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### Increasing Climate Change Resilience of Urban Water Infrastructure

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Based on a Case Study from Wuhan City, People's Republic of China

Asian Development Bank

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## **GUIDEBOOK**

# Increasing Climate Change Resilience of Urban Water Infrastructure

Based on a Case Study from Wuhan City, People's Republic of China

Asian Development Bank

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ISBN 978-92-9254-118-7 (Print), 978-92-9254-119-4 (PDF) Publication Stock No. TIM125167

Cataloging-In-Publication Data

Asian Development Bank.

Guidebook: Increasing climate change resilience of urban water infrastructure—Based on a case study from Wuhan City, People's Republic of China.

Mandaluyong City, Philippines: Asian Development Bank, 2013.

1. Climate change. 2. Urban water. 3. People's Republic of China. I. Asian Development Bank.

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Notes: In this publication, "\$" refers to US dollars at 2010 levels. Cover was designed by Nadejda Kondratiev.

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## Contents

List of Figures	iv
Abbreviations	V
Foreword	vi
Acknowledgments	vii
Executive Summary	Viii
PART I: AN APPROACH TO INCREASING CLIMATE CHANGE RESILIENCE OF URBAN WATER INFRASTRUCTURE	1
1. Introduction	2
2. Choosing an Approach for Increasing Climate Resilience	7
3. Applying the Approach-Step 1: Climate Change Impacts on the Water Sector	10
4. Applying the Approach—Step 2: Assessing Vulnerability	18
5. Applying the Approach—Step 3: Developing Climate Resilience Strategies and Responses	25
6. Measuring Success	41
PART II: SHORT-TERM INFRASTRUCTURE INVESTMENT OPPORTUNITIES 7. Initial Infrastructure Investments	43 44
Appendix 1: Common Methodological Approaches	49
Appendix 2: Decision Support Planning Methods	58
References for International Examples	59

# Figures

1	Location of Wuhan, People's Republic of China	5
2	Conceptual Process of the City Climate Resilience Approach	8
3	The City Climate Resilience Approach	9
4	Map of Wuhan, Hubei Province, and Bordering Provinces	14
5	Wuhan's Climate Change Impacts	17
6	Wuhan's Vulnerability Rankings	24
7	Wuhan's Water Cycle and How It Can Be Changed to Increase Climate Resilience	26
8	Implementation of Hard and Soft Infrastructure Investments	27
9	Sequence of Investments for Planning and Design	30
10	Sequence of Investments for Water Capture and Storage	31
11	Sequence of Investments for Water and Wastewater Reuse	32
12	Sequence of Investments for Stormwater Management and Flood Control	33
13	Sequence of Investments for Urban Agriculture and Greening	35
14	Sequence of Investments for Buildings and Water Savings	36
15	Reassessment of Vulnerability Process	42
16	Matrix for Positioning Wuhan's Office of Climate Change Management	47
A1.1	Conceptual Process of the Potsdam Institute/Allen Group Approach	49
A1.2	Conceptual Process of the Drivers: Pressure: State: Impact: Response Approach	50
A1.3	Conceptual Process of the City Climate Resilience Approach	51
A1.4	The DPSIR Approach Applied to Impacts on Wuhan	52
A1.5	The City Climate Resilience Approach Applied to Impacts on Wuhan	53
A1.6	The City Climate Resilience Approach Vulnerability Analysis of Wuhan's	
	Water Sector	55
A1.7	The City Climate Resilience Approach Applied to Developing Resilience of Wuhan's Water Sector	56



# Abbreviations

ADB	Asian Development Bank
°C	degrees celsius
CCR	city climate resilience
DPSIR	Drivers: Pressure: State: Impact: Response
DSPM	decision support planning methods
GIS	geographic information system
km	kilometer
m <sup>3</sup>	cubic meter
m <sup>3</sup> /sec	cubic meter per second
OCCM	Office of Climate Change Management
OECD	Organisation for Economic Co-operation and Development
PRC	People's Republic of China
WELS	water efficiency labeling scheme
WWF	World Wide Fund for Nature
WWTP	wastewater treatment plant



### Foreword

he future effects of climate change pose a significant challenge for planners and managers of services and utilities. Cities need to prepare for the changes that might occur as the climate changes. But what are these changes, how will they affect services and utilities, and what can we do now to prepare for them?

These questions go to the heart of the matter and show the dilemma faced by city governments. As the effects of climate change are not known with certainty, it is tempting to put off any action (especially actions requiring capital expenditure) until more is known. However, uncertainty will always be a factor, and to wait until more detailed predictive data are available may jeopardize existing infrastructure investments and the ability of cities to sustain their inhabitants.

In 2010, the Asian Development Bank funded a study on how these problems can be approached in the water sector (water supply and drainage) of Wuhan, a major urban center in eastern People's Republic of China (PRC), on the lower Yangtze River. This guide reports the findings of the study and describes the key activities that led to these findings.

The solutions proposed are presented as a program of investment decisions, which the city government and utility planners and managers could consider to increase the city's resilience to the effects of climate change. These investment decisions, and the assessment of impacts and vulnerability leading up to them, were developed through a "bottom-up" approach involving Wuhan City staff and stakeholders in workshops and plenary discussions. The framework for identifying and ranking impacts and vulnerabilities was derived from widely accepted international methodologies, tailored by the study team to suit local conditions.

This guide focuses on water infrastructure, but the steps and processes of the approach may also be of relevance to other sectors, or to integrated and cross-sector infrastructure in other cities in the PRC. This guide emphasizes that different areas and decision makers have different needs, and that the approach should be adjusted to suit the circumstances.

Robert Wihtol<sup>®</sup> Director General East Asia Department Asian Development Bank

### Acknowledgments

he project team consisted of Neil Urwin, lead author and climate change implementation specialist; Alan Kwok, team leader and environment specialist; Zhou Yueha, meteorologist; Zhou Huijun, water and wastewater engineer; and Qui Hanming, hydrologist and flood prevention officer. The team would like to thank the staff of the Asian Development Bank (ADB) who have guided this study through to its fruition as a guide for climate change resilience. In particular, we are grateful to Sergei Popov, who was the project manager of this study and provided overall guidance for the development of this guide. Thanks are also due to Arnaud Heckmann, the Wuhan project officer; and Masa Yoshida, ADB intern, for their valuable contributions.

This study could not have been completed without the assistance of the Wuhan Urban Development Management Office for Foreign Funded Projects; special thanks is extended to Wang Jianjun and the staff of line agencies. Zhou Yuehua of the Wuhan Regional Weather Center, Zou Huijun of the Wuhan Municipal Engineering Design and Research Institute, and Qiu Hanming of the Wuhan Survey and Design Institute of Flood Prevention, Wuhan City Foreign Funded Project Management Office, Wuhan City Development and Reform Commission, Wuhan City Environmental Protection Bureau, Wuhan City Planning and Design Institute, Hanxi Wastewater Treatment Plant, Sanjintan Wastewater Treatment Plant, Baihezui Water Treatment Plant, Baishazhou Water Treatment Plant, Luojialu Drainage Pumping Station all provided valuable assistance.

Finally, the staff of Arup, especially Debra Lam and the Arup Wuhan office, provided valuable and muchappreciated logistics support and data gathering.

### **Executive Summary**

### Purpose of the Guide

This guide describes a practical approach to bridge the gap between theoretical analyses of climate change impacts and the planning decisions that need to be made by city authorities and utility managers to increase climate change resilience of the water sector in the city of Wuhan, Hubei Province in the People's Republic of China (PRC). It focuses on answering the questions currently being asked by city planners and managers all over the world, as follows:

- What changes might be caused by climate change?
- How will these affect services and utilities?
- What can we do now to prepare for them?

The long lead time required to plan, finance, build, and commission city infrastructure facilities means that decision makers cannot wait for more detailed data on the effects of future climate change, especially those relating to local circumstances, but must make investment decisions based on what is known now and what can be readily predicted. An important principle in this kind of "robust" decision making is provided by the Intergovernmental Panel on Climate Change tenet that adaptation investments, which move a city's infrastructure toward sustainable development (such as providing safe drinking water and better sanitary conditions), are justifiable even without climate change.<sup>1</sup>

This guide is arranged in clear steps to provide direction and information for similar exercises in other areas. Having grown out of a specific locality and its needs, the principles and solutions developed in this guide are founded on real world situations and problems.

### Layout of the Guide

This guide describes the structured steps employed in the collaborative exercises with the staff of the Wuhan Government to determine the city's vulnerability to the impacts of climate change and to identify opportunities

<sup>&</sup>lt;sup>1</sup> This was articulated in Asian Development Bank. 2009. *The Economics of Climate Change in Southeast Asia: A Regional Review.* Manila.



to improve its resilience. In isolating these steps in the process, and in describing the activities undertaken in Wuhan, we hope to provide useful ideas for similar investigations elsewhere. This guide is presented in two parts.

**Part I** covers the steps to identify climate change impacts to Wuhan, to analyze the extent of its vulnerability to those impacts, and to develop recommendations for investments and actions to improve climate change resilience. **Part II** identifies a list of initial opportunities in current and planned projects in Wuhan, which have the potential to implement many of the infrastructure investments identified and recommended in Part I.

# PART I: An Approach to Increasing Climate Change Resilience of Urban Water Infrastructure

There are many different approaches to decision making for the adaptation of human-made and natural systems to reduce their vulnerability to the impacts of climate change. Most approaches are derived from a basic *Pressure: State: Response* approach and have parallel and common processes. The approach used in Wuhan (called the "City Climate Resilience" approach) is a combination of approaches, worked out in consultation with Wuhan city authorities. It exemplifies the important principles that (i) the most appropriate and practical approaches should be chosen for each situation, and (ii) measures that address climate change should also be good sustainable development practices.

The approach adopted has three steps, which address the questions asked at the beginning of this guide.

The Questions	The Steps
What changes might be caused by climate change?	Identify climate change impacts.
How will these affect services and utilities?	Assess vulnerability.
What can we do now to prepare for them?	Recommend actions to improve climate resilience.

### The Wuhan Case Study

Wuhan is the capital of Hubei Province and is a major metropolis in the PRC, with a population of just under 8.5 million and an area of 8,400 square kilometers (km<sup>2</sup>). The city is divided into three parts by the Yangtze River, and its longest tributary is the Han River. Wuhan is a financial and cultural center, as well as a major transport hub, in central PRC. It is located within 1,200 km from the major cities of Shanghai to the east, Chongqing to the west, Beijing to the north, and Guangzhou and Hong Kong, China to the south.

Wuhan was chosen as a case study because of its strategic location on the Yangtze River and because of the history of involvements of the Asian Development Bank (ADB) since 2000 in its water infrastructure planning and development.

A very significant lesson, which resulted from the case study, was that, while there is always a need for better and increasingly detailed information about what might happen in the future, a number of things can be done now. These include investing in infrastructure—which will strengthen the city against a range of possible eventualities— and become good planning, conservative, and sustainable practices.





In this way, the approach described in this guide is a practical route that takes account of the situation on the ground, including the local perceptions of both conditions and needs, the existing government plans, and the need to achieve consensus for investments in preparing for climate change.

### Steps in Increasing Climate Change Resilience

### Step 1: Identifying Impacts

The first step described in this guide consists of a series of stakeholder consultations and literature reviews that identify Wuhan's exposure to risks from extreme weather events. It was concluded that increasing temperature and precipitation intensities in and around Wuhan would cause (i) changes to the water cycle, affecting water supply; (ii) rising water levels that would affect the hydraulics of water intake and discharges; and (iii) landslide and soil erosion, floods, and heat waves and droughts that would put stress on water supply. Extreme weather events, such as droughts, floods, heat waves, and extreme low temperature with snowstorms, may also increase in frequency, intensity, and duration.

#### Step 2: Assessing Vulnerability

The second step seeks to identify the vulnerability of Wuhan's water sector infrastructure. The use of the concepts of hard and soft infrastructure is introduced to facilitate the analysis. Hard infrastructure refers to technical and engineering-led improvements, while soft infrastructure involves more institutional, social, community, and behavioral factors.

Vulnerability was assessed by comparing the expected impacts from climate change with the current preparedness of the city's infrastructure. This step depended upon building consensus among stakeholders on the degree to which future problems caused by climate change might be handled by current facilities and city management processes. It is a particular strength of the approach, since the consideration of vulnerability is always beset by uncertainties—yet, stakeholders were able to arrive at an agreement on the relative vulnerabilities of six major categories of infrastructure.

Overall, Wuhan is considered moderately vulnerable to climate change impacts on its existing hard and soft infrastructure, except for its water resources environment, which as agreed, is highly vulnerable. Wuhan is among the few fortunate cities in the PRC that currently have adequate water resource, with 100% coming from the Yangtze River and the Han River. Wuhan's water supply infrastructure is projected to meet the urban needs in 2020. However, total reliance on surface water from these two rivers makes the city's water supply vulnerable to changes in the flow and water quality, as well as water pollution incidents of these rivers.



### Step 3: Actions to Improve Climate Change Resilience

The third step recommends actions and investments to improve the resilience of Wuhan's urban water infrastructure to climate change. The investments were developed from an adaptation strategy for the city's water supply, which arose from the vulnerability assessments. The strategy is for Wuhan to explore alternative water sources or to implement water storage schemes in order to reduce reliance on just the Yangtze River and the Han River. Complementary investments should reduce the demand on potable use.

Recommendations in Step 3 cover both hard and soft infrastructure.

Hard infrastructure recommendations are in six areas: planning and design, water capture and storage, water and wastewater reuse, stormwater management and flood control, urban agriculture and greening, and buildings.

Soft infrastructure recommendations include the following four components: risk assessment, institutional capacity building, outreach and education, and research and technology.

Case studies are presented describing how other cities or countries deal with similar climate change resilience issues. These included best practices from Detroit, London, Los Angeles, Melbourne, New York City, Ottawa, Rotterdam, Singapore, Sydney, and Toronto. The examples point the way to more detail in appropriate climate change resilience themes and provide the opportunity to share the experiences of other city governments and utility operators of how their initiatives were achieved.

### PART II: Short-Term Infrastructure Investment Opportunities

Part II identifies a list of initial opportunities in current and planned projects in Wuhan, which have the potential to implement many of the investments in hard and soft infrastructure identified and recommended in Part I. These opportunities build on projects already committed to by the city government and, therefore, represent the best entry point into a program of investing in adaptation initiatives in the water sector.

The final step is to evaluate the outcomes of the projects to assess whether they have increased Wuhan's preparedness for climate change impacts. The city's vulnerability can then be reassessed to confirm that progress is being made in increasing overall resilience. The initial investment opportunities outlined in Part II can also be evaluated quantitatively. In this way, an index of improvements in resilience per unit of investment may be developed and investments in different areas of hard and soft infrastructure compared.

The full process, from the identification of likely impacts to the evaluation of climate resilience investments, is presented here. However, readers can use this guide to obtain information on any of the steps or recommended investments. This guide emphasizes that different areas and decision makers have different needs and that an appropriate approach should be tailored to the circumstances.

# Part I

An Approach to Increasing Climate Change Resilience of Urban Water Infrastructure

# Chapter

### Introduction

### In this Chapter

This chapter describes the purpose and evolution of this guide. We look at the basic concepts for discussing adaptation and resilience-building and how these can be used. We then look at how a series of practical and collaborative workshops with Wuhan's utility services planners and managers showed how we can plan for the uncertainties of climate change. Since the guide was developed from the work in Wuhan, we also discuss why this is an appropriate case study.

### 1.1 The Challenge of Climate Change

The People's Republic of China (PRC), along with other countries in Asia and the Pacific, needs to adapt to climate change impacts to protect the lives and livelihoods of millions of its citizens. Costs for adaptation will be high, but not adapting will involve even greater costs and will undermine regional progress toward poverty reduction and economic development.

The future effects of climate change pose a significant challenge for planners and managers of essential services and utilities. Cities need to prepare for the changes that might occur as the climate changes. The important questions therefore are as follows:

- (i) What are these changes?
- (ii) How will these affect services and utilities?
- (iii) What can we do now to prepare for them?

### 1.2 Key Concepts

A number of definitions are needed for this discussion, in order to establish a common understanding of the concepts and approaches we describe in this guide. The key concepts are impact, vulnerability, adaptation, resilience, and infrastructure. To facilitate this discussion, they may be quickly defined for the water sector as follows:

Impact	The effects of climate change on a system (in this case, human and/or engineered arrangements and processes).
Vulnerability	The degree to which a system is susceptible to, and unable to cope with, the adverse effects of climate change.
Adaptation	Adjustment in a system in response to actual or expected climatic stimuli or their effects, which moderates harm.
Resilience	The ability of a system to absorb disturbances while retaining the same ways of functioning.
Infrastructure	The basic equipment, utilities, productive enterprises, installations, and services essential for the development, operation, and growth of an organization, city, or nation.

Adaptation reduces vulnerability and increases resilience. Adaptation can operate at two broad levels—building national and local adaptive capacity, and delivering specific adaptation actions.

Adaptation decisions should be based on a sound scientific and economic foundation. Although uncertainty may make it difficult to fine-tune adaptation, there exist measures that address climate change that are also good sustainable development practices.<sup>1</sup>

Two useful ways of thinking about adaptation are as (i) risk management, and (ii) reducing vulnerability and/or increasing resilience. A risk management approach is likely to be more helpful at the enterprise level. Reducing vulnerability and/or increasing resilience is often more helpful at regional, catchment, or sectoral scale.<sup>2</sup> City infrastructure governance operates at both the sectoral and enterprise levels. A successful approach to adaptation will, therefore, contain elements of both reducing vulnerability and risk management.

### 1.3 The Development of this Guide

This does not intend to be a prescriptive guide for the assessment of impacts and vulnerability, and identification of adaptation responses for the water sector in the PRC. Instead, it is a structured description of the steps employed in a collaborative exercise with the staff of the city government to determine Wuhan's vulnerability to climate change and to develop the resilience of its water sector. In isolating these steps in the process, and in describing the approaches that facilitated the process in Wuhan, we have provided a guide for similar exercises in other cities. Since this guide is tied in with the environmental circumstances, infrastructure, preparedness, and the level of engagement with the stakeholders of Wuhan City, the guidance it provides for wider application should be in the way it can inform similar exercises in other jurisdictions.

The essential lesson from this case study is that action to increase resilience to climate change does not need to wait for studies of future climate conditions or detailed climate scenarios to be developed or for those scenarios, where they exist, to be incorporated into utility master plans. Although the development of future climate scenarios at the local level is among the recommended investments in increasing future resilience, the strength of the approach described in this guide is that it works with the expertise and plans that currently exist. In this way, it takes account of the situation on the ground, including the local perceptions of both conditions and needs, the existing government plans, and the need to achieve consensus for investments in climate change adaptation.

<sup>&</sup>lt;sup>1</sup> Asian Development Bank. 2009. The Economics of Climate Change in Southeast Asia: A Regional Review. Manila.

<sup>&</sup>lt;sup>2</sup> Campbell, A. 2008. *Managing Australian Landscapes in a Changing Climate: A Climate Change Primer for Regional Natural Resource Management Bodies.* Report to the Department of Climate Change. Canberra, Australia.

### LESSONS FROM THE CASE STUDY

- Action to increase resilience to climate change does not need to wait for studies of future climate scenarios.
- The **strength** of the approach described in this guide is that it works with the knowledge, expertise, and plans that currently exist.

This guide is, therefore, suited for stakeholders in government, businesses, academia, professional institutes, and international organizations that are interested in or responsible for climate change adaptation. While the city's local conditions are examined and assessed, the approach will have a wider applicability in other cities in the PRC, with Wuhan serving as a case study.

### 1.4 The Wuhan Water Sector as a Case Study

Wuhan was chosen because of its strategic location in the Yangtze River catchment and because of ongoing Asian Development Bank (ADB) involvements in the development and improvement of its urban infrastructure.

Wuhan is the capital of Hubei Province and is a major metropolis in the PRC with a population of 8.28 million in 2008 and an area of 8,400 square kilometers (km<sup>2</sup>). The city is trisected by the third-largest river in the world, the Yangtze River, and its longest tributary, the Han River. It is a financial and cultural center, as well as a major transport hub, in central PRC, being located within 1,200 km from the major cities of Shanghai to the east, Chongqing to the west, Beijing to the north, and Guangzhou and the Hong Kong, China region to the south.

While still not comparable to the coastal cities, Wuhan's economy is quickly catching up with its infrastructure and policy plans. Infrastructure investments are part of a much broader push to develop the PRC's central regions under the broad policy direction of "Rise of Central China," first announced by Premier Wen Jiabao in 2004. As costs along the coast rise, central and local authorities hope to attract more investments inland with extensive transport infrastructure investments that give enterprises access to the central region's lower-cost labor. Such new connections have already enhanced the city's effectiveness as a national distribution center, and has attracted new manufacturing industries.

ADB has funded water infrastructure and environmental improvement projects in Wuhan since 2000. It has been one of the major recipients of ADB funding for its water and wastewater infrastructure projects, with the aim of improving its water quality and supply as part of the city's master plan. ADB's first involvement in Wuhan was the Wuhan Wastewater Treatment Project.

This was followed by the Wuhan Wastewater and Stormwater Management Project. It included the upgrading of existing wastewater treatment plants and building of new sewers and pumping stations in urban Wuhan, construction of new wastewater treatment plants and collection systems in suburban Wuhan, improvement of stormwater drainage works and pumping capacities, and institutional strengthening. The project improved the urban environment, public health, and the quality of life of residents in Wuhan City.

In 2010, ADB embarked on the ongoing Wuhan Urban Environmental Improvement Project. It provides sludge treatment and disposal, rehabilitation of lakes and drainage channels, and institutional strengthening



FIGURE 1 Location of Wuhan, People's Republic of China

Note: Wuhan City is situated on the Yangtze River and central to major development centers in the People's Republic of China. Source: ADB.

and capacity building. It is ADB's first specialized sludge treatment and disposal project in the PRC that also promotes a decentralized approach and beneficial sludge reuse. It is part of the key Wuhan City master plan priorities in terms of sanitation, environmental improvements, and urban development. It contributes to establishing Wuhan City as a model city for sustainable development in the PRC.

### 1.5 What is Covered in Part I

Part I begins with a discussion of the steps used in determining Wuhan's vulnerability to climate change and in increasing its climate resilience. The approach employed establishes three steps. In the first step, a consideration of climate change trends and impacts in the PRC, Hubei Province, and Wuhan leads to the identification of climate change impacts, which the city is likely to experience in the future. This is followed, in the second step,

5

by a description of Wuhan's urban water infrastructure and its ability to cope with the identified impacts. From this, an assessment of the vulnerability to impacts is made. Based on the vulnerability assessment, in the third step, adaptation responses in hard and soft infrastructure to improve the climate resilience of the city's urban water sector are identified, along with investment sequences and resource estimates.

The three steps address the questions asked at the beginning of this chapter.

The Questions	The Steps
What changes might be caused by climate change?	Identify climate change impacts.
How will these affect services and utilities?	Assess vulnerability.
What can we do now to prepare for them?	Recommend actions to improve climate resilience.

All three steps focus on building stakeholder consensus through workshops. Key participants in all workshops were representatives from the Wuhan Development and Reform Commission, Wuhan Environmental Protection Bureau, Wuhan Planning Bureau, and Wuhan City Planning and Design Institute; local specialists from the Wuhan Water Bureau Flood Control and Response Division, Wuhan Weather Station; water and wastewater engineers from the Wuhan Municipal Design Institute; and representatives from the Foreign Investment Project Management Office.

The full process, from the identification of likely impacts to the identification of climate resilience investments, is presented here. However, readers can use this guide to obtain information on any of the steps or recommended investments. This guide emphasizes that different areas and decision makers have different needs, and that an appropriate approach should be tailored to the circumstances.

# Chapter

### Choosing an Approach for Increasing Climate Resilience

### In this Chapter

This chapter describes the building of an approach to answer the question: *How do we turn what we know now into a tool for planning and preparing for the effects of future climate change*? The approach described is practical and able to be implemented without exhaustive additional research. It also takes account of current thinking in climate change adaptation and builds on best practice in climate change planning.

### 2.1 Choosing the Right Approach

A number of approaches are used worldwide for taking account of climate change in decision making for the adaptation of human and natural systems to reduce their vulnerability. It is important to recognize that the commonly used approaches do not use distinct, mutually exclusive processes. They all derive from a basic *Pressure: State: Response* approach and have many parallels and common processes.

The main differences will be in their suitability to the decision makers that they might serve. City infrastructure governance operates at both sector and enterprise levels. A successful approach to adaptation will, therefore, need to contain both elements of reducing vulnerability and risk management.

This chapter discusses the steps to be taken when working with these approaches. The reader can thus understand the reasoning behind each step and can be in a better position to choose an approach or combine elements of different approaches to suit a specific jurisdiction or geographic situation.

The main types of methodological approaches currently used internationally, and how their features had been applied in the approach adopted for Wuhan, are described in Appendix 1.

### 2.2 Essential Features of a Climate Change Resilience Framework

The essential components of a framework for building climate change resilience are

- identification of climate change impacts,
- assessment of vulnerability, and
- development of resilience recommendations.



The approach used in Wuhan has all these features and augments them with (i) the establishment of priorities (for resource allocation), (ii) the development of specific and implementable adaptation investments, and (iii) a feedback and improvement loop for sustainability of the adaptation effort. It is called the City Climate Resilience (CCR) approach, and was developed by Arup and refined by the team for this exercise in close collaboration with technical staff from Wuhan's government agencies.

An important feature of the CCR approach was the use of pictorial representations in all steps. The pictorial representations include constituent elements of the assessments, which can be moved around in graphical space to reflect their significance or severity (see, for examples, Figures 5 and 8). This facilitates collaborative assessments and inputs from technical officers and utility managers and/or operators in workshops, and is an important tool in providing for maximum involvement of stakeholders.

### 2.3 The City Climate Resilience Approach

The CCR approach that was used to develop the climate change resilience of Wuhan's urban water infrastructure is composed of the following steps:

- Step 1 Identify and characterize potential climate change impacts.
- Step 2 Assess infrastructure vulnerability.
- Step 3 Develop a city climate resilience strategy.

These steps are shown in Figure 2.



FIGURE 2 Conceptual Process of the City Climate Resilience Approach

Source: ADB consultant.



Figure 3 below shows how the three steps are interpreted and implemented in the CCR approach.





CCR = City Climate Resilience. Source: ADB consultant.

# Chapter 3 Step 1: Climate Change Impacts on the Water Sector

### In this Chapter

In Chapter 2, we looked at methodologies and approaches and tailored an approach to suit local needs and circumstances. This and the next chapters will describe the process of implementing this approach. In Step 1, we will identify the risks of extreme weather events to Wuhan and rank them in terms of their expected frequency and severity.

This discussion has three parts. The first will identify the kinds of changes to rainfall and temperature that are likely to affect Wuhan in the future. The second will look at how the city uses its water resources. Finally, the effects of climatic change on the water sector are examined with a view to identifying the most important effects.

### 3.1 Understanding the Impacts

To understand the impacts of climate change on Wuhan's water sector, we first need to understand the major effects of climate change that will be experienced by the region. Then, we need to assess how it will affect Wuhan City.

### Climate Change in the People's Republic of China

The PRC's National Assessment Report on Climate Change 2007<sup>3</sup> reported changes in water resource distribution with decreasing trends in runoff in the last 40 years in the six main rivers, including the Yangtze River. It also reported the following noticeable weather and climate impacts in the recent past, as well as in the future:

- **Temperature**—Average temperature has increased by 0.5°C–0.8°C, slightly higher than the global average. The most significant temperature increases were in the winter, with 20 consecutive warm winters from 1986 to 2005. Temperature increases projected in the assessment report range from more than 1.3°C by 2020 and exceeding 2.3°C by 2050.
- **Precipitation**—Change in the annual precipitation pattern has differed by region and period but, generally, the north has shown a decreasing trend while the south and southwest have an increasing trend. Projected precipitation increases for the south and southwest are 2%–3% by 2020 and 5%–7% by 2050.

<sup>&</sup>lt;sup>3</sup> http://en.ndrc.gov.cn/newsrelease/P020070604561191006823.pdf



The PRC is an active participant in climate change talks and other multilateral environmental negotiations. It is a signatory to the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol, although the PRC, as a non-Annex I Party to the UNFCCC, is not required to reduce its carbon emissions under the terms of the present agreement.

The PRC has been noted for a number of national initiatives to combat climate change especially on the mitigation side, including renewable energy targets, energy efficiency programs, stimulus packages geared toward green jobs and the 11th–12th Five-Year Plans. In 2007 alone, the investment in developing renewable energy amounted to \$12 billion, with an estimated 500 million tons of carbon dioxide reduction from renewable energy consumption.<sup>4</sup> In 2011, the PRC announced carbon intensity reduction targets of 40%–45% by 2020. In the summer of 2010, the PRC national government promised strenuous efforts to make the nation more energy efficient. The PRC has surpassed the rest of the world as the biggest investor in wind turbines and other renewable energy technology, and has dictated tough new energy standards for lighting and fuel mileage for cars. Yet, comparatively little has been done on climate change adaptation at the national or city level, which is especially important for a country facing water stress and food security issues.

### **Regional Temperature Trends**

Hubei Province is experiencing an increasing trend in annual mean temperature, characterized by increases in winter and nighttime temperatures. The urban heat island effect is becoming more apparent. Since the 1960s, the annual mean temperature difference in urban compared with rural Wuhan has shown an increase of 0.235°C every 10 years.

The analysis of data and predictions for this century show annual mean temperatures in Hubei to increase by approximately 0.8°C in early 21st century, by 2.4°C in mid-21st century, and by 3.1°C in the late 21st century. The trend line for this century shows a temperature increase of 3.3°C in 100 years. On seasonal changes, summer and winter would experience larger temperature increases, especially in the late 21st century. Toward the late 21st century, the rate of increase in temperature anomalies in winter would be larger than that in summer, resulting in a smaller annual temperature range in Hubei. On spatial variation, the whole Hubei Province is predicted to experience continual temperature rise, with larger increases in the north compared to the south, and east compared to the west.<sup>5</sup>

#### Heat Waves

Increases in temperature cause groundwater and rainwater decrease, soil evaporation increase, plant transpiration increase, and smog increase. It will also increase the frequency of heat waves.<sup>6</sup> In Wuhan, this happened in 1988, 1995, 1998, 2000, 2003, and 2009. The heat waves lasted 33 days in 1998, 20 days in 1995,

<sup>&</sup>lt;sup>4</sup> Xie Hangsheng. 2009. Climate Change—People's Republic of China's Perspective. Keynote address to the Local Climate Change Leadership Summit in Copenhagen on 2 June 2009. http://www.fmprc.gov.cn/eng/wjb/zwjg/zwbd/t566228.htm

<sup>&</sup>lt;sup>5</sup> National Development and Reform Commission. 2007. [The People's Republic of] *China's National Climate Change Program.* June. People's Republic of China.

<sup>&</sup>lt;sup>6</sup> According to the World Meteorological Organization, heat waves are when the daily maximum temperature of five or more consecutive days exceeds the average maximum temperature by 5°C or more.



12 days in 2003, and 18 days in 2009.<sup>7</sup> Consequences included substantial increase in water and power demand. Heavy electricity users in industry were forced to stop production. The power grid was overloaded, resulting in power lines getting overheated and damaged. Water supply was jeopardized. Many people suffered heat stroke, and a number of deaths were also reported.

### Extreme Cold and/or Snowstorms

Extreme cold, wind chill, and snowstorms have occurred in January/February in Wuhan in 1984, 1988, 2000 and, more recently, in 2008. Snowstorms lasted 5 days in 1984 and 2000, and 8 days in 1988. The extreme low temperature and snowstorm in early 2008 lasted 23 days, shutting down transport in and out of Wuhan. The city had 27 centimeters of snow, the third highest historically. Serious ice and/or snow buildup on buildings and on power and communication facilities, caused substantial impact on the power grid, power supply, road safety, and livelihoods. Although direct impact on the water infrastructure was minimal, 3,273 houses, 1,608 households, 111,600 people, and 36% of agricultural products experienced disruption of water supply from the bursting of frozen water pipes. Power supply and air, rail, and road transport were all disrupted, with a total economic loss of CNY276 million. There were failures in the weather forecasting systems to provide early warning and subsequently slow responses during and after in information exchange. The 2008 snowstorm essentially shut down the city and exposed its difficulties in responding to extreme weather impacts.

### **Regional Precipitation Trends**

An analysis of precipitation in Hubei Province shows a decreasing trend in the early 21st century, shifting to an increasing trend in the mid-21st century, reaching a 6%–8% increase by the end of the 21st century. The precipitation trend line for this century shows an increase of 13% per 100 years. On seasonal variation, the extent of increase would be larger in spring and winter seasons. The rate of increase in monthly average precipitation anomaly would be greater in winter compared to summer in the late 21st century, and the annual precipitation range would become smaller. On spatial variation, the whole province will experience a gradual increase in precipitation in this century, with larger increases in the north compared to the south.

#### Droughts

Wuhan experienced three major droughts in 1988, 2000, and 2001. In these droughts, water levels in the Yangtze and Han rivers were extremely low, and most reservoirs were below the dead water level, meaning the water was unusable; or had completely dried up. The 2000 drought, which lasted 112 days from February to May, was the most serious since the keeping of meteorological record in 1880.<sup>8</sup> To compound the effect, Wuhan faced another severe drought the next year, in 2001, that lasted 109 days from June to October.

<sup>&</sup>lt;sup>7</sup> Based on information from the Wuhan Regional Weather Center.

<sup>&</sup>lt;sup>8</sup> In the last 2 decades, temperatures in the Yangtze River basin area have risen by an average of 1.8°F (1°C), causing a spike in flooding, heat waves, and drought. Over the next 50 years, temperatures will continue to climb by an average of 1.5°C-2°C. Report by WWF-International issued on 10 November 2009.



Supplying enough drinking water becomes a serious issue during droughts. So, too, does maintaining water quality to prevent disease and infection.

#### Floods

Another major weather trend for Wuhan is the significant increase in precipitation, usually resulting in flooding. The Wuhan lake system is part of a complex water system of water bodies and channels within the vast Jianghan floodplain that was originally connected to the Han and Yangtze rivers. The Yangtze floodplain area, where Wuhan City is located, is significantly vulnerable to climate change. Floods have occurred in 1983, 1991, 1996, 1998, 1999, and 2002, usually in the summer months from June to August. Since the devastating 1998 floods that ravaged the Yangtze region and was the worst in the latter half of the last century, Wuhan has reinforced its embankments at a cost of more than CNY5 billion.<sup>9</sup> The floods in 1998 and 1999 lasted 60 and 43 days, respectively, resulting in extensive flooding of low-lying areas, damaging farmlands, fishponds, and houses and causing disruptions to transport, power, and water infrastructure. The Wuhan government declared a state of emergency for the 2002 floods.<sup>10</sup>

Fortunately, to date, floods have had minimal impact on Wuhan's water supply system. The 1998 floods, however, exposed vulnerability of the drainage system, damaging 46 km of drainage pipelines and affecting the water quality. The completion of the Three Gorges Dam has reduced flooding risk from the Yangtze River. Flooding in Wuhan now is mainly due to prolonged heavy precipitation. Continued urbanization and environmental degradation, especially through deforestation and erosion, will increase flood risk. The urban area of Wuhan is lower than the historical average high water level in the Yangtze River. Most stormwater collected in the urban area has to be pumped out, placing an added burden on infrastructure services.

### 3.2 Implications for the Water Sector in Wuhan

To assess how Wuhan will be affected by these climatic changes, we need to fully understand the water sector infrastructure as it presently exists.

Some 5.1 million people reside in its urban core. The city is divided into three towns (Wuchang, Hankou, and Hanyang) that make up the city of Wuhan. Water is the city's most distinguishing identity and asset. Known as the "city with hundred lakes," Wuhan City has more than 160 lakes, 272 reservoirs, and 165 rivers or streams. Water covers 2,187 km<sup>2</sup>, or 25% of the total city area, which is the highest ratio of any provincial capital in the PRC.

The following sections describe the water resources and urban water infrastructure of Wuhan, based on information provided by the local municipal specialists who participated in this project.

<sup>&</sup>lt;sup>9</sup> http://www.chinadaily.com.cn/china/2007-07/27/content\_5445106.htm

<sup>&</sup>lt;sup>10</sup> http://news.bbc.co.uk/2/hi/asia-pacific/2215663.stm





Source: ADB.

### **Potable Water**

Wuhan is among the few fortunate cities in the PRC that have adequate water resources. Water resources available to the city total 4.046 billion cubic meters (m<sup>3</sup>), including 3.689 billion m<sup>3</sup> of surface water and 1.043 billion m<sup>3</sup> of groundwater. The urban area of Wuhan obtains 100% of its water supply from the Yangtze

14



River and the Han River. The water quality in both rivers met Class III (Surface Water Environmental Quality Standards, GB3838-2002) in 2008 and was suitable for potable use.<sup>11</sup> Of the 55 major lakes monitored in 2008 in Wuhan, 66% were categorized as Class V standards (the worst) and approximately 23% were of Class III standards or better.

There are 10 water treatment plants supplying water to an urban population of 5.103 million for industrial and domestic uses, with a total design capacity of 3.71 million m<sup>3</sup>/day and actual supply of 2.578 million m<sup>3</sup>/day in 2008. Of the actual supply in 2008, approximately 60% came from the Yangtze River through six water treatment plants and the remaining 40% came from the Han River through four water treatment plants, with approximately 72% consumed for domestic use and 28% for industrial use.

Average water consumption per capita in 2008 was 0.351 m<sup>3</sup>/day. Water consumption per capita is projected to increase to 0.434 m<sup>3</sup>/day by 2015 and 0.450 m<sup>3</sup>/day by 2020. Total urban water demand for 2020 is projected to reach 3.31 million m<sup>3</sup>/day (with 2.435 million m<sup>3</sup>/day and 0.875 million m<sup>3</sup>/day for domestic and industrial uses, respectively). The present design capacity of the 10 water treatment plants would be adequate to meet the 2020 urban water demand. There is no planning data beyond 2020.

### Wastewater

The urban population in 2008 generated 1.54 million m<sup>3</sup>/day of domestic wastewater while industries generated 616,000 m<sup>3</sup>/day of wastewater. The average daily wastewater volume was about 85% of the water consumption. This was treated by 10 wastewater treatment plants (WWTP) with a total design capacity of 1.59 million m<sup>3</sup>/day and actual treatment of 1.44 million m<sup>3</sup>/day in 2008. The treatment rates in 2008 varied in different urban districts and should average about 80%. Per capita generation of wastewater was 0.302 m<sup>3</sup>/day in 2008, which has been estimated to increase to 0.367 m<sup>3</sup>/day in 2015 and 0.383 m<sup>3</sup>/day in 2020.<sup>12</sup>

Two of the existing WWTPs are currently being upgraded. The upgrades will add 0.34 million m<sup>3</sup>/day in design capacity. Two new ones are under construction, and will add another 0.135 million m<sup>3</sup>/day capacity. Eight existing WWTPs and the two under construction discharge either directly or via tributaries into the Yangtze River. Two existing WWTPs discharge into lakes.

Three WWTPs have been planned, but construction works have not started. These would add another 0.19 million m<sup>3</sup>/day in design capacity. One WWTP would fully reuse its treated effluent, while the other WWTP would have partial effluent reuse with the rest discharging into the Yangtze River. The third one also would discharge into the Yangtze River with no effluent reuse.

In total, Wuhan will have 15 WWTPs with a total design capacity of 2.255 million m<sup>3</sup>/day by 2020. The targets are to achieve 90% centralized wastewater treatment by 2015 and 95% by 2020.

<sup>&</sup>lt;sup>11</sup> The PRC's surface water quality standards divide water bodies into five classes: Class I being the best and Class V being the worst in terms of water quality standard. Water bodies that are Class III or better could be used as drinking water supply.

<sup>&</sup>lt;sup>12</sup> Data provided by the Wuhan Municipal Engineering Design and Research Institute.

### Stormwater

16

Since the construction of the Three Gorges Dam upstream, the threat of flooding from the Yangtze River has been reduced substantially. Flooding in Wuhan is now mainly due to inadequate drainage to handle runoff from prolonged heavy precipitation. The urban area of Wuhan has an average elevation of 24 meters (m), which is lower than the historical average high water level of 25.97 m in the Yangtze River. As a result, most stormwater collected in the urban area of Wuhan has to be pumped out, and the city has built 28 pumping stations and 14 floodgates to alleviate flooding, with a total design capacity of removing stormwater at a rate of 1,618 m<sup>3</sup>/second (sec). Three new pumping stations are being built that will add another 210 m<sup>3</sup>/sec in design capacity. Two more pumping stations have been planned, but construction has not started. These will add another 145 m<sup>3</sup>/sec in design capacity. Stormwater is discharged into the Fu River, Han River, or the Yangtze River either directly or through tributaries and lake systems.

### 3.3 Scoring the Impacts

Extreme weather events that might affect Wuhan were identified using information from the Wuhan Regional Weather Center, interviews, literature review, and interactive workshop discussions. The extreme events identified are as follows:

- drought
- strong wind
- rainstorm
- heat wave
- snowstorm
- floods

The extreme weather events were further characterized by two criteria: **frequency** and **severity**. The nomenclature favored by workshop participants is used. In this case, the city utility managers and planners preferred the term "severity" to the more usual concept in risk assessment of "intensity." This is because the utility managers and planners tend to perceive issues in practical and problem-solving ways rather than in theoretical ways.

The workshops were interactive. Visual aids were used to facilitate discussion and record results of discussion. The stakeholders identified events that are relevant to Wuhan City, and moved them around on a chart (Figure 5) to show the frequency and severity of each. The workshops were full-day events with 10–12 key participants. The questions discussed among the stakeholders in determining the frequency and severity rankings were as follows:

- How exposed is Wuhan to climate change impacts?
- How often will the extreme weather events occur and what is the level of impact?
- How do the weather events connect with longer-term, gradual climatic changes, such as temperature increases in the next 100 years?





FIGURE 5 Wuhan's Climate Change Impacts

Source: ADB consultant.

These questions cannot be answered comprehensively, even if studies of future climate conditions or detailed climate scenarios were available. Participants and/or stakeholders used their knowledge of past and present conditions and levels of impacts to make informed assessments of future impacts associated with potential changes in temperature and precipitation patterns.

In Wuhan's case (Figure 5), flooding would be very severe, but is unlikely to occur frequently. On the other hand, heat waves would occur often and be severe. This rapid assessment helps us think about vulnerabilities and in prioritizing the appropriate strategies. For example, preserving enough drinking water for citizens and livestock is a priority response to heat waves, and might utilize infrastructure solutions such as water storage, treatment, and conservation. While flooding will not occur as often, infrastructure (such as dikes and pumping stations) to cope with flooding will take a number of years to build and will require planning and construction.

# Chapter 4

### Applying the Approach Step 2: Assessing Vulnerability

### In this Chapter

In Step 1, we identified the risks of extreme weather events to Wuhan and ranked them according to their expected frequency and severity. In this chapter, describing Step 2, we will examine how prepared Wuhan is in coping with these impacts (i.e., its vulnerability). In doing this, we introduce concepts of hard and soft infrastructure to sharpen the focus on vulnerable areas.

### 4.1 Assessing the Infrastructure

In this step, we examine Wuhan City's vulnerability to the identified impacts, in terms of its water-related **hard infrastructure** and **soft infrastructure**.

The expected frequency and severity of extreme weather events (impacts) are assessed against the city's preparedness—represented by the quality and extent of existing and committed hard infrastructure and management systems (soft infrastructure). The assessment is qualitative and is based upon a comprehensive assessment—by utility operators and city planners in a series of plenary sessions—on the ability of the city's infrastructure and systems to cope with change.

The descriptions presented in this section attempt to summarize the discussions and highlight the features, which led to an agreed vulnerability ranking.

The underlying principles of the ranking system, stated in the most simplistic terms, are that:

- If the water-related infrastructure, which will be impacted by extreme events, is robust and currently operating below capacity, then vulnerability is likely to be low.
- If the water-related infrastructure, which will be impacted by extreme events, is already operating at capacity and is already showing weakness during adverse weather events, then the vulnerability is likely to be high.

# The concept of hard and soft infrastructure is introduced to facilitate further climate change analysis.

Hard infrastructure refers to technical and engineering-led improvements and includes built facilities for potable water, wastewater, and stormwater.

**Soft infrastructure** includes Wuhan's economy, environment, and government and especially relates to the city's management, control, and knowledge systems.



These determinations, like the assessment of future impacts from climate change in the previous step, were undertaken in participatory workshops with the same stakeholders. The participants, especially representatives from the Wuhan Planning Bureau and the Wuhan City Planning and Design Institute, and water and wastewater engineers from the Wuhan Municipal Design Institute, compared the data sets on historical occurrences of severe weather events and their recorded impacts (economic losses, areas affected, population affected) with the current and planned capacities and operational preparedness of water infrastructure facilities. The discussions and the conclusions reached on vulnerabilities are reported below. The level of vulnerability determined in this way is both an indication of the priority for actions in that area and a pointer to the kind of action required.

### 4.2 Hard Infrastructure Vulnerabilities

### **Potable Water**

Total reliance on surface water from two rivers, the Yangtze River and the Han River, makes the city's water supply vulnerable to changes in the flow and water quality of these rivers and to water pollution incidents. The PRC's National Assessment Report on Climate Change, 2007 already indicated decreasing trends in runoff in the last 40 years in the six main rivers, including the Yangtze River, due to climate change. The watershed of the Han River catchment has been experiencing higher frequencies of consecutive years of drought. The Han River flow is also likely to decrease due to water storage upstream for the South-to-North Water Transfer Project. This planned \$62 billion project will divert up to 45 billion m<sup>3</sup> of water/year and includes building a reservoir upstream of the Han River. Water quality in these two rivers is deteriorating due to urban developments in their catchments. Although Wuhan is famous for its many lakes, water quality has deteriorated to such an extent that lake water is no longer extracted for potable use.

The city government is planning several major water infrastructure projects to clean and beautify the waterways, including constructing wetland conservancy areas and parks. There are 2.6 million m<sup>2</sup> combined riverbank restoration program in four regions of the city—Wuchang, Hanyang, Qingshan, and Hanjiang—along the Yangtze and Han rivers. The Dadong Lake Ecological Water Network will be the largest urban water eco-network in the PRC and a core water conservation project of the Yangtze River. The network, with its wastewater treatment facilities, aims to clean up polluted lakes and connecting waterways.

While Wuhan remains a water-rich city and has adequate capacity to meet the water demand in 2020, its total reliance on two rivers makes the water supply vulnerable. There are notable projects in water conservation and riverbank restoration, but there is also growing water consumption pressures, including those from northern PRC. Climate change has already led to runoff reduction in the Yangtze River catchment. Thus, Wuhan's potable water indicator has a moderate vulnerability to cope with climate change impacts.



### Wastewater

Wuhan has made substantial improvements to its wastewater treatment program over a relatively short period. Its treatment rate is higher than the national average; and more planned and improved infrastructure address the needs of a growing population and higher treatment goals.

Wuhan has not totally separated the wastewater and stormwater flows in the city. During heavy precipitation, wastewater treatment plants (WWTPs) could be overloaded and unable to treat the influent adequately on time. As climate change would increase the frequency, intensity, and duration of precipitation, WWTPs will face increasing vulnerability until the city has installed separate stormwater and wastewater collection and conveyance systems.

Wuhan also has the environmental challenge of treating and managing 657 tons of sewage sludge generated every day by the existing WWTPs. Transporting dewatered sludge to landfill sites is the current disposal practice for sewage sludge.

SUMMARY	Wastewater Infrastructure Vulnerability
	Main impacts: Rainstorm (high severity/high frequency) and floods (high severity/low frequency)
	Vulnerability ranking: Moderate

### Stormwater

The Wuhan lake system is part of a complex water system of lakes and channels within the vast Jianghan floodplain that was originally connected to the Han and the Yangtze rivers.

Wuhan has built 46 pumping stations and floodgates to minimize flood risk. The city has replaced many of the aging and poorly maintained drainage networks and under-capacity pumping stations. The city is also planning a comprehensive urban drainage and flood control program.

However, Wuhan has yet to account for the more frequent and severe climate change impacts, especially increased precipitation, in the planning and design of its urban drainage and flood control program. Changes in precipitation patterns will affect the design values of drainage systems and pumping stations. Without this consideration, such systems are vulnerable to climate change impacts.

#### Stormwater Infrastructure

Main impacts: Rainstorm (high severity/high frequency) and floods (high severity/low frequency) Vulnerability ranking: Moderate

# 20



### 4.3 Soft Infrastructure Vulnerabilities The City Economy and its Reliance on Water

Wuhan is the commercial and financial center of central PRC. Its economy has nearly tripled since 2000, contributing to almost 35% of Hubei's total gross domestic product. The Wuhan city government has drawn up an ambitious blueprint to maintain an average 12% economic growth rate over the next 5 years, with the Wuhan Economic Rim as the focal point linking the surrounding cities.

Wuhan has taken advantage of its rich natural resources and low labor costs to become a major manufacturing center for iron, steel, and machinery. It has the PRC's first major steel complex and the fourth-largest steel producer, and one of the largest local automobile industries. Many foreign automakers have established bases there, dubbing the city as the Detroit of the PRC.

There is also an increasingly conscious diversification from heavy manufacturing to high-tech, pharmaceutical, and bioengineering industries. Greater direct foreign investment is coming from real estate and finance, and more Fortune 500 companies are establishing new facilities in the city. It plans to increase its annual service industry income level in 2008 by 60% to more than CNY80 billion by 2010.

Wuhan supports this demand from new industries for highly skilled professionals through its large education and research network, and High Tech Development Zones. There are 17 national laboratories, 19 national engineering technological research centers, 15 state-affiliated corporate research and development centers, and 55 universities and colleges—home to more than 1 million students. Wuhan University, ranked seventh nationally, alone enrolled more than 740,000 students in 2006.

In addition to expanding highways, express lines, and light and heavy rail, the city will also utilize more of its water bodies for transport. By 2025, the Port of Wuhan would be PRC's largest river port on the Yangtze River. There will also be a Wuhan Yangtze River Tunnel, the first highway tunnel under the Yangtze River approved by the PRC government.

Meanwhile, Wuhan's Tianhe Airport, already the largest in central PRC, has plans to expand into the mainland's fourth-largest aviation hub—behind Beijing, Guangzhou, and Shanghai.

Previous extreme weather events described earlier above have caused substantial economic losses to Wuhan, demonstrating that the city's economy is vulnerable to climate change impacts. For example, heavy electricity users in industry had to stop production during previous heat waves. Flooding and poor water quality also affect industrial production. Wuhan is moving toward more sustainable industries, and the city government is becoming more aware of climate change issues. Yet, there is uncertainty on how well the economy can cope with climate change impacts. Thus, the economy is moderately vulnerable to extreme weather events.

SUMMARY

#### The City Economy and Water

Main impacts: Floods (high severity/low frequency) and heat wave (high severity/high frequency) Vulnerability ranking: Moderate

### **Environmental Quality of Water Resources**

The PRC has a water quality regulation that is divided into four classes. Class I and Class II are high quality, Class III is the minimum quality for municipal water supply, and Class V is only suitable for industrial use. Of the 10 rivers and streams flowing through Wuhan, 3 achieved Class II standards and 6 achieved Class III standards in 2008. Only the Fu River quality was worse than Class V. The major pollutant was ammonium nitrogen, indicative of sewage pollution. Water quality in the Yangtze and Han rivers met the Class III level of regulation (Surface Water Environmental Quality Standards, GB3838-2002) in 2008 and was suitable for potable use after treatment.

The same cannot be said for the lakes. Of the 55 major lakes monitored in Wuhan in 2008, two-thirds showed Class V standards (the worst), and only 23% showed Class III standards or better. The lake quality shows severe environmental degradation and biodiversity risk.

Poor environmental quality can also affect economic growth as local businesses and foreign investors choose to locate elsewhere, and may affect the city's efforts to keep and attract highly skilled workers. For example, clean water is an important requirement for manufacturers of silicon photovoltaic cells. Good environmental quality can mean fewer sick days from school and work. Highly skilled workers usually place the city's environment as one of their criteria for location. Tourists may see little reason to see the scenic, historic East Lake if it is polluted. Public health is at risk with contaminated water and seafood.

The high vulnerability of Wuhan's water resources environment is due to poor lake water quality, resulting in the reliance on just two rivers to supply drinking water to the city (60% from the Yangtze River and 40% from the Han River). These water sources are vulnerable to climate change impacts, such as decreasing trend in runoff in the Yangtze River catchment. Such vulnerability would further be exacerbated by human-made impacts such as water quality deterioration due to urbanization of catchments, the South-to-North Water Transfer Scheme, and pollution incidents. Should there be a pollution incident on the Yangtze River that affects Wuhan, 60% of its urban water supply could be cut off.

SUMMARY

Environmental Quality of Water Resources

Main impacts: Floods (high severity/low frequency), heat wave (high severity/high frequency), and drought (medium severity/high frequency) Vulnerability ranking: High

### Institutional Management of Water Resources and Infrastructure

Conscious of the economic and environment impact, the city leadership has begun to prioritize water restoration and cleanup. The 11th Five-Year Plan addresses wastewater collection, treatment, and disposal. The Urban Master Plan (1996–2020) includes planning for water supply, wastewater, and stormwater drainage management. The city's goals include

• maintaining drinking water quality in both the Yangtze River and Han River;



- implementing comprehensive water quality rehabilitation and protection for East Lake, Sha Lake, South Lake, and Mousui Lake; and
- meeting Class III National Standards for the major lakes in the urban area.

A long-term pollution control program was initiated in 2006 to help 40 lakes in the central urban area recuperate within 3–5 years by controlling nearby pollution and improving wastewater treatment. Water quality has since been restored in 29 lakes, with 224 pollution sources eliminated, and more than 470,000 m<sup>3</sup> of degraded water treated daily. The remaining lakes in the program are expected to recover soon.<sup>13</sup> Meanwhile, the "Wuhan New Zone Six Lake Dynamic Water Ecosystem Plan" creates a water and greenbelt network across six urban lakes (Moshui, Nantaizi, Beitaizi, Sanjiao, Longyang, and Houguan).

There has also been national and international support for Wuhan. The Ministry of Science and Technology selected the city as a pilot area for water pollution control in 2002, providing knowledge and technology support. In 2009, the Wuhan Water Ecosystem Protection and Restoration pilot program passed acceptance by the Ministry of Water Resources of both the national and provincial government—making Wuhan the first city in the PRC to have achieved this level.

This institutional indicator is very important as it will influence the other vulnerabilities. How the government decides to prioritize the economic, environment, and water infrastructure plans, and how it prepares the city's other sectors and people are key indicators. The government has enacted many ambitious plans and policies to improve the city of Wuhan. The mayor recognizes the importance of water to the city's identity and growth plans.

On 16 December 2009, the Hubei Provincial Government issued an announcement to all levels of government departments in the province on the course of action for Hubei to combat climate change. It includes directives on climate change mitigation and adaptation. Directives on adaptation include the following: (i) strengthen agricultural infrastructure, (ii) adjust the agriculture structural and planting regime, (iii) strongly promote eco-agriculture, (iv) 'reasonably' develop and assign water resources, (v) establish scientific and technological support to combat climate change by initiating the development of innovative technologies, and (vi) establish a system to improve integrated disaster prevention and minimization. There are also directives on safeguard measures. These include strengthening leadership and institutional arrangements, increasing investments to combat climate change, and increasing the development and promotion of advanced adaptation technologies.

In response to this announcement, the Government of Wuhan City is drafting a document to describe its way forward in combating climate change. Government plans on climate change adaptation and mitigation are therefore just getting started.

SUMMARY	Institutional Management of Water Resources
	Main impacts: All potential impact areas
	Vulnerability ranking: Moderate

<sup>&</sup>lt;sup>13</sup> Lihua Zhou. 2009. Wuhan Noted for Water, Cleanup Effort. China Daily. 31 October.
## 4.4 Overall Vulnerability

24

Overall, Wuhan shows moderate vulnerability to climate change impacts with its existing hard and soft infrastructure, except for its water resources environment, which shows high vulnerability (Figure 6).



#### FIGURE 6 Wuhan's Vulnerability Rankings

Source: ADB consultant.

The vulnerabilities identified and examined above relate to Wuhan City. In other cities and municipalities, vulnerability to climate change may vary, depending on particular environmental susceptibilities and levels of adaptive preparedness. The goal for Wuhan City, as well as other cities and municipalities, is to reduce vulnerability to as much as practicable. Step 2 (Vulnerability Analysis) is, therefore, a useful and proactive step for alerting decision makers to the need for high priority responses in some areas and to seek improved climate change resilience in all areas.

## Chapter 5

## Applying the Approach Step 3: Developing Climate Resilience Strategies and Responses

## In this Chapter

In the previous steps, we have identified the risks of extreme weather events to Wuhan and ranked them in terms of their expected frequency and severity. We then examined the city's vulnerability to these impacts, focusing on water-related infrastructure. In this chapter, we will describe Step 3, where we will develop a set of municipal investments to reduce the vulnerabilities we have identified. To do this, we first need to decide on our "adaptation strategy." This will ensure that the planned investments will fit together properly and complement each other. We then describe the investments, including a schedule of actions for each investment and a relevant international example.

## 5.1 Stages of Resilience Planning

There are three phases for climate change resilience planning. First, a strategy, which aims to lower the vulnerability of infrastructure, should be developed; second, specific investments in hard and soft infrastructure need to be aligned with this strategy; and third, the results of investments need to be evaluated and vulnerabilities reassessed to ensure that investments are acting to increase climate resilience.

## Choosing an Adaptation Strategy

For Wuhan's water sector, the strategic vision for investments is provided by the concept of "Total Water Management." Total water management is important for water-related adaptation to climate change. The city's overall adaptation strategy related to urban water infrastructure needs to reduce reliance on just two water sources. One way is to explore alternative water sources or to implement water storage schemes in order to reduce reliance on just the Yangtze River and the Han River. Another way is to separate the supply of water for potable use from that for non-potable use, reducing the demand and reliance on treated water. The city's soft infrastructure of water environment has been assessed as having high vulnerability, yet solutions to reducing such vulnerability would come from hard infrastructure.

Water needs to be treated to the highest potable standards for personal consumption. But for irrigation, industrial cooling, and toilet use, non-potable water would be suitable and this could save on treatment resources. More could be done to increase the supply and use of non-potable water and minimize the resources needed to treat water to potable standards. Figure 7 shows a schematic of Wuhan's water cycle. On the left side is the current water cycle application, and on the right side, the additional possibilities and sources to supply the city's water.



#### FIGURE 7 Wuhan's Water Cycle and How It Can Be Changed to Increase Climate Resilience

Source: ADB consultant.

The general aims are to weather-proof urban water infrastructure through planning and design, to increase the sources and quantities of water, to reduce the demand for potable supply (by separating supplies for potable and non-potable uses), to reduce the urban heat island effect to cut down water and power consumption, and to alleviate flooding disruptions and damages. Adaptation of hard infrastructure to climate change, therefore, is based on the following six components:

- Planning and design
- Water capture and storage
- Water and wastewater reuse
- Stormwater management and flood control
- Urban agriculture and greening
- Buildings

Adapting soft infrastructure for water can be divided into four components:

- Risk assessment
- Institutional capacity building



- Outreach and education
- Research and technology

Institutional capacity building, as well as outreach and education, is important to preparing the city and the citizens to respond to, and recover from, climate change impacts and disasters. Research and technology are important to monitor and evaluate the city's hard and soft infrastructure performance against climate change adaptation, as well as improving risk assessment tools to achieve better understanding and prediction of climate change and related impacts.

### Looking at the Mix of Investments for Climate Resilience

Identified investments in hard infrastructure refer to technical and engineering-led improvements, while soft infrastructure investments involve more institutional, social, and behavior changes. The investments are the result of a decision-support process involving interactive workshops with stakeholders and local specialists. The workshops were held to come up with recommendations on hard and soft infrastructure to improve climate resilience of Wuhan's urban water infrastructure. These are also expressed in a matrix showing implementation TIME versus COST based on workshop discussions (Figure 8).



#### FIGURE 8 Implementation of Hard and Soft Infrastructure Investments

Source: ADB consultant.

How this process aligns with commonly and internationally used decision support planning methods (DPSM) is briefly discussed in Appendix 2.

One of the main findings of a 2010 World Bank report is that adaptation to climate change should start with the adoption of measures that tackle the weather risks that countries already face, e.g., more investment in water storage in drought-prone basins or protection against storms and flooding in coastal zones and/or urban areas.<sup>14</sup> The same report also indicated the difficulties in putting a price tag on adaptation because of the so many uncertainties involved, such as climate outcomes, future rates of population and economic growth, energy availability and prices, and technological advances.

The hard infrastructure investments, which Wuhan would need to commit to in order to significantly raise its resilience to climate change, fall into two categories: (i) infrastructure related to water capture, storage, and reuse, and effluent reuse; and (ii) stormwater and flood management.

For water capture, storage and reuse, the investment sequence would be in the following order:

- (i) rainwater collection and reuse from large existing buildings;
- (ii) rainwater collection, storage, and reuse in planned communities; and
- (iii) effluent reuse from existing or planned WWTP for (a) river water replenishment, and (b) landscape irrigation.

For stormwater and flood management, the investment sequence would be in the following order:

- (i) identification of appropriate stormwater storage facilities,
- (ii) civil works to develop the storages, and
- (iii) drainage systems to collect and conduct stormwater to storage.

These investments will need to be supported by a design and planning effort, which will be a major shortto medium-term investment in itself. The design and planning of built infrastructure will be included in the following section on recommendations for Hard Infrastructure as they are an integral part of the suite of civil works that they support. Investment in design and planning will also spill over into the category of Soft Infrastructure (recommendations for which are also discussed here) since the research and development of technical skills, which comprises Soft Infrastructure, is needed for the design and planning to be successful.

## 5.2 Investments in Hard Infrastructure

For each of the six Hard Infrastructure components, the **Target Outcome** is first stated. This is the outcome (or outcomes) that would result from the diligent and adequately resourced implementation of the recommendations. To further clarify the process of implementation, the recommendations are followed by a flow diagram, which sets out the *sequence* of investments required, covering both civil works and design and/or planning. Rough time scales and indicative levels of resource investment are also proposed.

<sup>&</sup>lt;sup>14</sup> The World Bank Group. 2010. The Economics of Adaptation to Climate Change, A Synthesis Report, Final Consultation Draft.



## Planning and Design

The planning and design of urban water infrastructure for the future is the first important step in incorporating climate change resilience. Such consideration should be based on the best available information on climate change at the time, and reviewed at regular intervals when updated climate change information becomes available. It involves integrating climate change into the city's master plan, regeneration plans, or 5-year plans in the PRC's case. Planners, urban designers, transport planners, and other designers should be fluent about climate change and work together to incorporate total risk management principles into the city.

#### Target Outcome

Integrated City of Wuhan Water Master Plan documents which, like national policies, provide direction for both short- and long-term approaches and targets for planning and designing for climate change.

#### **Recommended Investments**

- (i) Consider climate change impacts on design codes,<sup>15</sup> for example:
  - Adaptation of water pipes, pumps, and chemical dosing equipment to extended periods of low temperatures;
  - Enhancing the ability of water tanks and building roofs to withstand the loading of snow deposits during extreme snowstorm events; and
  - Adaptation of the site levels and discharge and/or effluent systems of water treatment plants, wastewater treatment plants, and pumping stations to provide freeboard above flood levels.
- (ii) Review and strengthen the design values of water treatment plants, wastewater treatment plants, and floodwater discharge systems (because of changes in temperature and precipitation intensities).
- (iii) Conduct hydraulics assessment of influent and effluent of water treatment plants, wastewater treatment plants, and pumping stations (because of changes in the water levels of water bodies).

#### Example

#### Rotterdam

Rotterdam's location on the North Sea delta of the Rhine and Meuse rivers makes it highly vulnerable to the effects of climate change. The city has developed a Rotterdam Climate Proof Plan as climate adaptation strategy for water, and has incorporated this into its city development plans. The city has produced technical and planning reports on flood models, landslides, and levees. It developed new strategies in water storage, and enacted more green roofs and water plazas to combat heat stress. Rotterdam's example shows how innovative design and careful and coordinated forward planning can adapt and enhance the city's water infrastructure to climate change.

(iv) Research the impact on water sources from a climate change perspective (the purpose is to first protect the Yangtze River and Han River water sources and, secondly, to develop other water sources to reduce reliance on the Yangtze and Han rivers).

<sup>&</sup>lt;sup>15</sup> In most cases, design codes specify minimum standards. Implementing design features above or better than minimum standards to increase robustness of design would not violate codes. In time, codes could be revised.

- (V) Promote dual water supply in new urban development districts (separate the supply of potable and non-potable water, thereby reducing the pressure on potable water demand and also reducing the discharge of treated effluent externally).
- (vi) Develop a stormwater drainage master plan, with special reference to high-intensity rainfall events and flooding and emphasizing the principle of maximizing open space in developments to provide urban infiltration capacity for stormwater.

#### Sequence of Investments





Source: ADB consultant.

## Water Capture and Storage

Water capture and storage diversifies a city's water source, and increases the application of non-potable water. Potable water is reserved for drinking and bathing, but non-potable water collected from rainwater could be used for washing, irrigation, and toilet flushing. Dividing potable and non-potable water means that energy and costs could be reduced in water treatment, without jeopardizing water quality or public health. Water captured and stored could help delay or alleviate localized flooding. Storage structure can range from large scale, such as underground tunnels or reservoirs, to small storage tanks in homes.

Water capture and storage could be formalized in the planning and design process described earlier so that there is long-term planning on the selection, design, and management of these ponds and lakes. Wuhan already has demonstration projects at selected schools to collect and store rainwater underground for irrigating landscape. Such scheme could be expanded to include buildings with large roof areas, such as covered stadiums, and convention and exhibition centers.

#### Target Outcome

## Large and diversified water storage in Wuhan City, which integrates with the city's built forms and functions.

#### **Recommended Investments**

- Reduce the loss of water resources, carry out the collection of statistics on water leakage in the urban water supply system and rehabilitation or replacement of aged water pipes
- Carry out rainwater collection, storage, and reuse at existing large buildings (for example, covered sports stadium, and convention and exhibition centers, etc.)
- (iii) Require rainwater collection, storage, and reuse in the planning and design of large buildings
- (iv) Require planned development districts to collect, store, and reuse rainwater in planned, new district development projects.

### EXAMPLE

#### Tokyo

The Tokyo Waterworks Bureau has enacted a series of initiatives to protect the city's water against climate change, including river conservation, super levees, and flood hazard mapping. Although densely populated, Tokyo has innovative solutions to divert floods and store water. Diversion channels were built utilizing the space beneath roads along rivers, while tennis courts and other large, open facilities are constructed with the potential to double as water storage. Reservoirs were built under high-rise housing, and in tunnels under roads. A 12.5-meter inner diameter tunnel was constructed beneath a main highway to take in floodwater from Kanda, Zenpukuji, and Myoshoji rivers. The tunnel stores about 540,000 cubic meters of water. 31

Sequence of Investments



#### FIGURE 10 Sequence of Investments for Water Capture and Storage

Source: ADB consultant.

## Water and Wastewater Reuse

Effluent reuse, or the reuse of treated wastewater, diversifies the water sources and allows the reservation of potable water only for drinking. Effluent reuse should be integrated with water capture and storage strategies. Separating water quality between potable and non-potable standards can determine the level of treatment and associated energy usage and financial costs. Effluent reuse is becoming common in the PRC, that includes Wuhan. The majority of treated industrial wastewater in Wuhan is already being reused.

### Example

#### Singapore

Singapore has pioneered NEWater, using micro-filtration and ultra-filtration and reverse osmosis to treat used water to potable standards. NEWater met 30% of Singapore's water needs by the end of 2011. The city also has advanced desalinization plants, and deep tunnel sewerage systems for intercepting wastewater flows from existing sewerage network to centralized water reclamation plants in the eastern and western parts of Singapore.

Target Outcome

Sixty percent or more of treated effluent reused in the city area.

#### Recommended Investments

- (i) Implement effluent reuse and dual water supply in drought-prone areas.
- (ii) Research the application of alternative toilet systems and technologies.

#### Sequence of Investments

#### FIGURE 11 Sequence of Investments for Water and Wastewater Reuse



WWTPs = wastewater treatment plants.

## Stormwater Management and Flood Control

Since the level of Wuhan is lower than the water level in the Yangtze River, stormwater needs to be pumped out of the city area. The severity of flooding is, therefore, dependent on the pumping capacity relative to precipitation intensity and duration. With urbanization, more land areas would be paved for real estate development, increasing the amount of overland runoff. Climate change impacts will exacerbate the already flood-prone areas. There is a need for planning and design strategies to decrease new developments in flood-risk areas, or require better stormwater management or flood control measures in existing areas.

#### Target Outcome

Effective city flood control through integrated stormwater management and storage.

#### **Recommended Investments**

- (i) From a climate change perspective, research the linking up of urban lakes and ponds to form a water system network for stormwater management, and the development of buffer zones such as wetlands around lakes and rivers to increase overall retention capacity.
- Research the construction of underground water storage reservoir and/or tank for the temporary storage of stormwater.
- (iii) Require all urban development projects to conduct drainage impact assessment that follows the principles of the stormwater master plan.

#### EXAMPLE

#### London

London has enacted a series of initiatives to increase its resilience against floods. The City of London Corporation has also identified 'hot spots' vulnerable to flooding, where it plans to install new sustainable drainage system and invest in maintenance to accommodate the expected rise in the volume of precipitation. Finally, the Thames Estuary 2100 (TE2100) Plan was enacted. It serves as a long-term flood risk management plan for London and the Thames estuary. The plan describes the actions that are needed in the short (2010–2035), medium (2035–2070), and long (2070–2100) term to manage flood risk, and who will undertake them.



#### Sequence of Investments

#### FIGURE 12 Sequence of Investments for Stormwater Management and Flood Control

Source: ADB consultant.

## Urban Agriculture and Greening

34

Hard urban surfaces prevent the absorption of rainfall, create storm runoff that pollutes the lakes and rivers, and overwhelms the stormwater system—leading to sewer backups and flooding during heavy rains. While Wuhan's economic development is important, it should not aim to be another concrete city. Increasing urban greening and agriculture is a cost-effective way to help with its water management and combat climate change impacts. It can also mitigate some of the city's carbon dioxide emissions.

In addition to water management, urban agriculture and greening can reduce the heat island effect in an urban metropolis, improve food security, enhance biodiversity, and improve the quality of life and health for its residents. Heat island effects exacerbate increasing temperature impacts in urban areas. Studies have found that residential areas with access to parks or green space have increased

#### EXAMPLE

#### Los Angeles

Million Trees LA, an extensive urban greening program, is expected to help conserve water supply and improve quality, and bring other benefits, such as improved health, better air quality, and community engagement. Los Angeles' climate change action plan includes a goal to reduce per capita water consumption by 20%. Some of the wastewater is already used to support agriculture. A total of 927,425 liters of wet biosolids are fully recycled and used as fertilizers and soil amendments for agricultural and landscape applications.

property value and amenity. Residential health can improve with increased opportunities for exercise and community engagement. Pedestrian and bike paths can form green corridors around the city, easing travel pressures and fossil fuel consumption.

The World Health Organization recommends at least 8 square meters/capita of green space for urban areas. Wuhan has a greenbelt coverage of 37.4% in built urban areas and six wetland reserves with a total area of 3,370 km<sup>2</sup>. Implementation of urban agriculture and greening would further reduce the rate of temperature increase due to urban heat island effect.

#### **Target Outcome**

Reversal or lowering of Wuhan City's urban heat island effect.

#### **Recommended Investments**

- (i) Research on remote sensing, ground monitoring, and impact assessment of urban heat island effect.
- (ii) Develop research on Wuhan City's urban agriculture.
- (iii) Greening of public buildings, rooftops, and walls.



#### Sequence of Investments





Source: ADB consultant.

## Buildings

To achieve the established target that energy consumption in new buildings should be 65% less than that in existing buildings, the Ministry of Housing and Urban-Rural Development of the PRC has established an energy consumption standard for the construction sector. Buildings and their water infrastructure can also be adapted to climate change impacts, and there needs to be corresponding studies and policies to support such adaptations. Green building standards and design, such as building facade and microclimate strategies, will be critical. Previous recommendations, such as water capture and storage, or wastewater treatment and reuse, are applicable at the building level. Buildings can have green external and internal walls, and rooftop gardens, which provide cooling and help combat urban heat island effect. Green buildings can conserve potable water, with rainwater capture and gray water reuse in bathrooms.

#### EXAMPLE

#### Melbourne

The Parliament of the Australian State of Victoria approved a legislation dealing with the problem of existing run-down and energy-inefficient buildings. The Melbourne City Council—with state government backing—is offering \$2 billion worth of "green loans" to owners wanting to "retrofit" their old buildings in environmentally sound ways. Backed by the Council, property owners will be able to borrow funds from the banks to make old buildings more environmentally friendly and energy efficient. The City of Melbourne will get the money back through the rates it charges the building's owner—but only once the benefits of the energy-saving initiatives start to take effect.

As Wuhan continues to grow, new and retrofitted buildings should aim to have strong water management and climate performance. They should be adapted to withstand more severe and frequent climate change impacts.

#### Target Outcome

Residential communities with efficient and effective urban water management and savings.

#### Recommended Investments

- (i) To reduce water loss, each small district and/or community carries out water loss monitoring of the water supply system and rehabilitation or replacement of aged water pipes within the community.
- (ii) Prepare guidelines on protecting exposed water pipes and water tanks against low temperature.
- (iii) Incorporate water-saving measures and schemes in building design, for example:
  - suitable water-saving technologies for buildings,
  - smart water metering and self-diagnosing pressure pumps,
  - maintenance requirements, and
  - water-saving standards and implementation for commercial premises, public and community facilities, and households.

#### Sequence of Investments





Source: ADB consultant.

36



## 5.3 Investments in Soft Infrastructure

## Risk Assessment

There is an old saying that "we cannot manage what we don't know." To manage the risk of climate change impacts on urban water infrastructure, we must first understand what risks the urban water infrastructure faces.

It is essential that Wuhan has tools to predict climate change trends and impacts and also tools to assess risks. It also needs an updated inventory of its urban water infrastructure assets, in terms of their distribution and value.

#### **Recommended Investments**

- (i) Formulate a high-level risk assessment protocol for climate change impacts to water supply and drainage abilities, which includes the following activities:
  - Inventory the distribution of water supply and drainage facilities and assets and their conditions.
  - List climate change variables.
  - Develop climate change exposure and infrastructure sensitivity matrix for risk identification.
  - Determine risk rating based on consequence and likelihood.
  - Prioritize high and extreme risks.
  - Compare risk ratings of different assets.
  - Develop a decision tree for climate changeinduced emergencies to focus decisions and resources at the appropriate priority areas.

### EXAMPLE

#### New York City

With over 8.3 million inhabitants, New York City is the largest city in the United States. The NYC Department of Environmental Protection Climate Change Program is designed for decision makers to have better tools when dealing with climate change impacts, adaptation, review, and monitoring. The Climate Change Task Force was created to facilitate strategic planning, taking into account climate change impacts on New York City's water infrastructure. The Task Force was also mandated to coordinate scientific research across the research community and experts. It aims to improve its regional climate modeling, thereby reducing uncertainties in climate projections and improving infrastructure and investment planning.

- Map the locations of assets at risk using a geographic information system (GIS) spatial analysis.
- Develop time-bound GIS modeling to track and predict changes in water resources affecting the Yangtze and Han river valleys and Wuhan City.
- (ii) Research and develop climate change predictive tools for Wuhan City and undertake the following:
  - Continue research into and application of Coupled Model Intercomparison Project Phase 3 modeling for climate change prediction at the provincial level.
  - Conduct research toward enhancement of current climate change modeling for application at the city level.

- Review other climate change predictive models currently used in the country (for example, FGOALS, BCC\_CGCM, ECHAM5, HadCM3m, NCARCCSM3) and ensure continuing improvement of technical skills.
- Research and develop linkage models for connecting climate change modeling results to mapping tools and GIS modeling.
- Determine hardware (e.g., computing power) and software (e.g., GIS interface) needs for the predictive tools.
- Determine data needs for the predictive tools in terms of data types, data collection locations, and data collection frequencies (this feeds into the process of monitoring and evaluation).
- Establish data sharing agreements among agencies.

## Institutional Capacity Building

The most important aspect of policy mechanisms is establishing a strong institutional framework to carry out, enforce, monitor, and adjust the plans. Institutional capacity needs to be competent, strong, and able to withstand typical local governmental changes. Policy making is an iterative process and is driven by the institutions and the

personalities within those institutions. Local officials need to be trained to implement and enforce the policies. They then can be monitored and, to facilitate delivery of the intended goals, adjusted to new times and conditions. Clear roles and responsibilities need to be established for individuals, departments, and agencies to work together. There could be a framework with key performance indicators or targets to help monitor accountability and progress. Communication should occur not only between government officials, but also with other key stakeholders in the city, such as businesses, industry, and research institutes.

#### **Recommended Investments**

- Provide training to climate change management and implementation departments through recruitment and international cooperation that build and maintain capabilities on
  - climate change adaptation knowledge,
  - climate change mitigation knowledge,
  - climate change risk assessment,
  - preparation of plans on emergency response to extreme weather events,
  - drainage impact assessment,

#### EXAMPLE

#### Toronto

Toronto was one of the first Canadian cities to adopt a citywide climate change adaptation strategy. Like Wuhan, Toronto will face increasing rainfall, flooding, and snowstorms, much of it due to the Great Lakes effect nearby. Local capacity is built around this critical area. The city dedicated one staff member from the environment office full time to climate change adaptation. Staff from five divisions were also informally assigned to work on adaptation in an interdivisional working group. It further established a cross-divisional adaptation steering group with representatives from 15 city divisions and other local stakeholders to share climate change information and discuss strategy.

Under this structure, Toronto Water, in particular, has taken the lead in flood risk analysis and water efficiency. It has collaborated with the Toronto and Region Conservation Authority to improve stormwater infrastructure.



- water-saving technologies,
- monitoring and evaluation of climate change impacts, and
- total water asset management.
- (ii) Conduct research on policies that would ensure funding sources for the climate change management and implementation departments.

## **Outreach and Education**

A large gap exists between climate science and policy makers' understanding and utilization of that research in decision making and planning. An even wider gap exists in the public's understanding of what climate science means for their city and how they can properly prepare and respond to its impacts. There are many types of information—from disaster relief used during an emergency to adaptation strategies or water efficiency product labeling during preventative periods.

The Wuhan government could target different groups in the city with appropriate information. Local government officials need to be trained to understand and enforce water-related laws, shopkeepers need to know how flood and flood risk can affect their business, property management companies should learn how to maintain the green roofs or water metering in their buildings, and residents should actively conserve water and purchase water-efficient appliances. Schools naturally have an active role to play in education. Media is another outlet for wider public outreach.

#### **Recommended Investments**

- i) Establish a media program to include
  - websites,
  - posters,
  - television and radio,
  - newspapers,
  - publicity paintings and photos, and
  - exhibition boards.
- Start an outreach and educational program for students.
- (iii) Publish knowledge products on climate change and water conservation for distribution to citizens and owners and operators of residential, commercial, and industrial premises.

### EXAMPLE

#### Australia

The Water Efficiency Labelling and Standards (WELS) Act started in 2005. Manufacturers and importers are given advice on improving water efficiency on their products and training in proper testing and documentation. Architects and engineers are trained in proper design and application; retailers and wholesalers are taught how to sell their products; while plumbers and builders are educated on proper installation, repair, and maintenance. But most importantly, consumers are provided information to help with their purchasing decisions, including estimated savings costs.

## Research and Technology

Innovation and research are critical as Wuhan moves from a manufacturing center to a high-tech industrial base. Likewise, for climate change adaptation and water, research and technology are important aspects in building the city's resilience. Continuing research and development can advance knowledge and innovative work to combat climate change. The city can have more accurate climate change models and predict extreme weather events to prioritize its resource allocation, mobilize its citizens, and advance better policy responses. It can also develop better water infrastructure technologies to conserve, treat, and store water—at less financial cost and time. Closely aligning the research and technology development with Wuhan needs can fast track demonstration testing and wider market use and practice.

Research and technology are among the best ways to collaborate with different stakeholders in Wuhan. Private businesses can help support the research and provide advice on practicality and economic viability. Citizens can get involved with demonstration testing and usage, and communication outreach. Undergoing the process of research and development helps instill a sense of responsibility and engagement among the other city stakeholders for wider cooperation in combating climate change impacts and increasing water resilience. Cooperation can also be done with other cities in the PRC or international cities and foreign research institutions, businesses, and academia.

#### **Recommended Investments**

- (i) Formulate and implement a Monitoring and Evaluation Program to measure increases in resilience as hard and soft infrastructure investments are implemented.
- (ii) Conduct research on methodologies to downscale regional climate change models.
- (iii) Conduct research on enhancing climate change predictive tool for the city area.
- (iv) Conduct research on which water-efficient technologies (including hardware and software) and building designs are practicable for Wuhan.
- (v) Implement research and development programs in the development of climate change predictive tools to support Risk Assessment responses (see p. 37). Research and development should cover the areas of
  - (a) research on regional climate change and water resources predictive model, based on microclimate forecasts on water accumulation in Wuhan City's urban area (location, depth, and area);

#### EXAMPLE

#### Ottawa

Ottawa's smart water metering installation plan is a good example of research and technology being applied to policy and the marketplace. Water use declined by 6.5% last year. The city plans to connect 190,000 smart water meters in homes and businesses to the internet by 2012 to give the city real-time, accurate water information. Consumers, in turn, will pay a more accurate amount for their usage. The new meters will help the city determine which neighborhoods are using the most, allowing for better city planning in the future.

- (b) development of a GIS-based information management system for
  - climate and/or weather data management;
  - mapping, updating, and spatial analysis of locations of infrastructure assets at risk; and
  - mapping, updating, and spatial analysis of drought and flood-prone areas for planning, as well as for emergency response purposes.

# Chapter

## **Measuring Success**

## In this Chapter

In this chapter, we will look at a monitoring and feedback loop where the outcome of the investments made by a city or municipality is evaluated and vulnerabilities reassessed—to see if climate change resilience has been increased.

## 6.1 Monitoring and Evaluation

Adaptation is an iterative process, not an end state. It requires a degree of flexibility with updated information, new technology, and changing circumstances. The ongoing adjustments are based around the guiding principles of reducing the risks of climate change, making the water infrastructure resilient, and elevating the preparedness and knowledge of all the city's stakeholders. A continuous system of feedback and review binds the stakeholders to the success. It also builds local independent capacity for critical and innovative thinking.

The core exercise in evaluation is the reassessment of vulnerability. The measure of initial baseline vulnerability in this approach is a qualitative assessment based on the expected severity and frequency of future impacts and the preparedness of the city's hard and soft infrastructure.

## 6.2 Reassessing Vulnerability

The baseline vulnerability assessment assigned scores of "High," "Moderate," and "Low" vulnerability to the range of hard and soft infrastructure. Reassessment of vulnerability following the implementation of the identified investments and actions will move these scores progressively toward "Low" vulnerabilities. This will not be possible in all cases and, for major areas of hard infrastructure, progress will be gradual and incremental. The process is illustrated in Figure 15. The new vulnerability scores following reassessment will be the baseline for the next assessment.

As the building of city resilience gathers pace, the coarse classification of "High," "Moderate," and "Low" can be refined to provide more specificity and, as a consequence, better comparisons of before and after. Examples of this are provided in Part II of this guide, where specific investment opportunities in Wuhan are discussed. In each case, the implementation of these opportunities can result in quantifiable outcomes.



### FIGURE 15 Reassessment of Vulnerability Process

Source: ADB consultant.

## 6.3 Looking Ahead

Wuhan's water resilience strategy is a long-term investment in knowledge, people, and water infrastructure. The city can serve as a model of water and climate change resilience for other cities in the PRC.

Its scope can also be widened in the future to apply the city climate resilience methodology in other cities in the PRC for refinement and comparison. While this guide has focused on water infrastructure, the methodology is applicable to other sectors or to integrated and cross-sector infrastructure in Wuhan and other cities in the PRC.

## Part II

Short-Term Infrastructure Investment Opportunities

## Chapter 7

## Initial Infrastructure Investments

## In this Chapter

This chapter looks at the current and planned water infrastructure projects in Wuhan and identifies those which (i) reduce the vulnerabilities, and (ii) fit within the "adaptation strategy." By focusing on real projects, which are already in the pipeline, we are identifying entry points into the process of increasing the city's climate change resilience.

## 7.1 Current and Pipeline Projects

These projects embody, in varying degrees, all the investment categories in both hard and soft infrastructure (discussed in Chapter 5 of this guide).

## Promotion of Dual Water Supply in New Developments

The Hanyang Huangjinkou Wastewater Treatment Plant is under construction with a near-term treatment capacity of 15,000 m<sup>3</sup>/day. The treated effluent would meet Class 1A discharge standard and is proposed to be discharged into a nearby culvert. The culvert drains into a tributary of the Han River, which eventually flows into the Han River.

The Wuchang Baoxie Wastewater Treatment Plant is undergoing preliminary design with a near-term treatment capacity of 70,000 m<sup>3</sup>/day. The mid-term treatment capacity would be 140,000 m<sup>3</sup>/day, and the long-term treatment capacity would reach 220,000 m<sup>3</sup>/day. The treated effluent would meet Class 1A discharge standard. To protect the water quality of nearby water bodies, the treated effluent will be discharged, through a 33-km pipeline, into the Yangtze River.

It is suggested that a dual water supply in the above two districts be promoted, to use the treated effluent as non-potable water for industries in the district that do not require high-grade industrial water, for irrigation of landscape, and for street cleaning. This would reduce the demand on the potable water supply, reduce the quantity of treated effluent discharged into the Yangtze and Han rivers, and save substantial energy consumption at the same time. Implementing the following areas of investments: Hard Infrastructure — Planning and design (p. 29)

44

## 45

## Rainwater Collection, Storage, and Reuse at Existing Large Buildings

The Wuhan International Exhibition Center is located in the Sixin District. The project covers 6,339 mu ( $423 m^2$ ) of land, with a total ground floor area of  $457,000 m^2$ . The center covers an area of  $83,400 m^2$ . It provides facilities for international conferences, some with views of the Yangtze River, and a  $6,000 m^2$  banquet room, providing a necessary high-end public and commercial activity center for a core city in central PRC such as Wuhan.

One component of the project is the 319,000 m<sup>2</sup> Ocean Park, which is the first "water theme park" in central PRC, for experiencing a totally indoor and temperature-controlled sea view amusement park. It combines tourism, leisure, indoor sport, vacation, and shopping multifunctions in one place.

It is suggested that rainwater collection, storage, and reuse be incorporated into the Wuhan International Exhibition Center project.

## Implementing the following areas of investments:

Hard Infrastructure – Planning and design (p. 29); Water capture and storage (p. 30); Water and wastewater reuse (p. 32); Stormwater management and flood control (p. 33)

## Collection, Storage, and Reuse of Rainwater in New Development Projects

To effectively collect and use rainwater for waterscape and landscape irrigation within newly developed residential districts in Wuhan's Wangjiadun Commercial District and Houhu area, such as Baibuting Shibo Yuan and Tongan Jiayuan, incorporate rainwater storage and reuse of rainwater as part of design and construction. Implementing the following areas of investments:

Hard Infrastructure – Planning and design (p. 29); Water capture and storage (p. 30); Water and wastewater reuse (p. 32)

## Implementation of Effluent Reuse and Dual Water Supply

There is an opportunity for increased reuse of the treated effluent from the ADB-funded Sanjintan Wastewater Treatment Plant. This plant has a treatment capacity of 300,000 m<sup>3</sup>/day, treated to Category 1A discharge standard. A large volume of treated effluent is discharged directly into the Fu River with no reuse.

As replenishment water. Due to the lack of replenishing water sources nearby, the treated effluent from the Sanjintan wastewater treatment plant (WWTP) will be used as replenishing water, converting the Hankou Huangxiaoming River drainage and/or culvert ditch as an ecological corridor.

For irrigation, cleaning, and replenishment of scenic water bodies. Wuhan's Houhu area has been set for highend residential districts with a few communities already developed. At present, the largest scale of sports land use in Wuhan, the Wuhan Tazihu Sports Center, is also located in the Houhu area. The treated effluent from the Sanjintan WWTP could be used for cleaning the stadiums and streets, irrigating the sports fields and landscape, and replenishing the scenic water bodies.

Implementing the following areas of investments: Hard Infrastructure—Planning and design (p. 29); Water and wastewater reuse (p. 32)

## Drainage Impact Assessment for Urban Development Projects

The planning and construction of the Huashan Eco New Town. This new town consists of port and industrial park developments. A 10-km<sup>2</sup> port district has been planned along 8 km of waterfront around Yituo Beihu and Baixushan. A 27-km<sup>2</sup> industrial park will be built at Yituo Port near the waterfront and port facilities to accommodate industries in materials processing, manufacturing, and modern logistics. The development of the Huashan Eco New Town would have relatively large drainage impacts to the area at present.

This investment opportunity would conduct a drainage impact assessment for the development of Huashan Eco New Town and provide suitable solutions so that drainage in the vicinity would not be adversely affected.

## Research on Urban Heat Island Effect

Wuhan's newspaper, *Chutian Metropolitan Daily*, reported on 10 March 2010 that the city had planned the greening of 78 rooftops, 14 bridge surfaces and bridge piers, as well as 2–3 greening pilots on street facing walls within the inner ring road.

Building on this, an investment opportunity could involve the installation of calibration points for remote sensing at various greening locations described above, for establishing monitoring and assessment points on urban heat island effect.

### Greening of Public Buildings, Rooftops, and Walls

There is an opportunity to conduct research on the feasibility and methods for adopting green roofs and green facades at the Wuhan Wangjiadun commercial district development, which is entering its detailed design phase.

### Establishment of a Climate Change Office

The Hubei provincial government issued in December 2009 an announcement to all levels of government departments in the province on the courses of action for Hubei to combat climate change. This included directives

on climate change mitigation and adaptation. In response, Wuhan has proposed creating its own local Office of Climate Change Management (OCCM), to better plan and respond to climate change. OCCM will be accountable to the city leadership, with strong resource and political support. It should establish the roles Implementing the following areas of investments: Hard Infrastructure—Planning and design (p. 29); Stormwater management and flood control (p. 33)

Implementing the following areas of investments: Hard Infrastructure—Planning and design (p. 29) Soft Infrastructure—Risk assessment (p. 37); Research and technology (p. 40)

Implementing the following areas of investments: Hard Infrastructure—Urban agriculture (p. 34); Buildings (p. 35)

Implementing the following areas of investments: Soft Infrastructure – Institutional capacity building (p. 38)





and responsibilities of the people and departments involved. There should be firm lines of communication within the city, and to the public. OCCM should have the following responsibilities:

- Climate change policy formulation and implementation;
- Training and capacity building, including OCCM itself, other government departments and officials, and stakeholders;
- Research and technology;
- Climate change disaster preparedness and response plans;
- Climate change risk assessment; and
- Outreach and education.

While Wuhan's OCCM aims to be the first and best stop for climate change information and strategy, how it handles the strategy is up for discussion. As in most government agencies, OCCM will need to develop its own level of independence and level of influence and control—whether it will take on just a coordinator role and let other departments take on most of the work, or whether it will build up its own resources and capacities to take on most of the work. The office could use the following matrix (Figure 16) to scale these two factors for its different roles and responsibilities as outlined in this guide.



#### FIGURE 16 Matrix for Positioning Wuhan's Office of Climate Change Management

Source: ADB consultant.

Guidebook: Increasing Climate Change Resilience of Urban Water Infrastructure

## 7.2 Evaluation after Implementation

48

The hard and soft infrastructure investment recommendations can be initially implemented by building on a number of existing or planned city projects. The outcomes of the projects can be evaluated, in many cases quantitatively, and the city's vulnerability reassessed as a result.

The initial investment opportunities outlined earlier can also be evaluated quantitatively. In this way, an index of improvements in resilience per unit of investment can be developed and investments in different areas of hard and soft infrastructure can be compared.

## Appendix

## Common Methodological Approaches

## A1.1 International Methods

Many different methodologies are used for decision making for the adaptation of human-made and natural systems to reduce their vulnerability to climate change. Three methods that typify the main approaches are briefly described in this Appendix. These are the Potsdam Institute/Allen Group approach, the Drivers: Pressure: State: Impact: Response (DPSIR) approach, and Arup's City Climate Resilience (CCR) approach.

## Potsdam Institute/Allen Group Approach

This method provides a basic framework for initially assessing the vulnerability of a region or sector to climate change.<sup>16</sup> Vulnerability is a product of the potential impact of climate change and the capacity to adapt to that change.





Source: ADB consultant.

<sup>&</sup>lt;sup>16</sup> Potsdam Institute for Climate Impact Research. 2004. Global Change Vulnerability—Assessing the European Human–Environment System.



Appendix 1

The **Potsdam Institute/Allen Group** approach has a process for defining impacts. Impact risks are a function of exposure and sensitivity. Exposure relates to the influences or stimuli that act on a human–environment system. Exposure, therefore, encompasses the critical weather events and patterns that affect the system. Sensitivity is an indication of the responsiveness of a system to climatic influences and the degree to which changes in climate might alter its present condition or function. Sensitive systems are responsive to small changes.

## The Drivers: Pressure: State: Impact: Response Approach

The core of this approach is the *Pressure: State: Response* method widely used in the natural resources management, but strengthened and extended to show how drivers affect things and bring about impacts. The DPSIR model<sup>17</sup> was developed by the European Environment Agency to work through a framework for linking climate change signals (the pressures or threats, e.g., change in rainfall, increased temperature), with consequential changes in resource condition (or state) and the impacts of those changes.



FIGURE A1.2 Conceptual Process of the Drivers: Pressure: State: Impact: Response Approach

Source: Allen Consulting Group. 2005.

<sup>&</sup>lt;sup>17</sup> Allen Consulting Group. 2005. *Climate Change Risk and Vulnerability*. Report to the Australian Greenhouse Office, Department of the Environment and Heritage.



## City Climate Resilience Approach

The CCR approach is a three-step methodology developed by Arup and refined by the team for the Wuhan case study, in close collaboration with technical staff from government agencies and utilities. It aims to establish a high-level and rapid assessment of the city as a starting point, comprehensible to a range of stakeholders, and robust and practical enough to withstand ongoing evaluation and refinement. With graphic illustrations, it showcases the integrated issues the city faces and leads to decision making.



FIGURE A1.3 Conceptual Process of the City Climate Resilience Approach

Source: ADB consultant.

## A1.2 Methods Applied to the Analysis of Wuhan's Impact Risks Potsdam Institute/Allen Group Approach Impact Risks

Applied to the Wuhan region and water supply, an analysis of exposure and sensitivity would canvass the following issues:

Exposure	Overall decreased precipitation and increasing temperatures are likely to markedly affect water resources in terms of quantity and quality. Increasing incidence of floods and droughts will also impact on sustainability of the water supply.
Sensitivity	Sensitivity is low for water availability, moderate for changes in flow regimes, and high for extreme weather. Large water resources are available to Wuhan (4.046 billion m <sup>3</sup> , including 3.689 billion m <sup>3</sup> of surface water and 1.043 billion m <sup>3</sup> of groundwater). Water consumption now and projected to 2020 has a substantial surplus. However, total water supply is from the Yangtze River and Han River, and any change in either of these water bodies, which have sources far from Wuhan, would have a significant effect. Water covers 25% of the total city area (160 lakes, 272 reservoirs, and 165 rivers or streams) so effects of flooding and other weather events are magnified.

52

The availability of appropriate data will vary from sector to sector. In data-poor situations, it is possible to use, at least initially, proxy indicators that focus thinking on the sort of information that is relevant to the identification of impacts. Proxy indicators proposed in a modification of the Potsdam Approach by the Allen Group for Australian conditions<sup>18</sup> include

- sensitivity to low-range climate change and/or extreme events,
- known climate-related thresholds reached,
- systems operating at known climatic limits, and
- systems subject to multiple stresses.

Similar proxies could be applied to the Hubei/Wuhan region.

## Impact Risks of the Drivers: Pressure: State: Impact: Response Approach

The DPSIR approach derives impact via a drill-down process through "drivers," "pressures," and "state" to identify impacts. Applied to the Wuhan environment, this would identify the range of potential impacts (Figure A1.4).





Source: ADB consultant.

<sup>&</sup>lt;sup>18</sup> Allen Consulting Group. 2005. *Climate Change Risk and Vulnerability*. Report to the Australian Greenhouse Office, Department of the Environment and Heritage.



The strength of this approach is that it clearly indicates the progenitors of the impacts and allows decision makers to see the full range of potential problems and where they come from. The weakness is that this approach does not differentiate between impacts in terms of frequency or severity.

## City Climate Resilience Approach Impact Risks

The CCR approach identifies climate change impact risks for the city by

- identifying historical weather events that have caused impacts to the city based on literature review, interviews, and stakeholder consultation; and
- prioritizing these events based on history and future projections and scale on a matrix-ranking the severity and frequency of their impacts through workshop participation of local specialists on weather predictions, urban water infrastructure, and flood control, as well as data from relevant government departments.

This provides a good baseline of the city for its current and predicted climate impacts. This type of high-level and rapid analysis helps in the planning and securing of enough and appropriate resources for coordinated action and strategy. The ranking of specific climate impact risks would vary from city to city, and could also change with time and circumstances.



Source: ADB consultant.

FIGURE A1.5

54

## A1.3 Methods Applied to Wuhan's Vulnerability Analysis

The DPSIR approach does not identify vulnerabilities. Rather, it proceeds from identification of impacts to responses. The lack of an analysis of vulnerabilities (and thereby the lack of relative priorities) reduces its ready application by city decision makers.

The Potsdam Institute/Allen Group approach and the CCR approach are similar in this step. They both look at the adaptive capacity, which the responsible agencies can bring to bear on the different impact areas and thereby derive measures or indicators of the degree of vulnerability. This is a very important step because it is most helpful to decision makers who must decide upon the allocation of limited resources.

The Potsdam Institute/Allen Group approach can also use proxy indicators for analyzing adaptive capacity. These can be divided into negative and positive indicators.<sup>19</sup> Proxies of negative indicators include

- reliance on biological systems,
- reliance on long-lived core assets,
- constraints imposed by current development patterns, and
- low system flexibility to change.

Proxies of positive indicators include

- ability to cope with current climate variability,
- established mechanisms for generating and applying new knowledge, and
- resource mobility.

The Potsdam Institute/Allen Group approach can also bring into consideration the additional criteria of *Adverse Implications* and *Potential to Benefit.*<sup>20</sup> These elements can sharpen the analysis of vulnerability but require a level of input data on the economic sensitivity of a diverse range of sectors and sectoral forward planning, which may not be readily available in some jurisdictions.

The CCR approach, which has been applied in Wuhan, has made this adjustment by dividing the vulnerability ranking equally between **hard** and **soft infrastructure**. Every successful city is strongly supported by a mix of hard and soft infrastructure. Tasks include the following:

- Choosing a good mix of both hard and soft infrastructure indicators through literature review and stakeholder workshops based on the particular criteria or city issues. As this guide is water sector-based, hard infrastructure indicators were chosen to include **potable water**, **stormwater**, and **wastewater**; and soft infrastructure indicators to include **economy**, **environment**, and **government**.
- Evaluating each indicator based on the city's existing conditions and future plans through workshop discussions.

<sup>&</sup>lt;sup>19</sup> Allen Consulting Group. 2005. *op. cit.* 



#### FIGURE A1.6 The City Climate Resilience Approach Vulnerability Analysis of Wuhan's Water Sector

	Hard Infrastructure			Soft Infrastructure		
Vulnerability Rank	Potable Water	Wastewater	Stormwater	Institutions	Environment	Economic
Low						
Moderate						
High						

Source: ADB consultant.

• Graphically illustrating the level of vulnerability of each indicator and its corresponding color: high (gray), moderate (blue), and low (black). Each indicator supports an overall vulnerability ranking for the city, showcasing the interlinkages. However, splitting them into six parts also helps target the city recommendations in the most critical areas.

## A1.4 Developing Resilience

The development of recommended actions to reduce vulnerability (increase resilience) is the goal of all the approaches examined—although the Potsdam Institute/Allen Group approach, aimed primarily at identifying vulnerabilities, requires an additional analysis to achieve this goal. There is a wide range of responses to the threat of climate change, which have been summarized by the United Nations Environment Programme.<sup>21</sup> These cover the complete range available to decision makers, and may be summarized as

- bear the loss;
- share the loss;

<sup>&</sup>lt;sup>21</sup> Feenstra J. F., I. Burton, J. B. Smith, and R. S. J. Tol. 2003. *Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies*. Amsterdam: Institute for Environmental Studies.



- modify the threat;
- prevent effects;
- change use;
- change location;
- research; and
- educate, inform, and encourage behavior change.

The CCR approach has combined the city's climate impact risk and vulnerability assessment to identify and select hard and soft infrastructure strategies and actions. Further analyses on the infrastructure strategies and actions may be required before implementation, but this rapid assessment provides a first look at the possibilities for action on resilience. Tasks include

- developing hard and soft infrastructure investment solutions through stakeholder workshops based on results of the impact identification and assessment of vulnerabilities, examples of best practices in other cities, and local conditions; and
- prioritizing hard and soft infrastructure recommendations on a matrix of **time** and resources or **costs** required for implementation.

## FIGURE A1.7 The City Climate Resilience Approach Applied to Developing Resilience of Wuhan's Water Sector





## 57

## A1.5 Strengths and Weaknesses

What do Wuhan and other city and/or municipality managers need from a methodology for reducing vulnerability and/or increasing resilience? The main needs for responsible decision making in this context are

- the establishment of priorities (for resource allocation),
- the development of specific and implementable resilience recommendations, and
- a feedback and improvement loop for sustainability of the adaptive effort.

A comparison of the three approaches against these needs reveals the following attributes:

Method	Help for Decision Making
Method 1: Potsdam Institute/Allen Group Approach	<ul> <li>Derives vulnerabilities based on exposure and sensitivities and therefore provides a good indication of priorities.</li> <li>Does not develop specific and implementable resilience recommendations (although an additional analysis of the cost and/or benefit of adaptive responses would provide this).</li> <li>Would need to be supported by the preparation of a suitable feedback and improvement loop for sustainability of effort.</li> </ul>
Method 2: Drivers: Pressure: State: Impact: Response (DPSIR) Approach	<ul> <li>Method does not derive vulnerabilities and therefore does not provide an indication of priorities for responses.</li> <li>Can develop specific and implementable resilience recommendations.</li> <li>Provides a feedback and improvement loop for sustainability of effort.</li> </ul>
Method 3: City Climate Resilience (CCR) Approach	<ul> <li>Provides vulnerabilities derived from impacts (based on frequency and severity) and it therefore provides a good indication of priorities.</li> <li>Develops specific and implementable resilience recommendations.</li> <li>Provides a feedback and improvement loop for sustainability of effort.</li> </ul>

Source: ADB consultant.

The CCR approach satisfies all three decision-making criteria, and has been fully applied to the case of the Wuhan's water sector.

## Appendix

## Decision Support Planning Methods

A white paper by the Water Utility Climate Alliance (USA)<sup>22</sup> has sought to evaluate new planning techniques, called decision support planning methods (DSPMs), which can be used by utility managers in their climate adaptation efforts. DSPMs assist utility planners and managers in making and executing defensible water resources decisions while minimizing the threats associated with these decisions, and can be divided into five broad categories:

- Classic decision analysis
- Traditional scenario planning
- Robust decision making
- Real options
- Portfolio planning

The main objective of *traditional scenario planning* is to develop a plan that best prepares the water utility for a plausible range of uncertain circumstances. Scenarios are developed through the identification of critical uncertainties and driving forces. *Robust decision making* provides a systematic way of developing a water management strategy to best adapt to a wide range of plausible future conditions. Robust decision making uses existing or modified water management models to evaluate candidate strategies against scenarios that reflect future uncertainty.

The planning processes and investments described in this guide for the city of Wuhan are a combination of *traditional scenario planning* and *robust decision making*, although without the quantitative exactitude of scenarios usually associated with the process of *robust decision making*. Instead, analysts, stakeholders, and decision makers have studied the vulnerabilities to develop alternative strategies. The refinement and quantification of future scenarios will be achieved through the research and planning components of the soft Infrastructure investment recommendations of this guide.

<sup>&</sup>lt;sup>22</sup> Water Utility Climate Alliance. 2010. Decision Support Planning Methods: Incorporating Climate Change Uncertainties into Water Planning. United States.

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# Guidebook: Increasing Climate Change Resilience of Urban Water Infrastructure

Based on a Case Study from Wuhan City, People's Republic of China

This publication bridges the gap between the theoretical analyses of climate change impact on the urban water sector and the planning decisions that municipal authorities and utility managers need to make to increase the sector's climate change resilience. It answers questions that city planners and managers globally currently ask regarding the effects of climate change, particularly on services and utilities, and what we can do to prepare for these.

This guide presents steps to determine both Wuhan's vulnerability to the impact of climate change and the opportunities to improve its resilience. The methodology used combines known approaches and were worked out in consultation with Wuhan authorities. The solutions are presented in an easy-to-follow program of investment decisions, developed through a "bottom-up" approach involving Wuhan stakeholders.

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