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CLIMATE CHANGE IMPACT AND ADAPTATION STUDY FOR BANGKOK METROPOLITAN REGION

Final Report

Main Report

Panya Consultants Co., Ltd.

March 2009

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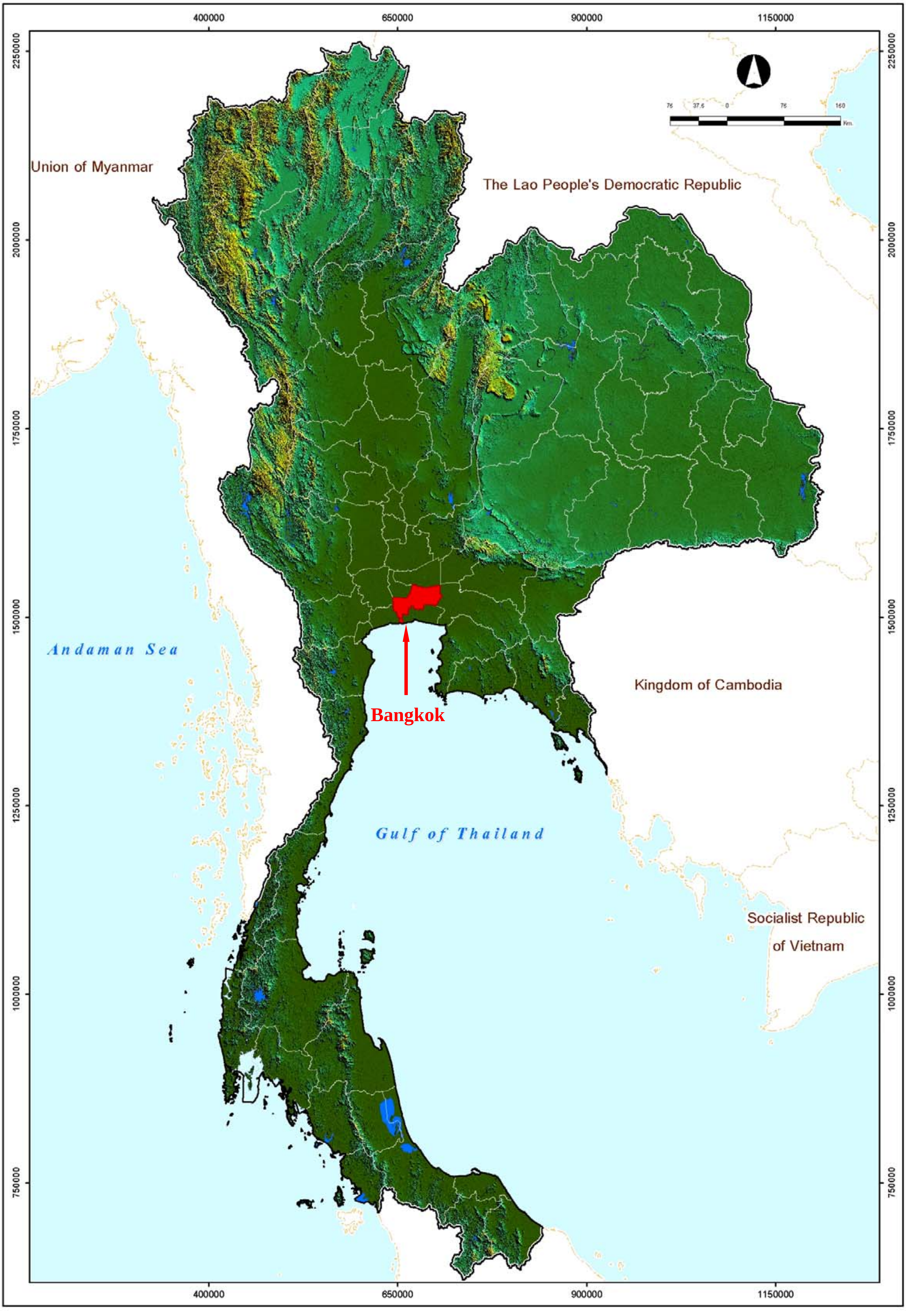

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ACKNOWLEDGEMENTS

This report benefited from reviews provided by a number of individuals, during Technical Review and Consultation with Stakeholders meetings held in Bangkok in the course of its preparation and organization by the study team.

We wish to specifically acknowledge the input and assistance of Warren Evans, Jan Bojo, Neeraj Prasad, Poonam Pillai, Manuel Cocco, and Pongtip Puvacharoen of the World Bank. Additionally, the World Bank consultant BR Philips and Priya Shyamsundar provided technical input, and acted as the day-to-day contact for the Client, during its completion. Every assistance was given to the study team, and we appreciate the thoughtfulness and active input of these individuals and of the World Bank as a whole. Further valuable input was received from staff members of the Bangkok Metropolitan Administration (BMA) and from those of various other organizations in Thailand and elsewhere, and these are acknowledged gratefully.

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ABBREVIATIONS

Thailand Government / Agencies

BMA	:	Bangkok Metropolitan Administration
BMTA	:	Bangkok Mass Transit Authority
BTS	:	Bangkok Mass Transit Public Company Limited
CU	:	Chulalongkorn University
DAE	:	Department of Agricultural Extension, MOAC
DCP	:	Department of City Planning, BMA
DDPM	:	Department of Disaster Prevention and Mitigation, MOI
DDS	:	Department of Drainage and Sewerage, BMA
DEDE	:	Department of Alternative Energy Development and Efficiency, MOEN
DEQP	:	Department of Environment and Quality Promotion, MONRE
DGR	:	Department of Groundwater Resources, MONRE
DIW	:	Department of Industrial Works, MOI
DMCR	:	Department of Marine and Coastal Resources, MONRE
DOF	:	Department of Fisheries, MOAC
DOH	:	Department of Highway, MOT
DPT	:	Department of Public Works and Town & Country Planning, MOI
DWR	:	Department of Water Resources, MONRE
EGAT	:	Electricity Generating Authority of Thailand
ETA	:	Expressway and Rapid Transit Authority of Thailand
MD	:	Marine Department, MOT
MEA	:	Metropolitan Electricity Authority
MICT	:	Ministry of Information and Technology
MOAC	:	Ministry of Agriculture and Cooperative
MOI	:	Ministry of Interior
MONRE	:	Ministry of Natural Resources and Environment
MOSTE	:	Ministry of Science, Technology and Environment
MWA	:	Metropolitan Waterworks Authority
NDPMC	:	National Disaster Prevention and Mitigation Committee
NDWC	:	National Disaster Warning Center, MICT
NESDB	:	Office of National Economic and Social Development Board
NHA	:	National Housing Authority
NSO	:	National Statistic Office
ONEP	:	Office of Natural Resources and Environmental Policy and Planning
OTP	:	Office of Transport and Traffic Policy and Planning, MOT
PTT	:	PTT Public Company Limited
PWA	:	Provincial Waterworks Authority
RFD	:	Royal Forest Department
RID	:	Royal Irrigation Department, MOAC
RTSD	:	Royal Thai Survey Department, Royal Thai Army
SLA	:	Social Local Administration
TAO	:	Tambon Administration Organization
TMD	:	Thai Meteorological Department, MICT

International Organization / Agencies

ADB	:	Asian Development Bank
AIT	:	Asian Institute of Technology
DHI	:	Danish Hydraulic Institute
ECLAC	:	Economic Commission for Latin America and the Caribbean
IPCC	:	Intergovernmental Panel on Climate Change
JBIC	:	Japan Bank for International Cooperation
UNCED	:	United Nations Conference on Environment and Development
UNDP	:	United Nations Development Programme

UNFCCC	:	United Nations Framework Convention on Climate Change
WB	:	World Bank

Others

B.E.	:	Buddhist Era
BMR	:	Bangkok Metropolitan Region
DEM	:	Digital Elevation Model
GDP	:	Gross Domestic Product
GHG	:	Greenhouse Gas
GIS	:	Geographical Information System
MRT	:	Mass Rapid Transit
SLR	:	Sea Level Rise
SPP	:	Small Power Producer
SRES	:	Special Report on Emissions Scenarios

Units of Measurement

mm	:	millimeter (s)
cm	:	centimeter (s)
m	:	meter (s)
km	:	kilometer (s)
km^2	:	square kilometer (s)
m^3	:	cubic meter (s)
MCM	:	million cubic meters
kg	:	kilogram (s)
sec	:	second (s)
kV	:	kilovolt (s)
MVA	:	megavolt-ampere (s)
m^3/sec	:	cubic meter per second
Baht	:	Thai baht (Thai currency)
MSL	:	mean sea level
%	:	percent
^oC	:	degree centigrade

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

This report is the primary output from the Climate Change Impact and Adaptation Study for the Bangkok Metropolitan Region (BMR) produced for the Bangkok Metropolitan Administration (BMA) with financial support provided by the World Bank. The views expressed in this report are those of the authors, and do not necessarily reflect the views of the World Bank.

The report concerns climate change, and provides an analysis of climate change impacts and adaptation options for the Bangkok Metropolitan Region. It is produced by a group of multi-disciplinary experts working under the company Panya Consultants Co. Ltd, based in Bangkok, Thailand. In addition to the more general matters on the physical setting and socioeconomics of BMR addressed herein, the report considers a number of issues related to climate change in detail. These are: changes in the inundation pattern, and impact on the population and socioeconomics, and coping mechanisms to deal with the changed situation.

A number of conclusions have been drawn from the analysis presented in this report. These are discussed below in categories that relate to specific objectives in the Terms of Reference for the current study.

Climate Forcing and Bangkok

Warming of the global climate system will have a multitude of impacts on the monsoon-driven climate of Bangkok. Based on analysis of a subset of models used for the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC), researchers at the Integrated Research System for Sustainability Science (IRS3) of the University of Tokyo estimate that by 2050 the local mean temperature will rise by 1.9^{o}C and 1.2^{o}C, and the basin mean precipitation will rise by 3 and 2% corresponding to IPCC A1FI and B1 climate scenarios (SRES - Special Reports on Emissions Scenarios) respectively. Furthermore, the sea level in the Gulf of Thailand will rise by 0.29 and 0.19 meters corresponding to IPCC A1FI and B1 climate scenarios. We adopted the climate forcing for the study.

Furthermore, we acknowledge that impacts on the hydrology of the city will be exacerbated by land subsidence (accumulated land subsidence would spatially vary from 0.05 to 0.30 meters depending on location in 2050), affecting storm surge (maximum 0.61 meters at the Chao Phraya River mouth) and urban infrastructural development. These were also included in the hydrological simulation for the study.

To aid informed decision-making based on likely impacts and costs of adaptation to climate variability and change, we looked at a number of climate scenarios for 2050. These were: Future with land subsidence; Future with land subsidence and A1FI or B1 scenario on a 1/10, 1/30 and 1/100 years occurrence basis; and with or without affecting storm surge. For purposes of comparison, the base year flood corresponds to probable flood in 2008.

Nevertheless, all of the discussion in the subsequent sections of the Executive Summary relates to the situation under Future climate in 2050 with land subsidence and A1FI climate scenario on a 1/30 year occurrence basis together with affecting storm surge. This circumstance is most likely to occur in the future.

Critical Characteristics of Climate Change Consequences on the Hydrology of the BMR

Certain characteristics of climate change consequences on the hydrology are of particular importance in determining the preferred approaches to reduce unfavorable impact in the future. A comprehensive modeling of the future hydrology of the city, and more importantly, its upper catchment areas has shown that:

- **Flood-prone area will expand in the future**. We estimate that an additional 180 km^2 of Bangkok and Samut Prakarn may be inundated under varying depths and to varying number of days under the A1FI climate change condition in 2050. The change marks about a 30% increase in the flood-prone area between 2008 and 2050. Furthermore, 7% of these provinces may remain inundated for over one month. Much of the increase in flood-prone area will be in the western part where the existing and planned flood protection infrastructures (dikes and pumps) may be inadequate to save the area from higher depths of flood in the future.

- **Flood volume will increase by the same percentage as precipitation, but flood peak discharge will increase more**. We observed a linear relationship between future precipitation and flood volume in the Chao Phraya River. Nevertheless, flood peak discharge in the Chao Phraya River will increase by a larger percentage than precipitation. This observation corresponds to unequal travel times of floods from upstream catchments.

- **Storm surges are important, but will have less effect on flooding**. Storm surges are not uncommon in the Gulf of Thailand. They are also responsible for flooding the BMR area. However, we estimate that the flood-prone area in Bangkok and Samut Prakarn will increase by about 2% due to affecting storm surge striking western coast of the Gulf of Thailand.

Impacts to be Considered

Climate change impact analysis of major infrastructural sectors (buildings and housing, transportation, water supply and sanitation, energy, and public health) has shown that several factors with potential contributions to the future development of the city are of importance and ought to receive prioritized attention from city planners and policy makers.

- **Large population will live in flooded area**. About one 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.

- **The economic damage of flooding will rise four-fold in 2050**. We found that under current climate and infrastructure conditions, economic damage from flooding (at current prices) would be 35 billion baht (about one billion U.S. dollars), which might rise to 148 billion baht (about 4.22 billion U.S. dollars) in 2050. However, 70% of the cost in 2050 would be attributed to land subsidence alone.

- **Buildings and houses are the most affected infrastructure**. More than a million buildings and housing (residential, commercial and industrial) units in Bangkok and Samut Prakarn might be impacted by flooding in 2050. These impacted buildings will include about 300,000 units in the western areas such as Bang Khun Thian, Bang Bon, Bang Khae, and Phra Samut Chedi districts. The total partial damage (to buildings and assets) may exceed 110 billion baht (3.14 billion U.S. dollars) at current prices. Nevertheless, half of the cost will be due to probable partial damage caused to the large number of new buildings that will be subjected to land subsidence in the flood-prone areas.

- **Commercial and industrial sectors will suffer substantially**. The commercial and industrial sectors will lose considerable income due to business suspension during flooding. We estimate that value-added income losses will be 22 and 10 billion baht (0.63 and 0.29 billion U.S. dollars) in commercial and industrial sectors respectively.

Now is the Time to Act

The causes and impacts of the climate change peril are so diverse that it is difficult to formulate a blueprint solution to the problems faced by the BMR. Thus, the options available for sustainable development of the city must rely on the implementation of a unique mix of structural and non-structural adaptation measures.

- **Mainstreaming climate change in national and sector development planning**. Lack of awareness of climate change within the government and insufficient relevance of available climate information to development-related decisions poses considerable difficulties in mainstreaming adaptation in the city's development planning. We propose mainstreaming climate concerns at both policy and operational levels. At the policy level, projected impacts of climate change should be embedded in all development planning. Operational level mainstreaming or climate proofing, on the other hand, will involve critical analysis of adaptation options for actual implementation of activities.

- **Implications for financing organizations**. We believe there is an urgent need for international financing and donor organizations to reconsider their policies pertaining to climate change impacts and adaptation options. While we acknowledge that climate change provides a considerable challenge to the development of coastal mega-cities such as Bangkok, it also stands as a common entry-point for much of the sectoral development works. Therefore, financing provided in different socioeconomic and infrastructure sectors must be hinged specifically on adaptation to climate impacts.

- **The business-as-usual measures may be inadequate to save the coasts from erosion**. The problem of coastal erosion along the shoreline in the Upper Gulf of Thailand is already a critical deterrent to the sustainable development of the BMR. The situation will only get worse when the sea level rises in the future. We propose initiation of an urgent research study to identify suitable solutions to protect the shoreline taking sea level rise and land subsidence into account.

- **Some issues must be addressed as a matter of urgency**. We found that the existing and planned flood protection dikes and drainage system will be largely inadequate to protect the western part of the BMR from any flood exceeding a 10-year return period in the future. We propose that some of the existing dikes be raised and the pumping capacity of three western pumps be increased. Our initial economic viability analysis of the proposed structural interventions indicates a favorable investment portfolio. Feasibility of these propositions, including rigorous appraisal of their environmental consequences, should be undertaken as a matter of urgency.

Finally, we applaud current initiatives of Bangkok city administrators and international financial institutions to 'unpack' impacts of climate change faced by Bangkok, reflecting trends toward climate mainstreaming in the development agenda, and call for a continued policy to specifically direct funds towards implementation of adaptation measures for truly sustainable development of Bangkok.

CHAPTER 1

INTRODUCTION

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INTRODUCTION

1.1 BACKGROUND

Asia is undergoing unprecedented urban growth in terms of population and socioeconomic development. Much of this growth is occurring in large coastal cities at high risk from climate change and sea level rise. Recent loss and damage to life and property due to flooding amply demonstrated the potential for loss in the coastal mega-cities. Bangkok is a case in point. Yet, comprehensive modeling for the local inundation pattern, as well as thorough assessment of consequent impacts on physical infrastructure and socioeconomics had been lacking. The gap seriously impaired the city government's ability to consider appropriate adaptation options.

To fill the gap, the World Bank (WB) is collaborating with the Asian Development Bank (ADB) and the Japan Bank for International Cooperation (JBIC) to carry out an assessment of the impacts of climate change on major coastal cities in Asia (Bangkok, Ho Chi Minh, Kolkata, and Manila). A separate study is conducted for each coastal city whereupon a synthesis report is produced, integrating results from city-specific works. The study will: (i) evaluate similarities and differences of results and by doing so (ii) identify common approaches to adaptation, which could be readily utilized in other coastal cities in the region.

The World Bank entrusted Panya Consultants Co., Ltd. (the Consultant) to carry out an assessment for Bangkok and vicinities. The study addresses three major questions: (i) what can Bangkok expect due to climate change and associated impacts and what are the projected magnitude of these impacts; (ii) what adaptation measures could be employed to address the threat of climate change related impacts; and (iii) what are the key policy priorities for decision-makers to deal with the threat of climate change impacts.

The project consisted of: generating an extensive knowledge base of past and present climatic and socioeconomic situations, developing a mathematical model for simulating climate change effect on hydrology, assessing impact for the year 2050 under different climate change scenarios, and recommending suitable adaptation options for the city. Moreover, consultations with stakeholders were carried out to facilitate informed decision-making on the part of government and the private sector on measures needed to address climate change and its consequences.

1.2 STUDY GOAL AND OBJECTIVES

The study strengthened the understanding of: (i) the socioeconomic impacts of climate variability and change, and associated vulnerabilities of the urban communities, especially the poor, to such impacts; and (ii) the need to adapt urban infrastructure to mitigate these impacts and protect the urban population.

While the overall goal of the study entailed the Bangkok Metropolitan Administration (BMA) and governments developing effective approaches to strengthen their adaptation and amelioration capacities against the impacts of climate change and variability, the specific objectives of the study were to:

1) Assess the current knowledge base, including historical climate information, coping strategies, and local capacity to deal with natural disasters- especially those that are related to floods, cyclones, and tides;
2) Assess climate change scenarios and their consequences on the hydrology of coastal watersheds;
3) Identify the most vulnerable coastal and urban resources, including infrastructure and communities in the area, to impacts of climate change and variability;

4) Assess and quantify the likely magnitude of social, environmental and economic damages expected in Bangkok because of climate change and variability;
5) Identify and assess appropriate alternative intervention scenarios, and prioritize suitable interventions according to their effectiveness in terms of reducing vulnerability to threats from climate change and variability, associated cost, and implementation potential within the institutional setting of the city; and
6) Analyze the capacity of the city's government to deal with natural disasters (emergency prevention and preparedness capacity, early warning system, emergency evacuation system, notification procedure and its effectiveness, etc.) vis-à-vis international best practices, and provide appropriate recommendations.

1.3 SCOPE OF WORK

Scope of work consisted of:

1) Establish a climate change related historical knowledge base to aid climate change impact analysis, adaptation strategy formulation, and raise public awareness;
2) Define and evaluate the impacts of climate change (from socioeconomic viewpoints) on the basis of scenarios for the area; and
3) Help formulate city-level strategies for implementation in the short-, medium- and long-term to make city development plans more robust to climate change and increase the resiliency of natural and physical systems.

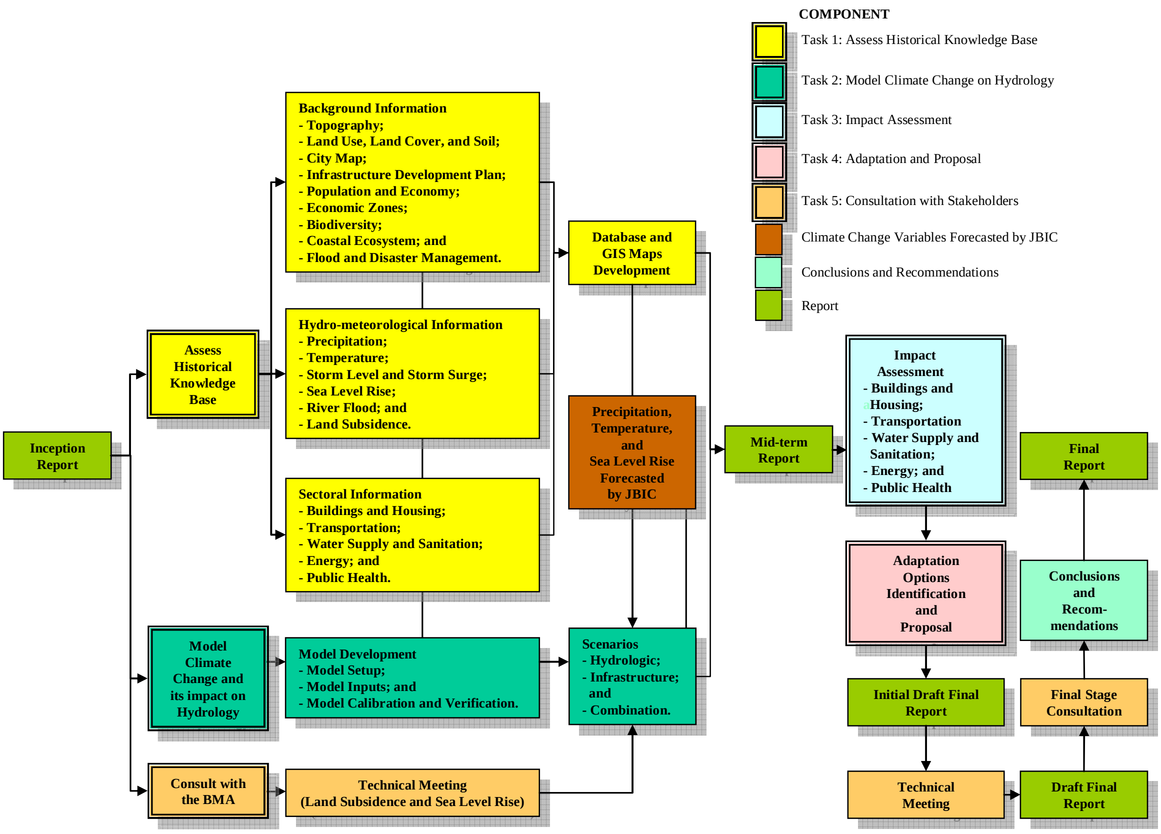
1.4 PROJECT AREA

The Bangkok Metropolitan Region (BMR) includes Bangkok and five provinces, namely Samut Prakarn, Samut Sakhon, Nonthaburi, Pathum Thani and Nakhon Pathom. The historical database for these areas is quite considerable. Therefore, this report focuses only on Bangkok and Samut Prakarn, which has shoreline along the Gulf of Thailand and will be directly affected by the sea level rise. However, the model on climate change on hydrology has to cover the whole Chao Phraya River Basin because most of the increased flood inflow from climate change into the delta area where Bangkok is situated comes from the upper basin.

1.5 ORGANIZATION OF WORK PROGRAM

To fulfill the objectives, five main tasks were accomplished. They are: assess the historical knowledge base; model climate change and its consequence on the hydrology of the area; impact assessment; adaptation and proposal; and consult with stakeholders. The tasks were carried out in order and relative to each other as shown in **Figure 1.5-1**.

Referring to the work flow diagram, the Inception Report was submitted in June 2008 to describe the proposed methodology approach and some collected data. After that, tasks 1 and 2 were accomplished in consultation with the BMA and the technical meeting on land subsidence and sea level rise was held in September 2008 at the World Bank's Office in Bangkok. The GIS database for this project was developed and applied throughout the study. The Mid-term Report was submitted in November 2008 and contained the historical knowledge base and the results of a hydrological simulation study under different climate scenarios. Tasks 3 and 4 evaluated the impact of climate change on hydrology and tested possible structural adaptation options. The second technical meeting was held in February 2009 after the submission of the Initial Draft Final Report and generated considerable feedback, especially on impacts and the adaptation study. The Draft Final Report was submitted in March 2009 and the final stage consultation was held in the same month. Subsequently, the report was finalized based on feedback from the stakeholder consultation.



Source: Panya Consultants

Figure 1.5-1 Work Flow Diagram

1.6 REPORT STRUCTURE

The Final Report consists of a Main Report and a number of Appendices. The Main Report summarizes major results contained in each appendix. There are six chapters in the main report along with an Executive Summary. The first chapter introduces the project while the second gives city descriptions from the historical knowledge base. Chapter 3 describes model development and simulation, presents the developed model and the results of flooding corresponding to the present situation and the future with climate change impact on hydrology. Chapter 4 presents the methodology and results of impact assessment. Chapter 5 is on adaptation and proposals to cope with the climate change. Chapter 6 elaborates the technical and stakeholder consultations carried out during the course of the project.

CHAPTER 2

CITY DESCRIPTIONS

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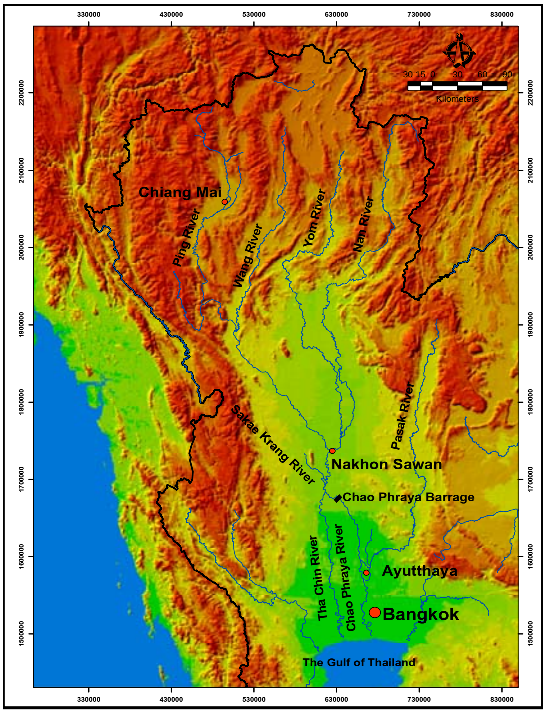
CITY DESCRIPTIONS

2.1 TOPOGRAPHY

2.1.1 River Basin



Source: Panya Consultants

Figure 2.1-1 River Network in the Chao Phraya River Basin

Bangkok covers an area of 1,569 km^2 located in the delta of the Chao Phraya River Basin, which is the largest basin in the country, covering an area of 159,000 km^2 or about 35% of the total land area of the country. There are two main rivers bisecting the delta area: the Tha Chin River on the west and the Chao Phraya River (the main stream) on the east. The basin forms up by 4 large tributaries: the Ping, Wang, Yom, and Nan originate from the mountainous terrain in the northern part of the country. These four tributaries flow southward to join each other in Nakhon Sawan to become the Chao Phraya River. The river flows southward through a large alluvial plain to reach the sea at the Gulf of Thailand as illustrated in **Figure 2.1-1**.

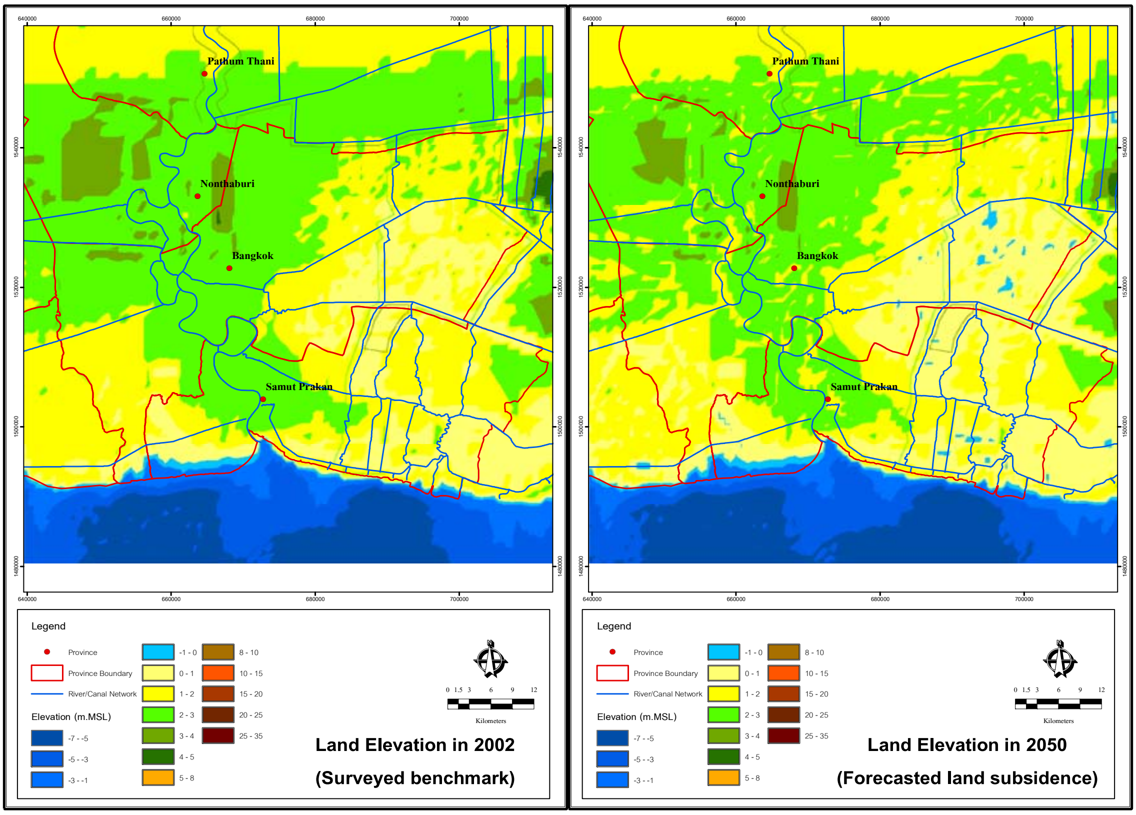
The basin area is flat at an average elevation of 1 to 2 m from the mean sea level (m.MSL), with certain spots where the elevation is lowered down to the sea level due to land subsidence. There are a number of canals crisscrossing the whole basin. Bangkok straddles the Chao Phraya River 33 km north of the Gulf of Thailand. Due to the flatness of the area and close proximity to the seashore, the area annually faces the problems of floods from rivers from the north and inundation due to the high tide from the sea. The topography of the Lower Chao Phraya River Basin is shown in **Figure 2.1-2**.

Source: Panya Consultants

Figure 2.1-2 Topography of the Lower Chao Phraya River Basin

2.1.2 Land Subsidence

From observed data, the average land subsidence rate in the Bangkok Metropolitan Region (BMR) has gradually reduced from 10 cm per year to 1-2 cm per year from 1978 to 2007. Furthermore, during the last 5 years (2002-2007), the average land subsidence rate has reduced to 0.97 cm per year. Therefore, it is expected that the land subsidence rate would reduce by 10% per year. Thus, the accumulated land subsidence during 2002-2050 (48 years) would spatially vary from 5 to 30 cm depending on location as shown in **Figure 2.1-3**.



Source: Royal Thai Survey Department (RTSD) and Panya Consultants' forecast

Figure 2.1-3 Land Elevation in 2002 and 2050 due to Land Subsidence

2.2 CLIMATE

2.2.1 General

The climate of the Chao Phraya River Basin belongs to the tropical monsoon. The average annual rainfall over the basin is 1,130 mm, varying from 1,000 to 1,600 mm and registering higher in the northeastern region of the basin. According to the rainfall pattern, about 85% of the average annual rainfall occurs between May and October. Tropical cyclones occur between September and October and may strike the basin. In this case, rainfall continues for a long period of time in a relatively wide area. The peak river discharge is registered in October, the end of the rainy season, and severe flood damage may arise with high tide in this period. The mean temperature ranges from 26^{o}C to 31^{o}C. Its maximum temperature is in April and its minimum is in December. The evaporation (Class-A Pan) in the basin is normally at its highest in April and lowest in October with an average annual value of about 1,700 mm.

2.2.2 Climate Change

The Intergovernmental Panel on Climate Change (IPCC) issued a Special Report on Emissions Scenarios (SRES). The scenarios are grouped as four Families (A1, A2, B1, and B2) with subsets, which each have different assumptions on the trend of global development. They are summarized as follows:

1) ***A1***: The A1 scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies);
2) ***A2:*** The A2 scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities;
3) ***B1:*** The B1 scenario family describes a convergent world with the same global population that peaks in mid-century and declines thereafter as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies; and
4) ***B2:*** The B2 scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability.

An illustrative scenario was chosen for each of the six scenario groups (A1B, A1FI, A1T, A2, B1 and B2). The IPCC AR4 projects that global greenhouse gas emissions will continue over the next few decades and that current warming trends and sea level rise will be larger than those observed in the latter 20^{th} Century. It also provides some projected regional impacts, including the following for Asia:

1) By the 2050s, freshwater availability in Central, South, East and South-East Asia, particularly in large river basins, is projected to decrease;
2) Coastal areas, especially heavily-populated mega-delta regions in South, East and South-East Asia, will be at greatest risk due to increased flooding from the sea and, in some mega-deltas, flooding from the rivers;
3) Climate change is projected to compound the pressures on natural resources and the environment associated with rapid urbanization, industrialization and economic development; and
4) Endemic morbidity and mortality due to diarrheal disease primarily associated with floods and droughts are expected to rise in East, South and South-East Asia due to projected changes in the hydrological cycle.

As part of the current study, the Japan Bank for International Cooperation (JBIC) commissioned the Integrated Research System for Sustainability Science (IRS3) of the University of Tokyo to investigate the projected future changes in precipitation, temperature and sea level rise pertinent to Bangkok. Based on analysis of a subset of the models used for the Fourth Assessment Report (AR4) of the IPCC, the IRS3 reported that the mean (June-August) basin precipitation for Bangkok would increase by 3 and 2% by 2050, corresponding to A1FI and B1 IPCC climate scenarios. Temperature increases in 2050 would be $1.9^{o}C$ and $1.2^{o}C$ while the sea level would rise 0.29 and 0.19 m for A1FI and B1 scenarios.

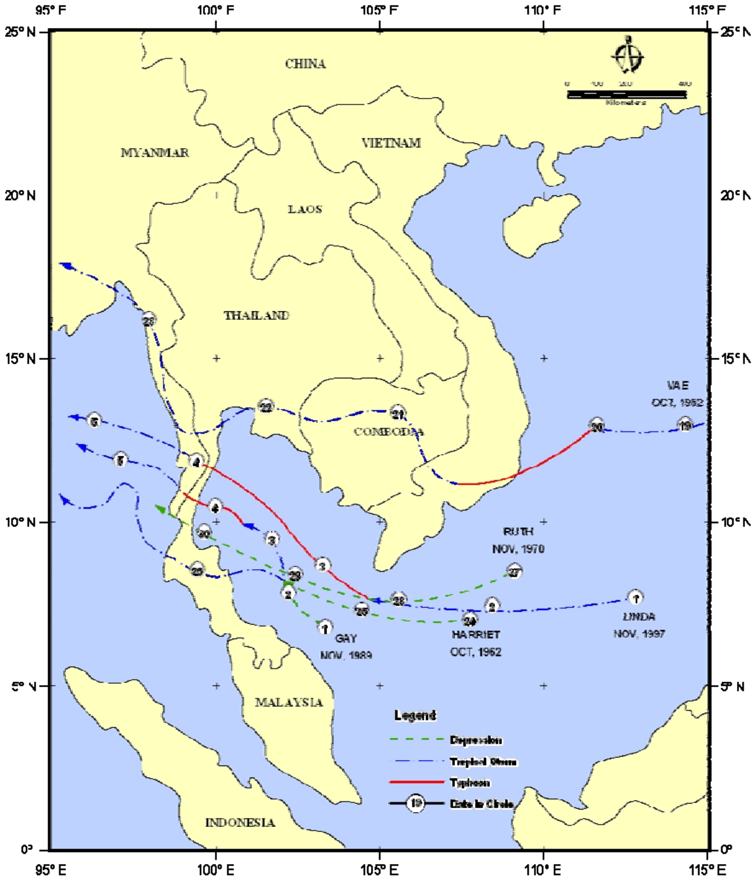
For the current study, forecasts provided by the IRS3 were used.

2.2.3 Sea Level Rise

In the Upper Gulf of Thailand (Bangkok, Samut Prakarn, Samut Sakhon, and Samut Songkram), the relative sea level rise is about 1-2 cm per year. The average value is 1.3 cm per year, implying a 3 mm per year rate of sea level rise considering a land subsidence rate of 1 cm/year. By 2050, the sea level should rise by 12.3 cm from 2009 to 2050. If the accumulated land subsidence in 2050 is taken as 20 cm, the relative sea level rise would be 32.3 cm.

Figure 2.2-1 Samut Prakarn Flood in September, 2002

2.2.4 Storm Surge



Source: The Meteorological Department (TMD), 2008

In the Gulf of Thailand, three storm surges occurred in the recent past. In 1962, the storm surge accompanying tropical storm Harriet caused severe impacts on the Lame Taloom Pook peninsula in Southern Thailand. More than 900 people were killed. In 1989, typhoon Gay also produced storm surge and attacked the eastern coast of Chumphon and along the Rayong coast in the inner Gulf area. In 1997, typhoon Linda originated in the South China Sea and upgraded to typhoon intensity shortly after entering the Gulf of Thailand. The cyclone turned northwestward following steering from the subtropical ridge.

Figure 2.2-2 Storm Tracks in the Gulf of Thailand

Typhoon Linda caused strong winds and heavy rainfall. A significant wave height of 3-4 m was measured. Linda weakened slightly to a wind velocity of 50 knots before it made landfall in Thabsakea, Prachuap Khiri Khan province. It should be noted that no typhoon has ever entered the Upper Gulf of Thailand. However, from the propagation of Linda's track, maximum storm surge at the Chao Phraya River mouth of 0.61 m was estimated.

2.3 SOCIO-ECONOMY

2.3.1 Administration

The administration of Thailand comprises three levels, namely central, provincial, and local. The central administration comprises 20 ministries and 164 departments, all are located in Bangkok. The provincial administration comprises 75 provinces (Changwat), 877 sub-districts (Amphoe/King-Amphoe), 7,255 sub-districts (Tambon), and 74,944 villages (Moo Ban). Local administration comprises provincial administration organization, municipalities, the Tambon Administration Organization (TAO), and the Special Local Administration (SLA). Bangkok is an SLA along with Muang Pattaya (Appendix A, page A-11). **Figure 2.3-1** shows 50 districts of Bangkok and 6 districts of Samut Prakarn.

2.3.2 Population

The BMR includes Bangkok and five vicinity provinces: Samut Prakarn, Samut Sakhon, Nonthaburi, Pathum Thani, and Nakhon Pathom. As of December 31, 2007, the total population of BMR was 10.07 million. The average growth rate during the 5-year period was 0.64% with the highest rate in Pathum Thani (4.95%). The average population density of BMR was 1,297 per km^2 with the highest density in Bangkok of 3,644 per km^2. The population in BMR for the period 2003 to 2007 is shown in **Table 2.3-1**.

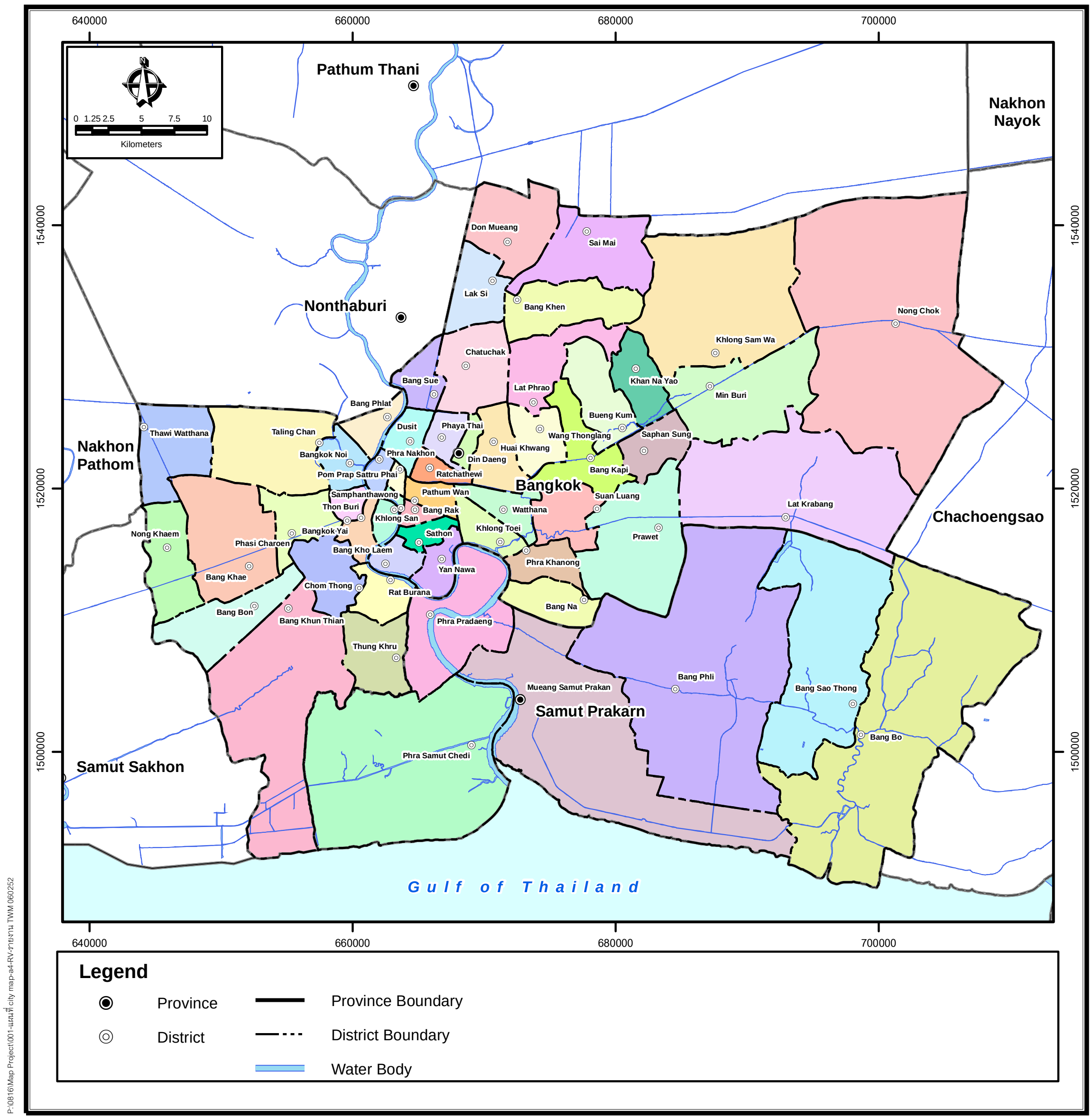
Table 2.3-1 Population in the BMR (2003-2007)

Province	No. of Population					Growth Rate (%)	Density (people per km^2)
	2003	2004	2005	2006	2007		
Bangkok	5,844,607	5,634,132	5,658,953	5,695,956	5,716,248	-0.54	3,644
Samut Prakarn	1,045,850	1,049,416	1,077,523	1,107,626	1,126,940	1.89	1,122
Samut Sakhon	448,199	442,687	452,017	462,510	469,934	1.20	539
Nonthaburi	924,890	942,292	972,280	999,057	1,024,191	2.58	1,646
Pathum Thani	739,404	769,998	815,402	861,338	896,843	4.95	588
Nakhon Pathom	812,404	798,016	808,961	821,905	830,970	0.58	383
BMR	9,815,354	9,636,541	9,785,136	9,948,392	10,065,126	0.64	1,297

Source: Department of Provincial Administration (DOPA), 2008

These numbers are based on the registration record and do not include the non-registered population. At present, there is no official statistical record on non-registered population in Thailand besides the estimation by the Department of City Planning (DCP), BMA. In 2007, the estimated non-registered population in Bangkok was 3.25 million. Therefore, the actual population of Bangkok in 2007 would be approximately 9 million.

To forecast the population in 2050 for BMR, the information on population projections for Thailand 2003–2030 prepared by NESDB was used as a base for the estimation. In the NESDB report, the projection was made to year 2030 for the whole kingdom and to year 2025 and 2020 for Bangkok and other provinces respectively. This projection was made at the provincial level and not for districts and sub-districts. In projecting the population to 2050, a regression function is applied. The summary of the projection with the non-registered population taken into account is shown in **Table 2.3-2**.



Source: BMA and Samut Prakarn

Figure 2.3-1 Districts of Bangkok and Samut Prakarn

Table 2.3-2 Population Projection including Non-registered (2050)

Unit: 1,000 people

Province	2008	2010	2015	2020	2025	2030	2040	2050
Bangkok	10,763	10,796	10,705	10,392	10,082	10,539	10,544	10,547
Samut Prakarn	1,286	1,320	1,391	1,438	1,445	1,469	1,507	1,537
Samut Sakhon	565	579	607	624	630	640	656	669
Nonthaburi	965	978	1,011	1,029	1,041	1,055	1,076	1,092
Pathum Thani	815	833	869	892	900	913	935	951
Nakhon Pathom	958	976	1,017	1,046	1,050	1,064	1,087	1,105
BMR	15,352	15,482	15,600	15,421	15,148	15,680	15,805	15,901

Source: Panya Consultants' calculation

2.3.3 Economy

The BMR is the economic center of Thailand. Bangkok is the headquarters for all of Thailand's large commercial banks and financial institutions. The east of Bangkok and Samut Prakarn are marked as an important industrial zone. In 2006, the Gross Domestic Product (GDP) of the BMR was 3,352 billion baht, or 43% of the country's GDP (7,830 billion baht). The annual average growth rate was 7.04%. Bangkok's GDP per capita was 311,225 baht (**Table 2.3-3**).

Table 2.3-3 GDP at 2006 Market Prices of the BMR

Province	GDP (billion Baht)	% GDP of the whole Kingdom	YOY Growth Rate (%)	GDP per Capita (Baht)
Bangkok	2,135	27.26	5.14	311,225
Samut Prakarn	514	6.57	7.71	404,807
Samut Sakhon	278	3.55	10.76	533,159
Nonthaburi	103	1.32	6.71	85,659
Pathum Thani	189	2.41	21.72	250,406
Nakhon Pathom	133	1.70	10.01	138,507
BMR	3,352	42.81	7.04	289,715

Remark: Year to Year
Source: The Office of National Economic and Social Development Board (NESDB), 2007

To project the BMR economy to 2050, the exponential regression function is applied by using GDP at constant 2007 prices as a base year. The summary of the moderate growth projection of the GDP of the BMR is presented in **Table 2.3-4**.

Table 2.3-4 GDP Projection for the BMR (2050)

Constant 2007 Prices Unit: billion Baht

Province	2008	2010	2015	2020	2025	2030	2040	2050
Bangkok	2,334	2,541	3,163	3,969	4,974	6,226	9,765	15,314
Samut Prakarn	582	642	809	1,011	1,265	1,585	2,485	3,897
Samut Sakhon	270	306	386	485	605	758	1,189	1,865
Nonthaburi	106	117	147	184	231	289	453	711
Pathum Thani	219	236	303	374	468	587	920	1,443
Nakhon Pathom	131	145	182	228	285	358	561	879
BMR	3,642	3,985	4,991	6,250	7,827	9,802	15,373	24,110

Source: Panya Consultants' calculation

2.3.4 Poverty

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. In 2007, 0.6% or 88,361 people in the BMR were poor. The poverty line in 2007 for the BMR was 1,638 baht per person per month. A summary of the poverty line, the proportion and the number of poor in each province of BMR is presented in **Table 2.3-5.**

It has to be noted that this accounting of the poor (88,361 people) is the official number based on people registered in the BMR populace. However, most of the poor are living in condensed housing and are non-registered. Statistics show 768,220 people living in 133,317 housing units of the condensed housing area. Therefore in the flood impact assessment on the poor this housing unit and population will be used as a base for the assessment of income loss of the poor.

Table 2.3-5 Poverty Line and the Poor in the BMR

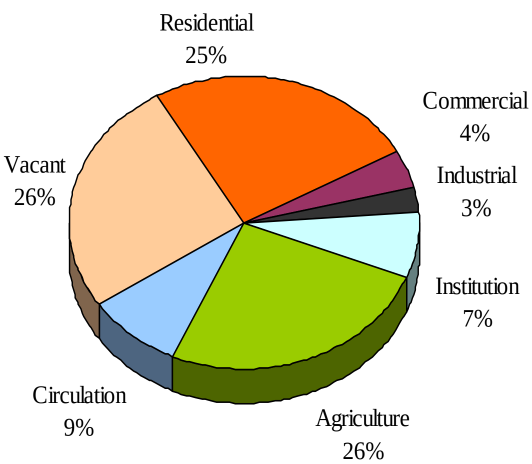
Province	Poverty Line (Baht/person/month)		Proportion of the Poor (%)		No. of the Poor (person)	
	2006	2007	2006	2007	2006	2007
BMA	2,020	2,065	0.51	1.14	28,692	64,422
Samut Prakarn	1,647	1,712	-	0.78	-	9,961
Samut Sakhon	1,511	1,564	0.76	0.42	4,313	2,436
Nonthaburi	1,529	1,561	0.30	0.06	4,124	845
Pathum 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

2.4 CITY PLANNING

Bangkok's oldest sector, the area enclosed within a loop of the Chao Phraya River, constitutes the central core of BMA. Major land uses in the core area include the King's Grand Palace, major temples, government offices, educational establishments, and 2-4 story row houses that serve as commercial retailing as well as living quarters. This area has been declared a national historical conservation area, and construction of high-rise buildings is forbidden.

Inner city districts are fully developed and densely populated and the land has already been utilized to near saturation point. Land uses in this area are intensified by vertical development in the form of high-rise buildings for offices and dwellings. The city expanded its urbanized areas in a V shape to the southeast and north directions along Sukhumvit and Phahol Yothin highways. The total built up area of Bangkok spreads from Nonthaburi in the north to Samut Prakarn in the south. One-fourth of Bangkok's area is still classified as agricultural land use, which is about the same size as residential land use. The proportion of land use in Bangkok is presented in **Figure 2.4-1**.



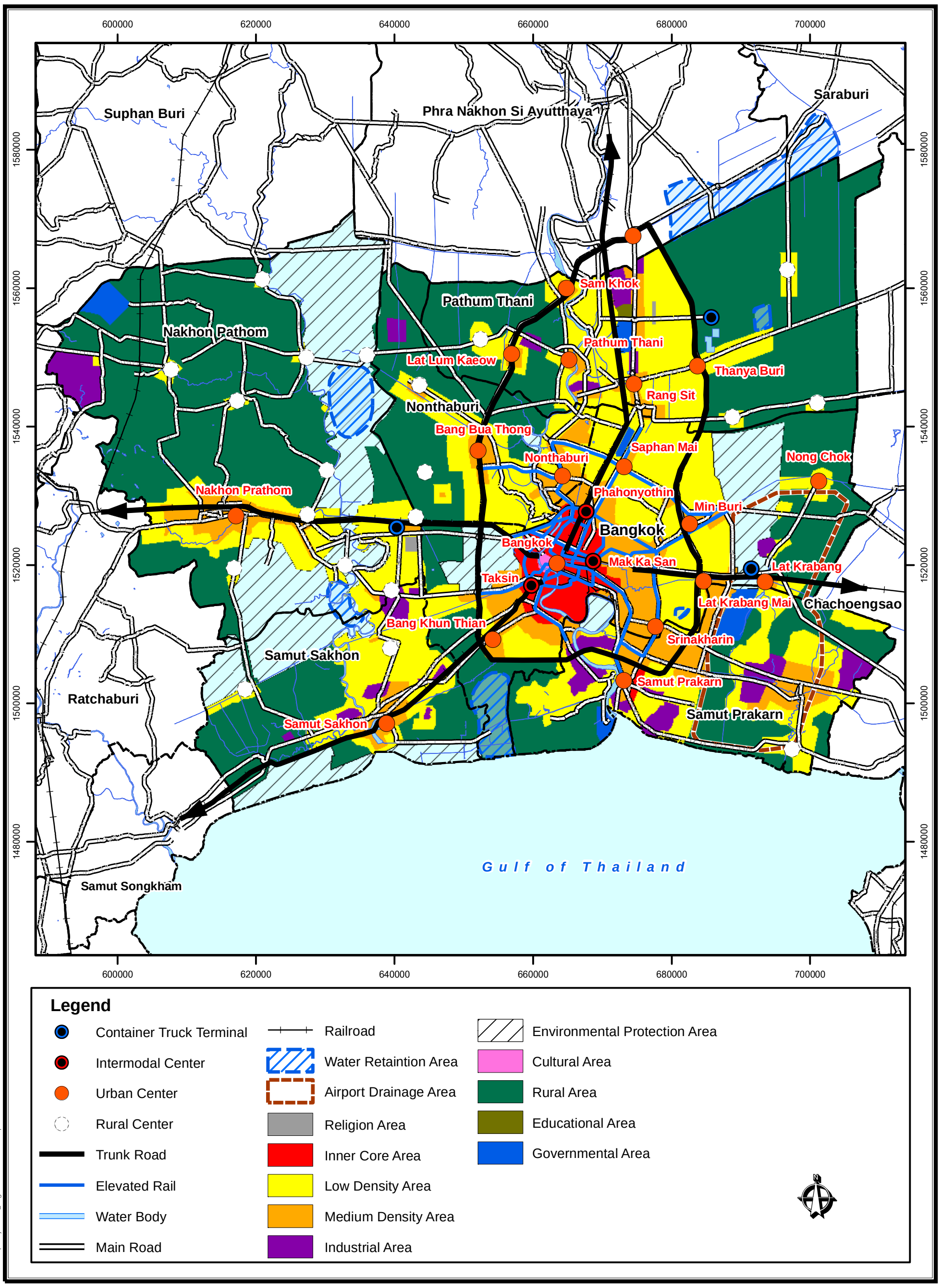
Source: Department of Public Works and Town & Country Planning (DPT), 2008

Figure 2.4-1 Proportion of Land Use in Bangkok

Although modern urban planning came to the kingdom nearly one-half century ago, implementation still poses a considerable challenge. For example, the majority of development projects in Bangkok were designed to solve immediate problems. Projects frequently squandered resources because they were not part of a broader and long-term strategy. Moreover, the government's policy represented a one-sided approach, which disregarded the management of surrounding towns, which have been planned separately in a piecemeal fashion.

To remedy these deficiencies, attempts have been made by planning agencies to prepare long-term, large scale national and regional development plans. A major step in the spatial planning process was the drafting of the fifty-year or 2057 (B.E.2600) national land use comprehensive plan that finished in 2007. Guided by the national plan, five regional development plans have been issued including a BMR Plan. The basic aim of the BMR plan is to give Bangkok the opportunity to shift from the relentless quantitative growth it experienced in recent decades to focus on qualitative growth in order to upgrade the quality of life of Bangkok residents. The major strategy aims for Bangkok to become "a center of culture, administration, service, and economic production using only high-skilled labor and sophisticated technology".

The development concept for the BMR is a multipolitan pattern with outlying areas developed as planned communities with a high degree of self-sufficiency, thereby ensuring residents need not commute to Bangkok for employment or high-level services. Economic activities will be decentralized from Bangkok and thereby diffuse growth from the capital to the five vicinities. The BMR land use conceptual plan for 2057 is shown in **Figure 2.4-2**. It illustrates tightened urban areas within the network of expressways bounded by large environmental protection areas to divert floods from the center.



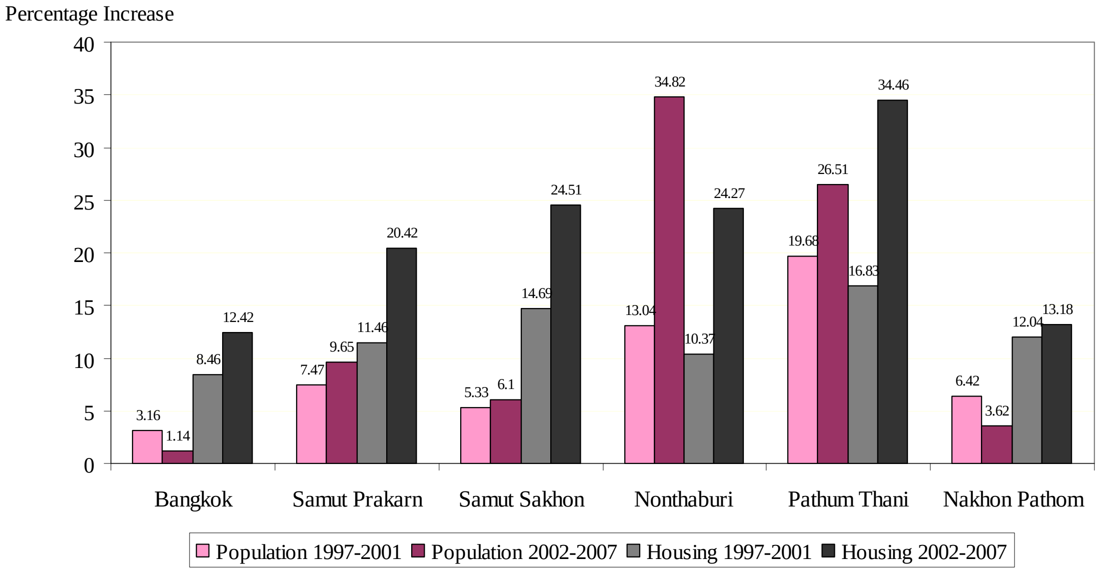
Source: Department of Public Works and Town & Country Planning (DPT), 2007

Figure 2.4-2 Land Use Conceptual Plan of the BMR (2057)

2.5 SECTOR INFORMATION

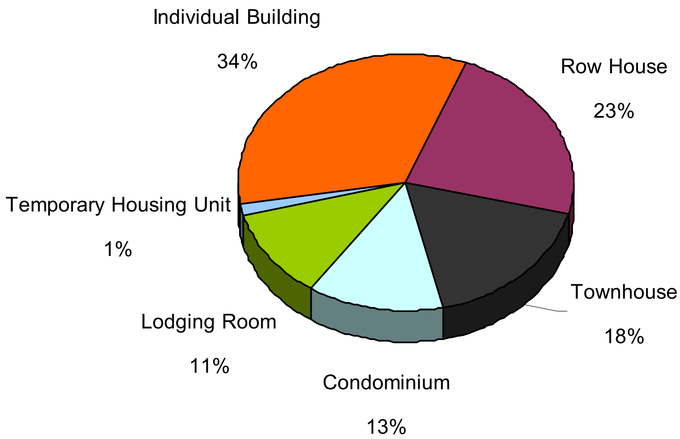
2.5.1 Buildings and Housing

Over the past decade (1997-2007), housing stock in Bangkok has been increasing at 2% per year in response to socioeconomic development (Appendix B, page B-10). The increase of housing stock in the neighboring province of Pathum Thani is even higher (5% per year) (**Figure 2.5-1**). Individual and row housing constitute the largest groups of houses by structure type (**Figure 2.5-2**).



Source: Panya Consultants

Figure 2.5-1 Population and Housing Growth in the BMR



Source: National Housing Authority (NHA), 2004

Figure 2.5-2 Housing Types in Bangkok

Concerning condensed housing neighborhoods (slums), the July 2008 housing data lists 805 such neighborhoods, reduced from 850 neighborhoods in 2005. The reduction can be attributed to destruction by fire and conversion to other land use. The analysis shows that the condensed housing neighborhoods are clustered around 5-10 km from the city center. Statistics report there are 768,220 people living in 805 condensed housing neighborhoods with 133,317 housing units and 186,017 households.

2.5.2 Transportation

The principal transportation network in the BMR comprises roads, rail, and waterways (Appendix C, page C-1) (**Figure 2.5-3**). The first urban expressway, the Chalerm Maha Nakhon Expressway, was opened in 1981. Since the mid-1990s, an extensive series of major road and expressway projects have been completed. Nevertheless, traffic jams on Bangkok's surface roads remain as private vehicle usage continues to outstrip infrastructure development.

The Bangkok Skytrain (BTS) was opened to the public in 1999 and connected to the MRT subway system in 2004. Bangkok commuters now have a convenient and fast way for travel to commercial areas like Sukhumvit Road. A new high-speed elevated railroad called the Suvarnabhumi Airport Link, currently under construction, will link the city with the airport.

Buses are the backbone of the passenger transportation system in Bangkok, accounting for more than 50% of all passenger trips and 75% of trips during the peak period. Bus service is provided by the Bangkok Mass Transit Authority (BMTA) and it operates throughout Bangkok as well as to adjoining provinces.

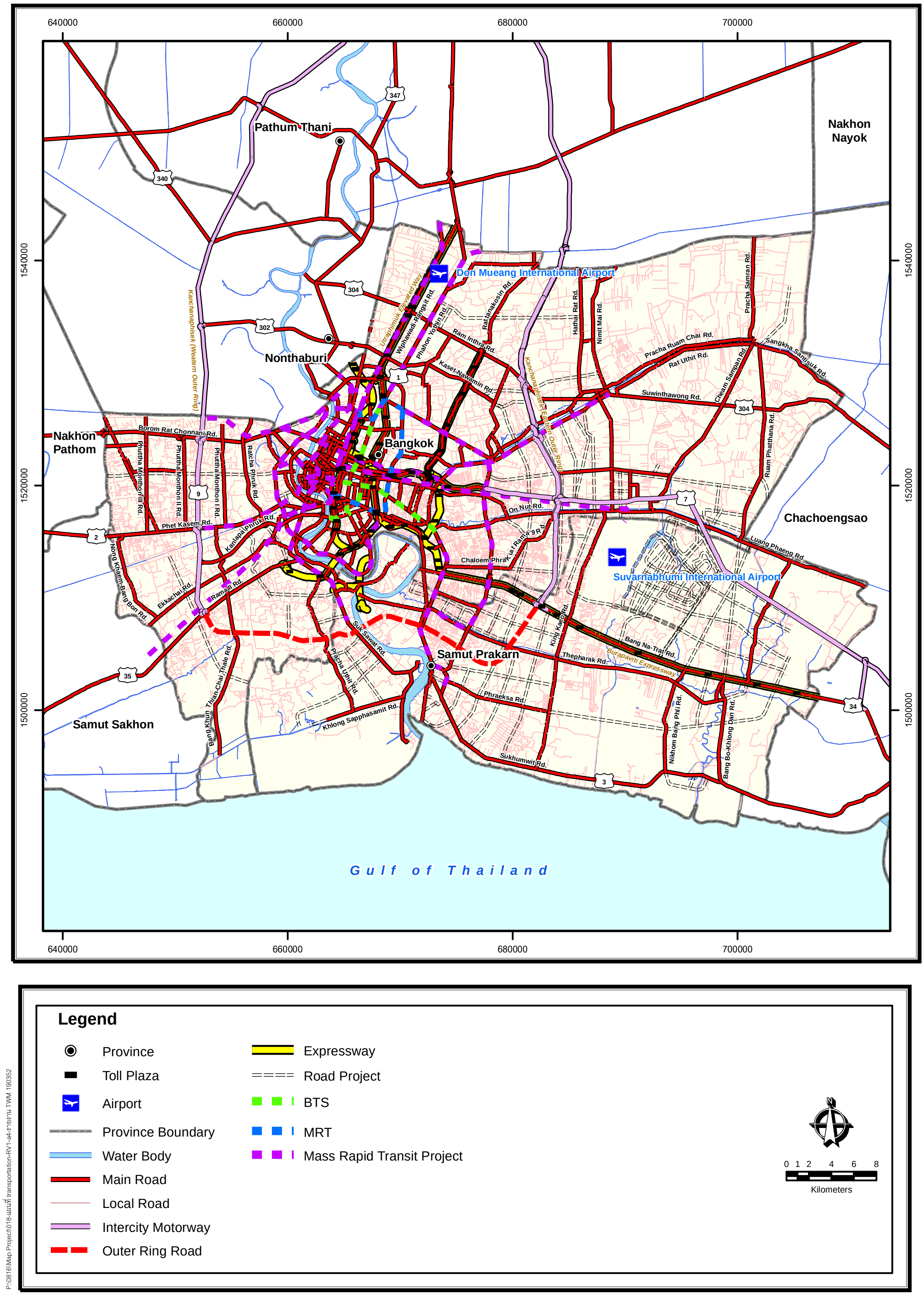
The waterway network was well-used when Bangkok was called “The Venice of the East”. Nowadays, the Chao Phraya express boats and Klong Saen Saep canal service boats have experienced a continuous decline in passengers due to mass transit diversion options.

2.5.3 Water Supply and Sanitation

The water supply and sanitation system in the BMR is presented in **Figure 2.5-4**. The Metropolitan Waterworks Authority (MWA) operates 4 treatment plants that provide the water supply to Bangkok, Samut Prakarn and Nonthaburi. Water resources are the Chao Phraya and Tha Chin Rivers. MWA prepared a plan to expand the serviced area and improve production capacity from 5.52 to 6.32 million cubic meters (MCM)/day. In the last 5 years, the average consumption of residential and non-residential users is 0.48 and 3.71 m^3/day/user and the average water revenue of residential and non-residential users is 2.06 and 2.83 baht/m^3, respectively. The water consumer projections in 2050 are 7.13 million for residences and 1 million for non-residences (Appendix D, page D-4).

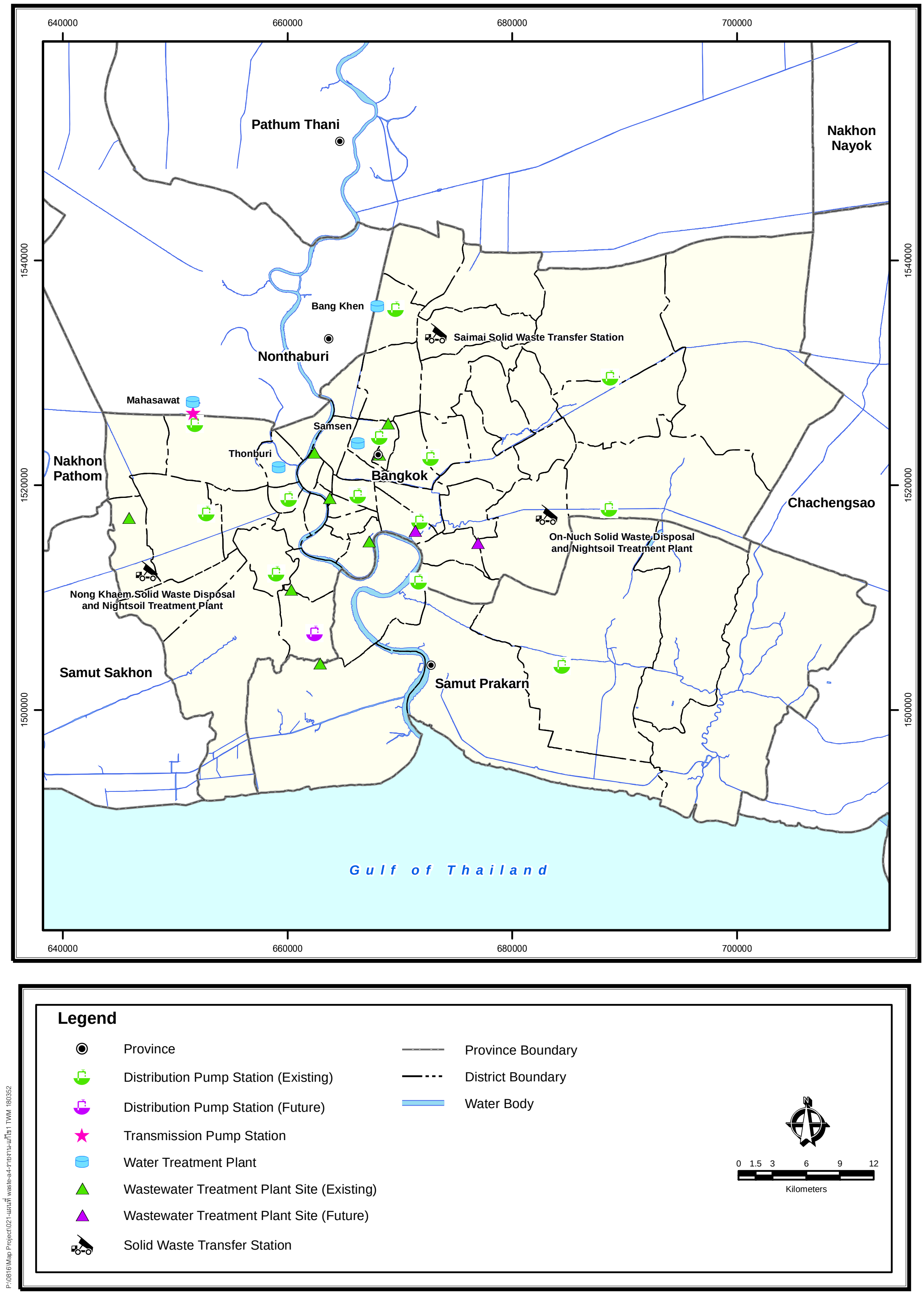
The BMA central environmental control plants have a total capacity of 1 MCM/day. Bangkok generates 2.6 MCM of wastewater per day. Together with 16 small treatment plants, BMA can treat 1.37 MCM/day or 50% of wastewater. In 2050, it is anticipated that daily wastewater generation in Bangkok will be around 2.47 MCM.

Solid waste in the BMA has two methods of treatment: composting and sanitary landfill. From 2003-2007, the average generation rate excluding the non-registered population was 1.55 kg/capita/day, of which 99% was collecting capacity. In the 6^{th} Bangkok Metropolitan Development Plan (2002–2006), the BMA proposed waste be reduced to less than 1 kg/capita/day, with 15% disposable waste reduction by the end of the plan. Subsequently, the solid waste generation rate was about 1.55 kg/capita/day in 2007 and should decrease to 1 kg/capita/day by 2010. This number should remain constant until 2050. It is projected that in 2050, Bangkok will generate solid waste of 6,718 tons/day.



Source: Bangkok Mass Transit Authority (BMTA), Department of Highway (DOH) and Expressway and Rapid Transit Authority of Thailand (ETA), 2008

Figure 2.5-3 Transportation Network in the BMR



Source: The Metropolitan Waterworks Authority (MWA) and BMA, 2008

Figure 2.5-4 Water Supply and Sanitation System in the BMR

2.5.4 Energy

Thailand has limited domestic petroleum production and reserves, and imports make up a significant proportion of its commercial energy resource requirement. The country also has substantial indigenous deposits of natural gas, but the rate of consumption outstrips the production rate and imports from Myanmar, a neighboring country, make up the short fall. It also has significant biomass and other renewable resources that are now being increasingly exploited.

Bangkok and Samut Prakarn are load centers for energy, especially for petroleum products and electricity. Consumption of fuel oil is used mainly in industry (36%), electricity generation (35%), and transportation (29%). Liquefied petroleum gas is used mainly as cooking fuel in residential and commercial sectors (64%), and smaller proportions are used in agriculture, industry (19%), and transportation (17%). Natural gas is used in power generation (90.3%), industry (9.4%), and transportation (0.4%). Electricity is used in all sectors (Appendix F, page F-3).

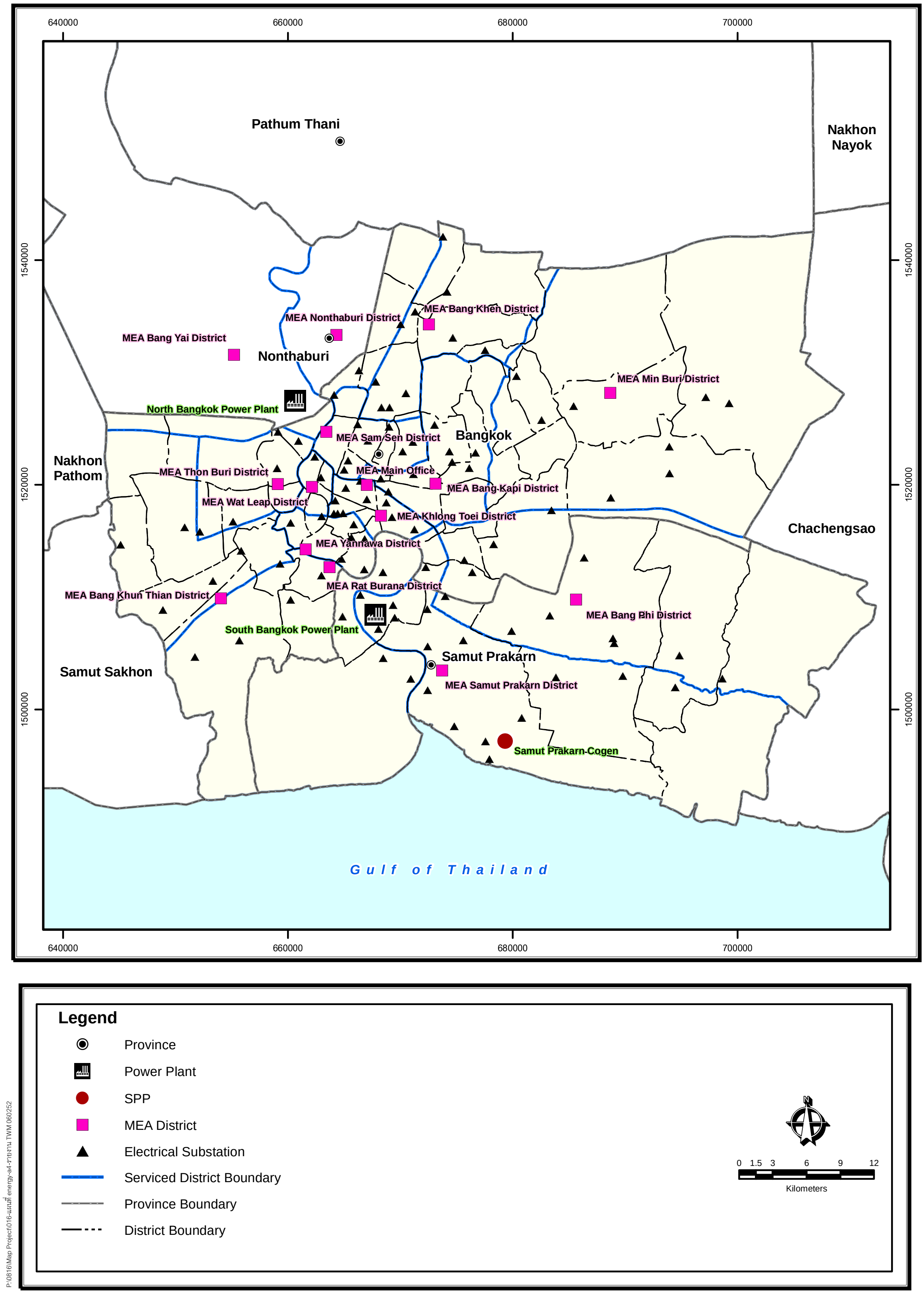
Electricity generation to supply the national grid is undertaken mainly by The Electricity Generating Authority of Thailand (EGAT). Distribution of electricity to customers in Bangkok, Samut Prakarn, and Nonthaburi is the responsibility of the Metropolitan Electricity Authority (MEA), another state enterprise. Distribution of electricity to the rest of the country is undertaken by the Provincial Electricity Authority (PEA), another state enterprise that also participates in specific small-scale power generation. Both MEA and PEA are under the administration of the Ministry of Interior (MOI). In 2007, the MEA's network comprised:

1) 17 terminal stations with installed transformer capacity of 15,356 megavolt-amperes (MVA);
2) 134 substations with installed transformer capacity of 15,785 MVA;
3) 230, 115, and 69 kV sub-transmission lines of 1,410 circuit-km; and
4) Total distribution line length of 12,823 circuit-km.

Energy infrastructure in Bangkok and Samut Prakarn is shown in **Figure 2.5-5**.

By 2050, it is assumed that natural gas will become scarce and expensive. It will be increasingly substituted by biomass in applications requiring heat, and by biofuel in applications requiring mechanical power (Appendix F, page F-10). Assuming the capacity of the network to be proportionate to electricity to be supplied due to increased demand, the following lists the number and capacity of facilities required:

1) 38 terminal stations with an installed transformer capacity of 35,660 MVA;
2) 310 substations with an installed transformer capacity of 36,658 MVA;
3) 500, 230, 115, and 69 kV sub-transmission lines of 3,275 circuit-km;
4) Total distribution line length of 29,778 circuit-km; and
5) 10 electric rail lines of 291 km with a substation capacity of 1,964 MVA.



Source: The Electricity Generating Authority of Thailand (EGAT), 2008

Figure 2.5-5 Energy Infrastructure in Bangkok and Samut Prakarn

2.5.5 Public Health

Climate change is projected to bring some mixed effects such as changes in range and transmission potential of malaria in Southeast Asia. Overall, it is expected that impacts will be outweighed by the negative health effects of rising temperatures, especially in developing countries. Critically important will be factors that directly renovate the health of populations such as education, health care, public health initiatives, and infrastructure and economic development.

Higher temperature has been found to be strongly associated with increased episodes of diarrhea disease in adults and children in tropical countries. Associations between monthly temperature and diarrhea episodes have also been reported in Asia and Australia. Although there is evidence that the bimodal seasonal pattern of cholera in Bangladesh is correlated with sea-surface temperatures in the Bay of Bengal and with seasonal plankton abundance (a possible environmental reservoir of the cholera pathogen, *Vibrio cholerae*), winter peaks in disease further inland are not associated with sea-surface temperatures. In many countries, cholera transmission is primarily associated with poor sanitation. The effect of sea-surface temperatures in cholera transmission has been mostly studied in the Bay of Bengal. In Africa, cholera outbreaks are often associated with flood events and fecal contamination of the water supplies.

Following on these trends, it is projected that the population of Bangkok may experience increasing threats of diseases and injury due to extreme weather events. For example, there will be increased burden of diarrheal diseases; increased frequency of cardio-respiratory diseases due to higher concentrations of ground-level ozone in urban areas related to climate change; and the altered spatial distribution of some infectious diseases. Nine contagious diseases related to water rising that should increase are diarrhea, dengue hemorrhagic fever, pneumonia, hand foot and mouth, tuberculosis, hemorrhagic conjunctivitis, typhoid, measles, and leptospirosis. On the contrary, occurrence of cholera may decrease in the long term because the disease would come under control as sanitation improves in Bangkok on pace with socioeconomic development.

2.6 COASTAL ENVIRONMENT

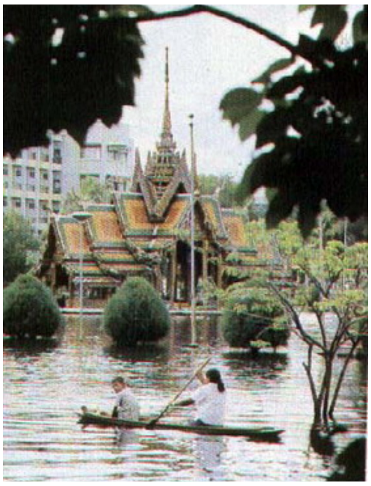
From Samut Sakhon to Samut Prakarn coastal areas, mangrove forests patch along the shoreline and create a channel network that provides an important stock for fishers. It has unfortunately been degraded by both natural and anthropogenic impacts. The mangrove forest along Bang Khun Thian coastline is sited in a zone affected by strong wind and severe wave surges. This condition has caused a high rate of coastal erosion and subsequently damaged the outermost stands of mangrove. Along with land use alteration from natural habitat to shrimp farms, the Bangkok green belt has gradually deteriorated and its buffer function incapacitated. The remaining narrow strip along the coastline is rather poor in species diversity and has less stem density than large-sized stands. The BMA has provided strategies to cease coastal erosion in this zone and rehabilitate mangrove under consultation with local communities and neighboring government agencies.

Figure 2.6-1 Wind Effects on Mangrove in Samut Prakarn

2.7 FLOOD MANAGEMENT

Flooding in Bangkok is mainly caused by large upstream runoff, heavy local rainfall and the tidal effect. In the Chao Phraya River Basin, there were exceptional large floods in 1942, 1978, 1980, 1983, 1995, 1996, 2002 and 2006. Completion of the Bhumibol Dam in 1964 and the Sirikit Dam in 1971 played a major part in reducing flooding risks in the lower delta including Bangkok.

In 1983, the low depression trough across the central plain and two tropical storms passing through the eastern part caused serious flooding problems for Bangkok because of runoff from the east, local rainfall and the high spring tide. After this flood, the government with inspiration from the King's initiative constructed a 72 km flood protection dike along the inner eastern border of the city. This dike effectively protects inner Bangkok from frequent flooding from the east.



In 1995, there was a sequence of tropical storms from the end of July to early September that caused heavy rainfall in the upper basins and especially the Nan River Basin (450 mm in August) where excess runoff far exceeded the capacity of the Sirikit Dam and 2,900 MCM had to be released. The discharge at Nakhon Sawan reached 4,800 m^3/sec. A substantial volume of water was released into the flood plain area between Chai Nat and Ayutthaya province, attenuating the flood discharge into 2,700 m^3/sec at Ang Thong province. In October, the peak flood flows coincided with the high spring tide causing very high water levels in the Chao Phraya River. The North, East, and West part of Bangkok were flooded extensively till December in some parts, resulting in heavy economic losses. The inundation depth was between 0.5 to 2.0 m.

Figure 2.7-1 Flood Effect in Ramkhamhaeng University, 1995

Additional flood protection works include the construction of additional storage dams, i.e. the Pasak Dam on the Pasak River, a tributary that has confluence with the Chao Phraya River at Phra Nakhon Sri Ayutthaya, in 1998 and the Khwae Noi Dam on a major tributary of the Nan River in 2008.

In 2006, there was again a very big flood from the northern Chao Phraya River Basin. The rainfall intensity during late September to early October was high, causing the flood discharge at Nakhon Sawan (the confluence of major tributaries of the Chao Phraya River) to be as high as 5,960 m^3/sec. Also, runoff from the Pasak River was high even with the storage dam. This large flood spilled over the river dikes and flooded the low lands on both sides of the Chao Phraya River north of Bangkok. The Royal Irrigation Department managed the flood by diverting part of it through canals in the east bank intended for drainage by the Bang Pakong River in the east and also through pumping stations along the eastern coast. In the west, the RID diverted the flood through canals and the Tachin River, which empties into the Gulf of Thailand at Samut Sakhon, thus bypassing Bangkok. Since rainfall in Bangkok itself was not very high, Bangkok and vicinities were saved by their polder and pumping system.

CHAPTER 3

MODEL DEVELOPMENT AND SIMULATION

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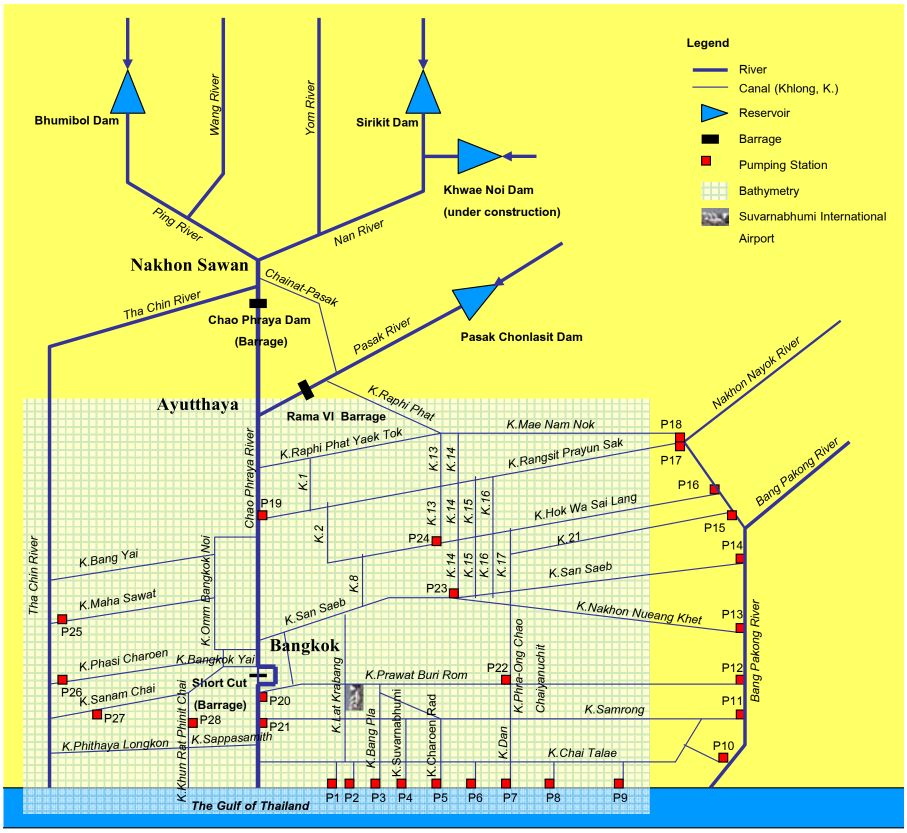
3.1 MODEL DEVELOPMENT

3.1.1 Model Setup

To set up a mathematical model for simulating the flood inundation mechanism caused by rainfall and affected by sea level rise in the delta area of the Lower Chao Phraya River Basin where the BMR is situated, it is necessary to consider the entire Chao Phraya River Basin of about 158,600 km^2 because most of the flood volume comes from the upper basin. The MIKE FLOOD (including MIKE 11 GIS) software package developed by the Danish Hydraulic Institute (DHI) was selected. The MIKE FLOOD is a unique integrated flood modeling package for rivers and flood plains (MIKE 11) and for flows, waves, estuaries, coastal areas and seas (MIKE 21). It dynamically couples well proven one-dimension (MIKE 11) and two-dimension (MIKE 21) modeling techniques into one single powerful tool. The MIKE 11 GIS is an extension for ArcView providing features for catchment/river delineation, cross-sections, and digital elevation model (DEM) data, flood visualization/animation as 2D maps, and result presentation/analysis using the Temporal Analyst.

The developed model generates runoffs from sub-basins and routes through the river/canal network and flood plain that include principal reservoirs, control structures, and pumping stations as shown in **Figure 3.1-1**. It was calibrated and verified based on the observed discharges and water levels at selected stations for the targeted flood years of 1995 and 2002. They were severe floods recorded in the recent past in the Chao Phraya River Basin and had complete observed data sets for rainfall, water level, and discharge at the selected stations. There was also a severe flood in 2006, but unfortunately the observed discharge data in Nakhon Sawan (C.2) is missing during the flooding period (Appendix K, page K-1).



Source: Panya Consultants

Figure 3.1-1 Schematic Diagram of Model Setup

3.1.2 Model Inputs

River/Canal Network and Cross-sections

The river and canal cross-sections surveyed by the Royal Irrigation Department (RID) in different years from 1983 to 2006 were used in the model. Intervals of the cross-sections range from 1 to 5 km. The flood plains outside the bathymetry area were treated as extended river cross-sections and ponds were treated as area-elevation curves obtained from the topographic map scale of 1:50,000 established by the Royal Thai Survey Department (RTSD).

Rainfall and Evaporation

The daily rainfall and pan evaporation data were monitored and gathered by the relevant agencies in Thailand. The rainfall data at 51 selected rainfall gauging stations was obtained from the Meteorological Department (TMD). The pan evaporation data at 9 selected meteorological stations was obtained from the same agency.

Water Level and Discharge

Most of the data was monitored by the RID. The daily water level data at 10 selected gauging stations on the Chao Phraya and Pasak Rivers were collected from RID. The daily discharge data at 8 selected gauging stations on the rivers were also collected from RID. The daily released discharge, water level, and calculated inflow of reservoirs at Bhumibol and Sirikit Dams operated by the Electricity Generating Authority of Thailand (EGAT) and Pasak Chonlasit Dam operated by RID were collected. In addition, hourly sea level data at the Phra Chunlachomklao Fort (Fort Chula) and the Tha Chin River mouth were collected from the Hydrographic Department and the Harbor Department respectively.

Hydraulic Structures

Flood protection dikes have been constructed mainly on the natural levees along both banks of the Chao Phraya, Tha Chin, and lower parts of the Pasak Rivers. The BMA has been constructing polder dike systems together with improvement of drainage systems including pump facilities and diversion tunnels to protect the city core and to drain local flood water along the roads during high intensity rainfall. The RID has been improving and constructing dikes, pumping stations, and diversion canals to protect the eastern and western areas of Bangkok from flooding. These existing and planned flood protection scheme data were obtained from the BMA and RID. The reservoir-capacity curves, operation rules (rule curves), and characteristics of spillways, outlets, and pumping stations were obtained from the agencies concerned (EGAT, RID, and BMA).

DEM

In this study, the Digital Elevation Model (DEM) was prepared from the data obtained from relevant agencies. Ground surface elevations in the eastern area of Bangkok were derived from the topographic maps scale of 1:4,000 surveyed by the BMA in 2006. For other areas, the spot elevations surveyed by the Department of Mineral Resources and the Royal Thai Survey Department in 2002 were used. Accuracy of the simulation depends on that of the DEM. However, the accuracy of the prepared DEM is different from area to area because a series of precise maps covering the whole inundation area is not available and several series of maps of different accuracies were used. Therefore, accurate simulation results are hardly expected for these areas.

Simulations were carried out for the entire flood season (from July to December). To generate flood hydrographs corresponding to 10, 30, and 100-year return periods of rainfall, frequency analysis of basin rainfall over the Chao Phraya River Basin was carried out. The model simulates flood flow along the river/canal network and flood plain covering the study area including Bangkok to identify the inundation area, water depth, and duration of each established scenario.

3.1.3 Model Calibration and Verification

Rainfall-Runoff Model
In this study, the Chao Phraya River Basin has been divided into 15 sub-basins based on major water control structures and the natural distribution of its river system. The NAM model of each sub-basin was calibrated by using the observed discharge from nearby gauging stations, and applying the catchment area proportion. For sub-basins with no nearby gauging station or those in the delta area, the normal parameters of the NAM model were applied. However, all parameters were adjusted again in the HD model calibration. In order to verify the land use change, the calibration was based on two periods: from April 1995 to March 1999 and from April 1999 to March 2003. These periods contain severe flood historical records (Appendix K, page K-12).

Hydrodynamic Model
The hydrodynamic model of the Chao Phraya River and its tributaries is separated into the upper and the lower basins. We applied MIKE 11 to the Upper Chao Phraya River Basin to simulate the flood hydrograph of each climate change scenario in Nakhon Sawan province. The observed water level data at Nakhon Sawan (C.2) is used as the end boundary condition of the Upper Model and the simulated result is used as the upstream boundary condition of the Lower Model. The generated discharge hydrographs from the NAM model of sub-basins are also the boundary conditions of both upper and lower models, taking into account the proportion of their catchment areas.

We used MIKE FLOOD (a coupling of MIKE 21 and MIKE 11) and MIKE 11 GIS for the Lower Chao Phraya River Basin to simulate flood inundation in the delta area of the river basin. The river/canal network in this area is so complicated that only the major components of the flood protection system are included in the model. The discharge from the drainage area of sub-polder dikes is treated to drain directly into the river or canal as it is. The end boundary conditions of MIKE 11 are the sea level at the river mouths and the pumping operations at the end of major drainage canals. The boundary conditions of MIKE 21 are the calculated discharge and water level from MIKE 11 and the sea level fluctuation at about 5 km from the shore, approximately equaling the water level at the river mouths. The calculated results at each time step are adjusted automatically to be the same values at the same locations in both MIKE 11 and MIKE 21 and then carried on in the next time step (Appendix K, page K-23).

The calibration results are generally good enough (Appendix K, page K-24). For the 1995 and 2002 floods, in particular, the hydrographs and the inundation maps show a good match with the observed ones. However, considerable gaps between the estimated and observed discharges, water levels, and inundation areas are found. These gaps might be attributed to the racking and accuracy of obtained data. In conclusion, the developed model is considered to be acceptable and applicable to the simulation study of the established scenarios.

3.2 SIMULATION

3.2.1 Return Periods

A return period, also known as a recurrence interval, is an estimate of the interval of time between events of a certain intensity or size. It is a statistical measurement denoting the average recurrence interval over an extended period of time or 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% chance of being exceeded in any one year. It is important to remember that a return period is an average frequency, not a schedule.

In the study, 10, 30 and 100-year return periods of rainfall are considered. A 30-year return period of rainfall is a frequency of rainfall events occurring with a magnitude similar to the flood of 1995.

3.2.2 Scenarios

In developing the scenarios, the future changes of precipitation, sea level rise, land subsidence and storm surge were determined as follows:

1) ***Precipitation:***
   (1) Based on past precipitation records; 10, 30 and 100-year return period basin precipitation as determined by the Consultant.
   (2) The future basin precipitation was determined by multiplying the precipitation by a factor provided by JBIC for climate change of A1FI and B1 scenarios.
   (3) The basin precipitation was distributed at rainfall stations according to the rainfall distribution pattern in 1995.
2) ***Land subsidence:*** The future land subsidence was analyzed using past data by the Consultant.
3) ***Sea level rise:*** The future sea level rise was provided by JBIC for climate change in A1FI and B1 scenarios.
4) ***Storm surge:*** The storm surge was based on the historical data collected and analyzed by the Consultant.

Scenarios for infrastructure were considered as follows:

1) Current condition (2008), existing and nearly completed flood protection infrastructures;
2) Future condition (2050) with land subsidence, assuming the planned flood protection infrastructures will have been implemented;
3) Future condition mentioned in 2) with climate change A1FI and B1 scenarios; and
4) Future condition mentioned in 3) with storm surge.

The combination scenarios were considered and summarized as shown in **Table 3.2-1**.

Table 3.2-1 Scenarios for Simulation Study

Description	Flood from Precipitation at Return Period		
	10 year	30 year	100 year
1. Current 2008	C2008-T10	C2008-T30	C2008-T100
2. Future in 2050 with land subsidence	C2050-LS-T10	C2050-LS-T30	C2050-LS-T100
3. Future in 2050 with land subsidence, sea level rise, and A1FI	C2050-LS-SR-A1F1-T10	C2050-LS-SR-A1F1-T30	C2050-LS-SR-A1F1-T100
4. Future in 2050 with land subsidence, sea level rise, and B1	C2050-LS-SR-B1-T10	C2050-LS-SR-B1-T30	C2050-LS-SR-B1-T100
5. Future in 2050 with land subsidence, sea level rise, storm surge, and A1FI	C2050-LS-SR-SS-A1F1-T10	C2050-LS-SR-SS-A1F1-T30	C2050-LS-SR-SS-A1F1-T100
6. Future in 2050 with land subsidence, sea level rise, storm surge, and B1			C2050-LS-SR-SS-B1-T100

Source: Panya Consultants

3.2.3 Flood from the Upper Chao Phraya River Basin

In the Upper Chao Phraya River Basin in its current condition and in the future, it is assumed that the Khwae Noi Dam is operated apart from the existing Bhumibol and Sirikit Dams. The Upper Model was applied to simulate the flood hydrographs in Nakhon Sawan (C.2) which were used to be the upper boundary conditions of the Lower Model. The Upper Chao Phraya River Basin will be affected by climate change only on increasing of precipitation. Sea level rise and storm surge will not be influent up to the upper basin. As a result of increasing precipitation of 3 and 2% of climate change A1FI and B1 scenarios, the flood volume of each return period is increased at about the same percentage but the increase in flood peak discharge is different due to the unequal travel times of flood hydrographs from sub-basins as shown in **Table 3.2-2**.

Table 3.2-2 Volume and Peak Discharge of Flood at C.2 and C.13 Gauging Stations

Description	1995	10-Year Return Period			30-Year Return Period			100-Year Return Period		
		T10	T10A1FI	T10B1	T30	T30A1FI	T30B1	T100	T100A1FI	T100B1
C.2 Gauging Station										
Flood Volume (MCM)	28,307	24,480	25,101	24,953	31,258	32,200	31,965	39,960	41,150	40,839
Factor Increase		1.00	1.03	1.02	1.00	1.03	1.02	1.00	1.03	1.02
Flood Peak (m^3/sec)	4,820	3,143	3,212	3,196	4,801	5,054	4,976	6,853	7,146	7,065
Factor Increase		1.00	1.02	1.02	1.00	1.05	1.04	1.00	1.04	1.03
C.13 Gauging Station										
Flood Volume (MCM)	24,744	20,320	20,795	20,695	27,756	28,485	28,235	36,997	38,378	38,019
Factor Increase		1.00	1.02	1.02	1.00	1.03	1.02	1.00	1.04	1.03
Flood Peak (m^3/sec)	4,501	2,935	3,000	2,984	4,484	4,720	4,646	6,399	6,673	6,598
Factor Increase		1.00	1.02	1.02	1.00	1.05	1.04	1.00	1.04	1.03

Remark: Flood volume is accumulated from July to December
Source: Recorded data in 1995 by RID and Panya Consultants' calculation

The runoff in Nakhon Sawan (C.2) flows to the Chao Phraya Barrage in Chai Nat province for 102 km and some of it is diverted into the Tha Chin River and Khlong Chai Nat-Pasak by the head regulators controlled by the RID. Therefore, the released discharge downstream of the Chao Phraya Barrage is controlled by the RID. The C.13 gauging station is located downstream of the barrage and the recorded runoffs are normally less than that at C.2 because of the diversion upstream, but the shape of the discharge hydrograph is close to that at C.2.

3.2.4 Flood in the Lower Chao Phraya River Basin

In the Lower Chao Phraya River Basin at current conditions, it is assumed that dikes along both banks of the Chao Phraya River, Khlong Maha Sawat and Khlong Bangkok Noi are completed and in the eastern area of Bangkok are protected by extending the flood protection system including the Suvarnabhumi drainage system. In the future, it is assumed that the diversion system that consists of the improvement of Khlong Raphi Phat, Khlong 13, 14, 17 and others, and pumping stations is completed. The Lower Model was applied to simulate the flood flow in the delta area to identify the inundation area, flood depth, and flood duration of each established scenario. The inundation area of each flood depth from the simulation results of all scenarios is shown in **Table 3.2-3**.

Current Condition (2008)

The total inundation areas of Bangkok and Samut Prakarn are 359.06, 550.37, and 736.68 km^2 for the flood at 10, 30, and 100-year return period respectively. The dike along both banks of the Chao Phraya River directly affects the water level in the river. Considering the same discharge, the water level with the dike is higher than that without. Therefore, the water level in the Chao Phraya River will be higher when a flood at a higher return period occurs. The tide from the Gulf of Thailand affects the water level in the Chao Phraya River but only in high tide periods from October to December.

Future with Land Subsidence (2050)

Land subsidence will increase the inundation area. For a flood at the 30-year return period that has the probability to occur as did the one in 1995, the total inundation area increases from 550.37 km^2 in 2008 to 568.80 km^2 in 2050 or about 3.35%.

Future with Climate Change

The increase in precipitation and sea level rise from climate change A1FI and B1 scenarios will result in increasing inundation areas. For example, for a flood at the 30-year return period, the total inundation area will increase from 550.37 km^2 in 2008 to 733.92 km^2 in 2050 or 33.35% for A1FI and to 718.53 km^2 or 30.55% for B1.

Future with Storm Surge and Climate Change

The increase in sea level from storm surge plus climate change scenarios will result in an increased inundation area. It is found that for a 30-year return period flood, the total inundation area will increase from 550.37 km^2 in 2008 to 744.34 km^2 in 2050 or 35.24% for A1FI (1.89% by storm surge).

Table 3.2-3 The Inundation Area in Different Flood Depths from Simulation Results

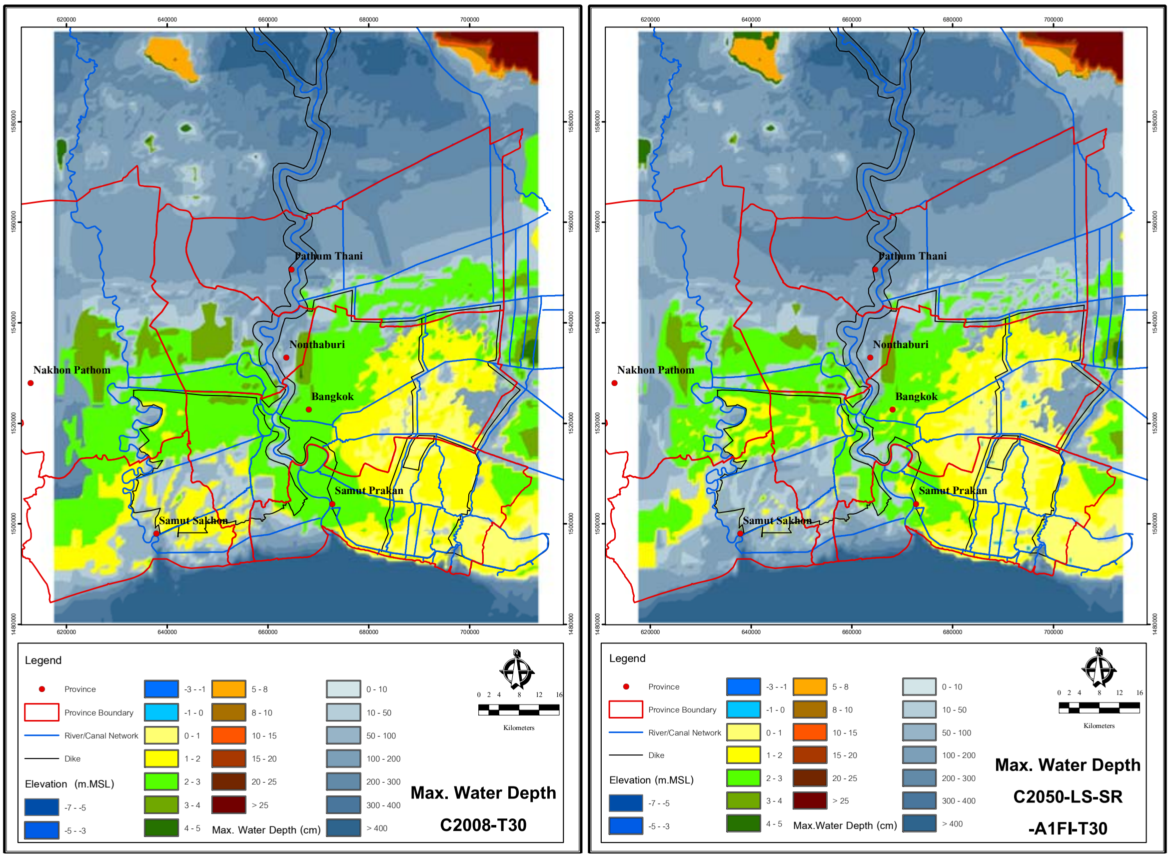
Unit: km^2

Depth of Flood (cm)	C2008-T10	C2050-LS-T10	C2050-LS-SR-B1-T10	C2050-LS-SR-A1FI-T10	C2050-LS-SR-SS-A1FI-T10	C2008-T30	C2050-LS-T30	C2050-LS-SR-B1-T30	C2050-LS-SR-A1FI-T30	C2050-LS-SR-SS-A1FI-T30	C2008-T100	C2050-LS-T100	C2050-LS-SR-B1-T100	C2050-LS-SR-SS-B1-T100	C2050-LS-SR-A1FI-T100	C2050-LS-SR-SS-A1FI-T100
Bangkok (BMA)																
0-10	1.71	2.01	1.88	1.99	1.89	1.71	1.49	2.12	2.02	2.01	3.49	2.41	2.13	2.12	2.05	1.89
10-50	123.34	136.84	151.35	158.37	161.18	180.27	176.36	176.91	170.06	163.14	166.23	157.02	164.03	161.73	156.54	154.27
50-100	55.63	89.05	116.42	128.91	133.44	121.65	154.66	181.13	191.99	201.96	203.56	211.38	225.87	229.17	236.94	240.29
100-200	7.72	13.78	17.96	22.69	21.28	66.61	47.24	137.05	138.80	137.70	147.76	226.69	239.21	238.41	251.38	249.89
>200	7.43	8.12	8.99	9.46	11.11	7.51	9.20	11.71	11.31	12.98	17.33	20.97	23.76	25.11	25.96	27.62
Sub-total	195.84	249.81	296.60	321.42	328.90	377.74	388.95	508.92	514.18	517.79	538.36	618.46	655.01	656.54	672.87	673.97
Samut Prakarn (SPK)																
0-10	0.32	0.39	1.02	1.06	1.18	0.97	0.68	1.41	1.59	1.45	1.09	1.29	1.04	1.00	1.19	1.15
10-50	31.70	30.26	35.57	41.63	40.97	34.52	32.18	53.22	56.93	54.97	52.83	61.83	75.55	74.05	81.85	78.91
50-100	40.70	37.80	35.69	36.37	34.95	43.54	38.81	40.71	42.21	44.86	46.77	42.21	41.42	43.31	44.53	50.13
100-200	46.72	47.79	54.13	56.82	50.58	48.35	54.64	58.07	59.31	54.02	53.60	58.13	64.93	59.71	66.07	60.66
>200	43.78	50.57	57.84	60.78	69.83	45.25	53.53	56.20	59.69	71.24	44.04	49.52	55.42	67.83	60.59	72.12
Sub-total	163.22	166.81	184.26	196.67	197.51	172.63	179.85	209.61	219.74	226.55	198.32	212.99	238.36	245.91	254.24	262.97
BMA&SPK																
0-10	2.04	2.40	2.90	3.06	3.07	2.68	2.17	3.53	3.61	3.45	4.57	3.70	3.17	3.13	3.24	3.05
10-50	155.04	167.10	186.92	200.00	202.15	214.79	208.54	230.13	226.99	218.11	219.06	218.85	239.58	235.78	238.39	233.18
50-100	96.34	126.85	152.12	165.28	168.38	165.19	193.47	221.84	234.21	246.83	250.33	253.59	267.30	272.49	281.47	290.42
100-200	54.43	61.57	72.09	79.51	71.86	114.96	101.88	195.13	198.11	191.72	201.35	284.82	304.13	298.12	317.46	310.56
>200	51.21	58.70	66.83	70.25	80.94	52.76	62.74	67.91	71.00	84.23	61.36	70.49	79.18	92.94	86.55	99.74
Total	359.06	416.62	480.86	518.09	526.40	550.37	568.80	718.53	733.92	744.34	736.68	831.45	893.36	902.45	927.11	936.94
Difference	-	57.56	121.80	159.03	167.34	-	18.43	168.16	183.55	193.97	-	94.77	156.68	165.76	190.42	200.26

Remark: Difference from the current condition (C2008)
Source: Panya Consultants' calculation

Figure 3.2-1 illustrates a comparison of maximum flood water depth between the current condition (C2008-T30) and the future with land subsidence, sea level rise, and a precipitation increase of 3% (C2050-LS-SR-A1FI-T30) for floods at the 30-year return period. Because of the flood protection system (polder dike and pumping system), most of the areas east of Bangkok will be protected except some areas where the crest elevations of dikes are not high enough, especially in the north and east of the area. For the western area of Bangkok, the crest elevations of dikes are not high enough to protect against flood and sea level rise, especially in the west and south of the area. In addition, the capacity of pumping stations of Phrasi Charoen, Sanam Chai, and Khun Rat Pinitchai are inadequate to pump the inside flood water out into the Tha Chin River and the Gulf of Thailand.

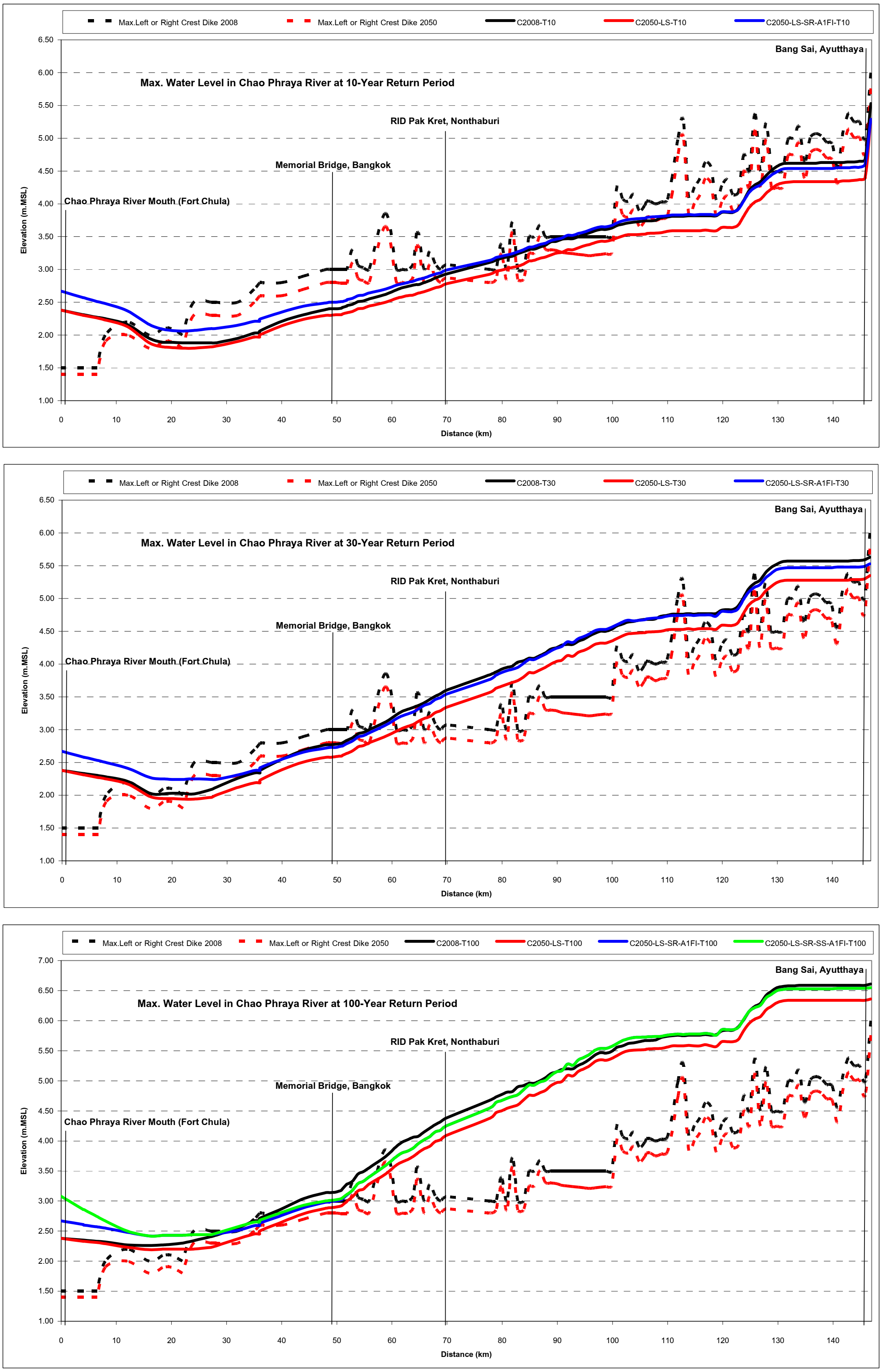
The inundation area on both banks of the Chao Phraya River will expand where the crest elevations of dikes are not high enough. However, the water level will be higher than the crest elevations of dikes along the river banks, but the duration is during the high tide period, so the flood water will not flow into the inner area of Bangkok. Furthermore, the inside drainage system can drain the overflow water into the rivers and the Gulf of Thailand, resulting in less inundation area in the east and the city core of Bangkok.



Source: Panya Consultants' calculation

Figure 3.2-1 Maximum Water Depth of Case C2008-T30 and C2050-LS-SR-A1FI-T30

Figure 3.2-2 illustrates the maximum water surface profile along the Chao Phraya River from the river mouth to Bang Sai district, Ayutthaya at 10, 30 and 100-year flood return periods. Comparing Case C2008-T100 and C2050-LS-T100, it reveals that the maximum water level will be reduced due to land subsidence of about 0.20 m, considering the sea level at the river mouth is not increased. Comparing Case C2050-LS-T100 and C2050-LS-SR-A1FI-T100, the maximum water level will be increased due to the increasing of flood water from the upper basin and the sea level rise. Comparing Case C2050-LS-SR-A1FI-T100 and C2050-LS-SR-SS-A1FI-T100, the maximum water level will be increased at the river mouth due to storm surge, but the effect will appear up to about 50 km from the river mouth.



Source: Panya Consultants' calculation

Figure 3.2-2 Maximum Water Level in the Chao Phraya River at Different Return Periods

CHAPTER 4

IMPACT ASSESSMENT

CHAPTER 4
IMPACT ASSESSMENT

4.1 METHODOLOGY

The impact assessment dealt with the estimation of potential socioeconomic loss due to climate change induced flooding and considered impacts on affected populations, buildings, and infrastructures. For this purpose, the study adopted a methodology based on recommendations of a number of authoritative literature on the subject: Handbook for Estimating the Socio-economic and Environmental Effects of Disasters (ECLAC, 2003), An Assessment of the Socio-Economic Impacts of Floods in Large Coastal Areas (AIT, 2004) and Study on Integrated Plan for Flood Mitigation in Chao Phraya River Basin Report (RID, 1999).

The impacts were explored by isolating strategically-important tangible damage related to potential future floods. Intangible damage, which includes negative physiological impact such as fear, depression, mental health, etc., were excluded from impact assessment since it was next to impossible to estimate such psychological conditions within the timeframe of this project. Evaluation of different tangible damages was done considering a number of constraints related to availability of data and information, and the limited timeframe of the project. Thus, this analysis is based on the premise that the impact assessment due to climate change must have a precise understanding of two components of the tangible damage as follows:

1) ***Direct damage*** is measurable and often relates to the replacement value of destroyed immovable assets and stocks including final goods, goods in process, raw materials, and spare parts. Direct damages occur at the time of the disaster or within a short time.
2) ***Indirect damage*** is not physical but can have a negative effect on the economy. Sales loss due to temporary suspension of business or income loss because of failure to operate normal economic activities are typical examples of indirect damage.

The main sectors that were assessed for both direct and indirect impacts include: population, building and housing (residential, commercial, and industrial), transportation, water supply and sanitation, energy, and public health. The summary of assessed damages is shown in **Table 4.1-1**.

Table 4.1-1 Summary of Assessed Damage

Damage Type	Sector	Damage Mechanism
Direct Damage	Residential unit	Damage to building and asset
	Commercial unit	Damage to building and asset
	Industrial unit	Damage to building and asset
	Transportation, Public health, Energy, Water supply and sanitation	No direct damage to these infrastructures expected in the future
Indirect Damage	Population	Loss of income
	Commercial unit	Loss of income
	Industrial unit	Loss of income
	Transportation	Negligible loss of revenue
	Public health	Additional cost of medical care
	Energy	Loss of net revenue
	Water supply and sanitation	Loss of net revenue

Remark: Only tangible damage taken in the assessment
Source: Panya Consultants

Damage costs were assessed for both base year (2008) and climate change scenarios in the future (2050). However, while valuing the damage cost, current (2008) unit costs were applied for both situations.

4.1.1 Population

There are several characteristics of flood that determine the impact severity, e.g. flood depth, duration of inundation, frequency of flood event, and velocity of floodwater or the rate of rising flood. This study considered two major characteristics of flood: flood depth and duration of inundation. Five critical flood depth ranges were categorized based on their effects on the livelihoods of the impacted population:

1) Depth of 0.00 to 0.10 m (Ankle height);
2) Depth of 0.10 to 0.50 m (Knee height);
3) Depth of 0.50 to 1.00 m (Waist height);
4) Depth of 1.00 to 2.00 m (One story house evacuated); and
5) Depth above 2.00 m (All evacuated).

Severity of impacts on the population refers to the impairment of daily livelihood activities and can be classified into four levels (**Table 4.1-2**):

1) No impact: Negligible inconvenience of daily livelihood activities;
2) Low impact: Minor health problems, some difficulty in living in a single floor house; disrupted vehicular movement brings hardship to regular livelihood activities;
3) Moderate impact: Major health problems requiring medical attention, disrupted mass transit system brings difficulty in accessing daily livelihood needs and necessity to move to upper floor or move out of single floor house; and
4) High impact: Serious impairment of livelihood activities; severe injury and illness requiring hospitalization or even loss of life; evacuation to safer locations.

Table 4.1-2 Flood Impact on Population

Flood Depth (cm)	Flood Duration				
	<1 day	1-7 days	7-15 days	15-30 days	> 30 days
0 – 10	No Impact	No Impact	No Impact	No Impact	No Impact
10 – 50	Low	Low	Low	Low	Moderate
50 – 100	Low	Low	Moderate	Moderate	Moderate
100 – 200	Moderate	Moderate	High	High	High
> 200	High	High	High	High	High

Source: Adjusted from the Assessment of the Socio-Economic Impacts of Floods in Large Coastal Areas (AIT, 2004)

Furthermore, it is evident that not all the people living in flood-prone areas are affected. Therefore, to estimate the number of affected people, it is assumed that 25% in the low impact flood-prone areas are affected while the corresponding percentages for moderate and high flood impact areas are 50 and 75%. Past records on fatalities due to flooding in Bangkok are not available. However, the flood damage record in Thailand (2001-2004) maintained by the Civil Defense Secretariat, the Royal Thai Police, and the Department of Pollution Control show 540 fatalities all over the country. Almost all of these fatalities are due to harsh flooding in other regions outside the BMR. For the BMR, most flood characteristics slowly rise, and it is expected that this type of flooding will not directly cause fatality. So it is assumed that there will be no casualties due to floods in the area.

Indirect impact refers to economic hardship of the affected population due to flooding. People may not have access to their work places. They may lose part of their income. However, it is assumed that the salaried population would not be affected by flooding and income loss of self-employed entrepreneurs is included when estimating the commercial sector's business loss income (see Section 4.1.2). Therefore, only daily wage earners living in condensed communities (slums) would lose income due to flooding. Moreover, it is assumed that people living in a condensed community have income below the poverty line of 68 baht per day per person (NESDB, 2007a).

Therefore, indirect impact on the population can be calculated as income loss (at the rate of 68 baht per day per person) of the number of affected condensed community dwellers.

4.1.2 Buildings and Housing

The direct flood damage refers to damage to buildings and housing (residential, commercial and industrial), and assets estimated by the equation below:

Direct damage = No. of affected buildings x Damage rate x Unit value of building and asset

Damage rate is dependent on the depth of inundation and can be differentiated between damage to building and damage to asset. There is no updated data on the damage rate. The Study on Integrated Plan for Flood Mitigation in Chao Phraya River Basin (RID, 1999) used the survey of the RID in 1997 to estimate the damage rate and recommended that same damage rate can be used irrespective of the type of building and housing (residential, commercial, and industrial). These damage rates were adopted for this study (**Table 4.1-3**).

Table 4.1-3 Flood Damage Rate of Building and Asset

Flood Depth (cm)	Damage Rate (% of value)	
	Building	Asset
0 – 10	0	0
10 – 50	3	1
50 – 100	5	8
100 – 200	7.5	15
> 200	9	19

Source: Adopted from the Study on Integrated Plan for Flood Mitigation in Chao Phraya River Basin Report (RID, 1999)

Unit value (average book value) of each type of building was estimated based on unit price used for the assessment of building and construction during the legal right registration of unmovable asset, (B.E.2551-2554 or 2008-2011) (Appendix L, page L-4). The asset value of residential units was estimated based on the possession of durable household appliances of households. Corresponding data were obtained from the Population and Housing Census of 2000. The unit costs of assets were estimated from average market prices. The average asset value based on 12 items for Bangkok and Samut Prakarn is 298,990 and 200,163 baht respectively. Additionally, to account for other assets that are vulnerable to flood damage, the asset value was increased by 10%. Therefore, average unit asset value for Bangkok and Samut Prakarn would be 328,889 and 220,180 baht respectively (Appendix L, page L-5).

For commerce, buildings are categorized into nine groups in accordance with the National Statistic office (NSO) classification. The book value of each group of commercial building is also obtained from the NSO's 2006 Business Trade and Services Survey.

In the case of industry, buildings are categorized into 11 and 12 groups for Bangkok and Samut Prakarn in accordance with the NSO classification. The book value of each group of industrial buildings is also obtained from the NSO's 2007 Industrial Census. It is assumed that large factories and factories located in the Industrial Estates, Industrial Zones, Industrial Community, and Industrial Parks would not be affected by flooding since these factories are protected from flood damage. Therefore, they were not included in the impact assessment.

Indirect damage costs of flooding on commerce and industry refer to the loss of income or business suspension due to flooding. The calculation of the total income loss due to flood damage is as follows:

Business income loss = No. of affected buildings x Income/day x Flood duration

To estimate the income loss of commerce, data from the NSO's 2006 Business Trade and Services Survey was used. The average annual value added per commercial establishment was 3,179,406 baht per year or 8,711 baht per day. It is assumed that during business suspension due to flooding 10% of average business operating cost (3,781 baht per day) will not be paid. Therefore, daily income loss of commerce is 4,930 baht per establishment.

In the case of income loss of industry, information was obtained from the NSO's 2007 Industrial Census in Bangkok and its vicinity. The average annual value added per industrial establishment was 7.4 and 23 million baht per year or 20,274 and 63,014 baht per day for Bangkok and Samut Prakarn respectively. It is assumed that during the business suspension due to flooding 10% of average business operating costs (5,601 and 18,971 baht for Bangkok and Samut Prakarn respectively) will not be paid. Therefore, daily income losses of industry are 14,673 and 44,043 baht per establishment in Bangkok and Samut Prakarn respectively.

4.1.3 Transportation

Railway
The level of rail lines is generally set at about one meter above the surrounding ground level. The history of flooding in Bangkok chronicles minimal effect on rail transportation. It can be safely assumed that railways will incur minimum damage and will be able to operate normally during and after flooding.

Mass Rapid Transit
The Mass Rapid Transit System, both elevated and underground, in Bangkok has been designed to be protected from overflow flood water. The elevation of the gates of the Mass Rapid Transit Authority (MRTA) underground Blue Line, linking to the streets, is set at one meter above the street level, and the door to the entrance will be shut down when water rises to one meter above the sidewalk. The Bangkok Mass Transit System Public Company Limited (BTS) elevated Green Line is also safe from high water levels.

Waterway Transport
Waterway transportation operated in the inner city of Bangkok is not affected by high water levels during flooding periods.

Air Transport
Both Suvarnabhumi International and Don Muang Airports, connected with land transport by Airport Rail Link and Elevated Expressway, have special measures to protect them from rising flood water. They are not expected to have serious impacts from flooding.

Road and Highway
More than 90% of inhabitants of Bangkok and Samut Prakarn travel by roads and highways. The road network in Bangkok, Samut Prakarn, and the BMR were set at an elevation at of 1.5-2.0 meters above ground, and most of them were covered with reinforced concrete pavement or 7-10 cm thick of asphaltic pavement. Therefore, they will not incur flood damage caused by rising water in the future and direct impact on these infrastructures can be neglected.

However, there might be indirect impact in terms of loss of revenue due to suspension of operation of inundated toll plazas. This type of indirect impact could be estimated based on loss of operation-days of toll plazas (inundated by more than one meter) and revenue generated by these toll plazas. Nevertheless, it was found that even under the worst case scenario of the future (C2050-LS-SR-SS-A1FI-T100) the flood water depth would remain less than one meter near all toll plazas and there would be no indirect impact on the road and highway transportation.

4.1.4 Water Supply and Sanitary System

Direct damage to the water supply and sanitary (WSS) infrastructure is not assessed since they are protected from the worst possible flood in the future. Historical records of damage of the WSS system also attest to this statement. Nevertheless, indirect impact which refers to income loss for the water supply system and operating losses of the wastewater treatment system and solid waste management system were estimated. Users were categorized into residential and non-residential based on different demands and sales rates.

It is assumed that the water supply system will become dysfunctional when flood water rises two meters above the surrounding ground surface. Subsequently, users in the flooded area will have no service from the water supply system. The calculation of sales loss for the water supply system due to flood damage follows:

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

The five-year record of the Metropolitan Waterworks Authority (MWA) 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 non-residential unit are 3.71 m^3 per day per customer and water revenue is 2.83 baht per m^3

With regards to the sanitation system which includes the wastewater treatment system and the solid waste management system, it is assumed that their operation would be suspended when the flood water rises two meters above the surrounding ground surface. The calculation of income loss from non-operation of the sanitation systems due to flooding follows:

Sanitation operating loss = No. affected population x Generated rate x Treatment cost x Flood duration

According to the Department of Drainage and Sewerage (DDS) record in 2007:

1) Wastewater generation rate is 0.37 m^3 per day per capita (80% of water demand);
2) Wastewater treatment cost is 12.17 baht per m^3;
3) Solid waste generation rate is 1 kg per day per capita; and
4) Solid waste disposal cost is 454.75 baht per ton.

4.1.5 Energy

There are two electricity generation plants in Bangkok. The North Bangkok power plant has already been retired, and the South Bangkok power plant will expire before 2050. Future power generation plants for Bangkok and Samut Prakarn are planned outside these two cities. Thus, there will be no direct impact to power generation plants in the future.

As for electricity distribution, 18 service-districts cover Bangkok, Samut Prakarn and Nonthaburi with 145 substations, according to the Metropolitan Electricity Authority (MEA). These substations (buildings and equipment) will not incur direct flood damage since floodwater remains below one meter depth in these substations. However, the MEA will lose revenue due to service suspension is indirect cost can be estimated from the loss of net revenue that will accrue when the electricity supply has to be shut down to areas inundated by more than one meter. Corresponding unit electricity sales-loss data were obtained from the MEA.

4.1.6 Public Health

There is no historical record of direct flood damage to public health facilities. However, the health facilities that are vulnerable to flood inundation are identified. Indirect damage cost on public health refers to the additional health care cost due to flooding. During a flood, occurrence of tropical infectious diseases such as acute diarrhea, pneumonia, conjunctivitis, typhoid, and cholera will increase due to the intrusion of waste water and hazardous waste into the living environment. It is assumed that 25% of the population living under 50-100 cm flood depth will be flood-affected while the corresponding percentages for 101-200 cm and >200 cm flood depth conditions will be 50 and 75% respectively. It is further assumed 50 percent of the population affected by flooding will need additional medical attention owing to flood related diseases.

Based on average health care costs of 7,582 and 3,786 baht per person per admission in Bangkok and Samut Prakarn, derived in 2005 by the Health and Welfare Survey of the NSO, and the estimated number of people requiring additional medical care, the indirect damage cost on the public health system was estimated.

4.2 IMPACT ASSESSMENT RESULTS

Impacts in terms of estimated damage costs of all scenarios are shown in **Table 4.2-1**.

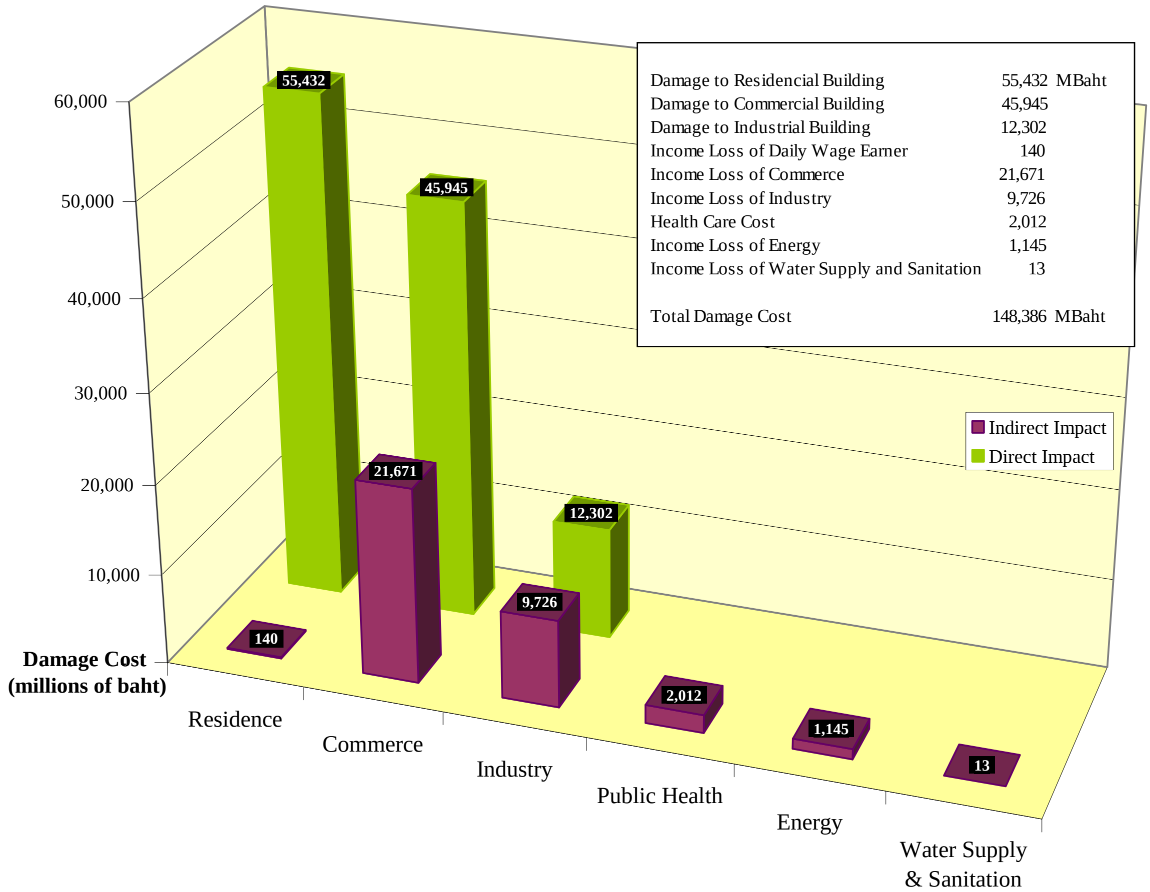
Table 4.2-1 The Damage Cost Estimation

Unit: million Baht

Item of Flood Losses	C2008-T10	C2050-LS-T10	C2050-LS-SR-B1-T10	C2050-LS-SR-A1FI-T10	C2050-LS-SR-SS-A1FI-T10	C2008-T30	C2050-LS-T30	C2050-LS-SR-B1-T30	C2050-LS-SR-A1FI-T30	C2050-LS-SR-SS-A1FI-T30	C2008-T100	C2050-LS-T100	C2050-LS-SR-B1-T100	C2050-LS-SR-SS-B1-T100	C2050-LS-SR-A1FI-T100	C2050-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 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
Increase from C2008		36,571	55,575	67,691	75,870		64,040	93,453	103,717	113,102		106,581	143,909	151,179	154,685	164,688

Source: Panya Consultants' calculation

In general, the largest affected sector would be direct damage of buildings (residential, commercial and industrial), which might account for 78% of the total damage cost. Income loss of the commercial and industrial sectors would account for approximately 14 and 7% of the total damage cost respectively. The additional health care cost would be 2%. **Figure 4.2-1** illustrates direct and indirect damage costs of case C2050-LS-SR-SS-A1FI-T30, which is a future climate change condition.



Source: Panya Consultants' calculation

Figure 4.2-1 Damage Cost of Case C2050-LS-SR-SS-A1FI-T30

To address the impact cost due to climate change, two scenarios are highlighted: (i) current condition (C2008-T30), and (ii) future climate change condition (C2050-LS-SR-SS-A1FI-T30). Under the current condition, impact costs would be 35 billion baht which might rise to 148 billion baht in the future climate changed scenario. This marks over a four-fold increase in the impact cost due to the 30-year return period flood under climate forcing corresponding to the A1FI scenario. The increase in impact cost will be a five-fold in between the 10-year return period floods that can occur today (2008) and in 2050 under A1FI climate forcing.

The effect of different return period flood on the impact cost is evident. For example, the current damage cost would be 15 billion baht for a 10-year return period flood while the damage cost will increase to 35 and 79 billion baht respectively for 30- and 100-year return period flood. The largest damage in 2050 will be due to land subsidence and will double the current damage costs. Also, storm surge will increase the current damage cost by the lowest margin compared to land subsidence, climate change and sea level rise.

Table 4.2-2 presents incremental damage cost. The cost of damage as a percentage of GDP for the BMA and Samut Prakarn is also given. For 2008 the cost is compared with a GDP of 2,916 billion baht and for 2050 the cost is compared with a GDP of 19,211 billion baht.

Table 4.2-2 Incremental Damage Costs

Factors	T10			T30			T100		
	Cost (million Baht)	% of base case	Cost as % of GDP	Cost (million Baht)	% of base case	Cost as % of GDP	Cost (million Baht)	% of base case	Cost as % of GDP
Current Condition 2008	15,248		0.52	35,285		1.21	79,178		2.72
Factor in Year 2050									
Land Subsidence	36,572	240	0.19	64,039	181	0.33	106,581	135	0.55
B1	19,003	125	0.10	29,412	83	0.15	37,328	47	0.19
B1& Storm Surge	-	-	-	-	-	-	7,270	9	0.04
A1FI	31,119	204	0.16	39,678	112	0.21	48,104	61	0.25
A1FI & Storm Surge	8,180	54	0.04	9,384	27	0.05	10,003	13	0.05

Source: Panya Consultants' Calculation

4.2.1 Affected Population

The worst recorded flooding of Bangkok (in terms of flood volume from the upstream catchment) occurred in 1995. Our hydrological simulation indicated that the 30-year return flood volume in 2008 corresponds to the recorded flood volume in 1995. Therefore, comparison of impacts on the population corresponding to the 30-year return period flood in 2008 and 2050 can shed light on the impact of climate change. The assessment results show that in C2050-LS-SR-SS-A1FI-T30 scenario, almost 1 million people in Bangkok and Samut Prakarn are impacted. The impact will be profuse for people living on the lower floor. 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. The comparison of flood-affected population in C2008-T30 and C2050-LS-SR-SS-A1FI-T30 scenarios by district is shown in **Figure 4.2-2**.

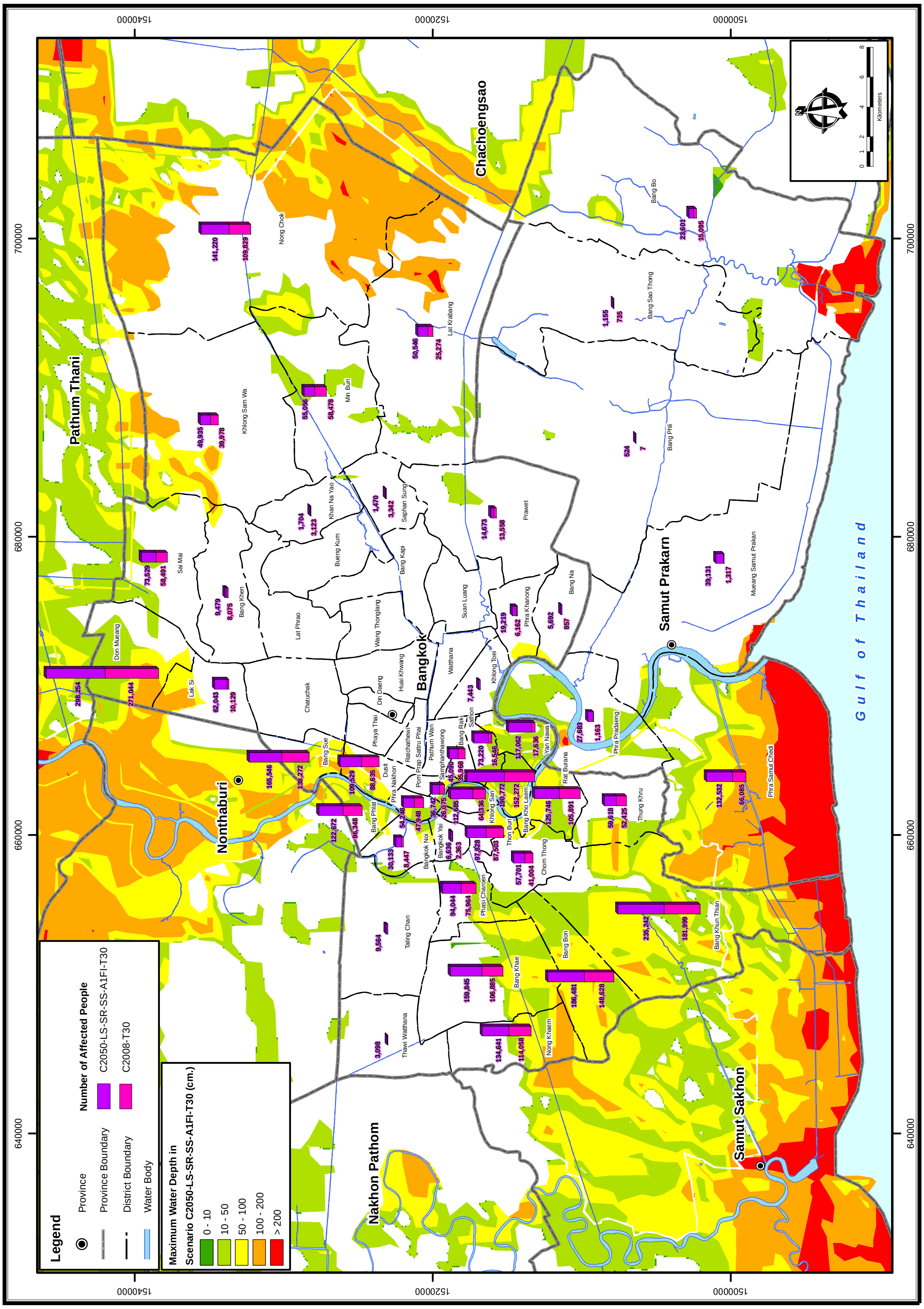
District-wise, Don Muang district in north Bangkok has the highest number of people affected by flood (approximately 90,000) owing to its higher population density. In the western part of the Chao Phraya River, about 200,000 people in Bang Khun Thian, Bang Bon, Bang Khae and Nong Kham districts might be impacted.

4.2.2 Affected Buildings

For the C2050-LS-SR-SS-A1FI-T30 case, approximately 1.1 million buildings in Bangkok and Samut Prakarn might be affected. In the eastern area of the Chao Phraya River, such as Bang Kho Laem and Yan Nawa districts, 120,000 buildings are vulnerable. In the western areas, such as Bang Khun Thian, Bang Bon, Bang Khae, and Phra Samut Chedi districts, 300,000 buildings might be affected. In North Bangkok, 80,000 houses in Don Muang might be flooded. The comparisons of affected buildings in between C2008-T30 and C2050-LS-SR-SS-A1FI-T30 scenarios by district are shown in **Figure 4.2-3**.

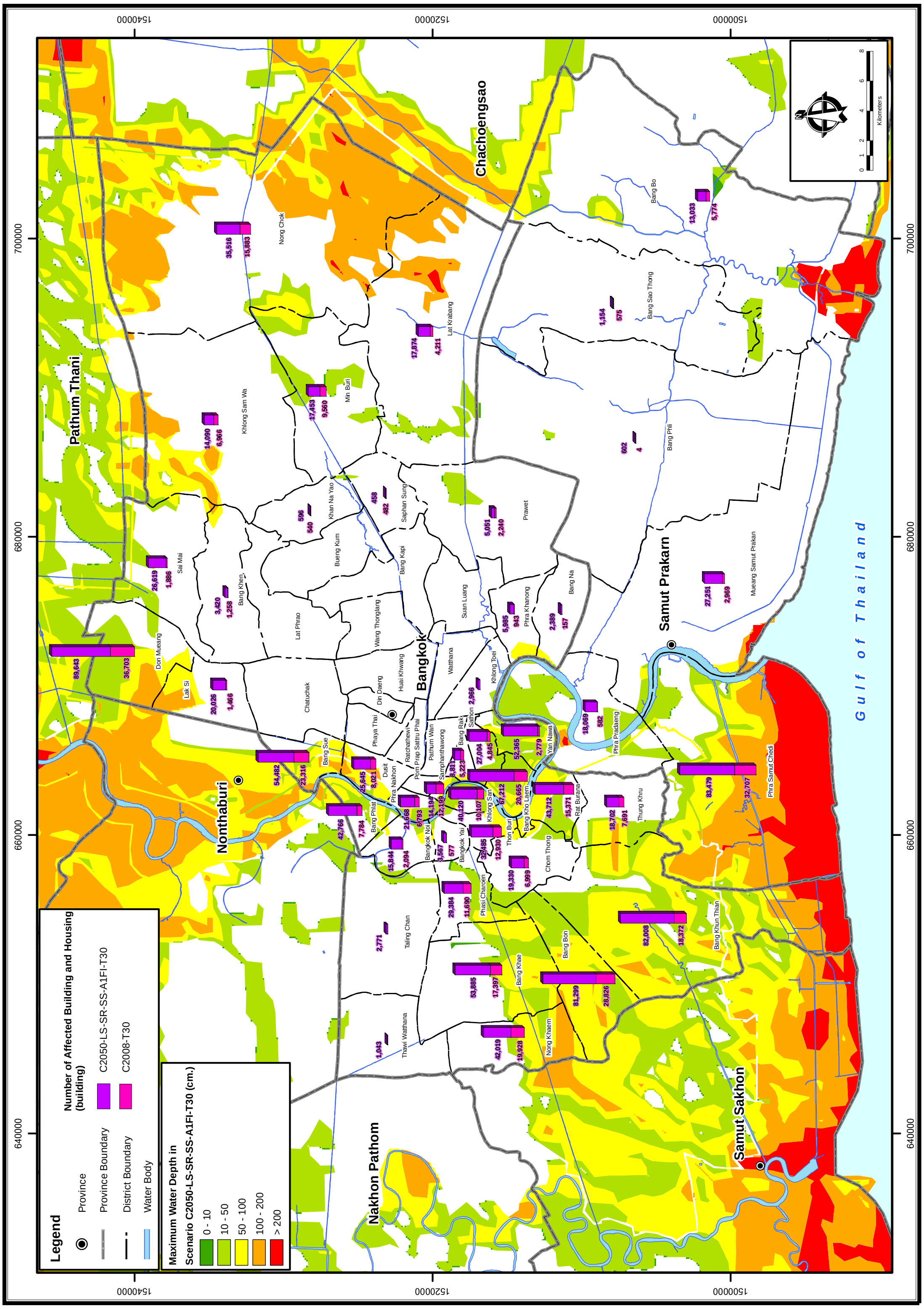
4.2.3 Losses of Income

The commercial sector might lose the highest income due to flooding in the future (Appendix L, page L-20). In this study, vulnerable daily wage earners are considered to be based in condensed communities. The location of affected condensed communities under C2008-T30 and C2050-LS-SR-SS-A1FI-T30 conditions are shown in **Figure 4.2-4**. For case C2008-T30, the income loss of daily wage earners is 92 million baht whereas the income loss of daily wage earners is 140 million baht in case C2050-LS-SR-SS-A1FI-T30.



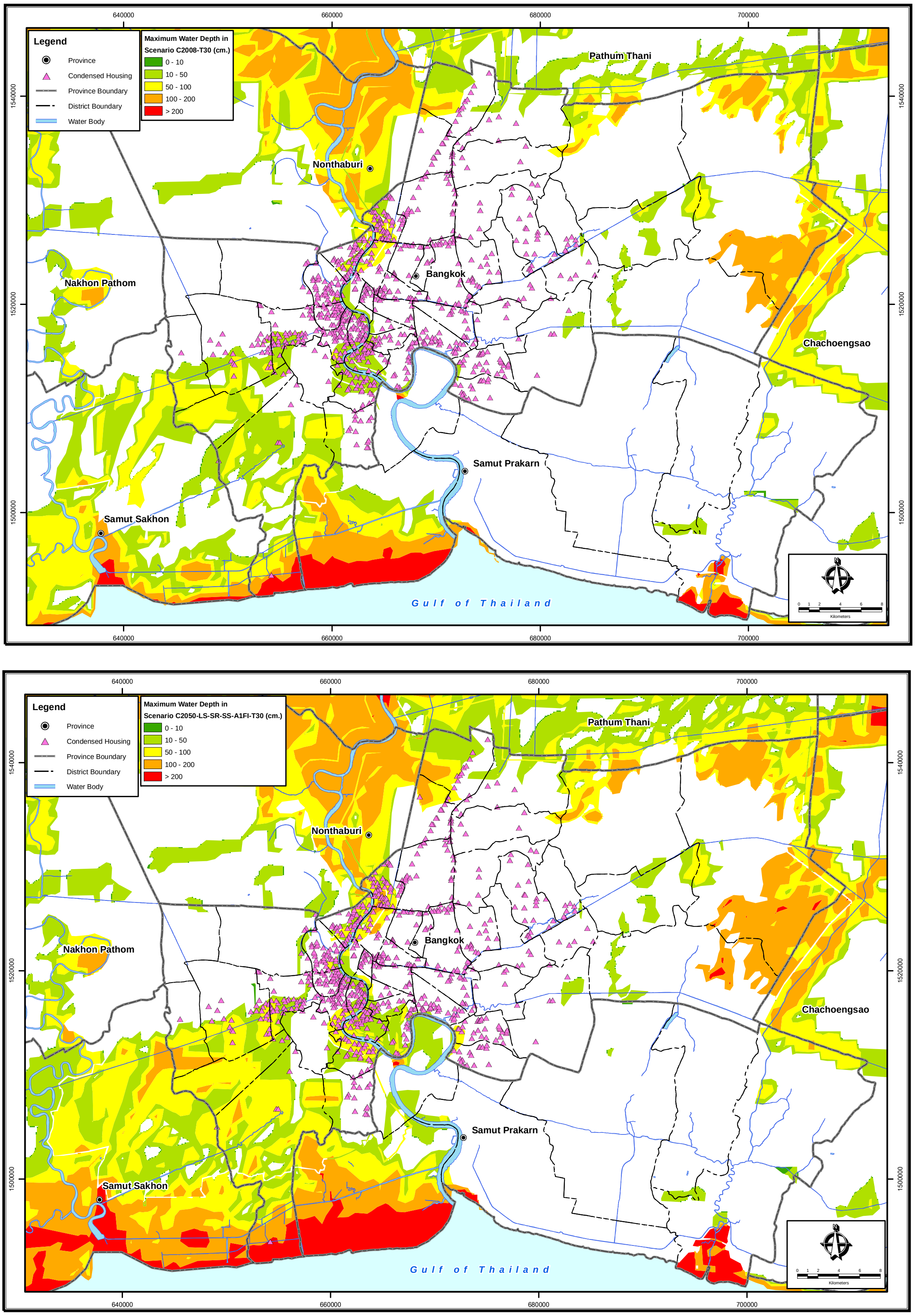
Source: Panya Consultants

Figure 4.2-2 Affected Population of Case C2008-T30 and C2050-LS-SR-SS-A1FI-T30



Source: Panya Consultants

Figure 4.2-3 Affected Buildings and Housing of Case C2008-T30 and C2050-LS-SR-SS-A1FI-T30



Source: Panya Consultants

Figure 4.2-4 Affected Condensed Community of Case C2008-T30 and C2050-LS-SR-SS-A1FI-T30

Commerce and Industry

For case C2008-T30, income losses of commerce and industry are 4 and 2.6 billion baht respectively, whereas they are 22 and 10 billion baht for case C2050-LS-SR-SS-A1FI-T30.

Transportation

The result finds operation losses for the expressway are zero as all expressway routes are above one meter of flood depth.

Water Supply and Sanitation System

The water supply and sanitation system had a minimal impact. For case C2008-T30, income loss for the water supply and sanitation system is 6 million baht, whereas for case C2050-LS-SR-SS-A1FI-T30 it is 13 million baht.

Energy

For case C2008-T30, income loss for energy is 254 million baht whereas for case C2050-LS-SR-SS-A1FI-T30 it is 1.1 billion baht.

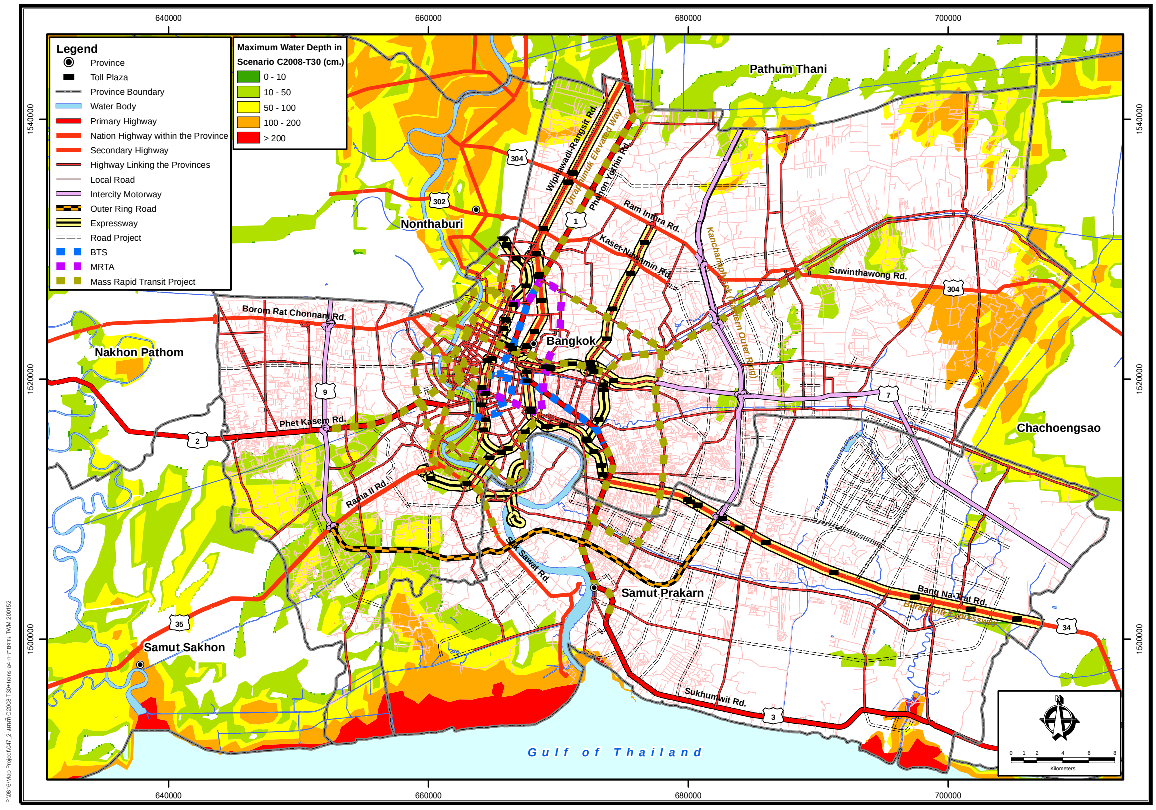
4.2.4 Affected Infrastructures

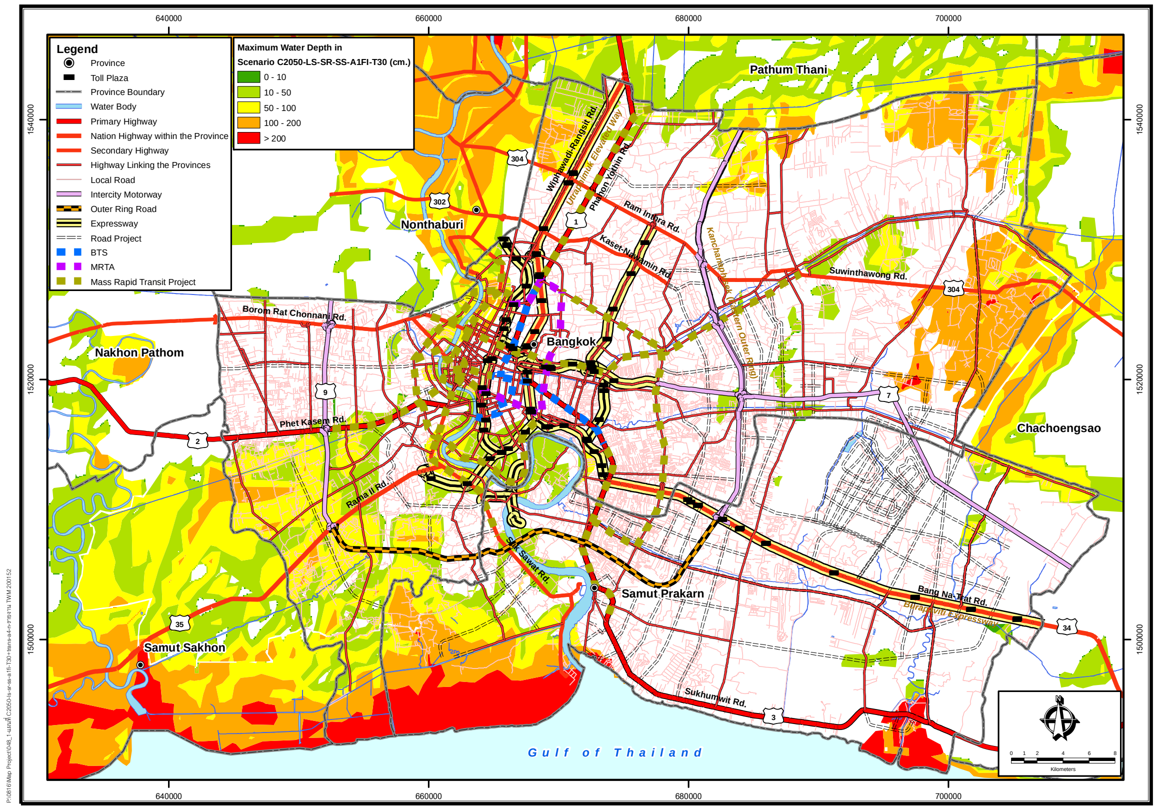
The results of case C2050-LS-SR-SS-A1FI-T30 shows roughly 1,700 km of roads in Bangkok and Samut Prakarn would be vulnerable to flood. Lat Krabang water supply distribution station and Nongkhaem solid waste transfer station flooded with a depth of 50-100 cm. However, flooding cannot affect any water supply and sanitation system. For the energy infrastructure, no electrical substations are affected.

Affected infrastructures in Bangkok and Samut Prakarn such as transportation, water supply, sanitation and energy of cases C2008-T30 and C2050-LS-SR-SS-A1FI-T30 are shown in **Figure 4.2-5** to **4.2-7**.

4.2.5 Affected Public Health Care System

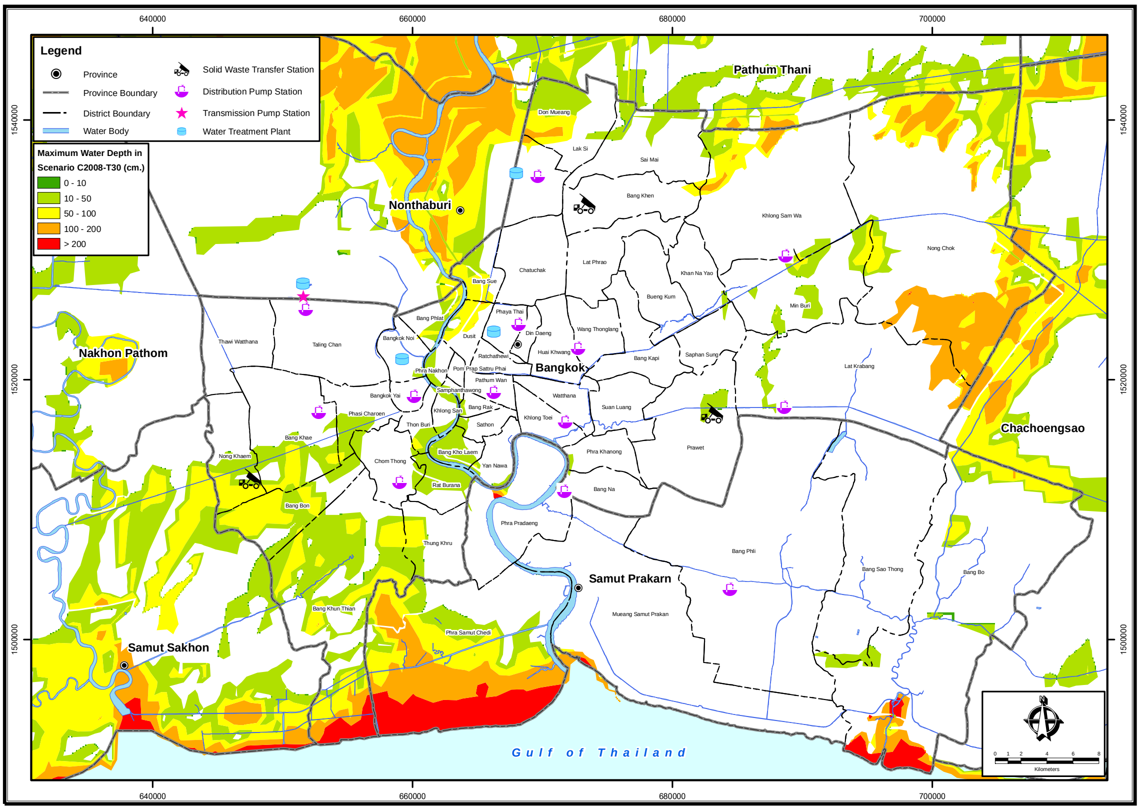
Under case C2008-T30, the health care cost is 934 million baht whereas for case C2050-LS-SR-SS-A1FI-T30 it is 2 billion baht. We predict 127 health care facilities flooded with a depth of 10-200 cm, with most located in Bang Khun Thian, Bang Bon, Bang Khae and Phra Samut Chedi Districts. Three kinds of health care facilities are available in the BMR: large hospitals (more than 250 beds), medium-sized hospitals (less than 250 beds) and clinic. Affected health care facilities in Bangkok and Samut Prakarn for cases C2008-T30 and C2050-LS-SR-SS-A1FI-T30 are shown in **Figure 4.2-8.**

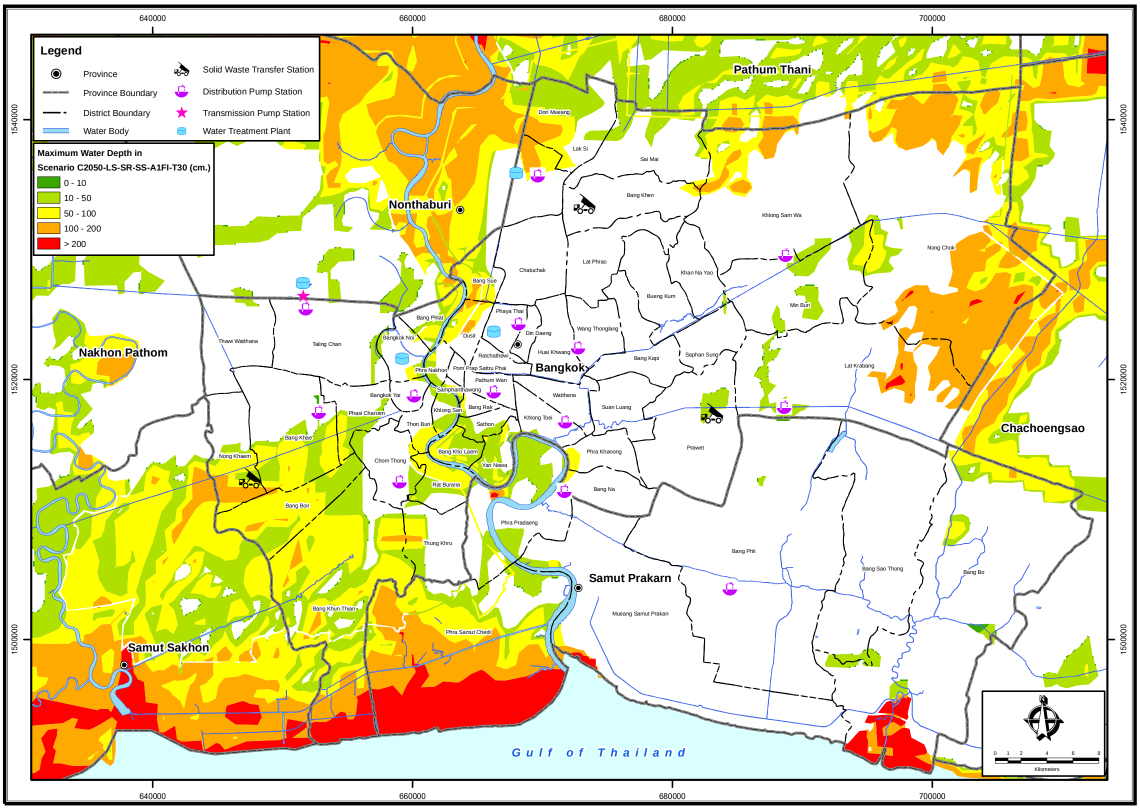




Source: Panya Consultants

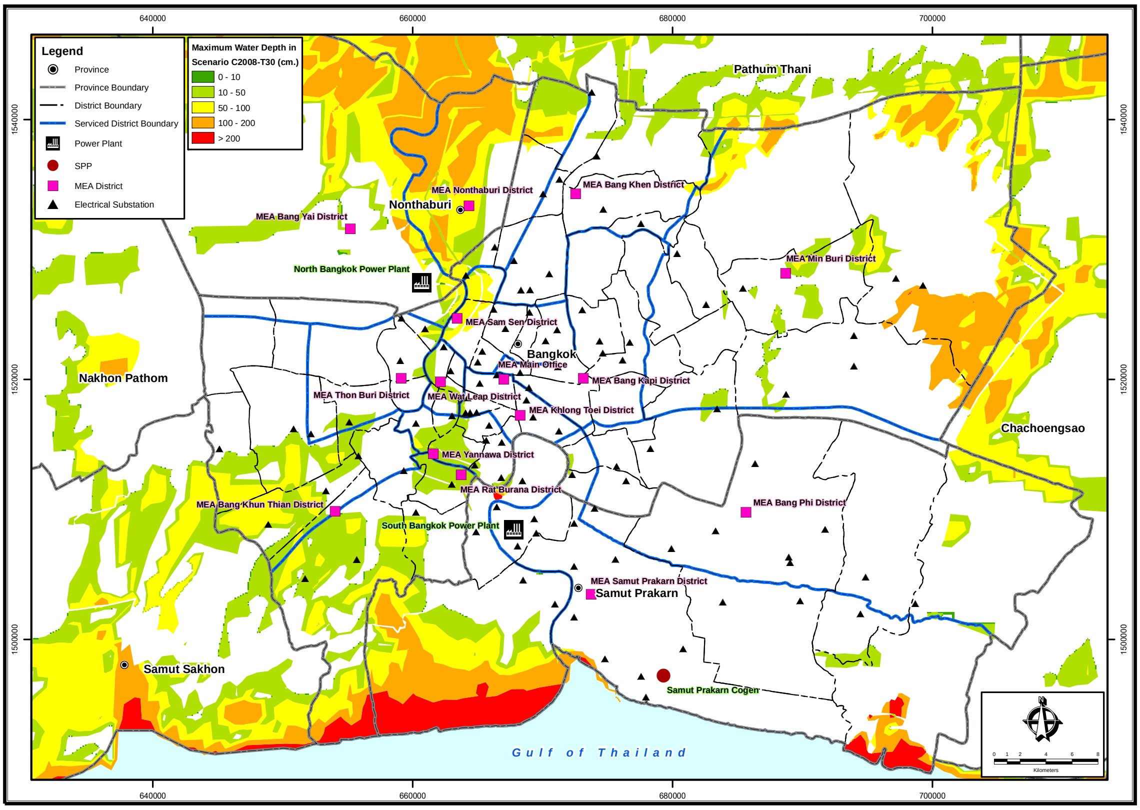
Figure 4.2-5 Affected Transportation Infrastructures of Case C2008-T30 and C2050-LS-SR-SS-A1FI-T30

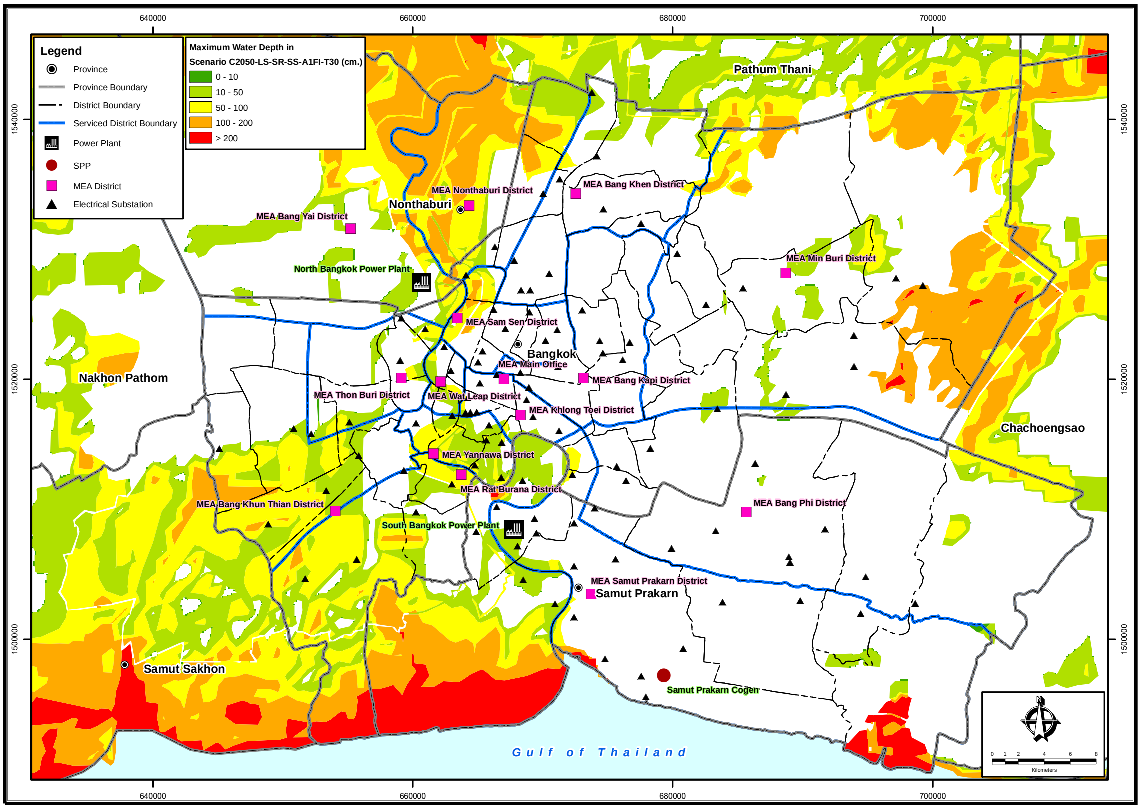




Source: Panya Consultants

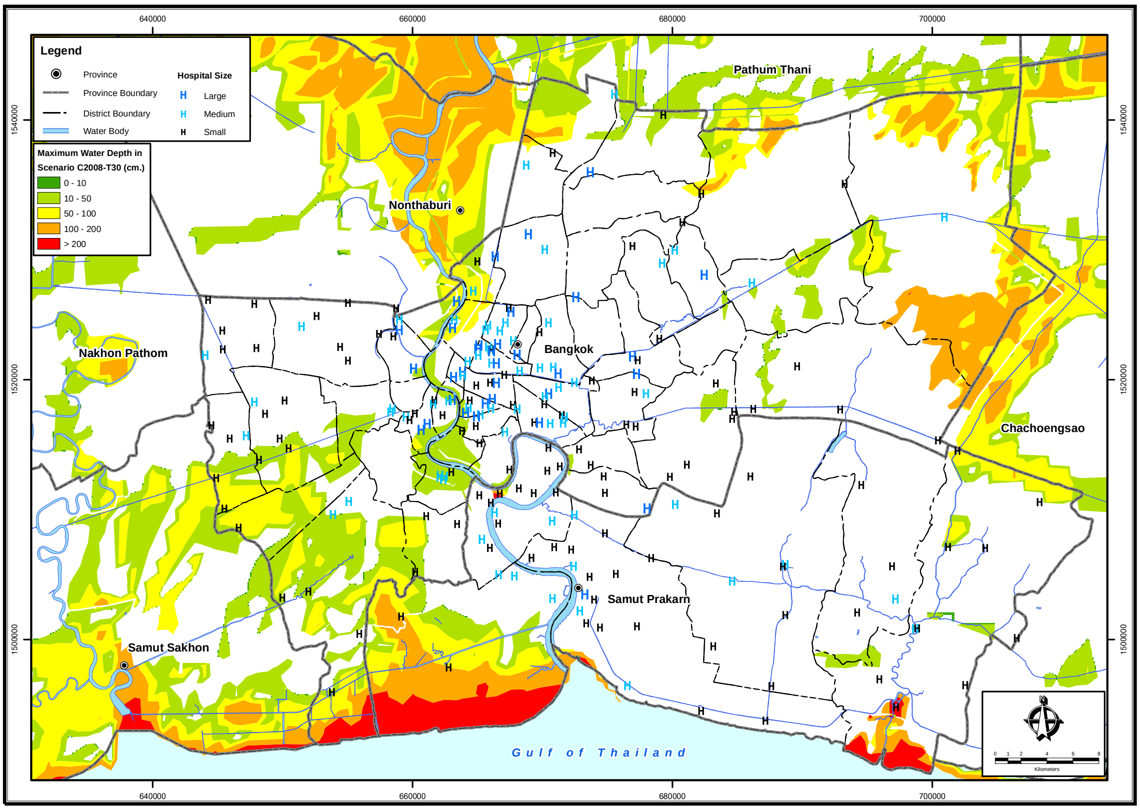
Figure 4.2-6 Affected Water Supply and Sanitation Infrastructures of Case C2008-T30 and C2050-LS-SR-SS-A1FI-T30

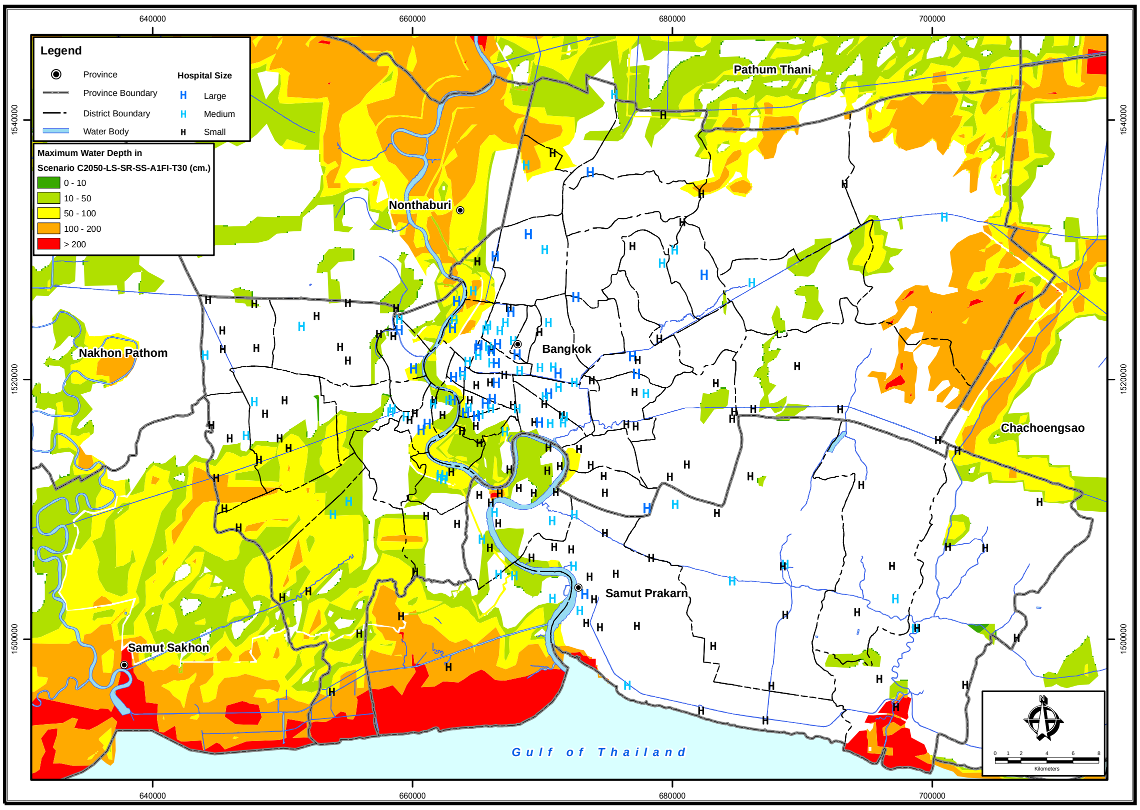




Source: Panya Consultants

Figure 4.2-7 Affected Energy Infrastructures of Case C2008-T30 and C2050-LS-SR-SS-A1FI-T30





Source: Panya Consultants

Figure 4.2-8 Affected Health Care Facility of Case C2008-T30 and C2050-LS-SR-SS-A1FI-T30

4.3 GIS DATABASE

The Geographic Information System (GIS) was developed from multiple resources include GIS data, maps, photos, reports, searchable databases, and tables. Non-digital data was converted to digital and integrated to data layers for flood impact analysis and display (**Table 4.3-1**).

Table 4.3-1 GIS Database of the BMR

Data	Description
Topography	
Contours	Lines data from RTSD 2000 Map 1:50,000
River	Lines and polygons data from RTSD 2000 Map 1:50,000
Slope	Polygons data adopted contour Map 1:50,000
Spot Elevations	Points data from RTSD 2000 Map 1:50,000
Administrative	
City/District Boundaries	Polygons data from NSO Map 1:50,000
Condensed Housing Neighborhood	Point locations based on BMA 2006 data
Population	NSO 2007 and BMA 2007 population data
Projected Population	Adopted 10th NESDP and city plan of BMA
Building	
Building	Building count from BMA 2008 data
Land Use	Polygons data from DPT 2006
Future Land Use	Adopted DPT 2057 conceptual plan
Transportation	
Airport	Polygons data from RTSD 2000 Map 1:50,000
Mass Rapid Transit	Lines data from ESRI (Thailand) Highway Map 2008
Railroad	Lines data from RTSD 2000 Map 1:50,000
Road	Lines data from RTSD 2000 Map 1:50,000
Future Transportation System	Integrated OTP-IMAC 2004 with BMTA, DOH and ETA projects plan
Toll plaza	Points locations integrated from ESRI (Thailand) Highway Map 2008 and Mappoint Asia
Water Supply and Sanitation System	
Water Facilities	Lines data and point locations from MWA 2008 data
Sanitation Facilities	Point locations from BMA 2008 data
Future Water System	Adopted BMA projects plan
Public Health	
Hospital	Point locations from RTSD 2000 Map 1:50,000
Energy	
Power Station	Point locations from EGAT 2005 data
Pipe Line	Lines data and point locations from PTT 2005 data
Flood Protection	
Canal	Lines data integrated from BMA and RID 2008 data
Detention Area	Polygons data integrated from BMA and RID 2008 data
Dike	Lines data integrated from BMA and RID 2008 data
Diversion Tunnel	Lines data integrated from BMA and RID 2008 data
Flood Protection Dike	Lines data integrated from BMA and RID 2008 data
Navigation Lock	Points location integrated from BMA and RID 2008 data
Polder Area	Polygons data integrated from BMA and RID 2008 data
Pumping Station	Points location integrated from BMA and RID 2008 data
Regulator	Points location integrated from BMA and RID 2008 data
Future Flood Protection System	Integrated BMA and RID projects plan
Environment	
Mangrove	Polygons data from DMCR 2000 Map 1:50,000

Source: Panya Consultants

CHAPTER 5

ADAPTATION AND PROPOSAL

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ADAPTATION AND PROPOSAL

5.1 GENERAL

Climate change impacts on Bangkok and vicinities are manifested through a higher risk of flooding and consequent effects on economic and social resilience of the area. Flooding is not uncommon in this area and was responsible for severe socio-economic losses in the past. Inhabitants of the area have been adapting to flooding for decades and strategies for managing flood risks have evolved through time. Nevertheless, additional adaptation measures will be required to reduce the adverse impacts of projected climate change and variability.

5.2 REVIEW OF ADAPTIVE PRACTICES

A wealth of well-tested experience, information and technology is already available to identify viable adaptation strategies. The Consultant 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; public information campaigns and training exercises (Appendix M, page M-1).

5.3 ADAPTATION OPTIONS

The adaptation options are intimately connected to social and economic context. At the same time, they are dynamic and influenced by the productive base including natural and man-made capital assets, social networks and entitlements, human capital and institutions, governance, national income, health, and technology. Nevertheless, available options vary unevenly across and within societies. A range of barriers limits the implementation and effectiveness of adaptive measures and even societies with high adaptive capacity remain vulnerable to climate change variability and extremes.

To cope with the recurring flooding in Bangkok, the agencies responsible for flood mitigation and drainage works have prepared a number of plans. These plans, in general, consist of structural and non-structural measures. However, in formulating these plans, climate change impact on hydrology was not considered. The results of simulation study revealed that the existing and planned flood protection system would be inadequate to cope with the impacts of flooding greater than a 10-year return period in 2050 and corresponding to the A1FI climate change scenario.

5.3.1 Structural Measures

Currently, a number of structural measures are adopted by the concerned agencies to cope with flooding. These are summarized as follows:

Polder, Dike, and Monkey Cheek
A polder with drainage system improvement covering the Bangkok metropolitan area has been developed and dike construction has progressed continuously along the Chao Phraya River even in rural areas. Moreover, several water conservation or retaining areas (named the Monkey Cheek by His Majesty King Bhumibol) in the western and eastern areas of the Chao Phraya River have been developed. While most of these structural measures are already in place, some are scheduled to be completed in 2011. All existing and on-going measures were included in the study.

Constructing Retaining Wall on the Bank of the Chao Phraya River

The Phrakanong Pumping Station

Large Storage Dam in the Upper Basin

A large storage dam in the upper basin has been proposed in the past to save Bangkok from flooding. For example, the Kaeng Sua Ten Dam has been proposed and studied several times whenever severe flood damage occurred in the Yom River Basin. Unfortunately, building new dams can be controversial due to their potential social and environmental impact, and therefore are not pursued as good options for flood control.

Barrage at the River Mouth

A tidal barrage at the mouth of the Chao Phraya River has been proposed and its effectiveness was examined in a previous study (RID, 1999). The barrage and pumps were found to be effective in lowering the floodwater in Bangkok but are not effective in controlling large flood discharge. Furthermore, this measure requires a huge investment cost (131 billion baht in 1998 prices), involves social and environmental problems, and may interfere with navigation. As such, barrage is not considered a suitable option in the long term.

Diversion Channel

A flood diversion channel from Ayutthaya to the river mouth (the Chao Phraya River II project) was proposed to mitigate flood damage (RID, 1999). Alternative routes were studied. However, due to a complicated land acquisition process and high investment cost (42 billion baht in 1998 for a capacity of 1,100 m^3/sec) the proposal was not pursued. In 2006, the RID proposed improvement of existing irrigation canals to divert water and increasing the pumping capacity on the right bank of the Bang Pakong River and on the coast of the Gulf of Thailand (RID, 2006). The latter proposal by the RID was included in the current adaptation plan.

Coastal Erosion and Wave Protection

The BMA has a plan to construct 10 T-groins along the 4.7-km shoreline at Bang Khun Thian district to protect against coastal erosion (BMA, 2007a). Apart from the T-groins, the BMA will grow mangrove trees to protect the shoreline. At present, more than 760 m of the Bang Khun Thian shoreline has eroded, resulting in a decrease in forest density.

Coastal Erosion T-groins Type

Sea Wave Protection Bamboo Type

The Department of Marine and Coastal Resources (DMCR) has been studying a Master Plan and Practice to Solve the Problem of Coastal Erosion on the Shoreline along the Upper Gulf of Thailand. The plan will propose a suitable solution to protect the shoreline. At present, local people construct bamboo barriers to weaken the strength of the waves hitting the coast to prevent coastal erosion. In addition, the bamboo barriers help to raise silt deposition on the coast.

Proposed Structural Measures

The results of the simulation study indicate that the crest elevations of dikes around Bangkok and vicinities and along both banks of the Chao Phraya River will not be high enough to cope with the flooding of more than a 10-year return period in the future. Moreover, the protected area in 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, dike and pumping capacity improvement are proposed.

For the eastern part of Bangkok, pumping capacity to drain floodwater into the Bang Pakong River and the Gulf of Thailand should be increased from 737 to 1,065 m^3/sec. The total capacity of canals should be improved from 607 to 1,580 m^3/sec.

For the western part of Bangkok, there are three major pumping stations at Khlong Phasi Charoeng, Sanam Chai, and Khun Rat Phinit Chai to drain the floodwater into the Tha Chin River and the Gulf of Thailand with capacities of 18, 36, and 30 m^3/sec respectively (totally 84 m^3/sec). The current capacity is inadequate to cope with future climate change. Based on the simulation results, the following improvement of pumping capacities and canal improvement is proposed (**Table 5.3-1**).

Table 5.3-1 Proposed Pumping Capacities at Three Stations in the Western Area of Bangkok

Unit: m^3/sec

Pumping Station	Existing*	30-Year Return Period	100-Year Return Period
1. Phasi Charoeng	18	400	550
2. Sanam Chai	36	200	350
3. Khun Rat Phinit Chai	30	100	250
Total	84	700	1,150

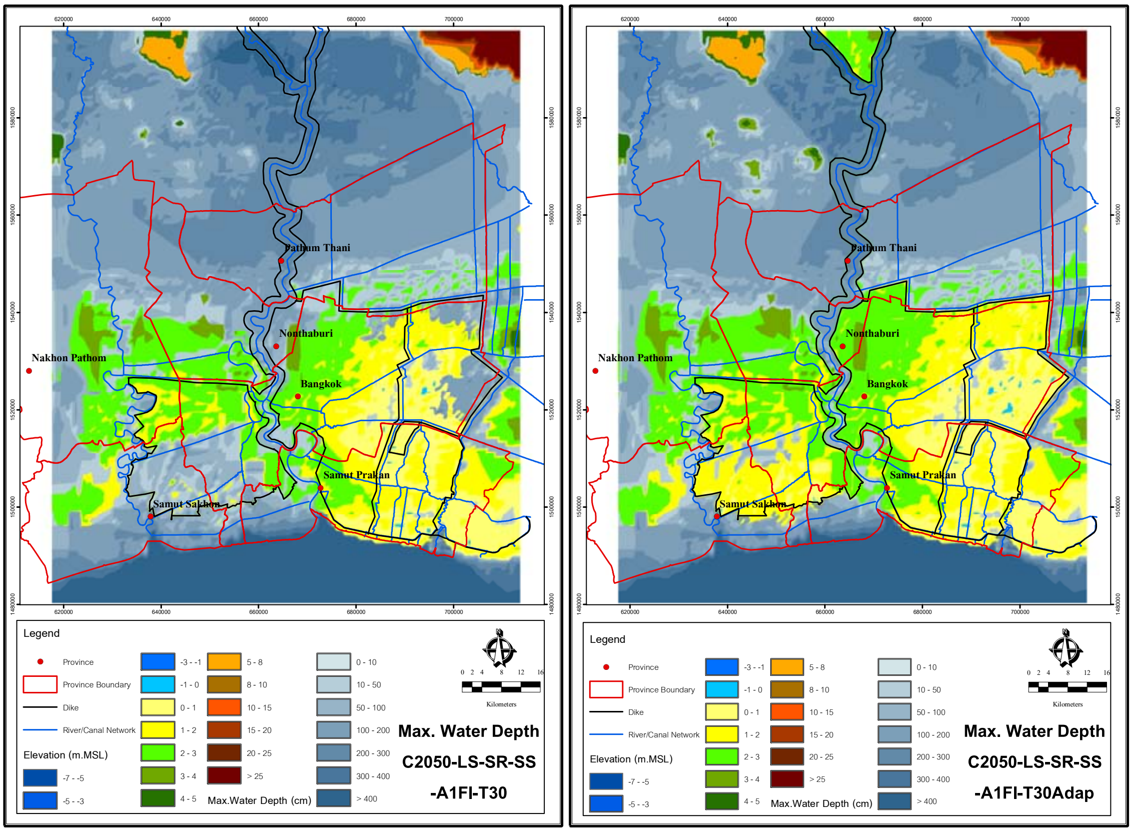
Source: * from RID's Office Region 11 and BMA and proposed by Panya Consultants

Since the area along the shoreline in Samut Prakarn on the east of the Chao Phraya River is an industrial community, the shoreline has been protected from erosion by rock-pile embankment constructed by the Department of Public Works and Town & Country Planning (DPT) in cooperation with the provincial authority. On the contrary, the area along the shoreline on the west of the Chao Phraya River has eroded about 5-10 m per year. Over the last 30 years, erosion and land subsidence in this area has caused the village's shoreline to diminish by more than one km.

Coastal Erosion on the Western Shoreline

Coastal Erosion Protection on the Eastern Shoreline

Figure 5.3-1 compares maximum inundation area corresponding to a 30-year return period flood with and without the proposed structural adaptation measures. It is observed that 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%.



Source: Panya Consultants' calculation

Figure 5.3-1 Maximum Inundation Area With and Without the Proposed Adaptation

5.3.2 Preliminary Cost Estimate

Dikes

As discussed in the previous section, the existing crest elevations of dikes will not be high enough to protect against flooding at a return period of higher than 10 years in the future (2050) under the A1FI climate change scenario (including land subsidence, sea level rise, and storm surge). To cope with future floods at a 30- or 100-year return period, the dike crest elevations have to be raised. The dike routes around the protected area and their length in the eastern area of the Chao Phraya River were delineated on a 1:50,000 scale map. The dike crest elevations at present were estimated from the collected information from the BMA and the RID together with a site visit. The dike crest elevations in the future were estimated by taking into account land subsidence of 0.20 m and free board of 0.30 m (Appendix M, page M-7). The dikes along the Chao Phraya River are mostly concrete retaining wall or raised elevations of roads. Four types of dike improvement method and their unit costs were derived from the study results of drainage system improvement in the western area of Bangkok (BMA, 2005a). The unit costs were adjusted to 2008 prices by applying the annual inflation rate obtained from the NESDB.

Pumps

Results from the simulation study reveal that in the future the pumping system in the eastern area of the Chao Phraya River will have enough capacity to cope with repeated flooding. On the other hand, the pumping system in the western area of the Chao Phraya River will not have enough capacity. The pumping stations at Phasi Charoen and Sanam Chai should be upgraded to capacities of 400 and 200 m^3/sec for floods of a 30-year return period (550 and 350 m^3/sec for floods at a 100-year return period) respectively. These two pumping stations will drain the flood water inside the protection area into the Tha Chin River. The pumping station at Klong Khun Rat Phinit Chai should also add capacity to reach 100 and 250 m^3/sec for floods at a 30-and 100-year return period respectively. However, drainage canals to convey the flood water from the inundated area to the pumping stations have to be trained. The unit costs of pumping station and drainage canal improvement were derived from the study results of the drainage system improvement in the area around Suvarnabhumi Airport (RID, 2004).

Coastal Erosion Protection

A number of agencies proposed and compared methods of coastal erosion protection in the past. However, their effectiveness and environmental impact are yet to be thoroughly scrutinized. The BMA (2007a) 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.

The total estimated costs are 35 and 49 billion baht to protect against floods at a 30- or 100-year return period respectively (Appendix M, page M-12).

5.3.3 Preliminary Economic Evaluation

The preliminary economic evaluation of the proposed flood protection improvement project is carried out by comparing the cost and benefits with and without the project in order to identify the incremental benefit of the project. The viability of the project is determined by the economic indicators, i.e., Net Present value (NPV), Economic Internal Rate of Return (EIRR) and Benefit Cost Ratio (B/C). In the analysis the discounted rates of 8%, 10%, and 12% will be used. The analysis period used is 38 years, of which the first 8 years are for studying, designing and construction and 30 years is the economic benefit period of the project.

Project Cost: The investment cost of the project includes civil work, pumps, design and contingency and related cost. The detailed design cost is estimated at 0.3% of the project. The total investment cost is estimated at 35.3 billion baht for 30 year return flood protection and 49.5 billion baht for 100 year return flood protection. The annual operation and maintenance cost is estimated at 1% of the civil work and 2.5% of the pump work. The total annual operation and maintenance cost for 30- and 100-year return flood is estimated at 584 and 874 million baht respectively.

Project Benefit: The expected benefit of the project is the annual reduction of flood damage cost. In estimating annual benefit, the damage cost at each return flood period from the result of flood damage assessment is used for the calculation taking into account the probability of occurrence of each flood period (Appendix M, Page M-15). The average annual flood damage reduction cost resulting from the proposed project was estimated at 4.4 and 5.9 billion baht for floods at 30-and 100-year return period respectively. It should be noted that if the protection work is designed for floods at a 30-year return period, the full damage will occur when a flood of higher than a 30-year return period happens.

Cost Benefit Analysis: The economic viability analysis is carried out for two cases. A base case considers the annual benefit of 4.4 and 5.9 billion baht for floods at a 30-and 100-year return period are constant throughout the analysis period. The other case considers the real value of the infrastructure damage, which will be increased in the future. It is assumed that the growth of real value is on average 3% per year (Appendix M, Page M-16). The summary result of the analysis for the base case and real growth case is presented in **Table 5.3-2** and **Table 5.3-3**.

Table 5.3-2 Economic Parameters of the Proposed Flood Protection Improvement Project (Base Case)

Description	Designed Flood Protection Improvement Project for					
	30-Year Return Period			100-Year Return Period		
Discounted Rate	8%	10%	12%	8%	10%	12%
Present Value of Cost (million Baht)	24,950	21,578	18,831	35,117	30,276	26,349
Present Value of Benefit (million Baht)	26,969	19,500	14,425	35,995	26,026	19,253
Net Present Value (NPV) (million Baht)	2,019	-2,078	-4,406	878	-4,250	-7,096
Benefit-Cost Ratio (B/C Ratio)	1.08	0.90	0.77	1.02	0.86	0.73
Economic Internal Rate of Return (EIRR)	8.85%			8.27%		

Source: Panya Consultants' calculation

The results of the base case indicate that the proposed structural measures for the flood protection improvement project are economic feasible for both floods of 30 and 100-year return periods if the opportunity cost of capital is not more than 8%.

Table 5.3-3 Economic Parameters of the Proposed Flood Protection Improvement Project (Real Growth Case)

Description	Designed Flood Protection Improvement Project for					
	30-Year Return Period			100-Year Return Period		
Discounted Rate	8%	10%	12%	8%	10%	12%
Present Value of Cost (million Baht)	24,950	21,578	18,831	35,117	30,276	26,349
Present Value of Benefit (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
Economic Internal Rate of Return (EIRR)	11.69%			11.18%		

Source: Panya Consultants' calculation

The results of the real growth case indicate that the proposed structural measures for the flood protection improvement project are economic feasible for both floods of 30- and 100-year return periods if the opportunity cost of capital is not more than 10%.

From this preliminary evaluation, and taking into account that presently Thailand's low economic discounted rate is approximately 8-9%, the proposal should be designed to protect against floods at a 100-year return period as it provides a higher net return (NPV=13.4 billion baht) than protect against floods at a 30-year return period (11.4 billion baht). Even though the EIRR may not be attractive, the elimination of intangible damages both economic and social and the needs of residents in the business area of Bangkok make the project highly feasible. Therefore, this project should be carried out in the next step in the feasibility study.

5.3.4 Non-structural Measures

Non-structural measures are essential to mitigate flood damage or risk through various means. They are also necessary to maximize the effect of structural measures. Based on review of adaptation options that have evolved over the years, the following are proposed (see also Appendix M, page M-18):

Modification of Reservoir Operation Rule

Reservoir operation rules of large dams have been revised by agencies concerned with mitigating flood damage downstream of the dams. However, this affects the original functions of reservoir (e.g. reduction of water supply for irrigation and hydropower generation). Therefore during the flooding period, the concerned agencies, such as the Electricity Generating Authority of Thailand

(EGAT), the Royal Irrigation Department (RID), the Department of Water Resources (DWR), the Meteorological Department (TMD) and the BMA continue to cooperate while operating reservoirs.

Land Subsidence Suppression

In Bangkok and vicinities in the Chao Phraya River Basin, land subsidence is one of the major issues related to flood control. Land subsidence is responsible for lowering dike height. Relevant regulations to control and land subsidence should be consolidated.

Flood Disaster Response

Flood Forecasting and Warning System: A flood forecasting and warning system is a pre-requisite to minimize the impacts of flooding and an essential component of any long-term flood risk management strategy. In Bangkok, several flood forecasting and warning systems are implemented by a number of agencies. For example, TMD issues flood warnings nationwide based on the weather forecasting results. The warning is issued through the mass media, such as TV, radio, newspapers, and websites. The DWR and the RID issue a warning when a large scale flood (over 3,000 m^3/sec) is expected at Nakhon Sawan on the Chao Phraya River. The warning is disseminated to the public through the mass media. The BMA issues a warning when a heavy rainfall occurs around or in Bangkok through the mass media.

The lead times of these systems are high due to the long travel time taken by the flood to propagate from upstream catchments. However, there is room for improvement to enhance the accuracy of the forecasts. We propose that current forecasting and warning systems be made more robust and systematic. A guideline should be prepared containing information on objective, roles, responsibilities and restrictions of the system.

Flood Fighting Activity: A complete flood-proofing of the city is not expected and flood fighting is one of the essential measures to mitigate flood damage. In the Chao Phraya River Basin, flood fighting is undertaken by the following agencies:

1) The Civil Defense Committee has responsibility for policy decisions and planning of flood fighting for all of Thailand. The Department of Disaster Prevention and Mitigation (DDPM) acts as the Secretariat to the Committee;
2) The Department of Drainage and Sewage (DDS) in the BMA is responsible for flood fighting in the Bangkok metropolitan area;
3) The RID is responsible for flood fighting in the agricultural areas;
4) Provincial governments execute flood fighting for the protection of provincial urban areas in cooperation with other agencies concerned; and
5) The military and volunteers assist agencies in flood fighting.

To cope with the climate change impacts, we propose that the existing flood fighting activities be further consolidated through:

1) Development of a readily deployable flood fighting system in terms of equipment, materials, and manpower based on past flood fighting experience;
2) Assurance of funds for a flood fighting operation including adequate equipment, materials, and manpower;
3) Period training of inhabitants in flood fighting works;
4) Educational campaign and advertisement on the necessity and modes of the flood fighting system; and
5) Promulgation of a law on flood fighting to clarify the administration structure and responsibilities of agencies concerned.

Disaster Recovery: Flood recovery refers to suitable actions that must be taken to bring socioeconomics to normalcy long after the direct damage of a flood has diminished. It is most relevant in the case of a slow-moving disaster like a probable future flood in Bangkok that may last for a prolonged period of time resulting in a secondary disaster (e.g. disease outbreak). We propose that the agencies concerned lay out an individual recovery plan to cope with climate change impacts.

Financial Response
Subsidy and Taxation: Subsidy for agricultural damage is one of the major current support systems provided by the government. It is established in the Ministry of Agriculture and Cooperatives (MOAC). The major characteristics are: (i) objective - compensate for agricultural damage due to natural disasters such as drought and flood and abnormal insect attacks, and (ii) compensation is in the form of seedlings and fertilizers for subsequent cropping and is not in the form of money, and (iii) the Department of Agriculture Extension (DAE) and the Department of Fisheries (DOF) are responsible for executing compensation.

Another support system is reduction of interest on loans provided by the government. For planting, farmers get loans to purchase seeds and fertilizers and to hire machinery for cultivation. In case agricultural products are damaged by flood, the interest on loans is reduced when the farmers repay the money.

However, some point out that the level of compensation is less than enough to cover damages, especially flood damage. Thus, strengthening the current support system to further compensate for flood damage and to reduce the interest on loans should be considered.

Flood Insurance: Records on subsidy provided by the government indicate that it is not sufficient to support frequent flood-affected farmers. Flood insurance offers promising scope to cope with this shortage. The public sector can play a major role in this respect. So far, several trials on agricultural insurance have been examined in the form of insurance for damage to agricultural products. However, not all trials have been successful mainly due to shortage of funds and insufficient information on insurance premiums. As a result, there is no law on agricultural insurance and no insurance company sells insurance for probable agricultural damage. Moreover, people engaged in agricultural production have no interest in buying such insurance due to lack of information and knowledge, and lack of finances. We propose the government promote agricultural insurance for products and necessary institutional arrangements to strengthen the agricultural insurance system.

Watershed Management
The influence of deforestation in the upstream catchments on downstream floods remains a matter of research. However, it is widely believed that deforestation may increase peak flood discharge and decrease low water discharge. Until a quantitative evaluation on the subject in Thailand is available, watershed management through logging restrictions and reforestation programs should be encouraged to decrease flood peak discharge and increase recharging capacity of the watershed. The Royal Forest Department (RFD) has responsibility for this matter.

Disaster Management
In 2002, Thailand established DDPM under the Ministry of Interior (MOI) as the principal agency for disaster management coordination among all agencies concerned at all levels (see Appendix M, page M-21). Additionally, the Ministry of Education is providing necessary information about disaster through formal school curricula. We propose further reform and consolidation of disaster management systems and mechanisms as follows:

1) ***Public Awareness and Education*****:** Improve public safety of every sector, particularly those who are living with risk, by enhancing people’s understanding of the threats posed by various types of disasters;

2) ***Materializing Early Warning Systems*****:** Following the catastrophic tsunami disaster in 2004, Thailand took immediate action to establish NDWC, which covers the warning of both natural and man-made disasters;
3) ***Establishing More International Disaster Management Networks*****:** Thailand needs to enhance the country's disaster management capacity and efficiency through the mobilization of technical assistance from foreign countries, particularly from developed and advanced countries;
4) ***Effective Damage Assessment*****:** Remote survey technology must be introduced to effectively assess the damages caused by large scale disaster. The staff of the agencies concerned need to be trained to enhance their capacity in applying satellite images to assess the damage;
5) ***Application of Community-Centered Approach*****:** Local authorities and communities are in the front line in the event of disaster occurrence, consequently, they are the most vulnerable and affected. It is indispensable to enhance their potential in responding to disasters, and to equip them with awareness and preparedness;
6) ***Highlight a Preventive Approach*****:** The new approach of disaster management has shifted its focus from assistance or relief to prevention. In this regard, risk reduction to be vigorously taken into account. So as to reduce risk, both structural and non-structural measures should be materialized. Thus, the cost of risk reduction will yield an invaluable rate of return when compared with the cost of disaster damage;
7) ***A Focus on Prevention*****:** Proactive disaster management can reduce the damage and impact substantially;
8) ***A Focus on Public Participation*****:** Past disaster management in Thailand underlined the roles of government agencies and simply ignored private sectors, non-government organizations, communities and even the public. Unfortunately, there has been a lack of cooperation among agencies concerned. This is a real challenge for DDPM to bring these stakeholders together;
9) ***A Focus on Unity in Management*****:** The application of the Incident Command System (ICS) will demonstrate unity in management;
10) ***A Focus on Efficient Communication*****:** An efficient communication system consists of the major system and the reserved system, which are vital for disaster management;
11) ***A Focus on Human Resource Development*****:** Human resource development is a key factor for disaster management; and
12) ***Livelihood Rehabilitation*****:** Livelihood rehabilitation activities such as community development, vocational training, and improving the standards of living should be immediately materialized to normalize disaster victims' means of living.

Disaster Management Plan: The Civil Defense Secretariat is responsible for identifying disaster prevention measures and policies and the National Civil Defense Plan. This plan serves as the master plan for all agencies concerned, and provides guidelines for the formulation of operational plans of agencies responsible for management of disasters. The Civil Defense Secretariat does not only implement policies, but also provides equipment, technical assistance, and training courses for local agencies and the public. It also coordinates with agencies that are in charge of disaster relief and rescue operations.

According to the Civil Defense Act B.E.2522 (1979), the functional agencies are responsible for formulating their own disaster management plan. The master disaster management plan regarded as a national civil defense plan is to be made by the Civil Defense Secretariat. The plan is to be reviewed and updated every three-year term and proposed to the National Civil Defense Committee for approval. The current national civil defense plan, which was reviewed and updated in 2008, consists of two components: Disaster Prevention and Mitigation and Civil Defense for Security (Rear-Area Protection).

Strengthening of City and Land Use Control and Guidelines

In the Chao Phraya River Basin, land development is being promoted in accordance with economic growth. Thus, it is necessary to control land use and provide guidance to land development to minimize the increase of flood damage potential and decrease of its flood retarding function. To control disorderly land use, it is essential to prepare a flood risk map that will show not only the flood risk area but also the retarding area. Land development shall thus be guided according to the flood risk map. If land development is planned in a habitually inundated area, protection works shall be obligatory to minimize the flood damage potential. Moreover, land development with the provision of public facilities shall be planned by referring to the flood risk map to minimize the decrease of its retarding function. Among public facilities, roads in a flood prone area are vulnerable to flood damage and they sometimes hamper the free movement of floodwater resulting in the loss of a retarding function. The construction of roads shall be planned in consideration of flood risk by minimizing the damage potential and not decreasing the retarding function of the flood prone area. Other infrastructures should be designed or improved based on the flood risk map.

Buildings and Housing

In principle, the climate change adaptation and mitigation measures on building and housing can be classified into two groups. The first group concerns design and construction, such as promoting energy-efficient design and buildings, energy-efficient technologies, construction practices encouraging greater use of natural light and ventilation, proper insulation and energy conservation measures. The second group is mitigation measures designed for flood risk areas, such as drainage systems, dikes and polders or diversion channels for the area; and non-structural measures, such as land use control, building site elevation and location adjustment and flood fighting management. Both categories of adaptation and mitigation measures need to be supported by proper rules and regulations for enforcement; thus the institutional mechanism must be arranged so the legal system can realize those measures.

Transportation

For the A1FI scenario of climate change, extreme rainfall intensity (mm per hour) would increase 15% over current levels. However, every civil design uses current levels for flood prevention and drainage requirement. Thus, the major infrastructures should use design criteria and be reviewed according to climate change conditions.

Considering global warming cities' objectives are typically to meet the mobility needs of citizens while minimizing the amount of the Greenhouse Gas (GHG) and air pollutants emitted, to create and operate functioning public transport systems and to reduce traffic and congestion. Managing the emissions from transport and traffic congestion is generally best achieved through the following policies (WB, 2008):

1) Managing and controlling vehicular usage;
2) Improving fuel efficiency of vehicles and promoting efficient modes of transport;
3) Promoting use of cleaner fuels and green vehicles; and
4) Developing economic instruments for congestion and pollution control in urban areas.

Water Supply and Sanitation

The whole waterworks, conduit and sewerage systems should be checked according to regulations and climate change conditions to reduce damages. Some can endure severe floods and ground subsidence, but others may need to be repaired and strengthened.

Energy

The design criteria for generation facilities should be strengthened in order to endure climate change because it can affect hydraulic, geographical and geological circumstances. Therefore, the design criteria should be reviewed to incorporate impacts of climate change.

With an eye on global warming, the most common strategies for mitigation in the energy sector are improving power generation efficiency, encouraging the move toward cleaner and less carbon-intensive fuels, keeping electricity costs affordable, and developing public/private partnerships (WB, 2008).

Public Health

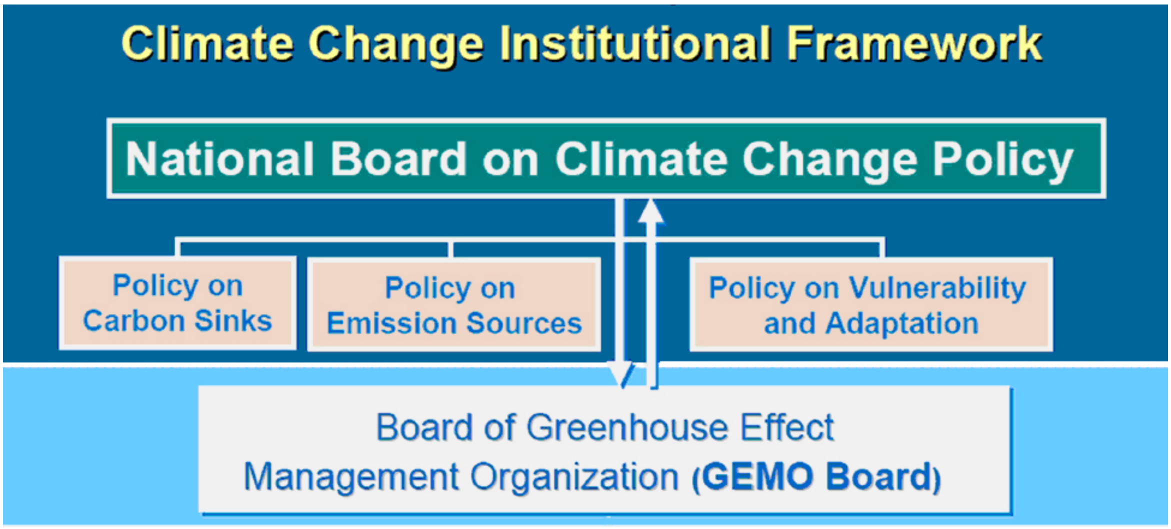
Although the statistics of the Ministry of Public Health do not suggest any causal relationship between recent floods and communicable waterborne diseases, the Ministry pointed out that diseases such as mosquito-borne diseases, skin diseases, and gastrointestinal diseases are remarkable when flood inundation is prolonged. To prevent such waterborne diseases, the Ministry makes effort to provide drinking water and first aid kits, including deployment of ambulances and district and sub-district health officers assisted by volunteers.

With global warming in mind, climate change has been identified as causing changes in the pattern of communicable diseases throughout the world. It may also lead to more heat-related diseases among the most vulnerable in society: the young, the elderly, and the sick and disabled. Tropical cities have developed specific communicable disease strategies, such as vector control (mainly against mosquitoes, flies, cockroaches and rodents) and light protections (tents and curtains) (WB, 2008).

5.4 INSTITUTIONAL MECHANISM

5.4.1 National Board on Climate Change Policy

In June 2007, the Office of Natural Resources and Environmental Policy and Planning (ONEP) established the National Board on Climate Change Policy, which is chaired by the Prime Minister. Currently, a new Divisional-level office (the Climate Change Coordination Office) was established under ONEP to serve as a secretariat of the National Board on Climate Change Policy, as well as to provide strong cooperation and networking with other implementing agencies related to carbon sinks, carbon source, climate change impact, vulnerability and adaptation. The structure of the climate change institutional framework is shown in **Figure 5.4-1**.



Source: Office of Natural Resources and Environmental Policy and Planning (ONEP)

Figure 5.4-1 Structure of Climate Change Institutional Framework

Moreover, the "National Strategy on Climate Change B.E.2551-2555 (2008-2012)" addressed the issue of climate change in Thailand by ONEP. The strategy outlines mechanisms and measures that need to be undertaken by various agencies. These include measures for mitigating greenhouse gas emissions and adapting to impacts of climate change, as well as incorporating into the National Social and Economic Development Plan details on:

- *Strategy 1*: Build capacity to adapt and reduce vulnerabilities to climate change impacts
- *Strategy 2*: Support greenhouse gas emission reduction and add more carbon dioxide sinks on integrity development
- *Strategy 3*: Support research and development to better understand climate change, its impacts and adaptation and mitigation options
- *Strategy 4*: Raise awareness and promote public participation
- *Strategy 5*: Build capacity of relevant personnel and institutions and establish a framework of coordination and integration
- *Strategy 6*: Support international cooperation to achieve the common goal of climate change mitigation and sustainable development

5.4.2 Proposed Projects

In Thailand, most of the necessary institutional arrangements were established together with the setting up of the necessary organization. In principle, there are no conflicts in the designation of the agencies responsible for operating and managing flood mitigation measures, as long as these measures can be solely managed in accordance with their purpose. However, to enhance the flood mitigation function of these measures, coordination of their operation and management among the agencies concerned is necessary. There is neither a single agency nor a coordination agency administering river and/or flood basin-wide, and thus such coordination is in general not undertaken. A coordinating committee among the agencies concerned has thus become necessary so that the Government set up the National Water Resource Committee in 1989. Recognition of current water-related problems such as shortages during dry season and flooding during rainy season led to preparation of the Water Resources Act, which establishes a River Basin Committee to handle all disputes. This project is still ongoing but setting up a new organization together with the provision of necessary law to designate its role will be timely. Resolution of most of the present deficiencies in comprehensive flood control is expected through the Water Resources Act. It is recommended that the Water Resources Act should be pursued and promulgated as early as possible.

The proposed projects which should be carried out to cope with the climate change on hydrologic effect are presented in **Table 5.4-1.** A Board of Hydrologic Effect on Climate Change is recommended to be appointed to coordinate and facilitate awareness regarding adaptation in hydrologic impact. In conjunction with the National Board on Climate Change Policy, the mitigation and adaptation for climate change will be covered.

Table 5.4-1 The Proposed Projects

Project	Client	Committee	Area
Structural Measures			
1. Coastal Erosion Protection	DMCR	DDS, HDD	Bangkok, Samut Prakarn, Samut Sakhon and Chachoensao
2. Flood Protection System Improvement	RID	DDS, EGAT, DWR	The Chao Phraya River Basin
3. Bangkok Drainage System Improvement	DDS	RID	Bangkok
Non-structural Measures			
1. Climate Change Impact and Adaptation Strategy	BMA	All	Bangkok and the whole country
2. Land Subsidence Suppression	DGR	DDS, RSTD	BMR
3. Flood Disaster Response and Management	DDPM	RID, DDS, TMD, NDWC	The Chao Phraya River Basin
4. Flood Insurance	OIC	DAE, DOF, RID, DDS	The Chao Phraya River Basin
5. City and Land Use Control and Guideline	DCP	DDS, DE, DPW, TTD	Bangkok

Source: Panya Consultants

Coastal Erosion Protection Project
Because of the severe coastal erosion problem along the shoreline in the Upper Gulf of Thailand, the Department of Marine and Coastal Resources (DMCR) should urgently carry out a study to identify a suitable solution to protect the shoreline taking into account the sea level rise resulting from climate change and land subsidence.

Flood Protection System Improvement Project
Climate change will increase rainfall during the flooding period and along with sea level rise, the existing flood protection system cannot cope with this problem. Therefore, the flood protection system together with modification of reservoir operation rules should be reviewed. The RID should take responsibility for this project. However, relevant agencies should be involved in the study.

Bangkok Drainage System Improvement Project
The existing drainage system in the Bangkok metropolitan area should be rechecked with respect to the impact of climate change. In addition, the drainage system should be designed to cope with the flood protection system.

Climate Change Impact and Adaptation Strategy Project
The BMA has carried out activities to cope with global warming such as reforestation and growing trees in the Bangkok area, energy reservation, etc. However, the climate change impact and adaptation strategy should be studied and planned in all sectors related to global warming and climate change. Coordination among the concerned agencies and implementation should be assessed by the Board of Hydrologic Effect on Climate Change.

Land Subsidence Suppression Project
The DGR has carried out a study on land subsidence. However, the impact of climate change on precipitation and sea level rise should be taken into consideration. The ground elevations in Bangkok and vicinities are controversial and have to be resurveyed to confirm their elevation taking into account the settlement of the reference benchmarks.

Flood Disaster Response and Management Project
The DDPM has carried out a study on a master plan of disaster response and management. However, disaster resulting from climate change should be taken into consideration, especially flooding which has a high risk of occurrence.

Flood Insurance Project
The RID studied the possibility of using agricultural areas as retarding basins during flooding. Compensation will be paid to owners who allow the RID to divert flood water into their cultivable area, which are mostly rice fields. An embankment will be constructed around the area to increase its storage capacity. However, flood insurance should be studied to identify an appropriate compensation at a reasonable price.

City and Land Use Control and Guideline Project
A flood risk map should be developed taking into account climate change on hydrology. The city and land use control and guideline should be revised by taking into account the flood risk map and any retarding area uncovered by the study of flood protection system.

CHAPTER 6

CONSULTATION WITH STAKEHOLDERS

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6.1 GENERAL

The methodology and operational plan for this important crosscutting task have been designed based on the project objective: to inform decision making on the part of the government and the private sector on measures needed to address climate change and its consequence. Two technical consultations were held to verify data and methodology used in the report and validation and acceptance from the technical/academic community. The final stage consultation was arranged for public announcement, to create city awareness and to receive recommendation for improvement of the Final Report.

6.2 TECHNICAL CONSULTATION 1

The first technical consultation, *"Sea Level Rise and Land Subsidence in the Bangkok Metropolitan Area"*, was held on September 23, 2008 at the World Bank Office, Bangkok. The program and list of participants are given in Appendix N.

6.2.1 Objectives

Sea level rise and land subsidence are major problems that have close links to climate change impacts in the Bangkok Metropolitan Region. Future rainfall and sea levels during the rainy season will increase with the future climate conditions. The present flood protection may not be sufficient for the future flood risks. The consultation was intended to seek expert inputs that will be critically important to achieve a broadly agreed upon solution for these problems.

6.2.2 Presentation and Discussion

The Consultant presented the project scope, variables and assumptions in model development and simulation. The discussion by experts on land subsidence was focused on sources of data used. Two government units have collected land subsidence data for organizational interest. The Royal Thai Survey Department had extensive records but just changed some point of reference benchmarks in 2006. The Bureau of Groundwater Conservation and Restoration recorded land subsidence and its correlation with groundwater used by increasing urban expansion in Bangkok. The limitation of data currently available was discussed as was the intensity of points of sampling. The meeting discussed the application and limitation of the records from the two organizations and concluded the data recorded by The Bureau of Groundwater Conservation and Restoration is the only official record reliable for use in the project. The meeting accepted that land subsidence rate related to groundwater use but needed clarification on the magnitude and scaling factors. The Consultant proposed using a predictive model of accumulated land subsidence in 2007-2050 based on an average land subsidence rate in the last 5 years (2003-2007) of 10% decrease per year for the study and it was accepted. The experts recommended the Consultant remark on the technical limitation in the data and scaling factors in land subsidence, and also give precaution in using the predicted values.

The Consultant also presented a variety of sea level rise studies and forecasting. The meeting discussed the possibility of using predicted sea level rise records from tide gauges in the Gulf of Thailand and realized that the current data available was derived from too short a time period. The experts discussed the uncertainty in using sea level rise from data recorded in the Gulf of Thailand and agreed that the JBIC study was reasonable enough for the study as it is a regional model and in the range of the IPCC. The expert group accepted the Consultant's proposal of using sea level rise forecasted by the JBIC (A1F1 and B1 scenario, 29 cm and 19 cm in 2050, respectively) and advised the Consultant to cite reference sources.

6.3 TECHNICAL CONSULTATION 2

The second technical consultation, *"Climate Change Impact and Adaptation Study for Bangkok Metropolitan Region"*, was held on February 19, 2009 at the Bangkok Metropolitan Youth Center (Thai-Japan), Bangkok. The program and list of participants are given in Appendix N.

6.3.1 Objectives

1) To verify the data and methodology used in model development and impact assessment and to report on progress up to the Initial Draft Final Report; and
2) To receive comments and recommendations from technical experts for study improvement.

6.3.2 Presentation and Discussion

Representative of the BMA introduced the project background and their interest and participation in the project. The Consultant briefly explained the scope and methodology of the study, the summary of technical consultation 1, and the findings up to the Initial Draft Final Report covering the Bangkok city description, model development and simulation, impact assessment and adaptation and proposal, including consultation with stakeholders.

There were several comments from the experts but no major challenges to the project assumption, the model development or impact assessment. Most of the technical comments were related to the source of data used in the model, especially the sea level rise, and mentioned incorporating the accumulate impact result from coastal buildings into the model. The Consultant responded by explaining the principles of using current data and its limitation. To absorb the cumulative impact from coastal buildings, the Consultant had put into the model a reduction rate factor. There were concerns about a change of climatic factor (e.g. atmospheric pressure) causing a sudden 10-30 cm rise in water level in the Chao Phraya River. The current trend of land use upstream in the Chao Phraya River Basin will have a negative impact in Bangkok as well as changing land use in Bangkok. The Consultant agreed with the comments on change of climatic factor, but could not find data for a projection to incorporate into the model, and also lacked data on land use change upstream of the basin relating to flood effects in Bangkok. The Consultant explained that the Bangkok area will not continue to grow at a significant rate as it is almost fully developed. Growth is expanding to its outer vicinities. Future land use in Bangkok will not significantly change. Other comments were to recheck and update data inputs. The Consultant has taken the remarks into consideration and they will be verified in the Draft Final Report.
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6.4 FINAL STAGE CONSULTATION

The Final Stage Consultation, *"Climate Change Impact and Adaptation Study for Bangkok Metropolitan Region"*, was held on March 12, 2009 at the Grand Ayutthaya Hotel, Bangkok. The program and list of participant are given in Appendix N.

6.4.1 Objectives

1) To inform the general public about the study, the results and proposed measures needed to address climate change and its consequence for the BMA and Samut Prakarn; and
2) To compile feedback information, comments and recommendations to be used for final improvement of the final report.

6.4.2 Presentation and Discussion

The Deputy Bangkok Governor presided, delivered an opening address, elaborated on the project's value to the BMA and Bangkok residents and cited the BMA's intention and cooperation in the project formulation and progress. The Consultant briefly presented the background of the project, objectives and scope of the study, the process, the summary of model and impact assessment results, and the purposed adaptation. The Consultant informed the participants that outputs presented are preliminary and require future data, calibration and verification to improve accuracy of the predicted impact.

The discussion session was chaired by the director of the Department of Drainage and Sewerage with two Consultants on the panel. Participation in the discussion was very active, expressing several remarks and giving advice. However, there were no challenging comments to the assumption, model development and impact assessment. The meeting proposed several adaptation options, and commented on investment cost and related issues. The consultation discussed various issues to be considered. Most issues were clarified by the panel.

The Department of Health was concerned flooding will increase wastewater volume, affecting health and living conditions in Bangkok. It suggested the BMA initiate a polluter pay principle and implement it as normal practice. Thousands of communities in the flood risk areas will have to improve their toilet systems to cope with projected higher flood levels and longer inundation periods. The chair person explained that the BMA has attempted to improve wastewater management by improving the capacity of the drainage system in many areas, but it is still not able to cope with increasing garbage and wastewater problems. At present, the BMA provides mobile and temporary toilet service to communities during flooding.

One suggestion was to include the indirect impact to tourism in the cost benefit analysis. The Consultant responded that this segment had been included in the economic analysis.

The groundwater expert pointed out that the most sensitive variable input to the model is land subsidence and requested the BMA to assist in establishment of a network of recording stations sufficient to provide reliable estimates for model improvement in the future.

There was a specific comment on the construction of dikes and consequent environmental impact. It was recommended that determination of environmental cost be incorporated in the economic analysis. The Consultant verified that the measure proposed had been to raise crest elevation of the existing dikes not to build new dikes, therefore the magnitude of environmental impact would not substantial.

There were several comments recommending the Consultant reconsider allocation of investment cost to other alternatives, e.g. increasing drainage volume of the Chao Phraya River, construction of a new dam upstream, establishment of a Monkey Cheek, forest plantation, cheek dams and improving watershed management. The Consultant explained that during the process of preparing an adaptation proposal, it had made a comprehensive analytical review of existing adaptive practices including structural and non-structural measures. The proposal of improving dikes, increasing pumps, and reducing coastal erosion would be sufficient to absorb projected flood magnitude impact to Bangkok. Measures recommended to be conducted outside and around the BMR have been carried out by responsible organizations. The Consultant felt it was very important to integrate plans and functions for sentiency in flood management.

Finally, the donor reminded the participants to consider the study the first attempt to seek understanding of the socio-economic impact of climate change and associated vulnerabilities of urban communities especially the poor, to such impact. This underscored the need to adapt urban infrastructure to mitigate the impacts and protect the urban population. The BMA still needs to improve its database and model reification in the future. The proposed investment cost has to be considered as long-term insurance coverage for flood risk for millions of Bangkok inhabitants, for considerable damage to several hundred thousand buildings and for substantial loss in the commercial and industrial sectors from climate change impact.

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