply and Sanitation	13
Total Damage Cost	**148,386 MBaht**

Source: Panya Consultants (2009).

It is useful to understand more carefully the relationship between the costs of hazards such as floods and the probability of their occurrence. Figure 4.2 plots total damage costs to Bangkok from floods in different scenarios against the probability of their occurrence. As this figure suggests, the costs of damage increase for higher intensity floods, but this also means that there is a lower probability of such floods occurring. The area beneath each flood exceedance curve represents the average total expected flood damage cost from floods of different intensity in any one year. The difference in the areas between different exceedance curves represents the *incremental annual* damages as a result of a new climate/land use scenario. These annualized values are discussed later in the chapter.

FIGURE 4.2 ■ Loss Exceedance Curves, Bangkok



Source: Based on calculations in Panya Consultants (2009).

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[46] 1 USD=33.3133 THB, which was the average exchange rate in 2008.

TABLE 4.2 ■ Summary of Flood and Storm Damages, Bangkok (million 2008 THB)

Damaged Items	2008-T10	2050-LS-T10	2050-LS-SR-B1-T10	2050-LS-SR-A1FI-T10	2050-LS-SR-SS-A1FI-T10	2008-T30	2050-LS-T30	2050-LS-SR-B1-T30	2050-LS-SR-A1FI-T30	2050-LS-SR-SS-A1FI-T30	2008-T100	2050-LS-T100	2050-LS-SR-B1-T100	2050-LS-SR-SS-B1-T100	2050-LS-SR-A1FI-T100	2050-LS-SR-SS-A1FI-T100
Damage building	12,166	40,277	54,231	63,982	70,058	27,281	75,500	97,761	105,575	113,679	61,037	142,432	170,368	176,328	179,695	188,215
Residence	7,462	21,500	27,813	31,907	34,465	15,894	37,739	48,746	52,072	55,432	33,557	68,420	80,591	83,312	84,631	88,628
Commerce	3,254	13,565	19,466	23,828	26,814	8,293	29,250	38,689	42,157	45,945	20,960	61,657	74,194	76,781	78,492	82,147
Industry	1,450	5,212	6,952	8,247	8,779	3,094	8,511	10,326	11,346	12,302	6,520	12,355	15,583	16,235	16,572	17,440
Income/revenue loss	2,761	11,005	15,875	18,132	20,188	7,069	22,717	29,311	31,533	32,695	14,901	39,854	48,699	50,009	50,223	51,629
Daily wage earner	27	47	71	80	89	92	102	128	137	140	167	176	205	205	205	205
Commerce	1,315	6,306	9,638	11,138	12,676	4,077	14,940	19,518	20,883	21,671	9,172	27,744	33,963	34,913	34,968	3,508
Industry	1,264	4,260	5,699	6,394	6,894	2,640	7,066	8,596	9,397	9,726	4,897	9,965	12,174	12,534	12,692	13,158
Energy	149	383	456	508	517	254	598	1,057	1,104	1,145	659	1,954	2,340	2,340	2,341	2,341
Water supply & sanitation	6	9	11	12	12	6	11	12	12	13	6	15	17	17	17	17
Health care cost	321	537	717	825	872	934	1,107	1,665	1,893	2,012	3,240	3,473	4,020	4,020	3,945	4,022
Total	15,248	51,819	70,823	82,939	91,118	35,284	99,324	128,737	139,001	148,386	79,178	185,759	223,087	230,357	233,863	243,866
Total USD	458	1,556	2,126	2,490	2,735	1,059	2,982	3,864	4,173	4,454	2,377	5,576	6,697	6,915	7,020	7,320

Source: Panya Consultants' calculation.

Notes: LS= land subsidence, SS=storm surge, SR= sea-level rise, B1 =low climate emissions, A1FI =high climate emissions, T10, T30, T100 = flood intensities

Damage costs in 2050 are largely attributable to land subsidence

Land subsidence as a result of groundwater utilization is a major problem in Bangkok. While there is reason to worry about climate change, the impacts of land subsidence are even bigger. For example, if we look at the impacts of a 1-in-30-year flood in Table 4.2, with current (2008) climate conditions, the costs are about THB 35 billion ($1 billion). However, this increases to THB 99 billion ($3 billion) in 2050, just from expected land subsidence (2050-LS). Thus, there is a nearly two-fold (181 percent) increase in flooding costs between 2050 and 2008 as a result of land subsidence.

If we add climate change to this projected change in land subsidence and estimate damage costs in the context of a 2050-LS-SR-SS-A1FI scenario, the costs of a 1-in-30-year flood are THB 148 billion ($4.5 billion). Climate change results in a further 49 percent increase in flood damage costs in 2050 (relative to 2050-LS). However, the bulk of the increase (67 percent) in flooding costs in 2050 is attributable to land subsidence. *Thus, in order to reduce the costs of flooding in 2050, a top priority should be policies to reduce land subsidence.*

Damage costs vary by sectors, with more than 75 percent of the costs attributable to buildings

Damage to buildings dominates flood-related costs in Bangkok. In the context of a 1-in-30-year flood, in each of the five climate and land scenarios considered for Bangkok, 76–77 percent of total damage costs are attributable to damage to buildings. As Table 4.2 shows, in 2008, a 1-in-30-year flood could cause building damages to the extent of THB 27 billion ($800 million) in Bangkok. A similar 1-in-30-year flood could cost up to THB 75 billion ($2.3 billion) in 2050 after taking into account land subsidence and economic development. If we add climate change impacts, the damage costs further increase by 51 percent to THB 110 billion ($3.4 billion).[47] There is a steep increase in building costs between 2008 and 2050 (177 percent) simply because of land subsidence (Table 4.2). The increase in damages from climate change is also significant, but less steep.

Damage costs to transport are likely to be limited

The Bangkok study examined different types of infrastructure and sought to understand the impact of floods on public investments. In general, new public infrastructure in Bangkok has taken the possibility of flooding into account. For example, because of the height at which highways and the metro rail are built, transportation will generally be unaffected by flooding. This does not mean that small streets in Bangkok will not be flooded, but the economic costs to transport infrastructure is expected to be limited. The Bangkok study was unable to estimate the traffic delay costs associated with flooding, and therefore this potentially important cost is not included.

There are unlikely to be direct water and sanitation infrastructure-related costs because of their location at higher than flood levels. However, there are likely to be revenue losses to water and sanitation agencies if flood waters rise above 2 meters. Under these conditions water supply may become dysfunctional and the agencies will likely incur revenue losses.[48] The revenue loss to water supply and sanitation utilities is expected to more than double to THB 13 million ($390, 235) in 2050, given climate change (A1FI), sea level rise, storm surge, and land subsidence. However, the bulk of this increase in costs is attributable to land subsidence.

If flooding is higher than 1 meter, the Metropolitan Electricity Authority will lose revenues to the extent of THB 1.1 billion ($33 million) in 2050 (A1FI-SL-SR-SS-T30). The damages with climate change are twice the damages that are likely to occur in a no-climate-change scenario (2050-LS-T30). However, infrastructural damages are limited because energy to Bangkok is supplied by two power plants that are either being retired or will be retired by 2050. Future infrastructure is expected to be

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[47] These values are all in 2008 THB and reflect simply the physical changes that would be wrought as a result of climate change, economic development, and land subsidence.

[48] The average losses are calculated by multiplying water charges by the average water used per day and scaling this up for the duration of floods and number people affected if flood waters were higher than 2 meters. Similarly, sanitation costs = No. of affected people x waste generation (solid and liquid) per capita per day x treatment cost x flood duration

built outside the cities and are not expected to be impacted by floods.

The Bangkok study estimates that health care costs could double with climate change (Table 4.2). The costs from a 1-in-30-year flood could be about THB 2 billion ($60 million) in 2050 with climate change (2050-LS-SS-SR-A1FI), sea level rise, storm surge, and land subsidence. This is about twice the cost that would occur in 2050 without climate change and only land subsidence (2050-LS). This increase in health costs is primarily triggered by the larger number of people likely to be affected by floods.

Daily wage earners will see significant increases in income losses

Climate change will affect the population of workers living in condensed housing areas and deliver significant income losses to daily wage earners. As Table 4.3 shows, losses to daily wage earners are likely to increase by 25 percent when we consider an A1FI climate change scenario (2050-LS-SR-SS-A1FI-T30) in 2050 relative to a scenario where there is only land subsidence (2050-LS-T30).

TABLE 4.3 ■ Changes in Income Losses to Wage Earners, Commerce, and Industry

Changes in income losses* from extreme weather (1/30 flood) under different scenarios			
Scenarios	2008-T30	2050-LS-T30 (%)	2050-LS-SR-SS-A1FI-T30 (%)
Daily wage earner	—	11	25
Commerce	—	266	45
Industry	—	168	38

*Each column represents the percentage change in income relative to the previous column.

However, as expected, the overall cost to low-income workers is very small relative to the estimated costs to industry and commerce (Table 4.2). Commercial income losses come second only to building damages as a source of losses from floods. For instance, in the case of a 1-in-30 -year flood in a climate change scenario (2050-LS-SR-SS- A1FI-T30), income losses to commerce are estimated at 21 billion THB ($630 million).

Box 4.1 ■ Examining Building Damages, Income Losses, and Health Costs in Bangkok

In order to estimate the damage to buildings, the Bangkok study developed GIS maps of areas likely to be flooded. Different categories of buildings likely to be impacted—identified using National Housing Authority data (2004)—were overlaid on these maps. Of particular concern was condensed housing, which refers to clusters of more than 15 houses in an area of 1 rai. These areas, where poverty is high, were separately identified.

To value buildings, the Bangkok case study identified the book value of buildings of different types and then depreciated these values. Damage costs were assessed as a percentage of total value based on the extent and duration of floods. Added to this was the value of assets that may be damaged. Average asset values associated with residential buildings (obtained from census data) are THB 328,889 for Bangkok and THB 220,180 for Samut Prakarn. Building damages were estimated separately for residential, commercial, and industrial buildings.

With extreme precipitation and flooding, income losses can be incurred in flooded and non-flooded areas. The Bangkok study estimated three types of income losses in flooded areas: (a) business income loss, (b) industrial income loss, and (c) losses to daily wage earners.

To obtain business losses, the Bangkok study first identified the average income per day from commercial establishments based on business surveys. This was then adjusted to reduce operational expenses. The average net commercial income was estimated to be THB 4,930 per establishment per day. A similar accounting was used to estimate average income to industrial establishments. These average values are multiplied by the number of days of flooding and the number of buildings affected by floods to estimate income losses from commerce and industry. Income losses to daily wage earners living in condensed housing areas were estimated based on the population in these areas affected by floods of different intensity.

Disease outbreaks in the form of diarrhea, cholera, typhoid, and other diseases are possible during times of flood, depending on the duration and nature of the areas affected. But few estimates are available of the likelihood of these outbreaks and what populations may be affected. In the absence of disease and cost information, the average cost of hospitalization in Bangkok and Samut Prakhan was used as a proxy for public health costs. These costs, which are THB 7,582 and THB 3,756 per person per admission in the two regions respectively, were multiplied by 50 percent of the affected population to get health damages.

Damage costs constitute approximately 2–8 percent of 2008 GDP for events of different intensities

Since Bangkok and Samut Prakarn are the two areas that are mainly affected, flood damages are compared to their gross regional domestic product (GRDP). Under assumptions of high emissions (2050-LS-SR-SS-A1FI), the impacts of a 1-in-30-year flood in 2050 will amount to THB 148 billion (5 percent of current GRDP). A bigger 1-in-100-year flood would cost about 8 percent of current GRDP.[49] Similar sized floods would cost 1–3 percent of GRDP under a no-climate-change scenario (2008), as indicated in Table 4.4.

To carefully estimate the costs of climate change, Table 4.4 compares 2050 flood damages with climate change (2050-LS-SR-SS-A1FI) to a scenario where there is land subsidence but no climate change (2050-LS). The net impact of climate change is then the difference in costs between these two scenarios. This amounts to THB 49 billion ($1.5 billion) in 2008 values, or approximately 2 percent of 2008 GRDP.

PRIORITIZATION OF ADAPTATION OPTIONS IN BANGKOK

As discussed earlier, Bangkok has a long history of floods and its residents have developed numerous adaptation measures to cope with the risk of floods. A wealth of well-tested experience, information, and technology is already available to identify viable adaptation strategies. The Bangkok study reviewed and analyzed some of the more prominent practices and potential adaptive interventions, such as improving flood forecasting and preparing strategies for flood warnings, evacuation, transport during floods, and post-flood recovery; implementing protection (e.g. construction of dikes/seawalls) or retreat strategies for coastal development; changes in coastal development and land use; and public information campaigns and training exercises. The municipal agencies in BMR have also developed several plans for flood mitigation and drainage works that include both structural and non-structural measures. *However, these plans do not include climate change considerations*.

The Bangkok study proposes a portfolio of adaptation options in the form of structural measures that can mitigate the impact of 1-in-30-year or 1-in-100-year floods.

- The results of the simulations indicate that the crest elevations of dikes around Bangkok and along both banks of the Chao Phraya River will not be high enough to cope with flooding of more than a 10-year return period in the future. Moreover, the protected area to the west of the Chao Phraya River has insufficient pump capacity to drain the floodwater into the Tha Chin River and the Gulf of Thailand. *Thus, the first set of options includes dike and pumping capacity improvement*.

TABLE 4.4 ■ Damage Costs in Bangkok and Regional GRDP

Damage Costs	Million THB (2008)				% of 2008 GRDP			
Mill THB	C2008	C2050-LS	c2050-LS-SR-SS-A1FI	Costs of Climate Change	C2008	C2050-LS	c2050-LS-SR-SS-A1FI	Costs of Climate Change
T 10	15,248	51,819	91,118	39,299	0.52	1.78	3.12	1.35
T30	35,284	99,324	148,386	49,062	1.21	3.41	5.09	1.68
T100	79,178	185,759	243,866	58,107	2.72	6.37	8.36	1.99

Source: Based on estimates in Panya Consultants (2009).

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[49] In terms of GDP, the Bangkok study identifies the current 2008 GDP for Bangkok and Samut Prakarn to be 2,916 billion THB and estimates that GDP in 2050 will be 19,211 billion THB. All damage costs are represented in 2008 THB, thus to estimate percent of GDP, 2008 GDP values were used.

- For the eastern part of Bangkok, *pumping capacity to drain floodwater into the Bang Pakong River and the Gulf of Thailand needs to be increased*. Based on simulations, the study considers investments that would increase pumping capacity from 737 to 1,065 m^3/sec. The total capacity of canals would be improved from 607 to 1,580 m^3/sec.
- In western Bangkok, there are three major pumping stations at Khlong Phasi Charoeng, Sanam Chai, and Khun Rat Phinit Chai, which drain the floodwater into the Tha Chin River and the Gulf of Thailand with a total capacity of 84 m^3/sec. This current capacity is inadequate to cope with future climate change. *Based on simulation results, increased pumping capacities and canal improvements are proposed.*
- The BMA has proposed *coastal erosion protection, including the rehabilitation of mangrove forest along the shoreline of Bang Khun Thian*. In the eastern area of the Chao Phraya River, there are *plans to construct rock-pile embankments along the shoreline to protect the industrial community area from coastal erosion and waves*. These considerations would cost 35 and 49 billion THB to protect against floods of a 30- or 100-year return period respectively.

Table 4.5 presents the investment costs required to protect Bangkok against a 1-in-30-year flood and a 1-in-100-year flood in the context of an A1FI climate scenario. The Bangkok study estimates the total investment costs of making structural adaptations investments to be 35.3 billion THB ($1.06 billion) for a 30-year return flood protection project, and 49.5 billion THB ($1.5 billion) for 100-year return flood protection. The total annual operation and maintenance cost for 30- and 100-year return floods is estimated at 584 ($17.5 million) and 874 million THB ($26 million) respectively.

Proposed adaptation options can reduce flooded areas by 51 percent

The maximum inundation area corresponding to a 30-year return period flood with and without the proposed structural adaptation measures is presented in Figure 4.3. The maximum inundation area of Bangkok and Samut Prakarn will reduce with adaptation measures from 744.34 to 362.14 km^2, a decrease of 382 km^2 or 51 percent.

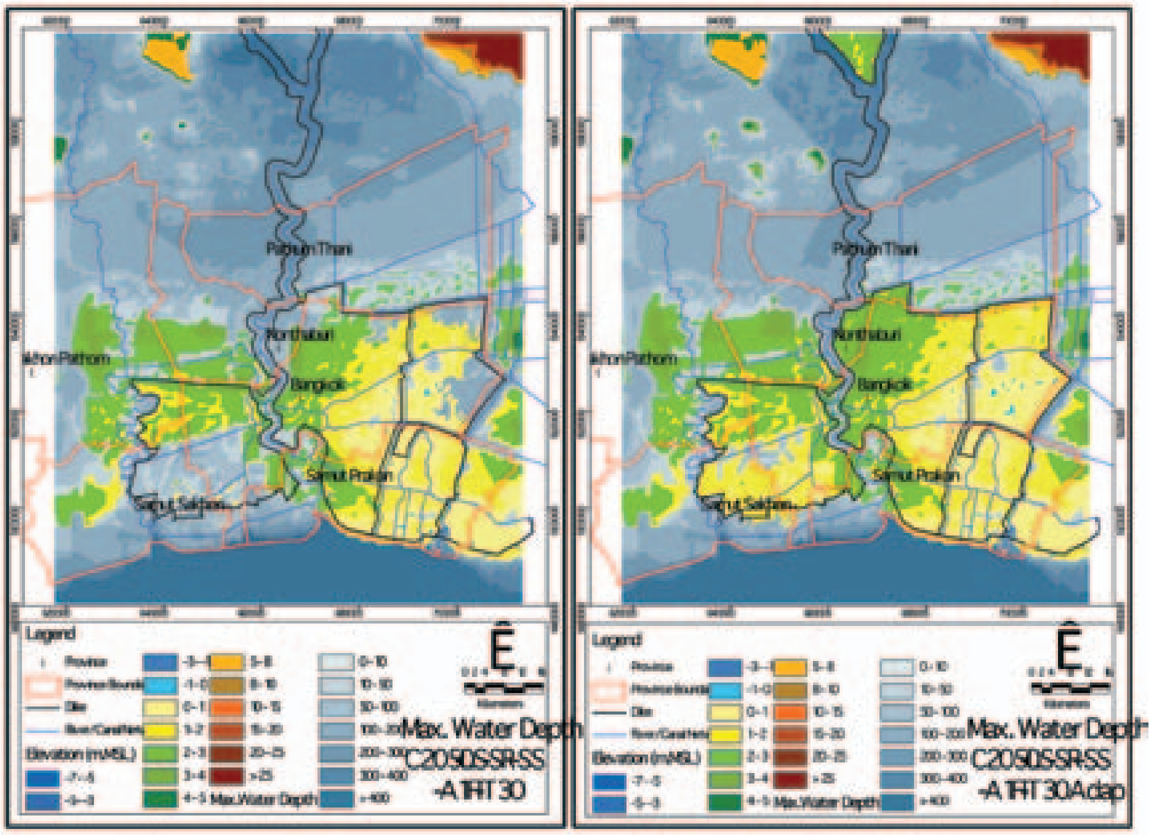
Table 4. 6 shows flood damage costs in Bangkok with and without an adaptation-related infrastructure investment project. The difference in flood damage costs "with" and "without" adaptation investments represents the benefits of the adaptation investment projects. The expected benefit of the project is the *expected annual reduction* in flood damage cost. Box 4.2 describes how the annual benefits are estimated as the *incremental* benefits of having flood control projects of different return periods. The average annual benefits (or reduction in flood damage cost) are estimated at 4.4 and 5.9

TABLE 4.5 ■ Investment Costs for Adaptation Projects in Bangkok (million THB)

	Investment Cost for 30-year Return Period				Investment Cost for 100-year Return Period			
Year	FS & DD	Civil Work	Pump	Total	FS & DD	Civil Work	Pump	Total
1	21			21	30			30
2	42			42	59			59
3	42			42	59			59
4		1,981		1,981		2,405		2,405
5		3,962		3,962		4,811		4,811
6		5,944	3,083	9,027		7,216	5,065	12,281
7		5,944	6,166	12,110		7,216	10,130	17,347
8		1,981	6,166	8,148		2,405	10,130	12,536

Source: Panya Consultants (2009).
Notes: FS=feasibility study; DD=detailed design.

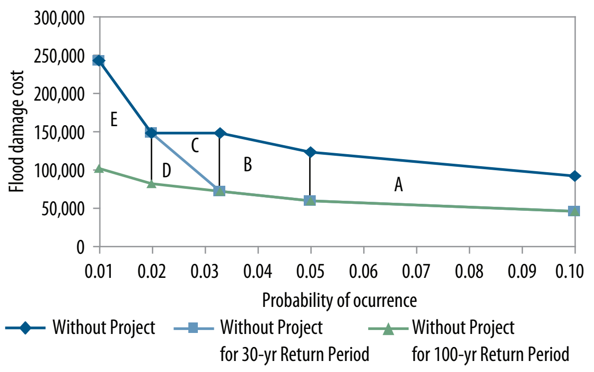
FIGURE 4.3 ■ Maximum Inundation Area Without and With the Proposed Adaptation



Source: Panya Consultants (2009).

Box 4.2 ■ Expected Annual Benefits from Adaptation in Bangkok

Annual Flood Damage Cost with and without the Project



The figure above shows flood damage costs in Bangkok with and without an adaption-related infrastructure investment project. A climate change scenario of A1FI is assumed.

Expected annual benefits from flood control investments are based on the probability of floods of different intensity (return period) occurring. Thus, the expected annual cost of flood damage is the area under the flood exceedance curve, which plots the probability of occurrence against costs of damage. Thus, the expected annual benefit from a flood protection project is the difference in the area without and with the project.

In the case of Bangkok, the expected annual benefit with an investment project for 30-year return period (or a flood infrastructure project that could handle a 30-year flood), is the sum of areas of A, B, and C. For a 100-year return period, this is the sum of areas of A, B, C, D, and E. In the context of a cost-benefit analysis of flood damages, the discounted value of the damages from a 30-year / 100-year return period project is compared to the costs of the project. This allows decision makers to look at net discounted benefits and make a decision on which investment to undertake.

Source: Zhang and Bojo (2009).

TABLE 4.6 ■ Flood Damage Costs With and Without a 30-year Return Period Flood Protection Project (million THB)

		Flood Damage Cost		Flood Damage Cost by Return	
Return Period (Year)	Probability of occurrence	Without Project	With Project	Without Project	With Project
10	0.100	91,145	45,465	9,115	4,547
20	0.050	123,308	59,337	6,165	2,967
30	0.033	148,412	71,811	4,947	2,394
50	0.020	148,412	148,412	2,968	2,968
100	0.010	243,902	243,902	2,439	2,439

Source: Panya Consultants (2009).

billion THB ($132 to $177 million) for investments that would protect against floods of 30-and 100-year return periods respectively. These benefits are estimated for the case of an A1FI climate scenario.

The viability of these investments was determined by estimating the net present value (NPV) of benefits for two scenarios. A base case considered the real value of annual benefits to be constant throughout the analysis period. The second case incorporated growth in the real value of infrastructure damage ; it was assumed that damages (or benefits from flood control) would grow at an average rate of 3 percent per year. Discount rates of 8 percent, 10 percent, and 12 percent were used to estimate the NPV.[50]

Investments to reduce the impacts of a 1-in-100-year flood economically viable for Bangkok

Table 4.7 presents the results of the NPV calculations assuming that there is 3 percent growth in the real value of damage costs. The results indicate that the flood protection was economically feasible for both floods of 30- and 100-year return periods if the opportunity cost of capital is not more than 10 percent.

From this preliminary evaluation and with the understanding that Thailand uses a discount rate of 8 percent for public investments, the Bangkok study proposes that flood infrastructure should be designed to protect against a 100-year return period flood as it provides a higher net return (NPV=13.4 billion THB, or $0.4 billion). Such an investment will be economically efficient given an A1FI climate change scenario. However, if a discount rate of 10 percent is applied, Bangkok should opt for the adaptation project aimed at a 30-year return period.

TABLE 4.7 ■ Net Present Value of Adaptation Measures to Provide Protection Against a 1-in-30 and 1-in-100-year Flood (million THB)

	Designed Flood Protection Improvement Project for					
Description	30-Year Return Period			100-Year Return Period		
Discount Rate (%)	8	10	12	8	10	12
Present Value of Costs (million Baht)	24,950	21,578	18,831	35,117	30,276	26,349
Present Value of Benefits (million Baht)	36,354	25,439	18,286	48,521	33,954	24,406
Net Present Value (NPV) (million Baht)	11,404	3,862	–545	13,405	3,678	–1,944
Benefit-Cost Ratio (B/C Ratio)	1.46	1.18	0.97	1.38	1.12	0.93

Source: Panya Consultants (2009).

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[50] The period of analysis was 38 years (2012–50), of which the first 8 years are for studying, designing, and construction, and 30 years is the economic benefit period of the project.

ANALYSIS OF DAMAGE COSTS RELATED TO FLOODING IN METRO MANILA

As discussed in the previous chapter, Manila City is a semi-alluvial plain formed by sediment flows from four different river basins. Its drainage and location between Manila Bay in the west and a large lake, Laguna de Bay to the southeast, makes it "a vast drainage basin" that is subject to frequent overflowing of storm waters. Manila is vulnerable to different types of flooding, including overbanking, storage-related floods, and interior floods.

The government of the Philippines is well aware of the flooding problems in Manila; a master plan for flood control infrastructure was developed over a decade ago. If this plan is implemented, the city will see a significant decline in flood impacts. Thus, the Manila study discusses the implications of climate change in the context of the master plan as well as what would happen without it. Like Bangkok, the Manila study examines flooding impacts in three climate change scenarios (no change, B1, and A1FI). Overall, the Manila study identifies impacts in terms of damage costs in relation to 18 different scenarios. In evaluating costs in dollars, an average exchange rate for 2008 of 1USD = 44.47 PHP was used.

The Manila case study, like Bangkok, uses a sectoral approach to estimate costs. Flood-related costs are a result of (a) building damages; (b) losses to public infrastructure and utilities; (c) income losses to firms and residents; and (d) income losses from transportation blockages. It undertakes a more detailed analysis of the transport sector and identifies increased costs associated with flood-related traffic disruptions. The study assumes that the value of various costs in 2050 are much higher than 2008, and that these costs generally increase at a rate of 5 percent per year. However, in the paragraphs below, the 2008 values of all costs are reported in order to enable a comparison across cities. Like the Bangkok study and as noted in chapter 3, the Manila case study makes a series of assumptions in valuing damages and uses best available information to obtain cost estimates. Thus, damage cost estimates are better viewed as an indicator of damages rather than as point estimates of actual costs that may be incurred.

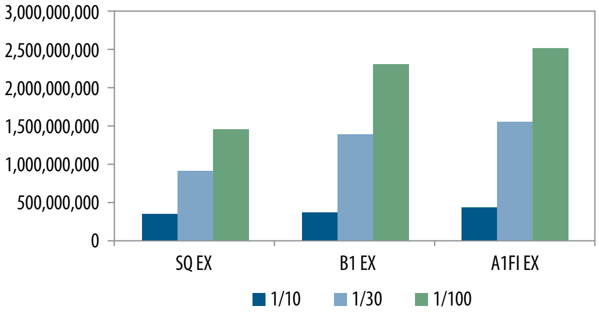
Flooding in Manila can cause varying damages ranging from $109 million to $2.5 billion in different current and future scenarios

Flood costs as a result of various climate and infrastructure scenarios are presented in Table 4.8. The table presents flood damages associated with floods of three different intensities (1/10, 1/30, and 1/100) under current no-climate-change conditions (SQ), under scenarios where flood control infrastructure is in place (MP) or not (EX), and under two climate change scenarios (A1FI and B1). Flood-related costs range from 5 billion PHP ($109 million)—in a scenario where this a 1-in-10-year flood, master plan infrastructure is in place, and there is no climate change (10-SQ-MP)—to 112 billion PHP ($2.5 billion) in a situation where the planned infrastructure is not in place and climate change contributes to a 1-in-100-year flood (100-A1FI-EX).

Figure 4.4 shows the effects of different intensity floods in different climate scenarios, given Manila's existing flood control infrastructure. It is useful to consider the impact, for example, of a medium-sized 1-in-30-year flood. A 1-in-30-year flood would cost $0.9 billion in a no-climate-change scenario (30-SQ-EX). These costs would increase by 72 percent to $1.5 billion in the case of climate change (30-A1FI-EX). In a B1 climate change scenario, the cost would increase by 55 percent to $1.4 billion.

Figure 4.5 presents the loss exceedance curves for Manila. This shows the cost of floods increasing

FIGURE 4.4 ■ **Flood Costs under Three Return Periods and Two Climate Scenarios (PHP)**



Source: Based on estimations in Muto et al. (2010).

TABLE 4.8 ■ Flood Damage Costs in Manila (2008 PHP)

Cost in 2008 in Pesos		P10 SQ EX	P10 SQ MP	P10 B1 EX	P10 B1 MP	P10 A1FI-EX	P10 A1FI MP
Damages to Buildings	Residential	785,486,988	320,880,033	842,295,372	491,606,130	595,395,243	546,225,294
	Commercial	8,641,501,748	610,789,400	9,658,314,207	1,611,046,487	13,750,520,244	2,326,289,074
	Institutional	66,863,814	20,189,999	91,707,535	37,209,916	96,826,650	37,268,296
	Industrial	2,890,401,496	1,173,449,757	2,414,697,965	1,461,799,749	1,756,641,760	1,346,409,219
Maintenance cost	Current roads	1,162,100	346,199	1,587,787	463,132	2,632,955	543,277
	Future roads	44,014	30,219	44,014	31,532	91,969	38,102
Vehicle operating costs		8,823,186	2,628,501	12,055,195	3,516,306	19,990,575	4,124,802
Travel time cost savings		33,199,847	8,380,787	45,754,992	11,655,307	71,672,669	13,646,330
Loss to Firms	Sales	2,816,137,180	2,704,662,851	2,961,770,824	2,822,212,152	3,044,628,088	2,881,793,868
Income loss of settlers	Formal settlers	32,629,500	20,444,625	49,763,250	26,401,500	49,437,000	29,098,125
	Informal settlers	85,652	51,072	151,620	51,072	255,892	72,352
Total		15,276,335,523	4,861,853,444	16,078,142,760	6,465,993,284	19,388,093,046	7,185,508,737
Total USD		343,484,797	109,317,627	361,513,243	145,386,332	435,936,694	161,564,467
Cost in 2008 in Pesos		P30 SQ EX	P30 SQ MP	P30 B1 EX	P30 B1 MP	P30 A1FI-EX	P30 A1FI MP
Damage to Buildings	Residential	1,802,689,882	399,849,739	3,660,228,253	549,439,668	4,210,760,389	637,339,590
	Commercial	22,710,938,518	2,273,492,105	35,692,199,142	7,069,333,943	39,538,199,655	10,143,817,110
	Institutional	158,250,637	23,533,947	270,248,699	85,001,479	334,199,868	96,920,697
	Industrial	4,216,676,982	1,330,430,240	9,932,796,023	2,657,311,465	11,606,388,976	3,456,942,255
Maintenance cost	Current roads	5,286,655	1,102,956	6,846,841	1,937,811	7,482,737	2,313,418
	Future roads	244,376	244,376	302,185	302,185	329,119	329,119
Vehicle operating costs		40,138,658	8,374,141	51,984,296	14,712,729	56,812,303	17,564,506
Travel time cost savings		374,633,321	31,760,926	421,032,785	74,184,136	573,888,428	85,170,808
Loss to Firms	Sales	10,756,786,447	3,281,670,824	11,832,564,006	4,515,810,393	12,434,679,407	5,075,470,880
Income loss of settlers	Formal settlers	93,848,625	39,640,500	184,246,875	49,636,125	196,321,500	51,926,625
	Informal settlers	4,731,076	92,036	5,367,880	111,188	5,750,388	118,636
Total		40,164,225,177	7,390,191,790	62,057,816,985	15,017,781,123	68,964,812,770	19,567,913,643
Total USD		903,083,118	166,166,717	1,395,355,360	337,671,262	1,550,657,529	439,979,917

(Continued to next page)

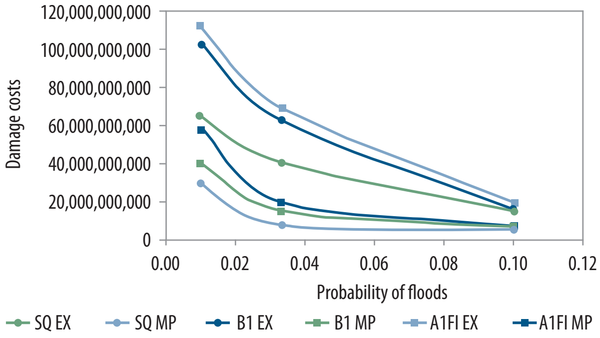
TABLE 4.8 ■ Flood Damage Costs in Manila (2008 PHP) (*Continued*)

Cost in 2008 in Pesos		P100 SQ EX	P100 SQ MP	P100 B1 EX	P100 B1 MP	P100 A1FI-EX	P100 A1FI MP
Damage to Buildings	Residential	3,688,647,788	1,045,670,772	6,022,893,816	1,326,288,039	7,517,544,912	2,101,690,472
	Commercial	37,699,327,245	15,298,341,749	63,871,514,594	25,506,211,401	68,021,524,157	37,713,082,264
	Institutional	298,785,692	158,994,559	485,447,235	173,893,911	1,874,981,233	253,765,175
	Industrial	8,650,623,155	5,694,313,706	16,556,719,073	5,532,356,399	17,850,618,995	9,193,023,327
Maintenance costs	Current roads	8,143,240	3,010,272	9,677,159	4,831,659	10,443,791	5,780,183
	Future roads	360,001	360,001	485,467	485,467	524,226	524,226
Vehicle operating costs		50,729,576	22,855,337	62,246,103	36,684,130	68,001,872	43,885,751
Travel time costs		706,986,380	277,477,558	1,082,134,984	197,675,748	1,420,426,406	340,173,579
Loss to Firms	Sales	13,403,412,143	6,567,976,899	14,085,687,162	7,745,705,319	14,639,854,088	8,339,388,091
Income loss of settlers	Formal settlers	214,933,500	67,473,375	230,942,250	95,140,125	481,092,750	105,586,875
	Informal settlers	6,050,968	584,668	6,881,952	1,247,540	7,089,432	2,091,824
Total (PHP)		64,727,999,688	29,137,058,896	102,414,629,796	40,620,519,739	111,892,101,862	58,098,991,768
Total (USD)		1,455,393,788	655,139,889	2,302,768,766	913,342,794	2,515,867,487	1,306,342,110

1 USD=44.474561 PHP

Source: Muto et al. (2010).

FIGURE 4.5 ■ Loss Exceedance Curves for Manila (PHP)



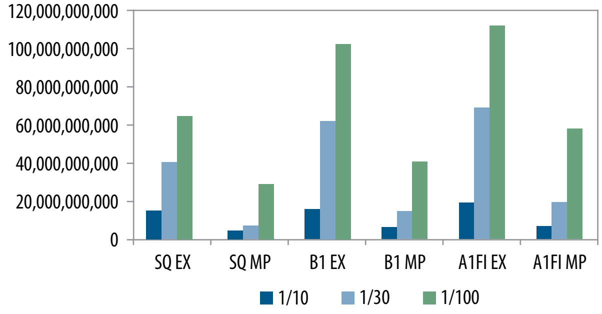
Source: Based on estimations in Muto et al. (2010).

as the probability of their occurrence decreases. As previously discussed, the area beneath each curve represents the average total annual *expected* damage costs from floods of all intensities (also see adaptation section). Note that the loss exceedance curve is highest for the A1FI emissions scenario (A1FI-EX). Climate change increases the extent of damages in all types of floods.

Implementing existing Master Plans related to infrastructure development will significantly reduce flooding related costs

As Figure 4.6 shows, under each climate scenario, implementing the master plan will result in a significant reduction in costs. In an A1FI climate change scenario, for example, a 1-in-30-year flood will result in damages to the extent of PHP 69 billion ($1.5 billion) without the master plan and PHP 19 billion ($427 million) with the master plan implemented, so implementing the master plan would reduce flood damages by over 70 percent, given climate change and the possibility of a 1-in-30-year flood. Thus, a very good starting point for Manila, in terms of its response to climate change, would be to reconsider and evaluate the master plans that are already on the books.

FIGURE 4.6 ■ Damage Costs Associated with Different Scenarios (PHP)



Source: Based on estimations in Muto et al. (2010).

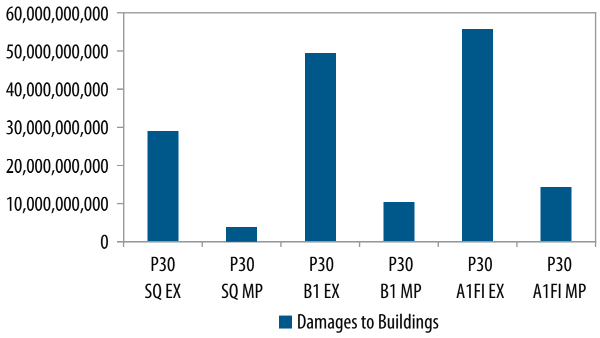
Building damages make up a major portion of flood-induced costs

The single most important contributor to total damage costs in each of the climate scenarios is damage to buildings. Approximately 72 percent of the costs from a 1-in-30-year flood (averaged across all scenarios), for instance, result from damage to buildings. Figure 4.7 shows the damage to buildings in the case of a 1-in-30-year flood. The damages are significant. Implementing the master plan will reduce damages significantly. In the case of a 1-in-30-year flood with an A1FI emissions scenario, implementing the master plan will reduce damages to buildings by 74 percent (relative to A1FI-EX).

Income losses from climate change associated floods will increase by 9 to 16 percent

Floods will result in income or revenue losses to individuals and firms. A 1-in-30-year flood with

FIGURE 4.7 ■ Damages to Buildings from a 1-in-30-year Flood (2008 PHP)



Source: Based on estimations in Muto et al. (2010).

TABLE 4.9 ■ Income and Revenue Losses to Individuals and Firms Associated with Floods (2008 PHP)

Flood Intensity	SQ EX	A1FI-EX	Income Costs of Climate Change (A1FI)	% increase in income costs from Climate Change
T 10	2,848,852,332	3,094,320,980	245,468,648	9
T 30	10,855,366,148	12,636,751,295	1,781,385,147	16
T 100	13,624,396,611	15,128,036,270	1,503,639,659	11

Source: Muto et al. (2010).

an AIFI climate scenario, for instance, will result in income losses to the extent of 12.6 billion PHP ($284 million) (Table 4.9). Significant income losses are expected for residents of parts of Manila. The population in the Pasig-Marikina River basin in Manila and Malabon and Navatos in Kamanava are most likely to be affected.

Examining a with (A1FI) and without (SQ) climate change scenario, Table 4.9 shows that climate change is likely to contribute to a 9 percent increase in income losses given a 1-in-10-year flood, a 16 percent increase in income losses from a 1-in-30-year flood, and an 11 percent increase in income losses if a 1-in-100-year flood occurs. More than 95 percent of the flood-related income losses, however, will be a result of losses borne by firms.[51] Given a 1-in-30-year flood, firms will see a 16 percent increase in costs in a climate change (T30 A1FI-EX) relative to a no-climate-change scenario (T 30 SQ EX). Comparing the same scenarios, formal settlers or residents [52] will see an over 100 percent increase in costs. Informal settlers will see their damage costs from flooding increase by 22 percent as a result of climate change associated with a 1-in-30-year flood.

Sectoral Impacts will Vary

Most of the power stations that distribute energy to Manila will not be damaged by floods because of their location on high ground. However, a few substations in the flood-prone areas may be shut down for a few hours if flood waters reach the ground level. This would mostly lead to some revenue losses because of closure. In terms of water and sanitation services, piped water supply is not expected to be affected by flooding. Water pressure within pipes is expected to be strong enough to prevent infiltration by contaminated water. Pumping stations are also above flood level. Floods will affect many roads in Manila and will render them not passable. A 1-in-100-year flood in a climate change scenario, for example, is likely to inundate over 30 km of roads. Some parts of Manila's rail system will be affected by flooding, particularly if power cuts occur during floods. Under some flooding scenarios, the railway system, LRT1 will be affected by power cuts and could be stopped.

Increase in cost of flooding on road networks

Road and transportation delay-related damages from a 1-in-30-year flood with climate change (A1FI-EX) would be 638 million PHP ($14 million). This represents an over 52 percent increase in costs relative to a no-climate change scenario (SQ EX). Over 90 percent of the road and transport-related costs are related to time-cost delays from traffic disruptions.

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[51] Because of lack of data, the Manila case study uses revenues instead of net revenue losses to firms. Thus, firm-related losses are likely to be overestimated. A 2008 survey on business income losses to firms is used to examine the costs of flooding to business. The average income or sales data was obtained for firms that undertake different economic activities such as manufacturing, construction, hotels, and so on. Affected buildings were classified according to different uses and the sales losses from each of the buildings obtained, assuming one firm per floor.

[52] The income of individuals directly affected by floods is difficult to measure. The Manila study assesses income by first estimating the number of households that are affected by flooded buildings. The income loss to these households is then estimated using average per capita income data from the National Statistics Office.

BOX 4.3 ■ Increased Time Costs and Health Risk from Flooding in Manila

The Manila study aggregates two different estimates to establish the cost of flooding on road networks. It estimates the cost of maintenance on flood-affected roads and adds to this the cost of delays to private individuals that would result from flooding. The cost of delays in travel because of floods are categorized into vehicle operating costs and time costs. Vehicle operating costs are estimated by examining the increased operating costs as a result of flooding for public and private vehicles. For time costs, the Manila study relies on a survey of travelers and uses the average value of time to evaluate private individuals time costs—separate costs are obtained for individuals using private and public transportation.

The Manila study assesses the increase in likely gastrointestinal diseases as a result of water ingestion and exposure to pathogens in flood water. Based on coefficients from a dose-response model and the average number of floods that occur per year, the study estimates the increase in the annual risk in gastrointestinal diseases in the areas that are likely to be flooded. The risk of gastrointestinal diseases from accidental ingestion of water rose from 0.0134 at inundation levels of 50 cm of flood waters to 0.187 for inundation levels above 200 cm of flood water. This analysis, while undertaken, was not directly used in the damage cost assessment.

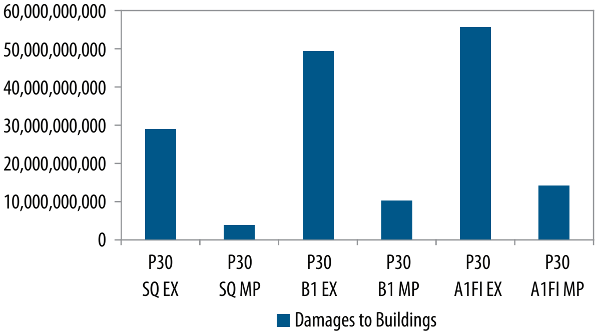
Source: Muto et al. (2010).

Floods of different intensity can cost between 3 percent and 24 percent of GDP

Table 4.10 compares a "without climate change" (SQ EX) and "with climate change" (A1FI-EX) scenario, indicating that the costs of flooding can range from PHP 15 billion ($337 million) (SQ-EX-10) to PHP 111 billion ($2.5 billion) (A1FI-EX-100). Since these numbers are presented in 2008 values, we can compare them to Metro Manila's regional GDP of 468 billion PHP (National Statistical Coordination Board). Damage costs range from 3 percent of GDP (SQ-EX-10) to 24 percent (A1FI-EX-100).

The costs of climate change range from PHP 4 billion ($89 million) (1/10 flood) to 47 billion PHP (approximately $ 1 billion) (1/100 flood). As Figure 4.8 shows, climate change costs represent 1 percent (1-in-10 flood), 6 percent (1-in-30 flood) and 10 percent (1-in-100 flood) of GDP.

FIGURE 4.8 ■ Flood Costs as a Percent of 2008 GDP



Source: Based on estimations in Muto et al. (2010).

TABLE 4.10 ■ Damage Costs from 1-in-10, 1-in-30, and 1-in-100-year Floods in Different Scenarios (2008 PHP)

Flood Intensity	SQ EX	A1FI-EX	Climate Change Damage Costs (2008 PHP) with an A1FI Scenario with EX
1/10	15,276,335,523	19,388,093,046	4,111,757,522.59
1/30	40,164,225,177	68,964,812,770	28,800,587,593.15
1/100	64,727,999,688	111,892,101,862	47,164,102,174.61

Source: Muto et al. (2010).

PRIORITIZATION OF ADAPTATION OPTIONS IN MANILA

The Manila case study looked at a variety of adaptation options that could reduce the impact of 1-in-30 and 1-in-100-year floods. The adaption options examined included improving current practices, capacity building and better coordination among local government and national flood management agencies and structural measures such as dam construction, raising dikes, and improved pumping capacity that would reduce and/or eliminate the impacts of floods.

Manila targets adaptation options that would almost eliminate floods in the Pasig-Marikina River basin

Several structural measures are examined in order to analyze the economic implications of these investments. The Manila study focused on analyzing adaptation options that could eliminate floods to the extent possible.[53] These include:

- Pasig-Marikina River: In this area, in order to prevent overbanking and flooding from the river, investments in raising the embankment are considered. Embankment raising is considered both with the possibility of building the Marikina Dam and without. The Marikina Dam was initially proposed as part of the 1990 master plan and would be able to prevent a 1-in-100-year flood.
- West of Mangahan and KAMANAVA area: In these areas, improved pumping capacity and storm surge barriers are required to reduce floods. The investment required for installing pump capacity to control flooding under an allowable inundation depth of 30 cm is considered. For preventing overflows from Manila Bay caused by typhoons, the study looks at options for increasing the height of storm surge barriers in coastal areas.

The Manila study examines adaptation options among a number of different scenarios involving different types of construction in different areas. Table 4. 11 identifies the options that were considered under each scenario. Notably, while the Bangkok study looks at adaptation only in the context of an A1FI scenario, the Manila case study looks at adaptation options in the context of no-climate-change (SQ), B1 and A1FI scenarios. The Manila study also explores scenarios in which a major investment in constructing the Marikina dam is undertaken (wD) and cases where the dam is not constructed (nD). The costs of adaptation are also considered in the context of whether the existing master plan (MP) is implemented or not (EX).

Table 4.12 presents the estimated initial costs of each adaptation option considered.[54]In this analysis, the construction period considered is 5 years starting from 2010 and the project's life is expected to last until 2060. Investments after the completion of the master plan are assumed to start from 2014. No maintenance cost was included.

The incremental benefits of moving from the current situation to full adaptation and from implementing the master plan and then moving to full adaptation considered

The investment costs (assumed to occur over a 5-year period) are compared with the incremental *expected annual benefits* from flood reduction associated with a 1-in-10-year, 1-in-30-year, and 1-in-100-year flood protection projects. The incremental benefits emerge from adaptation investments that would take Metro Manila from its:

- existing infrastructure (EX) to full adaptation level (difference between EX and full adaptation in Figure)
- 1990 master plan level (MP) to full adaptation level (difference between MP and full adaptation in Figure)

The annual benefits are identified in Figure 4.9. The area between the existing infrastructure curve and full adaptation level are the annual benefits from making investments in the current situation where the master plan has not been implemented. The area between the master plan curve and the full adaptation level refers to the annual benefits from going beyond the master plan.

In the cost benefit analysis of the different investments, flood control benefits are assumed to grow at an annual rate of 5 percent. The net present value (NPV) of benefits was obtained using a dis-

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[53] For KAMANAVA and West of Mangahan areas, total elimination is not possible because of their low height. Rather, pumping capacity improvement is considered to minimize the duration of the flooding.

[54] For each scenario only certain types of adaptation investments are considered. For example, in a B1EXwD scenario, there is no investment considered for a 1/10 flood since this scenario already includes a dam, which is expected provide protection for a 1/10 flood.

TABLE 4.11 ■ Adaptation Investments Considered for Different Return Periods and Climate Scenarios

		Adaptation Investment Options/Costs Considered		
Climate	Scenario	1/10 flood	1/30 flood	1/100 flood
SQ	SQ EX wD		Pasig Marikina River embankment + Marikina Dam	Pasig Marikina River embankment+ Marikina Dam
	SQ EX nD	Storm surge barrier	Pasig Marikina River embankment	
	SQ MP wD		Marikina Dam in addition to investments already considered under the MP	0 costs because flood prevention costs, including Marikina Dam, area already incorporated into the MP
	SQ MP nD		0 costs because additional flood prevention investments are already incorporated under the MP	
B1	B1 EX wD		Pasig Marikina River Embankment + Additional embankment in Marikina River + Marikina Dam + storm surge barrier	Pasig Marikina River embankment + Marikina Dam +additional embankment in Pasig and Marikina River basin
	B1 EX nD	Storm surge barrier + Pump capacity improvement (KA-MANAVA +West of Mangahan)	Pasig Marikina River embankment +additional embankment in Marikina River + storm surge barrier	
	B1 MP wD		Additional embankment in Marikina River + Marikina Dam	Additional embankment in Pasig and Marikina River basin
	B1 MP nD		Additional embankment in Marikina river	
A1FI	A1FI-EX wD		Pasig Marikina River embankment +additional embankment in Marikina River + Marikina Dam + storm surge barrier	Pasig Marikina River embankment + Marikina Dam +additional embankment in Pasig and Marikina River basin
	A1FI-EX nD	Storm surge barrier + Pump capacity improvement (KA-MANAVA +West of Mangahan)	Pasig Marikina River embankment +additional embankment in Pasig and Marikina River + storm surge barrier	
	A1FI MPwD		Additional embankment in Marikina River + Marikina Dam	Additional embankment in Pasig and Marikina River basin
	A1FI MP nD		Additional embankment in Pasig and Marikina River	

TABLE 4.12 ■ Investment Costs and Net Present Value of Benefits Associated with Different Flood Control Projects in Manila (PHP) using a 15 percent discount rate

		1/10 Flood		1/30 Flood		1/100 Flood	
Climate	Scenario	Investment Cost	NPV	Investment Cost	NPV	Investment Cost	NPV
SQ	SQ EX wD	NA		14,121,102,133	809,000,801	13,501,553,721	3,763,340,285
	SQ EX nD	42,887,291	209,952,438	10,943,489,020	2,939,371,200	NA	
	SQ MP wD	NA		3,177,613,113	1,199,401,356	0.00	4,755,005,784
	SQ MP nD	NA		0.00	3,329,771,755	NA	
B1	B1 EX wD	NA		14,232,087,722	5,634,294,466	13,604,450,310	10,150,493,344
	B1 EX nD	1,003,222,253	(349,951,115)	11,054,474,609	7,764,664,865	NA	
	B1 MP wD	NA		3,216,390,949	3,512,076,308	102,896,589	7,587,409,494
	B1 MP nD	NA		38,777,837	5,642,446,707	NA	

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TABLE 4.12 ■ Investment Costs and Net Present Value of Benefits Associated with Different Flood Control Projects in Manila (PHP) using a 15 percent discount rate (*Continued*)

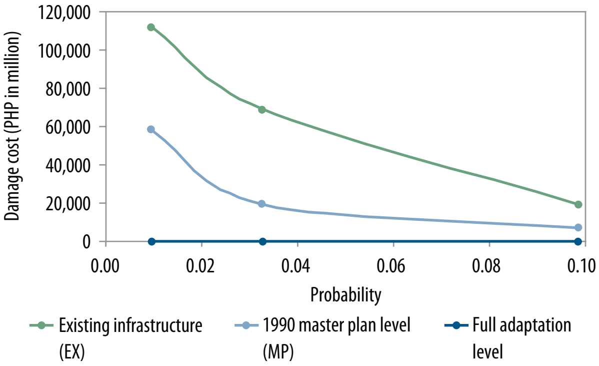
		1/10 Flood		1/30 Flood		1/100 Flood	
Climate	Scenario	Investment Cost	NPV	Investment Cost	NPV	Investment Cost	NPV
A1FI	A1FI-EX wD	NA		14,248,304,696	7,092,797,122	13,640,673,269	12,011,488,435
	A1FI-EX nD	1,409,166,226	(581,704,127)	11,099,925,438	9,203,568,238	NA	
	A1FI MP wD	NA		3,216,390,949	5,509,802,569	139,119,548	10,411,715,022
	A1FI MP nD	NA		68,011,692	7,620,573,684	NA	

Source: Muto et al. (2010).

SQ=Status Quo, EX=Existing Infrastructure, B1, A1FI=Climate Change Scenarios, wD=With Marikina Dam, nD=No Dam, NA=not applicable. Costs are 0 in certain cases because it is assumed that these costs are incorporated in the master plan.

count rate of 15 percent, which is what is used by the Philippines National Economic and Development authority to estimate project feasibility.[55]

FIGURE 4.9 ■ Annual Benefits from Adaptation Investments in Metro Manila



Source: Based on estimations in Muto et al. (2010).

Dam construction emerges as an economically viable option in both climate change scenarios, followed by embankment building in the Pasig-Marikina basin

Table 4.12 presents the present value of net benefits from different investments considered. The NPV at12 billion PHP ($269 million) is highest among all the different scenarios. This suggests that constructing the Marikina Dam would maximize benefits relative to other adaptation options in the case of an A1FI or B1 scenario. The investments that would be required in this scenario are building the Pasig-Marikina River basin embankment, the Marikina Dam, and some additional embankments along the Pasig and Marikina rivers. These investments would largely eliminate floods in this part of Metro Manila.

However, given that constructing the dam is a decision that may or may not be taken, it is useful to consider what alternative options emerge. In this case, in an A1FI scenario it is recommended that the Pasig Marikina River embankment be built with some additional components along the Pasig and Marikina rivers, and that storm surge barriers be constructed. This basically means that investments under the current master plan in the Pasig-Marikina River basin should be prioritized and continued and some additional investments need to be made for full adaptation to an A1FI climate. This is what is currently being undertaken by the government of the Philippines in implementing the Pasig-Marikina Flood Control Project Phase II to avoid damages from P30 floods. The recommendations in the context of a B1 climate change scenario are similar. In sum, the first priority is to control flooding in the Pasig-

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[55] It is important to note that the total avoided damages (gross) in chapter 3 do not directly feed into the NPV calculations. This is because there are three geographical areas, and depending on the return period and adaptation investments, only the relevant benefits are considered for each scenario. (For example, the embankment for Pasig-Marikina River does not affect KAMANAVA coastal area and there is thus no benefit in that area).

Marikina River areas through a dam, embankments, and storm surge barriers. While adaptation to climate change would require significant investments, in the case of Metro Manila, these are investments that are already planned. Thus, climate change adaptation would require the government to commit to implementing plans that are currently on the books.

ANALYSIS OF DAMAGE COSTS IN HCMC

HCMC has a long history of extreme weather events. Between 1997 and 2007, almost all of the districts of Ho Chi Minh City have been directly affected by natural disasters to some extent. The total value of damage to property from natural disasters over the last 10 years is estimated at over $12.6 million (202 billion VND). Most impacts have been concentrated in the predominantly rural Can Gio and Nha Be districts. However, with increased levels of flooding and extreme events due to climate change, urban areas are likely to suffer increasing levels of damage. This is likely to increase costs significantly.

The HCMC study used a different approach from Bangkok and Manila to estimate the aggregate costs of climate change impacts to 2050. It does not take a sectoral approach and estimate in detail the costs that will be incurred as a result of climate change. While areas of vulnerability and risks are clear, there has been no attempt to value specific risks directly. Rather, a first approximation of the likely costs of climate change is undertaken based on macro data. Further, the HCMC study estimates the present value of flooding from the current period up to 2050. Thus, it presents cost estimates today that reflect repeated flooding over a long period of time. In contrast, the Manila and Bangkok studies estimate the costs of specific single events of flooding in different scenarios.

As discussed in chapter 2, the HCMC study uses two approaches to estimate the costs of climate change: (1) cost estimates based on expected lost land values; and (2) cost estimates based on aggregate GDP loss. To recap briefly, the land value method estimates how climate change may affect the value of the land stock in HCMC. The first step in the analysis was to determine land prices. The area subject to flooding both in extreme events and regular flooding was then determined under future scenarios using HydroGIS modeling. Once average land price and flooding extent and duration were estimated, the relationship between the flooding and the decline in the economic value of the flooded land was determined to calculate the cost of flooding due to climate change. The value of land affected by flooding is assessed assuming linear and quadratic relationships between flood duration and land values. The second approach used by HCMC is to calculate costs on the basis of expected losses in production (proxied by GDP) due to climate-change-induced flooding. For each district and for each year (2006 to 2050), the annual cost of flooding was calculated and the discounted costs summed for the whole period to find the present value of expected lost GDP. In the following pages and the rest of this report, an average exchange rate for 2008 of 1 USD = 16302.25 VND is used to convert Vietnamese dong to U.S. dollars.

Macro level analyses suggest that there will be significant costs as a result of climate change

The study estimates that the losses in the economic value of land affected by 2050 climate change would range from VND 100,358 billion ($6.15 billion) for regular flooding to VND 6,905 billion ($0.42 billion) for extreme flooding, assuming a quadratic relationship between flood duration and land value (Table 4.13).[56] The HCMC study also reports climate change costs assuming a linear relationship between flood duration and land values. In this context, the cost of climate change is estimated to be VND 369,377 billion ($22.7 billion) for regular floods and VND 111,678 billion ($6.9 billion) for extreme events. *The highest costs (using either method) are borne by Binh Chanh district, district 9, Can Gio, and Nha Be district*.

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[56] In all estimates, the costs of extreme events are much smaller than those of regular flooding because (a) flooding due to extreme events lasts for a smaller number of days than that for regular flooding; and (b) the calculation of flooding assumes a return period of 30 years for extreme flooding. The expected value in any given year is therefore 1/30th of the cost of an extreme event.

Uncertainty in the estimation of costs

These land-based estimates represent a first approximation of potential losses. There remains considerable uncertainty as to how land values may be impacted by increases in the frequency or duration of flooding. To the extent that the impacts of existing flood events (climate variability) have already been capitalized in the price of land, the above results should be interpreted as the possible changes in land values resulting from additional (and as of now unexpected) days of flooding resulting from climate change.

Using the GDP loss estimation method (Table 4.14), the cost of regular flooding in terms of GDP loss is estimated to be about VND 806,831 billion ($49.5 billion) in present value terms. The cost of extreme flooding is estimated to be approximately VND 7,978 billion ($0.49 billion).

TABLE 4.13 ■ Expected Cost of Flooding based on Quadratic Relationship between Duration of Flooding and Land Values in HCMC

District	Flooded area (ha)		Average duration (days)		Land value (1,000VND/sq.m)	Expected cost (billion VND)	
	Regular	Extreme	Regular	Extreme		Regular	Extreme
1	34	249	81	12	22,410	380	60
2	3,036	4,115	127	22	1,556	5,719	233
3	0	105	0	0	17,407	0	0
4	78	348	21	6	7,369	19	7
5	12	243	95	10	12,946	103	24
6	45	594	4	2	8,508	0	2
7	1,004	2,451	52	9	4,070	830	61
8	655	1,768	12	4	4,318	31	9
9	5,877	6,696	140	28	1,621	14,014	639
10	30	198	88	11	10,759	189	19
11	14	99	73	11	7,245	40	7
12	2,241	2,465	140	29	2,043	6,735	318
Go Vap	184	455	65	12	4,072	237	20
Binh Thanh	685	1,383	62	10	10,127	2,001	105
Phu Nhuan	0	9	0	0	9,234	0	0
Thu Duc	1,593	1,913	95	21	3,995	4,312	253
Cu Chi	7,234	10,875	117	26	717	5,330	396
Hoc Mon	3,538	5,040	155	35	1,237	7,892	573
Nha Be	7,948	8,421	95	20	1,778	9,572	450
Can Gio	46,435	48,486	88	20	423	11,417	616
Tan Phu	0	45	0	0	4,796	0	0
Tan Binh	0	58	0	1	4,934	0	0
Binh Tan	917	2,300	29	12	1,932	112	48
Binh Chanh	18,890	22,057	83	24	3,217	31,423	3,068
Total	100,450	120,372			VND	100,358	6,905
Total (USD)						6.156083	0.4235612

Source: ADB (2010). Some differences due to exchange rate variations.
1 USD=16302.25

TABLE 4.14 ■ Present Value of the Cost of Floods up to 2050 using the GDP Estimation Method

District	Regular Flooding GDP Loss (VND)	Extreme Flooding GDP Loss (VND)	Total GDP Loss (VND)
District 1	4,262,678,022,700	118,930,920,400	4,381,608,943,100
District 2	91,872,408,828,200	684,250,653,100	92,556,659,481,300
District 3	—	1,045,570,300	1,045,570,300
District 4	2,111,546,363,400	79,830,492,300	2,191,376,855,700
District 5	2,036,113,916,300	63,099,964,700	2,099,213,881,000
District 6	102,479,383,000	23,505,283,400	125,984,666,400
District 7	23,901,066,736,700	319,603,147,100	24,220,669,883,800
District 8	3,089,545,724,600	162,117,638,100	3,251,663,362,700
District 9	203,476,562,493,300	1,573,188,396,600	205,049,750,889,900
District 10	5,608,083,746,600	104,469,939,500	5,712,553,686,100
District 11	1,631,296,447,400	36,684,956,800	1,667,981,404,200
District 12	107,560,392,251,700	816,151,762,100	108,376,544,013,800
District Go Vap	13,980,278,430,700	30,422,891,000	14,010,701,321,700
District Tan Binh	—	1,135,984,100	1,135,984,100
District Binh Thanh	43,871,270,790,100	414,883,343,800	44,286,154,133,900
District Phu Nhuan	—	2,004,000	2,004,000
District Thu Duc	59,101,002,606,400	533,992,286,200	59,634,994,892,600
District Cu Chi	28,955,319,716,000	365,741,723,400	29,321,061,439,400
District Hoc Mon	44,762,782,087,100	565,835,862,900	45,328,617,950,000
District Binh Chanh	97,469,697,076,900	1,276,837,444,400	98,746,534,521,300
District Nha Be	42,592,220,679,200	331,433,560,700	42,923,654,239,900
District Can Gio	24,169,804,222,200	206,645,566,200	24,376,449,788,400
District Tan Phu	—	23,680,600	23,680,600
District Binh Tan	6,276,999,023,500	268,297,958,200	6,545,296,981,700
Total	806,831,548,546,000	7,978,131,029,900	814,809,679,575,900
USD	49,492,036,286	489,388,338	49,981,424,624

Source: ADB (2010). Some differences due to exchange rate variations.
1 USD=16302.25

Table 4.15 presents a summary of the cost estimates from HCMC based on different methodologies. In summary, a first approximation of the costs of climate change for regular flooding events is between $6.15 billion and $49.5 billion in present value terms, and between $0.42 billion and $6.9 billion for extreme flooding.[57]

The results of the two damage valuations show considerable divergence, with GDP figures suggesting double the damage costs achieved using the land value methodology. This may result from two different factors. First, it is well known that administratively determined land prices (as opposed

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[57] The HCMC numbers are much higher than the damage costs associated with flooding in Manila and Bangkok. However, as previously noted, these numbers reflect the sum of a series of annual damages that are expected to occur from now up to 2050 and are not directly comparable with the damage costs of one event in Bangkok or Manila.

TABLE 4.15 ■ Summary of Present Value of Climate Change Costs in HCMC (USD)

	Regular Flooding	Extreme Flooding	Total
Land (linear)	22,658,038,001	6,850,465,427	29,508,503,427
Land (quadratic)	6,156,082,749	423,561,165	6,579,643,914
GDP	49,492,036,285	489,388,337	49,981,424,623

Source: ADB (2010). Some differences due to exchange rate variations.
1 USD=16302.25

to market prices for land) undervalue land in the city. On this basis alone, had market prices for land values been used instead of administratively determined land prices (which were effectively used), the estimated cost of climate change using land values would have been higher than presented earlier. Second, GDP per capita figures at the district level were unavailable. This may overestimate the GDP loss across the city as rural districts in the south such as Can Gio and Nha Be are responsible for very little GDP production, and yet which may be more vulnerable to climate change. Further detailed investigations and data collection would be required to refine these figures.

BOX 4.4 ■ Rough Estimate of Viability of Proposed Flood Control Measures

HCMC has already proposed to build a system of flood defenses that will significantly alter the pattern of flooding and the hydrology of the city. This project has an estimated capital cost of $750 million and is expected to be completed by 2025. The effects of the proposed flood control measures on regular flooding would seem to be significant in reducing the population exposed to flooding in 2050 from an estimated 10.2 million to 6.7 million, a reduction of 35 percent. Based on the GDP method of estimation, the project would proportionately decrease damage costs by 35 percent, making this an economically viable project. However, further economic analyses of this project needs to be carefully undertaken.

Source: ADB (2010).

ANALYSIS OF ADAPTATION IN HCMC

Unlike the Bangkok and Manila studies, the HCMC study did not undertake a detailed cost benefit analysis to prioritize adaptation options. While it did provide an estimate of the viability of the government's flood protection project (Box 4.4), the main focus was to identify institutional mandates with respect to urban planning, flood protection, and adaptation and propose a range of adaptation options that need to be undertaken in coordination with different sectors.

Broadly, adaptation measures in the context of managing floods can be categorized as those that involve (a) protection against predicted climate change, (b) accommodation to improve resilience, (c) retreat to reduce exposure, and (d) improved management (see Annex C).[58] For instance, infrastructural measures such as construction of flood embankments, polders, sea walls, and pumped drainage are common engineering solutions and are being implemented in all three cities discussed in this report. "Accommodation" measures that seek to minimize vulnerability include measures such as raising houses on stilts, adjusting cropping patterns, and revising building codes for housing and industry. In some cases, where the risks of loss of life or assets is severe, "retreat" as a planning option can reduce exposure to extreme events. Used in conjunction with restoring natural ecosystems that provide flood protection benefits, it can be a useful planning tool. Finally, flooding needs to be considered in the context of overall water basin management and the institutional capacity to manage the resource.

Developing sector specific adaptation options with focus on the poor

In the HCMC study, a combination of these measures is proposed. Specifically, the study argues for development of sector specific adaptation options with a focus on the poor. For instance, in terms

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[58] Drawn from IPCC, AR4, chapter 6, Coastal systems and low-lying areas, Figure 6.11 Evolution of planned coastal adaptation measures, pg. 342, 2007.

of reducing vulnerability of the poor, the study recommends livelihood protection and livelihood diversification schemes, improved early warning systems, improved building construction requirements, land use planning and use of open space for flood management, zoning controls to ensure that low income housing is located outside of flood prone zones. HCMC already has a planned program of resettlement away from rivers and drains and this may require expansion to include vulnerable areas (Can Gio and Nha Be districts) identified by the HCMC analysis. Priority adaptation actions in the transport sector include review and revision of design standards for roads, bridges, and embankments so they are consistent with expected flooding and climate conditions. Further, in light of the findings of the study, new transport infrastructure needs to be reassessed. Given that most industrial zones and clusters in HCMC will be at direct risk of flooding with or without the proposed flood control plan, a number of adaptation measures—such as locating industrial zones outside of vulnerable areas and retrofitting existing infrastructure—are proposed.

Combining infrastructure based solutions with eco-system based adaptation measures

An important recommendation of the HCMC study is to combine infrastructure-based solutions with the use of ecosystem-based adaptation measures, which provide a buffer against climate risks. The mangrove forests to the south of HCMC provide significant protection against storm surges, but are under severe pressure due to land use change and encroachment. Natural systems of the Dong Nai River basin provide a range of ecosystem services such as regulation of hydrological flows, freshwater storage, erosion control, and water purification. These too are under threat due to land use change and urban development. Adaptation approaches suggested by the study include reforestation of the Dong Nai River basin watershed, restoration of wetlands, rehabilitation of canals and rivers, strengthening zoning regulations to protect ecosystem resilience, and planting of buffer zones along dykes and riverbanks, including dykes proposed by the planned flood control system.

Strengthening institutional capacity to adapt to climate related risks

The HCMC study argues that comprehensive adaptation planning is needed to provide the overall framework and direction for adaptation at the city level, in line with national level goals and targets. A key institutional recommendation arising from the study is the development of an *HCMC Climate Change Adaptation Plan*. The HCMC Peoples Committee (PC), the study argues, can take a proactive leadership role in this context and in driving climate change adaptation in the city. Further, there are several key agencies that shape overall land use, spatial zoning, environmental quality, and natural disaster response management in the city, each of which can pursue a range of actions within their sectoral domain (Table 4.16). Since one sector or area's plan has implications on activities carried out by other sectors, coordination between different adaptation plans and planning processes is critical.

CONCLUSION

Given the magnitude of climate change costs, adaptation to climate change clearly needs to be a serious consideration. As discussed, adaptation investments are already under way in all three cities. Each of the cities will be better protected against climate change with the flood control measures that are either already planned or are slowly being implemented. However, additional policy, institutional, and ecosystem-based measures also need to be put in place and prioritized by the city governments.

The analysis undertaken in the three case studies needs to be viewed as an initial attempt at estimating the impacts and damage costs related to climate change. As discussed in chapter 2, there are a number of uncertainties associated with each level of analysis. The climate downscaling and the hydrological models provide results that are by no means certain. The economic analysis overlays a large number of assumptions related to prices, GDP, population distribution, growth, the structure of cities and so on, over and above these uncertainties. Therefore, they should be viewed as a preliminary attempt to be followed by improved studies.

TABLE 4.16 ■ Proposed Implementation Arrangements for HCMC

Authority	Priority actions
HCMC DONRE	(i) Revise the HCMC land use strategy and action plan to incorporate climate change issues and adaptation measures (ii) Prepare assessment guidelines for reviewing sector and spatial plans adaptation requirements and consistency with the city adaptation plan (iii) Prepare assessment guidelines for integrating adaptation in SEA and EIA when applied to development plans and project proposals
HCMC Environment Protection Agency (HEPA)	Prepare adaptation monitoring and audit guidelines to keep track of adaptation performance
Department of Planning and Architecture and its Institute for Urban Planning	Revise the HCMC urban strategy and plan to set out the spatial land uses, controls, and safeguards for adaptation
Department of Construction with MOC	Revise and pilot the Building Code in the city so that it responds to climate change
Line departments and institutes responsible for (a) transport, (b) power supply, (c) water management and supply, (d) water quality and sanitation, (e) industry, (f) agriculture and fisheries, and (g) public health	(i) Audit existing infrastructure and development plans and orientations (ii) Retrofit adaptation measures in existing infrastructure (iii) Define sector-specific adaptation options (iv)Upgrade sector design standards (v) Prepare strategies and plans for the next development period so they address climate change (vi)Introduce monitoring, auditing, and reporting on adaptation performance
HCMC Steering Committee for Flood and Storm Control	(i) Support each commune and district in reviewing and revising their specific contingency plans to protect and cope with more extreme flooding and storm events, and identifying the key assets and residential areas that need to be protected, up to and including evacuation of residents if necessary (ii) Improve early warning systems for floods, storms, tidal conditions, and drought (iii) Support ports, airports, and rail authorities in developing contingency plans in the event of major flood events (iv) Develop an early warning system for traffic and alternative transport routes in the event of floods

Source: ADB (2010).

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Conclusions and Policy Implications

The studies undertaken in the three cities show the challenges faced by coastal megacities with respect to regional and global climate change and variability. These studies highlight the importance of achieving sustainability in urban areas through a better understanding of the relationship between urbanization, local hydrological systems, and climate. All of the cities considered in this report are megacities with (registered and unregistered) populations close to or greater than 10 million. Each is a driver of national and/or regional economic growth and all depend on the capacity of local hydrological systems—such as rivers and streams, watersheds, and wetlands—to provide a range of services that are critical to the sustainability of these cities and its residents. Given that these are all coastal megacities, they face increased climate-related risks such as sea level rise and increased frequency of extreme events. In this chapter, we conclude by highlighting key findings and policy implications that would be useful for urban policy makers to consider with respect to adaptation at the city level.

KEY FINDINGS AND LESSONS FOR POLICY MAKERS

Major risks are posed by increased temperature and precipitation in coastal megacities

All three cities are likely to witness increases in temperature and precipitation linked with climate change and variability. In Bangkok, temperature increases of 1.9°C and 1.2°C for the A1FI and B1 scenarios respectively are estimated for 2050 and are linked with a 3 percent and 2 percent increase in mean seasonal precipitation for the high and low emissions scenarios. A flood that currently occurs once in fifty years may occur as frequently as once in 15 years by 2050, highlighting the potential for an increase in the frequency of extreme events. In Manila, the mean seasonal precipitation is expected to increase by 4 percent and 2.6 percent for the high and low emissions scenarios. In HCMC, the average annual temperature is expected to rise by 1.4°C in 2050 (with only slight differences between the high and low emissions scenarios). Further, a 20 percent and 30 percent increase in precipitation is expected for a 1-in-30-year and a 1-in-100-year event respectively under the high emission (A2) scenario. While extreme rainfall linked with storms is expected to become more common, preliminary analysis suggests that the frequency of dry season drought in HCMC is also likely to increase by 10 percent under the low emissions scenario. These risks need to be recognized and better understood by urban planners in the context of specific coastal cities, particularly in developing countries.

Increase in flood-prone areas due to climate change in all three cities

In all three megacities in 2050, there is an increase in the area likely to be flooded under different climate scenarios compared to a situation without climate change. In Bangkok, for instance, under the conditions that currently generate a 1-in-30-year flood but with the added precipitation projected for a high emissions scenario, there will be approximately a 30 percent increase in the flood-prone area. In Manila, even if current flood infrastructure plans are implemented, the area flooded in 2050 will increase by 42 percent in the event of a 1-in-100-year flood under the high emission scenario compared to a situation without climate change. In HCMC, the area inundated increases (from 54 percent in a situation without climate change to 61 percent in 2050 with climate risks considered) for regular events and for extreme (1-in-30 year) events from 68 percent (without climate change) to 71 percent (with climate risks considered) in 2050 under the high emission scenario. Further, there is a significant increase in both depth and duration for both regular and extreme floods over current levels in 2050. The analysis also highlights areas that will be at greater risk of flooding in each metropolitan area. In Metro Manila, for instance, areas of high population density such as Manila City, Quezon City, Pasig City, Marikina City, and San Juan Mandaluyong City are likely to face serious risks of flooding.

Increase in population exposed to flooding due to climate change

In all three cities, there is likely to be an increase in the number of persons exposed to flooding in 2050 under different climate scenarios compared to a situation without climate change. For instance, in Bangkok, in 2050, the number of persons affected (flooded for more than 30 days) by a 1-in-30-year event will rise sharply for both the low and high emission scenarios by 47 percent and 75 percent respectively compared to those affected by floods in a situation without climate change. In Manila, for a 1-in-100-year flood in 2050, under the high emission scenario more than 2.5 million people are likely to be affected assuming that the infrastructure in 2050 is the same as in the base year, and about 1.3 million people if the 1990 master plan is implemented. In HCMC, currently, about 26 percent of the population would be affected by a 1-in-30-year event. However, by 2050, it is estimated that approximately 62 percent of the population will be affected under the high emission scenario without implementation of the proposed flood control measures. Even with the implementation of these flood control measures, more than half of the projected 2050 population is still likely to be at risk from flooding during extreme events. How to plan for such large percentages of population being exposed to future flooding needs to be seriously considered.

Costs of damage likely to be substantial in and can range from 2 to 6 percent of regional GDP

In Bangkok, the increased costs associated with climate change (in an A1FI scenario) from a 1-in-30-year flood is THB 49 billion ($1.5 billion) or approximately 2 percent of GRDP. These are the additional costs associated with climate change. The actual costs of a 1-in-30-year flood would include costs resulting from land subsidence and would be even higher. In Manila, a similar 1-in-30-year flood can lead to costs of flooding ranging from PHP 40 billion ($0.9 billion) given current flood control infrastructure and climate conditions to PHP 70 billion ($1.5 billion) with similar infrastructure but future A1FI climate. Thus, the additional costs of climate change from a 1-in-30-year flood would be approximately PHP 30 billion ($0.65 billion) or 6 percent of GRDP. The HCMC study adopts a different methodology to analyze costs and its results cannot directly be compared to the costs of Manila and Bangkok. The HCMC study uses a macro approach and estimates a series of annual costs up to 2050. The flood costs to HCMC, in present value terms, range from $6.5 to $50 billion. The "annualized" costs of flooding would likely be comparable to the costs of Bangkok and Manila.

Damages to buildings is an important component of flood-related costs

Damage to buildings emerges as a dominant component of flood-related costs, at least in Bangkok and Manila. In these cities, over 70 percent of flood-related costs in all scenarios are a result of damage to buildings. Cities are, almost by definition, built-up areas full of concrete structures. It is, therefore, not surprising that the main impacts of floods is on these structures and the assets they carry. In HCMC, 61 percent of urban land use, 67 percent of industrial land use, and 77 percent of open land use is expected to be flooded in 2050 in an extreme event if the proposed flood control measures are not implemented. Future flooding also has major sector implications. For instance, in the transportation sector in HCMC, even with the implementation of the proposed flood protection system, a significant percentage (76 percent of axis roads, 58 percent of ring roads) of the existing and planned roads will be exposed to increased flooding. Thus, as cities develop over the next 40 years, it would be important to design their commercial, residential, and industrial assets and zones to minimize these costs.

Impact on the poor and vulnerable will be substantial; however, even better-off communities will be affected by flooding

In Bangkok and Samut Prakarn, the study estimates that about 1 million inhabitants will be affected by the A1FI climate change condition in 2050. One out of eight of the affected inhabitants will be those living in condensed housing areas where the population primarily lives below the poverty line. Of the total affected population, approximately one-third may have to encounter more than a half-meter inundation for at least one week, marking a two-fold increase in the vulnerable population. People living in the Bang Khun Thian district of Bangkok and the Phra Samut Chedi district of Samut Prakarn will be especially affected. In HCMC, in general, poorer areas in HCMC are more vulnerable to flooding. However, in some of the areas, the poor and non-poor are both at risk. The Manila study shows that while low-income residents have devised many coping strategies to extreme events, state and non-state actors need to play a more proactive role in addressing vulnerability of the urban poor.

Urban plans and flood protection infrastructure need to take climate risks into account

Flood protection plans are already in place in all three mega-cities considered. However, in all three cities, these have been prepared without considering future climate-related risks, which need to be considered for the infrastructure to provide the expected level of protection from future climate risks. In HCMC for example, which has a long history of responding to natural disasters, a number of measures such as dykes and early warning systems (which are also important aspects of a climate change adaptation strategy) have been developed. However, the likelihood of increasing frequency and intensity of extreme events has not been built into these disaster management plans. Consideration of climate-related risks has also not been sufficiently integrated into urban planning and in various sectoral plans in the cities. As the HCMC case shows, in addition to the urban master plan, there are a number of city-level sectoral plans with little coordination between them. The main policy implication is that climate change adaptation measures need to be well-integrated into urban, sectoral, and flood protection plans and the coordination between these plans needs to be strengthened.

Reduction of land subsidence should be considered an important part of urban adaptation

One of the main findings of this study is that non-climate-related factors such as land subsidence are important and in some cases even more important than climate risks in contributing to urban flooding. In Bangkok, for instance, there is nearly a two-fold increase in damage costs between 2008 and 2050 due to land subsidence. Further, almost 70 percent of the increase in flooding costs in 2050 in the city is due to land subsidence. While data for land subsidence was not available for Manila and HCMC and this issue was not considered in the hydrological modeling for these two cities, available literature suggests that it is an important factor in all three cities and should be considered in follow-up studies. Even though the megacities have already undertaken a number of measures to slow down land subsidence, further regulatory and market incentives are clearly required to stem groundwater losses. City governments need to better assess factors contributing to land subsidence and consider options to reduce it. Based on qualitative information provided in the city studies —the impact of other non climate factors such as dumping of solid waste into the city's canals and waterways, poor dredging of canals, siltation of drains, deforestation and soil erosion in the upper watershed, and land use patterns—are also critical and should be part of a broader and multisectoral approach to addressing urban adaptation.

Important to consider variation in climate risks and factors contributing to flooding

An important finding of this study is that while a combination of climate-related factors can contribute to urban flooding, some factors are much more important than others in different cities. For instance, in HCMC, storm surges and sea level rise are important factors contributing to flooding. However, in Bangkok these factors seem to be relatively less important. In part this has to do with the location, elevation, and topography of the city. The policy implication is that adaptation measures need to be designed based on the specific hydrological and climate characteristics of each city.

Need for greater emphasis on ecosystem-based approaches

In all of the cities considered, an important focus of flood management and control is on hard infrastructure solutions. However, the studies (Bangkok and HCMC) show that ecosystem-based approaches are also important and can be usefully combined with infrastructure interventions. The HCMC study, for instance, argues for combining construction of dykes (as approached by the planned flood control measure) with management and rehabilitation of the mangrove systems in Can Gio, reforestation of the Dong Nai River Basin upper watersheds, river and canal bank protection, and implementation of basin-wide flow management strategies. Urban wetlands provide a range of services, including flood resilience, allowing groundwater recharge and infiltration, and providing a buffer against fluctuations of sea level and storm surges. Rehabilitation of urban wetlands is therefore critical. Upstream protection of watersheds through reforestation is also important in managing the release of runoff into the reservoirs that serve urban residents. These options need to be considered in developing a comprehensive approach to urban adaptation. Dykes themselves are susceptible to erosion by rainfall and storms. As such, it is also important to consider protection of dykes through planting.

Importance of locally induced climate change factors

Even though this report does not take into account locally induced climate change factors, these are very significant (Grimm et al. 2008). For example, the rate of increase of temperature in HCMC is almost double that of the surrounding Mekong Delta region. Between 1997 to 2006, the average temperature of HCMC increased .34° C compared to .16° C for the Mekong Delta region. This increase in temperature for HCMC has coincided with increasing urbanization in the city. In HCMC, the heat island effect is changing the climate and urbanization is having a significant effect on increases in temperature, rainfall, and flooding in and around HCMC. Further analysis is needed to better understand this issue.

LESSONS ON METHODOLOGY FOR FOLLOW-UP STUDIES

Even though analysis similar to that undertaken in this report has been carried out for cities in developed countries (Rosenzweig et al. 2007), it has so far not been done in developing country cities. Moreover, preparation of this report has spurred similar studies in other cities in the Africa and Middle East and North Africa regions. It is important therefore to conclude with a few lessons for follow-up studies.

Approaches to downscaling

In this study two different approaches to downscaling were used, namely statistical scaling used by JICA and use of a dynamic regional model as done by the HCMC study. Each method has its strengths and limitations. Dynamic regional models can simulate daily information on a broad range of hydrometeorological data, yielding information on floods and droughts and on the joint occurrence of variables, like the pattern of precipitation over a large watershed. Dynamic models that are nested in AOGCMs are necessarily bound to the parent model's intrinsic biases. There is, for example, a wide variation in the results of the AOGCMs in forecasting extreme precipitation, and use of one model alone can yield unreliable results. Statistical models yield single parameters and shed little light on the joint probability of occurrence. Nevertheless, because the results are based on a correlation with the results of many models, the downscaled parameters have less intrinsic bias than those generated by a single model. These constraints need to be considered in undertaking similar city-level studies.

Need to forge stronger links between methodologies developed by disaster risk reduction community and climate change adaptation

There is a strong global consensus on the increasingly urgent need to address the underlying causes of climate change and its impacts through mitigation of greenhouse gas emissions and development of effective adaptation strategies. This has been underscored at the recent United Nations Framework Convention on Climate Change (UNFCCC) Conferences of Parties (COP) in Copenhagen (COP-15), which again highlighted the need to foster better linkages between climate change adaptation (CCA) and disaster risk reduction (DRR). The Hyogo Framework of Action, signed by 168 countries in 2005, is the guiding document for the DRR initiatives to mainstream DRR into the national, sectoral, and local-level development planning process. The DRR community has well-established procedures and terms of reference for risk assessment, including probabilistic risk assessment, that allow assessment of risks based on an analysis of hazards, exposure, vulnerability, and capacity (ECLAC 2003). The use of simulation models to develop event-loss relationships are likewise commonly applied in the DRR work (e.g., hydrometeorological, earthquake, storm surge, tsunami, and landslide models). In addition, the DRR community has the local networks and knowledge management systems that will provide significant benefit for climate change adaptation studies. These synergies need to be recognized and strengthened.

Lessons with respect to damage cost analysis and prioritizing adaptation options

The three studies were based on available data. This meant that various assumptions had to be made regarding the number of households affected, the "damage rate" or extent of damage to various assets as a result of floods of different intensity, and the costs associated with these damages. The underlying data and valuation would be much improved if there was scope for survey-based data collection. A rather important gap in the studies is the analysis of health impacts. Floods do have serious health consequences and while the studies have attempted to estimate these, the full importance of these impacts has not been captured. To carefully examine the health impacts of floods would require first an estimation of disease prevalence in the future (taking into account climate and economic conditions) and second, application of robust dose-response relationships to establish the extent of flood-related illnesses. This is an impact issue that requires more careful consideration. In terms of adaptation to climate change, the Bangkok and Manila studies are unable to incorporate "soft options" such as changes in legal and institutional issues into their cost-benefit analyses. Thus, it is possible that there are less costly policy changes that might bring about the same type of results as the engineering solutions identified. However, identifying the full implications of different policy reforms and then incorporating these into a cost-benefit framework is difficult. Future studies would do well to look at behavioral change options, zoning possibilities, legal and institutional reforms, and conservation possibilities carefully and rank them relative to engineering solutions.

Need for detailed institutional analysis in future studies

In undertaking similar studies in the future, a more detailed analysis of institutional and organizational capacity for urban adaptation is suggested. While all three city studies considered in this report do consider broad institutional issues, a more detailed capacity analysis could provide a more nuanced understanding of policy and regulatory gaps, existing planning and decision-making processes, coordination between key municipal organizations, and entry points for strengthening state, private sector and civil society relations with respect to addressing urban adaptation.

Uncertainties, limitations, and interpreting the findings of this study

Any study forecasting conditions four decades hence will be faced with large uncertainties. One issue facing the analysis was what would be the pathway of GHG emissions. To address that issue, the city case studies examined both a high and a low GHG emissions scenario to bracket the likely future conditions. In the climate change downscaling methodologies, there are uncertainties in forecasting the increase in extreme and seasonal precipitation under the different scenarios. The techniques applied in the statistical downscaling examined the results from numerous AOGCMs. Robust relationships were identified for temperature and precipitable water increases, where the internal error was estimated at ~ 10 percent error and ~ 10–20 percent error, respectively (Sugiyama 2008). Hydrologic models can simulate flood events with relatively small errors (<10 percent) if sufficient data is available for good calibration. For future forecasts, however, land use changes in the watersheds and drainage areas can dramatically affect flood patterns and can be further examined in future sensitivity analyses. In addition, each of the studies makes numerous assumptions regarding what each city will look like (for example in terms of growth, population increase) in 2050. These uncertainties and errors need to be considered in interpreting the results of this study.

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ANNEX A

Vulnerability of Kolkata Metropolitan Area to increased Precipitation in a Changing Climate

GLOBAL AND REGIONAL CONTEXT

Low-lying coastal areas are highly vulnerable to flooding. A number of recent studies have shown that coastal areas are vulnerable to a range of risks related to climate change, including coastal flooding. Among these coastal areas, the Intergovernmental Panel on Climate Change specifically identifies as hotspots the heavily urbanized megacities in the low-lying deltas of Asia (IPCC 2007 b). Among Asian countries, India— with its 7,500 km long predominantly low-lying and densely populated coastline—is particularly vulnerable. A recent global survey identified Kolkata and Mumbai as among the top ten cities with high exposure to flooding under the current climate change forecasts (Nicholls et al. 2008). The study also shows that exposure will increase in the future; by 2070, Kolkata is expected to lead the top 10 list in terms of population exposure.

In response, the World Bank—in collaboration with the Asian Development Bank (ADB) and the Japan Japan International Cooperation Agency (JICA)—launched four country-level studies for Manila (led by JICA), Ho Chi Minh City (led by ADB), and Bangkok and Kolkata (led by the World Bank).

Study Objectives

This study sought to:

- Compile a database with past weather-related information and damage caused by extreme weather-related episodes.
- Determine scenarios most appropriate for assessing the impact of climate change.
- Develop hydrological, hydraulic, and storm drainage models to identify vulnerable areas and determine physical damage estimates resulting from climate change effects.
- Assess monetary, social, and environmental impacts resulting from such climate change events.
- Formulate adaptation proposals to cope with damage arising from climate change effects.
- Strengthen local capabilities so that Kolkata's planning process can account for climate-related damage effects in analyzing new projects.

In this study, precipitation events in Kolkata based on available historical rainfall data for 25 years were used as a baseline (without climate change) scenario. For modeling climate change, predictions for temperature and precipitation changes in Kolkata in 2050 for A1FI and B1 emission scenarios—from an analysis of 16 GCMs used for the IPCC Fourth Assessment Report—were provided by a paper commissioned by JICA (Sugiyama 2008). A sea level rise of 0.27 m by 2050 was also added to the storm surge for the A1FI and B1 climate change scenarios based on current estimates. All these scenarios (without and with climate change effects) were then modeled to assess the impact in terms of the extent, magnitude, and duration of flooding.

GEOGRAPHIC AND SOCIOECONOMIC CONTEXTS

The geographic area covered in the study is the Kolkata Metropolitan Area (KMA), a continuous urban area stretching along the east and west bank of the Hooghly River surrounded by some rural areas lying as a ring around the conurbation and acting as a protective green belt. KMA has an area of 1,851 square kilometers and consists of a complex set of administrative entities comprising 3 municipal corporations (including Kolkata Municipal Corporation, or KMC), 38 other municipalities, 77 non-municipal urban towns, 16 out growths, and 445 rural areas. KMC, the core of the city, lies along the tidal reaches of the Hooghly and was once mostly a wetland area. The elevation of KMA ranges from 1.5 to 11 meters above sea level (masl). The elevation of KMC area ranges from 1.5 to 9 masl with an average of 6 masl.

With a population of about 14.7 million (including 4.6 million in KMC), KMA is one of the 30 largest megacities in the world (United Nations 2007). The average population density in KMA is 7,950 people per km^2; in KMC, it is 23,149 per km^2. The average per-capita income in KMA in 2001–02 was $341 (at 1993–94 prices).

THE STUDY AREA

A special characteristic of KMA is its large slum population, comprising more than a third of the total population. These slums not only lack basic infrastructure and services, but are also the hub of many informal manufacturing activities, some of which involve highly toxic industries. Little oversight of such activities is carried out by government agencies. This mixed residential and commercial/industrial land use in slums make these areas highly vulnerable to extreme weather-related events, especially flooding.

METHODOLOGY

The study modeled the impact of climate change on increased flooding in KMA. The main causes of flooding in KMA are intense precipitation, overtopping of the Hooghly River due to water inflow from local precipitation as well as that from the catchment area, and storm surge effects. Land subsidence—which occurs in a few pockets—was not included in the study. The study covered three main sources that aggravate flooding in KMA:

- *Natural factors*. Natural factors include flat topography and low relief that cause riverine flooding and problems with drainage.
- *Developmental factors*. Developmental factors include unplanned and unregulated urbanization**;** low capacity drainage; sewerage infrastructure that has not kept pace with the growth of the city or demand for services; siltation in available channels; obstructions caused by uncontrolled construction in the natural flow of storm water; and reclamation of natural drainage areas (marshlands).
- *Climate change factors.* Climate change factors include an increase in the intensity of rainfall, sea level rise, and an increase in storm surge caused by climate change effects.

Flooding from intense precipitation was modeled for three scenarios—30-year, 50-year, and 100-year return period flood events—assuming no climate change effects. The climate change effects were added to the 100-year flood event using the A1FI and the B1 scenarios.

Assumptions about the impacts of climate change in Kolkata in 2050 (Sugiyama 2008) included (a) a temperature increase of 1.8°C for the A1FI scenario and 1.2°C for the B1 scenario; (b) a fractional increase in the precipitation extremes of about 16 percent for the A1FI and 11 percent for the B1 scenarios; and (c) sea level rise of 0.27 m by 2050, which was added to the storm surge for the A1FI and B1 climate change scenarios based on current estimates. All these scenarios (with and without climate change effects) were then modeled to assess the impact in terms of the extent, magnitude, and duration of flooding.

Three separate models were used to capture the overall effect of natural, developmental, and climate change factors that lead to flooding in KMA. A hydrological model (SWAT model) was used to develop the flow series for the whole Hooghly catchment. The generated data was then fed into a hydraulic model (HECRAS model) to analyze the implication of the flood passing through the river stretch. Finally, a storm drainage model (SWMM model) was used to determine the flooding that will result once the river flooding is combined with local precipitation and drainage capability of the urban area under an extreme flood situation.

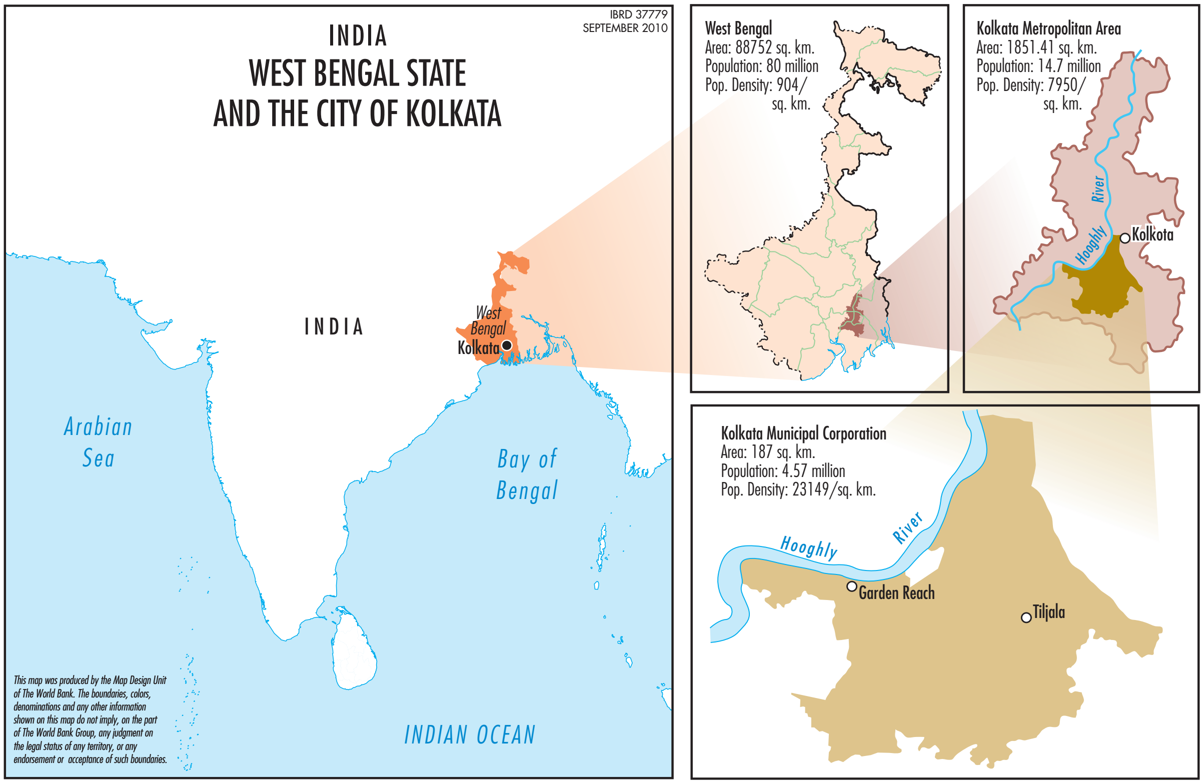
VULNERABILITY ANALYSIS

The models generated the increase in depth, duration, and extent of flooding in Kolkata due to climate change effects. A separate vulnerability analysis was done to assess the impact of flooding; this part of the analysis was restricted to only the KMC area because of data limitations. The vulnerability analysis was based on three separate indices: (1) a flood vulnerability index based on the depth and duration of flooding, (2) a land-use vulnerability index based on the nature of land use, and (3) a social vulnerability index based on the existing infrastructure and the socioeconomic characteristics of the population. Finally, the three separate indices were combined to form a composite vulnerability index.

Vulnerability was assessed at both the ward and subward levels. To evaluate the impact of flooding in KMC, the analysis identified the 9 most vulnerable wards that may need specific attention in designing adaptation strategies. To assess vulnerability within each ward in greater detail, the analysis was extended to the sub-ward level using spatial data.

DAMAGE ASSESSMENT

The vulnerability analysis was followed by a separate economic damage assessment. Due to data limitations, this was also restricted to the KMC area. Damage to *stocks* measured primarily physical damage arising out of water submersion (sectors included residential buildings and property, com-


INDIA
WEST BENGAL STATE
AND THE CITY OF KOLKATA

IBRD 37779
SEPTEMBER 2010

This map was produced by the Map Design Unit of The World Bank. The boundaries, colors, denominations and any other information shown on this map do not imply, on the part of The World Bank Group, any judgment on the legal status of any territory, or any endorsement or acceptance of such boundaries.

mercial and industrial establishments, and major public infrastructure). *Flow* damage included loss of income and increased morbidity, which are primarily linked to the duration of a flood. The damage estimates were based on data extrapolated to the KMC population in 2050. The analysis assumed no additional investments in flood protection measures that may be implemented in the future to lower flood damage. Inflation also was not considered, and all estimates used 2009 prices. Damage assessments were estimated for the 100 year flood return period and the A1FI climate change scenario to determine the additional damage caused by climate change effects.

ADAPTATION ANALYSIS

Finally, a separate analysis was done to examine adaptation measures in KMC that can alleviate some of the problems posed by flooding. The analysis mainly focused on gains from the complete de-siltation of trunk sewers by modeling flooding under a completely de-silted trunk sewer scenario. The study also examined other proposals to build new sewers and upgrade sewers in vulnerable areas, as well as institutional changes that can help cope with future flood damage.

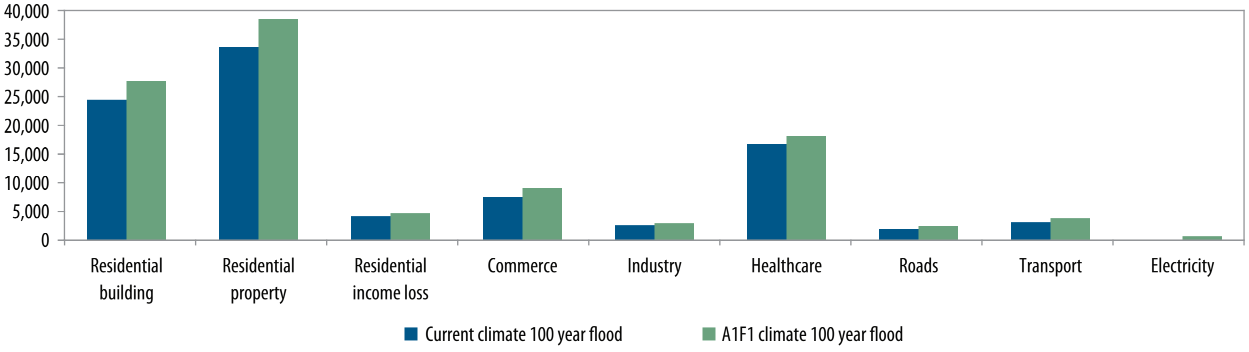
MAIN FINDINGS

The most vulnerable wards to climate change. The study identified the most vulnerable wards to climate change—namely, wards14, 57, 58, 63, 66, 67, 74, 80, and 108. Six wards (14, 57, 58, 66, 67, and 108) in the eastern part of the city and ward 80 are vulnerable because of inadequate infrastructure, unplanned land use, and poor socioeconomic and environmental conditions. Infrastructural problems are getting worse with increased building activity, as these areas have become attractive to developers after becoming part of KMC.

The other two wards—63 and 74—are highly vulnerable due to their topography. In these wards the capacity of the sewerage system has not kept pace with changes in population. These have been further aggravated by inadequate maintenance, as well as the siltation of the existing trunk sewer systems, which have considerably reduced their carrying capacity. While the sewer networks in KMC under such partially silted condition still provide reasonable hydraulic capacity for carrying the dry weather flow, they are inadequate for carrying storm weather flow, even with normal precipitation during the rainy season.

Additional losses likely to occur due to climate change. Damage from a 100-year flood will increase by about $800 million—to more than $6.8 billion in 2050—due to climate change (A1FI scenario). The impacts by sector (in Indian rupees at 2009 prices) are shown in the chart below. Local currency was converted to dollars using the purchasing power parity index for India of 2.88 (IMF 2009). The largest damage components—under both the 100-year return period flood and the A1FI climate change scenario—are for residential property and buildings and health care. Commerce, industry, and other infrastructure like roads and transport services also

Total losses in major sectors in KMC (Rs million in 2050)



sustain significant damage. Due to data constraints, some impacts could not be quantified in this analysis, so the estimates provided are likely to understate the overall impact of climate change.

Investing in de-silting of trunk sewers will reduce the area and population affected by floods. The study looked at the impact of investing in de-silting trunk sewers both in the town and suburban systems of KMC. The business as usual scenario considers an average 30 percent silting in trunk sewers. The adaptation scenario considers investing in de-silting and reducing it to zero. The findings indicate that this simple investment can reduce the area affected by a flood by 4 per cent and the population affected by floods by at least 5 percent.

ADAPTATION MEASURES

The current adaptation deficit. Climate change is likely to intensify urban flooding through a combination of more intense local precipitation, riverine flooding in the Hooghly, and coastal storm surges A major cause of such periodic flooding during the rainy season is the city's current adaptation deficit, including deficiencies in physical infrastructure, problems with land use, and socioeconomic and environmental factors.

Adaptation strategy. The city needs a comprehensive and effective strategy that invests in both soft and hard infrastructure to tackle flooding problems in Kolkata. The goal of the strategy is to (a) reduce the percentage of people affected by flooding and sewage-related diseases in KMC, and (b) target the most vulnerable areas. The strategy should include preparedness both before and during the event, as well as post-event rehabilitation strategies.

Investing in hard infrastructure. Investing in hard infrastructure should take into account the following:

- The strategy needs to follow a comprehensive approach to planning that recognizes drainage system complexity and interconnectivity of its elements such as storm water drainage, water supply, wastewater, water pollution control, water reuse, soil erosion, and solid waste management.
- The strategy should protect major urban services, including roads, traffic, water supply, electricity, and telecommunications. It should recognize the importance of open space and green areas as an integral part of city development.
- The strategy should spell out the climate risks and mitigating factors needed in operational plans for key relevant agencies.

Investing in soft infrastructure. To ensure long-term financial, institutional, and environmental sustainability, the adaptation strategy should also include:

- Strengthening disaster management and preparedness for both pre- and post-disaster situations.
- Enforcing land use and building codes to reduce obstruction and encroachment of floodplains and environmentally sensitive areas such as canal banks and wetlands and to prevent conversion of green spaces and natural areas that can act as retaining zones during flooding.
- Introducing sustainable financing—emphasizing both cost reduction and cost recovery—for infrastructure investment and maintenance.
- Increasing the budget for sewerage and drainage maintenance and the allocation of money for silt removal and mechanical sewer cleaning.
- Adopting flood insurance that incorporates suitable incentives for adaptation and minimizes flood damage.
- Strengthening the regulatory and enforcement process, including improving institutional management and accountability.
- Enforcing pollution management frameworks, including introduction of incentives and disincentives to ensure compliance with regulations.

The government of West Bengal has already started investing in adaptation. Among the suggested adaptation measures, a number of projects are either currently under way or are planned for future implementation in KMA under the Jawaharlal Nehru National Urban Renewal Mission (JNNURM) and the KEIP scheme funded by

ADB. The selection and prioritization of projects for adaptation should be based on cost benefit analysis using the net present value (NPV) approach. Factoring in the additional impact due to climate change in such cost benefit analysis may render many projects—which previously did not show an adequate return on investment—economically viable.

ANNEX B

Scenarios Applied in the Hydrodynamic Modeling in the HCMC study

	INPUTS						
SCENARIOS	Seasonal Rainfall	Extreme Rainfall	Storm Surge	Mean Sea Level	Upstream Inflow	Landuse	PURPOSES
I.BL.0	Baseline_Max	No	No	Baseline	Baseline	Baseline	Extent and duration of the "regular" seasonal monsoon floods with current land use
I.B2.0	B2_Max	No	No	B2 2050+24cm	Baseline	Baseline	
I.A2.0	A2_Max	No	No	A2 2050+26cm	Baseline	Baseline	
I.BL.1	Baseline_Max	No	No	No	Baseline	2050	Extent and duration of the "regular" seasonal monsoon floods with planned future land use and flood control system
I.B2.1	B2_Max	No	No	B2 2050+24cm	Baseline	2050	
I.A2.1	A2_Max	No	No	A2 2050+26cm	Baseline	2050	
I.BL.0_1	Baseline_Max	Baseline_30y	No	No	100y	2050	Extent of the floods caused by 30y storm rainfall (but without storm surge) and 100y extreme upstream inflow; with planned future land use and flood control system
I.B2.0_1	B2_Max	B2_30y	No	B2 2050+24cm	100y	2050	
I.A2.0_1	A2_Max	A2_30y	No	A2 2050+26cm	100y	2050	
II.BL.0	Baseline_Max	Baseline_30y	Linda	No	100y	Baseline	Extent of the "extreme" floods driven by combination of tropical storms (typhoons) surge, mean sea level rise, 30y rainfall and 100y upstream inflow; with current land use
II.B2.0	B2_Max	B2_30y	Linda	B2 2050+24cm	100y	Baseline	
II.A2.0	A2_Max	A2_30y	Linda	A2 2050+26cm	100y	Baseline	
II.BL.1	Baseline_Max	Baseline_30y	Linda	No	100y	2050	Extent of the "extreme" floods driven by combination of storms surge, mean sea level rise, 30y rainfall and 100y upstream inflow; with planned future land use and flood control system
II.B2.1	B2_Max	B2_30y	Linda	B2 2050+24cm	100y	2050	
II.A2.1	A2_Max	A2_30y	Linda	A2 2050 +26cm	100y	2050	
II.BL.0_a	Baseline_Max	No	Linda	No	Baseline	Baseline	Extent of floods and saltwater intrusion caused by storm surge and sea level rise only in current land use
II.B2.0_a	B2_Max	No	Linda	B2 2050 +24cm	Baseline	Baseline	
II.A2.0_a	A2_Max	No	Linda	A2 2050 +26cm	Baseline	Baseline	
II.BL.0_b	Baseline_Max	Baseline_30y	No	No	100y	Baseline	Extent of the floods caused by 100 y extreme upstream inflow and 30y storm rainfall (without storm surge) in current land use
II.B2.0_b	B2_Max	B2_30y	No	B2 2050 +24cm	100y	Baseline	
II.A2.0_b	A2_Max	A2_30y	No	A2 2050 +26cm	100y	Baseline	
III.bl.0	Baseline_Min	No	No	No	Baseline	Baseline	Extent of combination effect of drought and sea level rise on water quality especially risk of salinization under current land use
III.B2.0	B2_Min	No	No	B2 2050 +24cm	Baseline	Baseline	
III.A2.0	A2_Min	No	No	A2 2050 +26cm	Baseline	Baseline	
I.BL.1_1	Baseline_Max	Baseline_30y	No	No	100y	2050	Extent of floods driven by 30y rainfall, 100y upstream inflow and mean sea level rise; with planned future land use and flood control system
I.B2.1_1	B2_Max	B2_30y	No	B2 2050 +24cm	100y	2050	
I.A2.1_1	A2_Max	A2_30y	No	A2 2050 +26cm	100y	2050	

Source: ADB (2010).

ANNEX C

Adaptation to Increased Flooding: Brief Overview

In response to the hazard of floods increasing from climate change, the Asian coastal cities in the study have a range of possible adaptation approaches drawn from existing flood management techniques. Each adaptation approach attempts to reduce risk by either reducing exposure or vulnerability, or by increasing capacity. The adaptation measures can be broadly grouped as:[59]

- Protect
- Accommodate
- Retreat
- Improved management

Protection—reducing exposure with structural interventions

Flood protection measures seek to minimize the exposure of urban areas to inundation from floods. Common engineering interventions include flood embankments, polders, and sea walls, frequently combined with pumped drainage. To allow the transfer of a flood wave past a city without damage, other protection techniques include (a) increasing the hydraulic efficiency[60] of the flood channel with dredging, widening, and removal of obstructions; (b) diverting the flood flows around the city through diversion channels; and (c) attenuating[61] the flood flows upstream with reservoirs or through the managed flooding of the agricultural and wetland areas. With the exception of planned flooding of agricultural and wetlands to attenuate flood peaks, the measures outlined above would be classified primarily as structural adaptation measures.

Within a city, storm drainage systems are designed to remove storm runoff without flooding. The design discharge for the conveyance systems are normally based on storms with a return period between 1-in-5-years to 1-in-10-years, as compared to design standards of 1-in-30 to 1-in-100-year return periods commonly used for flood protection embankments. In an urban setting, roads, buildings, and paved surfaces offer little opportunity for infiltration of storm rainfall, which means that most of the precipitation appears as storm runoff. In this regard, the predicted increase in storm precipitation (ranging from 9 to 15 percent depending on the city and the scenario) will generate a similar increase in the design discharge for the storm drainage systems. To provide the same level of protection against storm-induced urban flooding, the cities will need to adapt by either increasing the discharge capacity of their storm drainage systems or identifying ways to delay or reduce precipitation runoff. For example, adaptation measures might include storm attenuate ponds (using inner city parks) or making streets, alleys, and other paved areas more porous to rainfall to facilitate infiltration.

Flood protection measures always carry a residual risk of failure, which can be catastrophic as in the case of New Orleans. An important outcome of the study is that even for cities with well-designed flood protection plans (e.g., Bangkok and Manila), the flood protection measures as currently planned will not offer the expected level of protection.

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[59] Drawn from IPCC, AR4, Chapter 6, Coastal systems and low-lying areas, Figure 6.11 Evolution of planned coastal adaptation measures, pg. 342, 2007.

[60] Improving the hydraulic efficiency lowers the flood profile.

[61] Attenuation upstream lowers the flood profile downstream.

ACCOMMODATE—A TRADITION APPROACH IN MONSOONAL ASIA TO REDUCING VULNERABILITY

Accommodation acknowledges that people and assets are exposed to floods, but seeks to minimize vulnerability. In rural Asia, houses located in flood plains and exposed to frequent flooding are usually built on stilts, which reduces the vulnerability of the people and the household assets to flooding. Cropping calendars designed around annual monsoon floods and floating varieties of rice are other ways in which rural Asia accommodates floods. In cities where ankle-deep flooding occurs regularly, wooden planks on blocks are common sights to allow passage and access of pedestrians. In periurban areas, landfill is frequently used to elevate new construction sites along major roads above the expected flood levels.

Accommodation, however, can be applied on a broader scale. Flood losses in urban areas arise primarily from damage to buildings, houses, and commercial/industrial properties. In this regard, risks could be dramatically reduced if building codes specified minimum elevations for the first occupied level for housing, commerce, or industry (based on predicted inundation levels for the zones in the city). These elevations could be reviewed and increased as warranted with long-term (5 to 10 year) advance projections to developers. Given the time frame of the study (40 years), this gradual approach gives urban planners a powerful tool to reduce risks with minimal economic impact.

Accommodation also relates to measures to "flood-proof" structures and building exteriors that may be exposed to floods. Flood-proofing dramatically reduces damages from floods. These standards should be included in urban building codes as part of an adaptation program. The study has demonstrated that traditional accommodation methods may not reduce vulnerability in 2050. In HCMC, for example, areas with frequent ankle-deep flooding will be facing knee-to-waist-deep floods, which are not easily managed by pedestrians. This will reduce access and increase losses. Similarly, many houses and buildings that have been built with main floors above the current 1-in-30-year flood levels will be inundated by 1-in-30-year floods in 2050.

RETREAT—WHEN RISKS ARE TOO HIGH, RETREAT REDUCES EXPOSURE

Retreat as planning option to reduce exposure can be applied in urban areas through urban land use plans and zoning codes. The social, environmental, and economic implications need to be carefully studied. In urban areas with high property values, it is usually only applicable where the risks of loss of life or assets are high enough to warrant the action. In rural areas, retreat is common practice vis-à-vis flood embankments as rivers modify courses and erode embankments. Forced retreats are occurring in Bangkok's coastal area due to coastal erosion and land subsidence.

Used in conjunction with restoring natural ecosystems that provide flood protection benefits, retreat can be a useful adaptation planning tool. In coastal areas, land that becomes untenable due to SLR could be converted to natural systems (e.g., mangroves) that can help capture sediment and protect against SLR and storm surges. In urban areas, reclaiming land along rivers and converting these to linear parks that will inundate during floods (increasing hydraulic capacity and lowering the flood profile) help beautify the city while providing a range of benefits. Similarly, agricultural lands that may become unviable due to flooding could be purchased and converted to wetlands. Retreat sometimes occurs following major disasters when the perceived risks outweigh the desire to reconstruct among the private sector. Planners should seize such opportunities and develop the lands for their ecological and flood protection potential.

In addition to the retreat from section of a city or coast line, facilities that are critical in disaster situations or at particular risk (like schools) can be retired and moved as part of a longer term adaptation program.

IMPROVED MANAGEMENT—BUILDING CAPACITY TO REDUCE RISKS

Flooding needs to be considered in the context of overall water basin management and the capacity of people and institutions to manage the resource. Experience has shown that piecemeal or *ad hoc* approaches are at risk of causing significant adverse impacts elsewhere. For example, flood embankments protect one area by aggravating the flood in another area. Water uses and hazards need to be addressed holistically for the water basin to maximize benefits.

With the hazard of flooding increasing, adaptation measures aimed at improved management can focus on (a) reassessing operational rule curves for reservoirs, given the increasing precipitation variability; (b) increasing awareness and community-based adaptation initiatives (e.g., shelters and early warning systems); and (c) strengthening the planning and risk-sharing mechanisms related to controlled flooding of agriculture lands to attenuate flood peaks when protecting cities.

ANNEX
D

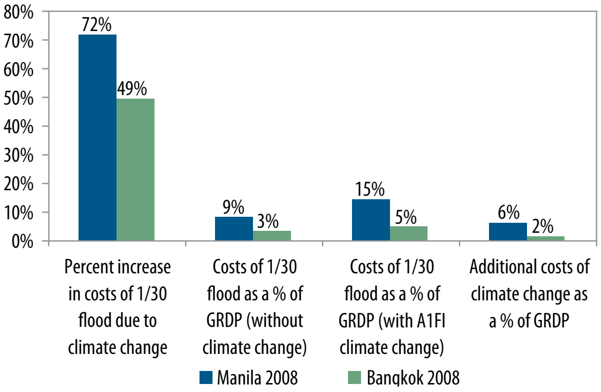
Comparison of Costs across Cities

An interesting question to ask is how climate change costs compare across the different cities. The figure below provides a comparison between the Manila and Bangkok case studies in the context of a 1-in-30-year flood. HCMC is not included in this analysis because the methods for assessing damage costs were very different. The figure below shows that in Bangkok, for instance, the damages from a 1-in-30-year flood would increase by almost 50 percent going from current climate to an A1FI climate change scenario, while a similar flood in Manila will have a larger effect and increase costs by some 79 percent. However, while the Bangkok damage costs account for land subsidence, the Manila costs do not. Thus, accounting for land subsidence may make the increase in costs in the two cities rather similar.

The costs of climate change are accurately measured as the costs in similar scenarios with and without climate change. Thus for Manila, the costs of climate change are represented by the difference between the 30-A1FI-EX and 30-SQ-EX scenarios. The costs for Manila from a 1-in-30-year flood are $0.67 billion, which amounts to 6 percent of its 2008 GRDP. Similarly, the costs for Bangkok—the difference between 2050-LS-SR-SS-A1FI and 2050-LS scenarios—amount to $1.47 billion, or 2 percent of Bangkok's 2008 GRDP. Given that Bangkok is a much wealthier city than Manila, these numbers are credible.

How does HCMC stand in relation to the two cities? As previously noted, the costs to HCMC, because they are in present value terms and because of the different methodology used, are not comparable to the estimates from Bangkok and Manila. However, to get a rough understanding of whether they are in the same order of magnitude, we annualize these costs. We find that annual equivalent of the damage costs to HCMC falls between $0.67 and $5 billion,[62] which on the lower end is comparable to the costs borne by Bangkok and Manila.

Comparing Damage Costs in Bangkok and Manila



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[62] These numbers are the equal annual equivalents (EAE) (using a 10 percent discount rate and time period of 42 years) of the present value of total costs from regular and extreme flooding. The range reflects the minimum and maximum present values of the two land and GDP-based estimations of climate change costs. EAE = NPV [(i(1 + i) n] / [(1 + i)n – 1)] where i=interest rate and n=time period.

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