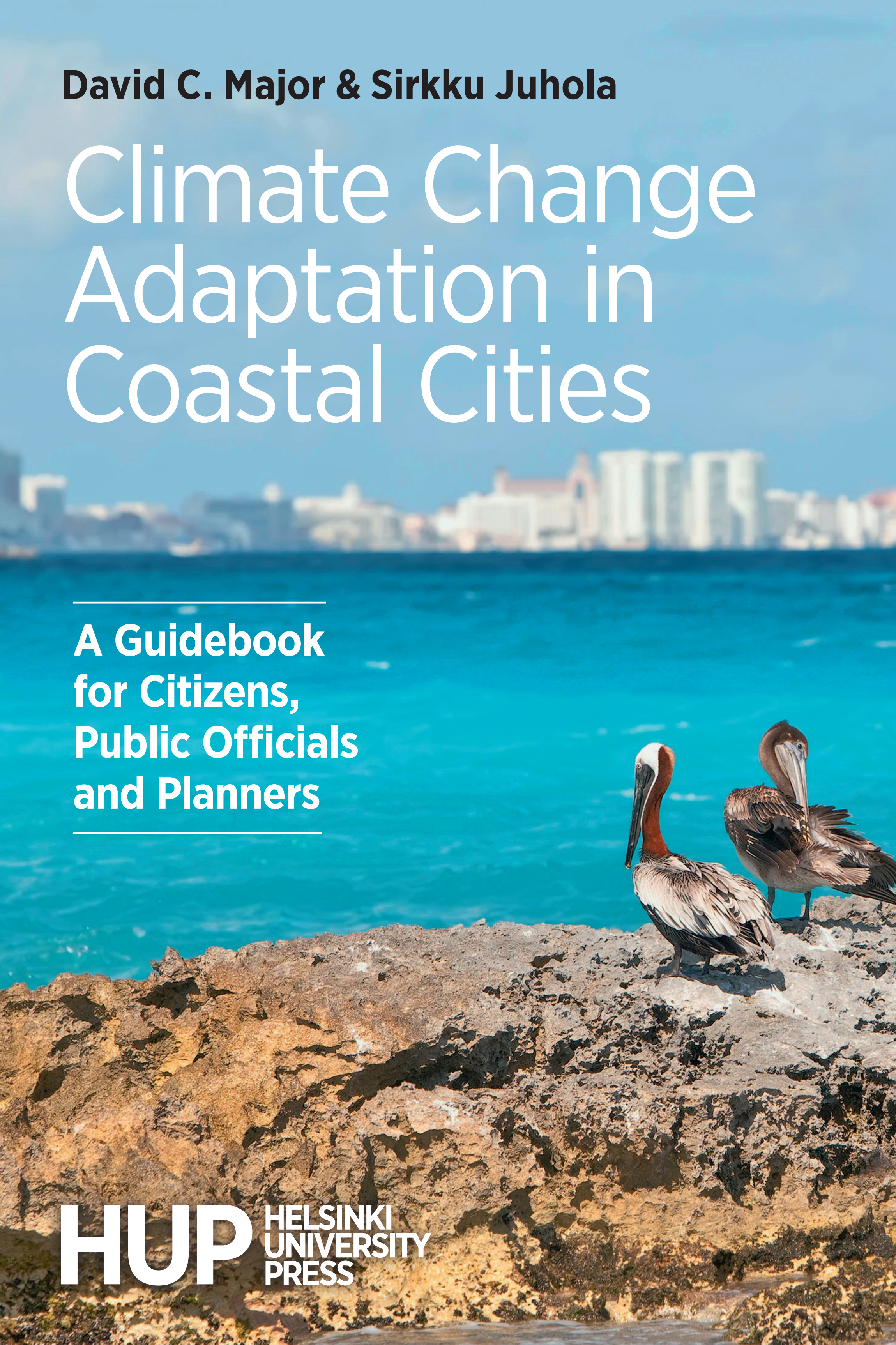

David C. Major & Sirkku Juhola

# Climate Change Adaptation in Coastal Cities

## A Guidebook for Citizens, Public Officials and Planners

HUP HELSINKI UNIVERSITY PRESS

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# Contents

# Foreword

Tarja Halonen

On behalf of the University of Helsinki, we are delighted and thankful to have a practical guide such as this book to help manage adaptation to climate change. We hope that this guidebook will further encourage multi-sectoral networking around these topics.

As background, the United Nations Sustainable Development Goals (SDGs) are a framework to guide societies toward sustainable transformations. The goals cover the world's most pressing issues, from ending poverty and hunger to conserving biodiversity. I was personally involved in developing the SDGs as co-chair of the UN Millennium Summit, and later as the co-chair of the High-level Panel on Global Sustainability.

Our generation is the first one to completely understand the magnitude of climate change, and the last one that can change the current direction. Indeed, the year 2015 was a turning point for both sustainable development and climate change with the adoption of two major agreements: the 2030 Agenda for Sustainable Development with its 17 goals and the Paris Agreement on Climate Change. These two agreements have both synergies and trade-offs that are crucial to take into consideration.

While it is important to set the goals, it is also wise to prepare ourselves for challenges along the way. Climate change is one of the most daunting threats today and combined with the current global megatrend of urbanization, it can cause problems, especially in the most densely populated cities that are located in coastal areas. I am honored to be one of the UN Global Champions for Disaster Risk Reduction (the Sendai Framework) and am delighted that this book helps to execute that Framework. We need to understand these disaster risks and strengthen risk-related governance. In addition, we need public and private investments in disaster risk reduction and preparedness for response.

Extreme weather conditions are already a reality today and are predicted to increase. We need to be able to minimize their harmful effects and take preventative actions. It is also important to adapt to changing climate conditions. The carbon dioxide level is now the highest that it has been in three million years, and climate change's contribution to global sea level rise is already observable. Even if we are able to cut down greenhouse gas emissions now, sea level will continue to rise for centuries due to feedback loops. Although we must to respond to climate change, it needs to be done in a sustainable way, and this book has examples of how to do that.

As Chair of the Board of the University of Helsinki, I find it very important to have practical and science-based knowledge easily available for everyone. Our university's new cross-faculty research unit in sustainability science, the Helsinki Institute of Sustainability Science, HELSUS, is currently strengthening efforts to address and provide solutions for the most pressing global challenges, including the ones in this book.

*Tarja Halonen was the 11th President of the Republic of Finland, 2000–2012, and Finland's first female head of state. She was inaugurated to her first term on March 1, 2000, and was re-elected in 2006 for a second six-year term. Halonen is Chair of the Board of the University of Helsinki for 2018–2021.*

# Preface

It is now widely acknowledged that even if humanity is successful in curbing climate change, adaptation will be an essential component of public policy for many decades to come. Such adaptation will be an important component of sustainability. This book is designed to help coastal cities, large and small, to understand and develop effective adaptation measures in a sustainable way. Much will be written on this topic in the decades to come; our hope is that our guidebook will be a worthy initial contribution. We intend the work to be broadly valuable, setting out general principles and methods of adaptation to climate change for coastal communities. We also hope that it will help smaller coastal cities and towns to deal with climate change as well as more advantaged, large, wealthy cities do.

This volume had its genesis during the tenure of a Fulbright Scholar grant by one of us (David C. Major) to the University of Helsinki, with the other author (Sirkku Juhola) the host academic. It is an example of the importance of international professional cooperation that we hope will continue to increase in the world as we are faced with the enormous challenge of climate change.

As with all writing on climate change, this volume owes much to the essential work of the Intergovernmental Panel on Climate Change, to which both of the authors have contributed. The volumes of the IPCC's Sixth Assessment Report are scheduled to appear beginning in 2021.

David C. Major wishes to acknowledge his debt to fellow members of the Climate Impacts Group of the Center for Climate Systems Research at Columbia University, especially the Impacts group leader, Cynthia Rosenzweig, and many individual members, including Daniel Bader, Vivien Gornitz, Radley Horton and Somayya Ali Ibrahim, as well as colleagues in the Urban Climate Change Research Network (UCCRN).

Sirkku Juhola wishes to acknowledge the members of the Urban Environmental Policy Research Group at the University of Helsinki, who have contributed to a stimulating and enjoyable work environment.

The authors thank the US and Finland Fulbright Programs and the Universities of Helsinki and Aalto, Finland, and Columbia University for support during the preparation of this book, and the following for helpful reviews of all or parts of the manuscript: Daniel Bader, Viliina Evokari, James Fitton, Radley Horton, Johannes Klein, Martin Lehmann, John S. Major, Sean O'Donaghue and anonymous reviewers for the Helsinki University Press. The authors also express their gratitude to President Halonen for kindly supplying the Foreword to the volume.

David C. Major and Sirkku Juhola<br>New York<br>Helsinki<br>January 2021

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CHAPTER 1

# Introduction and Overview

Global sea levels are projected to rise by as much as one meter and perhaps significantly more by the end of the 21st century.[1] Temperatures will rise, precipitation patterns will change, and there is the probability of more intense storms. All of these changes present coastal cities and towns with enormous challenges. In coastal cities, sea level rise, more extensive flooding from storm surge, erosion, salt water intrusion and other impacts of climate change are now affecting populations, assets, and ecosystems. Climate change has already caused significant impacts on natural and human systems,[2] and these impacts are expected to increase given trends in demographics, urbanization, economic development, and land use, especially in developing countries.[3]

It is widely recognized that even with successful mitigation efforts adaptation will be necessary,[4] and adaptation needs are expected to increase over time.[5] Thus, there is a need for adaptation guidance for coastal cities and towns, including small and medium-sized ones, now and for many years to come. Beginning to meet this need in the context of sustainability is the purpose of this guidebook.[6]

The guidebook presents a framework for adaptation planning, focusing on the important roles of citizens, public officials, and planners in a series of key adaptation planning steps that can be undertaken. Within this framework, points of guidance for these stakeholders are provided throughout the volume. The introductory material in this chapter includes: information on using the guidebook; climate change; mitigation and adaptation; sustainability; adaptation, equity, and resources; and the chapters of the book. The adaptation framework and the roles of stakeholders are presented in Chapter 2; the details of adaptation challenges and methods are presented in Chapters 3–9.

## Using the Guidebook

Coastal cities and towns, large and small, have a wide variety of physical, economic, demographic, environmental, social, cultural and historical characteristics. There is a large number of such settlements in the world—many thousands, including cities, towns, and informal and non-incorporated settlements—which together contain a significant proportion of coastal populations.[7] In recent years, well-managed, wealthy coastal cities with large engineering and scientific establishments have led the way in urban adaptation to climate change.[8] By contrast, most small coastal towns and cities, in both developed and developing countries, do not have the advantages of the wealthy coastal cities that have taken the lead in adaptation planning. This guidebook is therefore designed to be used in different ways under differing circumstances. In that regard, it is helpful to consider four groups of coastal cities and towns.

- For the large, wealthy coastal cities that have taken the lead in adaptation, the guidebook will better enable citizens and public officials to participate in a fully informed way in the ongoing work of a city's planners, engineers, and scientists.
- For wealthier small cities and towns in developed countries, the guidebook can be used both for planning and as a convenient checklist to aid in choosing and overseeing engineering and other firms that will be employed to supplement local capabilities.
- For cities and towns with some but limited adaptive capacity, the volume is designed to bolster such capacity by providing an

overall framework and an orderly guide to help citizens, public officials, and planners to explore and make adaptation decisions, including implementation and monitoring.

- For very poor cities and towns with potentially serious issues of adaptive capacity and few resources, it can be used as a guide for regional, national, and international bodies, including non-governmental organizations (NGOs), to help citizens, local public officials and planners arrive at more effective decisions on adapting to climate change in challenging circumstances.

The guidebook is intended for coastal towns and cities in all four categories, but at some points throughout the text there is particular emphasis on guidelines for those in the last two groups, which constitute the vast majority of the world's coastal towns and cities and which have the greatest needs for assistance and the greatest issues of capacity. Fortunately, in some instances, approaches to adaptation in more advantaged cities can be studied and borrowed. And for all coastal towns and cities, the guidebook will be a resource that will help stakeholders to keep the needs and opportunities for climate change adaptation to the fore to help assure the timely and appropriate allocation of scarce resources to adaptation.

Throughout the text, tables are used to provide guidelines for planning. To provide a convenient reference for these planning tables, they are listed in Appendix A. To encourage their use (and adaptation or adjustment as needed) in actual planning, especially for readers using the print version of this volume, the tables are available for digital download on the following website: https://www.helsinki.fi/en/researchgroups/urban-environmental-policy.

Further, because adaptation to climate change in coastal cities and towns is a developing field, the volume points the way toward additional work to aid both researchers and practitioners. While the guidebook is not intended as a complete engineering/planning text, references are made to more extensive sources where appropriate. Some of these sources, noted throughout the volume, provide regularly updated information on climate change and adaptation.

## Climate Change

There has been some skepticism in the past about climate change and whether it was caused by human activities, but the science is now clear and unequivocal. As the Intergovernmental Panel on Climate Change (IPPC) notes:

> Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen. Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history.[9]

The main drivers of human-caused global warming are the heat-trapping greenhouse gases (GHGs): the principal GHGs are carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxides ($NO_x$), and certain fluorinated gases used as refrigerants and for other purposes.[10] The best record of carbon dioxide, the most important GHG in the atmosphere, is provided by readings from Mauna Loa in Hawaii (see Figure 1.1). This graph is perhaps the best-known figure in climate science.

The effects of GHGs, together with those of other anthropogenic drivers, such as land-use changes, 'have been detected throughout the climate system and are *extremely likely* to have been the dominant cause of the observed warming since the mid-20th century.'[11] (The italicized words are a likelihood term used by the IPCC, in this case meaning a 95% to 100% probability; the definitions of all of the IPCC likelihood terms are given in Appendix B.)

These effects are represented in global temperature records: 'Overall, the global annual temperature has increased at an average rate of 0.07°C (0.13°F) per decade since 1880 and at an average rate of 0.17°C (0.31°F) per decade since 1970.'[12] In addition, according to the IPCC's Fifth Assessment Report: 'Each of the last three decades has been successively warmer at the Earth's

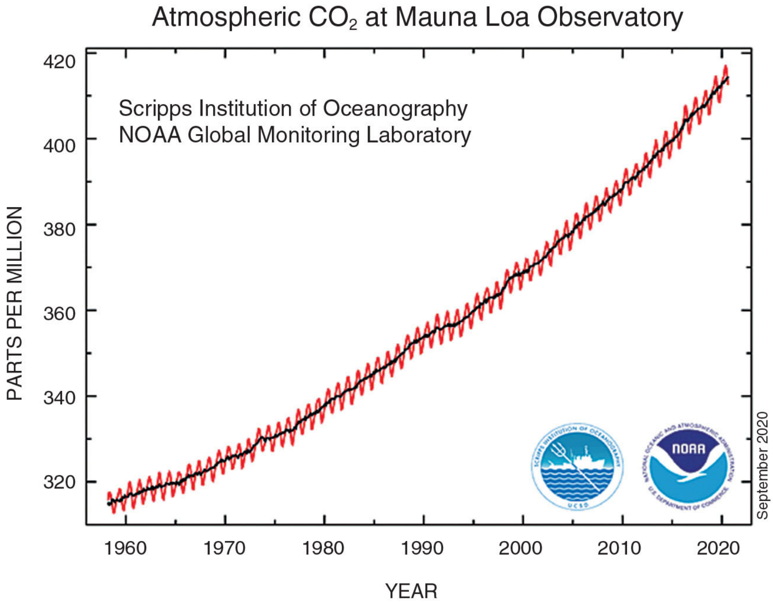



**Figure 1.1:** Atmospheric $CO_2$ concentrations.
Source: NOAA n.d.b.

surface than any preceding decade since 1850.'[13] Moreover, the IPCC's modeling projections for the end of the 21st century show the possibility, depending on the success of mitigation efforts, of significantly higher temperatures than today.[14]

International efforts to agree on the control of anthropogenic emissions of GHGs have been long-standing, primarily through the United Nations Framework Convention on Climate Change (UNFCCC),[15] but until recently have been relatively ineffective, although some nations have moved aggressively into renewable energy sources. International agreements and commitments, such as the landmark Paris Agreement of December 2015, provide a more forceful framework for both emissions control and adaptation.[16] In 2018, the Paris Agreement was operationalized, setting the guidelines for implementation in the Katowice Climate Package.[17] These efforts, which it must be hoped will be effective at local and regional levels, if not always at national levels, will reduce but not eliminate the need for adaptation.

## Mitigation and Adaptation

There are two principal elements of climate change policy: mitigation, the reduction of GHG emissions to the atmosphere (or the enhancement of 'sinks,' such as reforestation), and adaptation, policies to confront climate change impacts. The reduction of emissions ('mitigation') has generally been the focus of international discussions and agreements, but the landmark Paris agreement of 2015 commits the nations of the world to work on both mitigation and adaptation.

There are clear definitions of both mitigation and adaptation in the reports of the IPCC: 'Mitigation is a human intervention to reduce the sources or enhance the sinks of greenhouse gases,' and adaptation is the 'process of adjustment to actual or expected climate and its effects.'[18]

Mitigation is perhaps more readily understood by citizens and political leaders; emission reductions impact each person's daily life, and involve such policies as more energy-efficient vehicles, better-designed buildings that use less energy for heating and cooling, and renewable energy sources (see Figure 1.2). Mitigation

**Figure 1.2:** Middelgrunden Offshore Wind Park, Denmark.
Source: Wikimedia Commons n.d.

is often controlled 'top-down' with regulations and legislation, including taxes and subsidies.

By contrast, adaptations are more complex in terms of local decision-making, and that is a fundamental reason for this guidebook. The benefits and costs of adaptations are 'internalized', that is, those who bear the cost reap the benefits (e.g. coastal defenses in a city). The decision-making, by contrast to emissions control, can primarily be done locally. It is in many respects more complex than that for emissions because each adaptation decision is a risk management problem that involves the integration of science, engineering, risk, cost, and social and environmental impact. Adaptations can range widely from traditional engineering works, such as the sea wall shown in Figure 1.3, to green shore protection measures, such as artificial wetlands and reefs[19] (a salt-water marsh restoration project is shown in Figure 1.4), and measures for managed retreat.

Some policy measures impact both mitigation and adaptation. One example is green roofs, which insulate buildings and thus

**Figure 1.3:** Island Bay sea wall, Wellington, New Zealand. The sea wall was repaired and upgraded in 2015–2016.

Source: Wellington City Council.

**Figure 1.4:** Restored salt marshes in the Salmon River Estuary, Coastal Oregon State, USA.

Source: US Forest Service n.d.

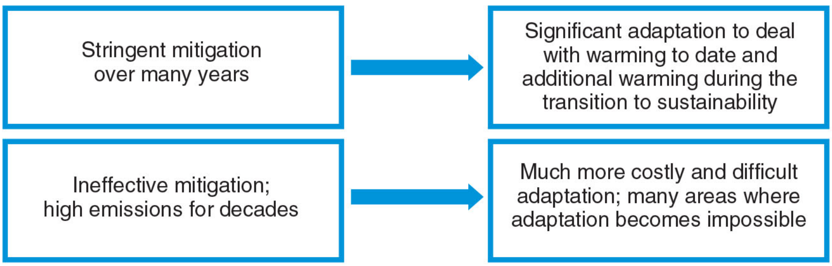



**Figure 1.5:** Mitigation and Adaptation. A wide range of emissions scenarios is possible for the decades to come. The scenarios used for IPCC modeling reports are in IPCC 2014c: 57, and are discussed in Chapter 4.

Source: David C. Major and Sirkku Juhola.

reduce emissions (mitigation),[20] and attenuate rainfall run-off (adaptation).[21] There is an important linkage between mitigation and adaptation, although they are frequently considered independently in policy-making. The greater the extent of mitigation, the less need there will be for adaptation (Figure 1.5), although to be sure significant efforts at adaptation will be required even if the world is able to successfully implement stringent mitigation policies. The need for more and sooner adaptation is suggested by a UN Emissions gap report: 'There is no sign of GHG emissions peaking in the next few years; every year of postponed peaking means that deeper and faster cuts will be required.'[22] And, if they are not made, the need for adaptation will grow all the more.

## Sustainability and the Sustainable Development Goals

The concept of sustainability in the modern world represents not a condition of stasis, but rather a continuous goal that can guide effective decision-making within a constantly altering context, including human-caused climate change. In the words of the World Commission on Environment and Development: 'Humanity has the ability to make development sustainable—to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs.'[23]

In September 2015, world leaders adopted the declaration 'Transforming our world: the 2030 agenda for sustainable development.'[24] This declaration sets out 17 Sustainable Development Goals (SDGs) that capture the range of elements in sustainability. Each of the goals has a series of targets, with one or more indicators that serve to show how well a target has been met.[25] The many interacting elements of sustainability are set out in 'Transforming our world' (para. 9).

The topic on which this guidebook is focused is just a part of sustainability, albeit a significant part for coastal cities, as can be seen from reviewing the SDGs (Figure 1.6). Adaptation to climate change in coastal communities is related to substantially all of the SDGs, including most particularly SDG 11, 'Make cities and human settlements inclusive, safe, resilient and sustainable,' and SDG 13, 'Take urgent action to combat climate change and its impacts' (the titles of the SDGs are abbreviated in the figure). Climate change adaptation is both a part of sustainability and also contributes to it; when done effectively, it enables societies to better achieve the many other elements of sustainability.[26] (For a complete description of SDG 13, see Appendix C.)


**Figure 1.6:** Sustainable Development Goals.

Source: United Nations, 2020. (The content of this publication has not been approved by the United Nations and does not reflect the views of the United Nations or its officials or Member States).[27]

**Figure 1.7:** Image of Earth. This image shows the extent of coastal land from the Horn of Africa through East Asia.

Source: NASA.gov n.d.

The Earth from space image in Figure 1.7 suggests both the larger idea of sustainability for the whole Earth and the need for coastal adaption. It is the whole Earth that must be made sustainable on a continuous basis; the need for the coastal adaptation to protect against the impacts of climate change, which is the subject of this volume, is well illustrated by the extensive coastlines shown in the figure.

## Adaptation, Equity, and Resources

Adaptation, using the methods in these guidelines and others, will broadly take place within: (1) an evolving institutional framework, for at least some years spearheaded by the implementation of the United Nations' SDGs discussed above; (2) an increasing call for equity; and (3) the search for and development of adequate resources. The extent and speed of required adaptations will depend on the global management of emissions, land use, and other factors, but the total amount of adaptation required will be large and the costs will be very substantial. This section treats briefly equity, resources, and additional information on the application of planning methods.

Equity. In 2015, 10% of the world's population lived on less than US$1.90 a day, for a total of 736 million people.[28] However, these extreme poor are only part of the challenge of equity. There are many other poor people living in informal settlements in areas of megacities in the Global South, and in a large but unknown number of poorer, smaller coastal settlements throughout the world. In terms of climate change adaptation in coastal areas, '[p]eople on extremely low incomes often live along coasts and riversides that are prone to flooding, and in other exposed areas,'[29] that is, equity is a significant issue in coastal cities and towns.

The case for emphasizing equity can be presented as follows: 'Adaptation must meet the needs of the poorest directly, putting them at the centre of decision-making with funding. The case for equitable adaptation is clear: it is a moral duty, and it improves economic productivity, social cohesion, health and peace.'[30] One significant element of the moral issue is that many poor communities have contributed little to emissions and global warming, but bear the greatest burdens from it. But equity is not just a moral issue; improved equity also has multidimensional economic, social, and well-being gains.

In sum, in the UN's foundation document of the SDGs, it is said that: 'We recognize that eradicating poverty in all its forms and dimensions, including extreme poverty, is the greatest global challenge and an indispensable requirement for sustainable development.'[31] Well-planned adaptation can make significant contributions to increased equity.

*Global costs of adaptation*. The economics of adaptation are highly uncertain: estimates of the global costs of adaptation vary widely, based on a variety of methods.[32] Global adaptation costs will depend on the global management of emissions, land use, and other factors, all of which have a wide range, but orders of magnitude are helpful in framing the issue. A UN Environment Programme (UNEP) global estimate of the costs of adaptation reports a range of US$70 billion to US$100 billion per year globally by 2050 for developing countries. The findings of that review suggest that these values are likely to be a significant underestimate, particularly in the years 2030 and beyond.[33] These estimates do not include expenditures by wealthy developed cities and towns, which presumably can self-finance in many cases.

On a continental scale, taking the example of Africa, adaptation costs estimates for Africa as a whole vary between US$35 billion and US$70 billion annually by the 2040s for the low and high emission scenarios.[34] 'Our estimates demonstrate that in a 2°C temperature increase scenario, meeting adaptation costs in Africa by the 2020s will require a steep increase in annual funding for adaptation in Africa from 2011 levels onwards by about 10–20% annually,'[35] a significant funding gap. A large funding gap is expected worldwide: 'there is likely to be a major adaptation funding gap after 2020 unless scaled-up, new and additional finance becomes available,'[36] a very significant challenge. This indicates the substantial room for reducing adaptation costs and the funding gap if strong mitigation actions are implemented globally. In terms of coastal adaptation, it is expected that most adaptation costs in Africa can be attributed to sea level rise in 2050 and 2100,[37] suggesting the importance of coastal adaptation.

*Adaptation methods, equity, and resources*. The information on equity and resources above indicates the wide range of uncertainty within which climate adaptation methods must be applied to coastal cities and towns. The methods described in this guidebook are designed to produce better social and equity outcomes by: (1) bringing in more stakeholders in both wealthy and poor settlements; and (2) providing more efficient adaptation planning through the implementation of better planning methods, such as improved scheduling and flexible pathways. These methods will help to improve the outcomes both of equity in adaptation and the extent of resources needed for adaptation.

The methods in this guidebook will fit more easily into the adaptation capacity of wealthy communities than in poorer settlements, but better outcomes are possible in many circumstances. To take just the economic dimension, given the enormous costs of adaptation, if better methods can reduce costs by just a few percent, that is a large amount of funding that can be available for other purposes. And, as better methods are implemented in more communities, there will be more examples from which to borrow, and more learned about costs and equity. There are thus good possibilities of forward movement on coastal adaptation. These issues are explored further in later sections of the book.

## Overview of Chapters

The material in the chapters that follow is designed to be clear and accessible, with the aim of providing a full and effective framework for citizens, public officials, planners, and other stakeholders in making complex decisions on adaptation to climate change. The chapters are organized so as to guide the reader through the adaptation planning process: preparing, implementing, and monitoring climate change adaptations. Each chapter has a concluding section on 'What to Know and Do' about the topics treated in the chapter.

Chapter 2, 'Adaptation Assessment Steps and the Roles of Citizens, Public Officials, and Planners,' presents adaptation steps and discusses the role of citizens, public officials, and planners in each step of the climate adaptation process. This focus distinguishes the guidebook from many other reports and publications. The roles of these stakeholders are then elaborated at suitable points in other chapters.

Chapter 3, 'Impacts and Vulnerabilities of Climate Change on Coastal Cities,' describes the range of impacts and vulnerabilities of climate change for which adaptations must be developed. These include: sea level rise (and the consequent loss of land through permanent flooding; intrusion of salt water into aquifers; and destruction of infrastructure, communities, and ecosystems); storm surge (higher and more frequent flooding); greater rainfall intensity and inland flooding; higher temperatures; droughts; heat waves; and other impacts. These sections are followed by sections on the characterization of impacts, and sources of data on impacts and vulnerabilities.

Chapter 4, 'Using Climate Information: Global Climate Models and Climate Scenarios,' describes Global Climate Models (GCMs) and how they work; how regional climate scenarios (sea level rise, temperature, precipitation, and others) are developed; and, in the section on 'What to Know and Do,' how to access and keep up with the scientific basis of adaptation planning.

Chapter 5, 'Coastal Cities and Towns: Characteristics and Challenges,' deals with the important elements of coastal cities and towns that are essential to the development of good adaptation plans. These include: a brief overview of coastal cities and towns worldwide; physical, economic, and demographic characteristics; environmental, social, cultural, and historical characteristics; governance; adaptive capacity; barriers to implementation; and environmental justice.

Chapter 6, 'The Range of Adaptations to Climate Change,' provides information on the available adaptations to climate change, describing the types of adaptations: system management (such as pre-flood preparation, evacuation); infrastructure (e.g. flood walls); and policy (regional cooperation, retreat). Examples of adaptations for the short, medium and long terms are given. Several example adaptation pathways for coastal towns and cities are described, and an assessment of what citizens, public officials, and planners should know and do about engineering, planning, and design of adaptations is provided.

Chapter 7, 'Evaluation of Projects and Programs,' describes evaluation challenges and opportunities in adaptation planning. These include: methods of economic, financial, environmental, and social evaluation of adaptations; scheduling adaptations over time; finance, cost constraints, and planning time lags; adaptation checklists; and examples of adaptation costs. Guidance is provided on what to know and do about each of these elements of adaptation planning.

Chapter 8, 'Getting It Done: Working Together to Develop and Finance Adaptations', includes: discussions of plan formulation; questions all stakeholders should ask throughout the planning process; working with all those who will be involved in adaptation planning in some degree, including stakeholders from neighboring cities, towns, and counties, climate science centers, state and national governments, businesses and NGOs; monitoring and assessment of adaptation; and what to know and do about these topics.

Chapter 9, 'Future Prospects,' discusses the wide range of potential futures of climate and the Earth that might occur, and the factors that may determine which of these futures might be realized. Given the significant uncertainties that exist about the future, a prudent policy of both mitigation and well-planned adaptation is required.

In each of these chapters, clear and concise guidance is provided, together with appropriate examples. At the same time, references to more detailed information are included in endnotes. Comprehensive references and an index are at the end of the book.

CHAPTER 2

# Adaptation Assessment Steps and the Roles of Citizens, Public Officials, and Planners

This chapter presents the overall framework of the volume: the steps of adaptation assessment and the essential roles of citizens, public officials, and planners in the successful implementation of the steps. It also describes the roles of each of these groups in terms of the adaptation assessment steps most relevant to them, while emphasizing that these stakeholders should be involved throughout the adaptation process. The final section summarizes what to know and do about the adaptation steps and the roles of stakeholders in them.

## Adaptation Assessment Steps

Climate change will impact everyone living and working in coastal cities and towns, and each person needs to consider what they have to do to adapt. How climate change affects towns and cities depends on the particular physical, economic, demographic, environmental and other characteristics of the area. The adaptation steps (Figure 2.1) are a concise way of identifying the kinds of activities that are involved in adapting to climate change. These steps were originally developed for critical urban infrastructure;

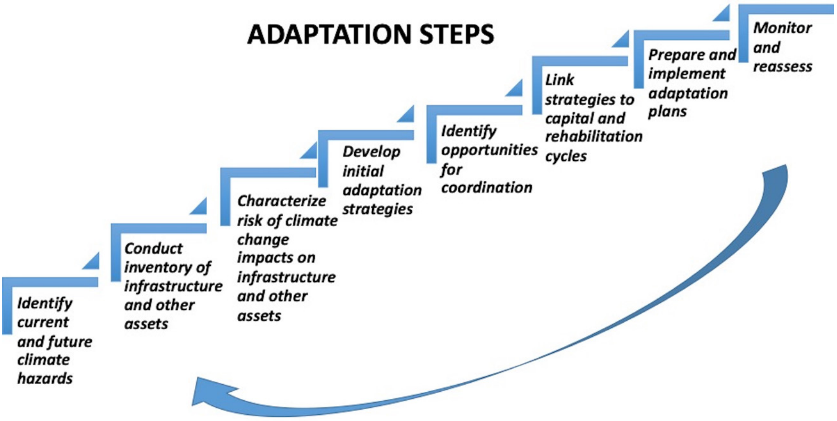



**Figure 2.1:** The eight adaptation steps.
Source: David C. Major and Sirkku Juhola.

in this guidebook, the steps are extended to apply to the entire range of infrastructure and other assets—social, economic, and environmental, both tangible and intangible, relevant to adaptation planning in a coastal community. There are eight steps in the process, shown in Figure 2.1 in sequence.[1] In planning applications, some steps will need to be repeated as new information emerges; and over time the sequence should be repeated as climate challenges and planning resources are more clearly identified.

The roles of different stakeholders in the steps are discussed in this chapter and are also considered in more detail at appropriate points in later chapters. The key stakeholders who are involved in supporting the adaptation process include citizens, public officials, and planners. Citizens are stakeholders both as individuals and as part of private groups and enterprises, such as non-governmental organizations, community groups, aid agencies, and private companies. Climate change will impact them in their daily lives and may also threaten their homes and livelihoods. Public officials include elected and appointed officials in city and town government. They are often elected or appointed for periods of years, and are ultimately responsible for making decisions on adaptation.

Planners are those who work in local (and perhaps higher-level) government in various capacities, including departments of urban infrastructure, housing, environmental planning, and health. Planners help to shape decisions that affect a town or city over long periods of time, making them key players in adaptation. Their work includes the supervision of planning and engineering firms and other organizations that plan and implement adaptation for cities and towns.

Adaptation planning is a participatory process, and a well-organized process includes a suitable balance of influence among stakeholders, with a fair consideration of all views and opinions. In addition, every stakeholder has a responsibility in the overall adaptation process to ensure that adaptation needs and opportunities are kept to the fore in discussions of resource allocation. Further, stakeholders may take adaptation measures in their individual capacities either within or outside of the planning that takes place officially. The overall planning process should be designed to help coordinate these activities to the extent possible, to ensure that the city or town provides opportunities for sustainable living environments for all citizens.

Step 1: *Identify current and future climate hazards*. This step includes using available climate change-related information and future projections. It takes into account that current context-specific, climate-related challenges and opportunities will almost certainly change in frequency and severity due to climate change.

Step 2: *Conduct inventory of infrastructure and other assets*. Key infrastructure and assets that are vulnerable to climate change need to be identified and mapped. All assets, physical, economic, environmental, social, cultural and historical, should be fully included in inventories. An inventory should include an assessment of the current conditions of assets and the identification of caretaking and maintenance responsibilities.

Step 3: *Characterize risk of climate change impacts on infrastructure and other assets*. This step includes cross-referencing the expected impacts from climate change, including interrelated impacts,[2] with the inventory of infrastructure and other assets. This allows for a locally specific understanding of climate change impacts, vulnerabilities and risks, where vulnerabilities are the extent to which a community can be affected by an impact, and risk is the likelihood of adverse consequences resulting from impacts and vulnerabilities.[3]

Step 4: *Develop initial adaptation strategies*. After assessing impacts, vulnerabilities, and risks, it is possible to identify what kinds of adaptation measures can be taken. These can include short-term immediate measures, mid-term adaptations, or longer-term strategic ones.

Step 5: *Identify opportunities for coordination*. Many adaptation measures are likely to cut across multiple sectors relevant to different local, regional, and national agencies. It is important to find where and when collaboration is necessary or can be beneficial.

Step 6: *Link strategies to capital and rehabilitation cycles*. Adaptation strategies should be linked to normal processes of urban planning and city management, including capital replacement and rehabilitation cycles. Mainstreaming adaptation planning into these cycles helps to ensure that a city's resources are used effectively, often significantly reducing the costs of adaptation measures.

Step 7: *Prepare and implement adaptation plans*. Adaptation plans should be prepared that identify a range of measures that cover a city's different sectors, depending on what the key impacts, vulnerabilities, and risks are. Implementation, depending on the urgency of risks, can take place immediately or later according to careful evaluation and scheduling that includes the identification of financial and other resources.

Step 8: *Monitor and reassess*. After implementation, it is necessary to monitor the success of adaptation measures and make adjustments if necessary. Given the changing nature of climate impacts, it is important to keep reassessing impacts, vulnerabilities, and risks and adjust adaptation measures accordingly.

**Table 2.1:** The most important roles of citizens, public officials, and planners in the adaptation assessment steps, identified by checkmarks.

| Assessment steps | Citizens | Public officials | Planners |
|---|---|---|---|
| 1. Identify current and future climate hazards | ✓ | ✓ | ✓ |
| 2. Conduct inventory of infrastructure and other assets | ✓ | | ✓ |
| 3. Characterize risk of climate change impacts on infrastructure and other assets | ✓ | | ✓ |
| 4. Develop initial adaptation strategies | | | ✓ |
| 5. Identify opportunities for coordination | | ✓ | ✓ |
| 6. Link strategies to capital and rehabilitation cycles | | | ✓ |
| 7. Prepare and implement adaptation plans | ✓ | ✓ | ✓ |
| 8. Monitor and reassess | ✓ | | ✓ |

Source: David C. Major and Sirkku Juhola.

Table 2.1 identifies the most important roles of citizens, planners, and public officials in the adaptation assessment steps. These roles are discussed in this chapter for each of these groups of stakeholders, and in further detail in the chapters that follow.

Throughout the planning process, it should be taken into account that all stakeholders are related in some way to all of the steps, not just those in which their roles are most significant. Adaptation planning is a participatory process; Figures 2.2 and 2.3 show examples of the many interactions required both on site and in meeting rooms.


**Figure 2.2:** Stakeholders participating in a Durban Adaptation Charter learning exchange between the coastal city of Durban, South Africa, and the deep-water port of Nacala, Mozambique.

Source: Isabel Njihia.

**Figure 2.3:** Stakeholders discussing water management practices relating to climate change in Vientiane, Laos, 2015. Many estuarine and riverine cities have climate impact challenges similar to those of coastal cities.

Source: Sirkku Juhola.

## Citizens

Citizens play a role as stakeholders in all of the adaption steps, but most importantly in five steps (see Table 2.1 above): 1, 2, 3, 7, and 8. Citizens have a dual role: as stakeholders in the adaptation process, and as individuals who may engage in personal adaptations to climate change. Citizens include not only those living or working in a locality, but in some cases others who are affected indirectly or who have a general concern with climate adaptation. How climate change affects each citizen will depend on the particular characteristics of the area, and the individual circumstances of the citizen.

Citizens play a significant role in Step 1, *Identify current and future climate hazards*. It is important to find information that will help to decide what climate hazards are relevant both to individual citizens and to the community. For example, those living near the coastline will be directly impacted by sea level rise; those living inland may be impacted indirectly through economic, physical, and social changes due to sea level rise. Such differences will affect the ways in which individuals respond to climate change. Citizens' roles as stakeholders will reflect not only these individual impacts, but also more general views about community adaptation. (In this regard, it is important to note that not all members of one family or group will be able to deal with the impacts of climate change with equal effectiveness. For example, very young children or the elderly may need special attention during heat waves.)

There are a number of ways for citizens to access or help to develop information on hazards. For example, it is possible that there are projections for the rise in mean temperatures or sea level rise regionally, calculated by the national meteorological office, and these can be accessed. In addition, there is an increasing number of different types of information portals (see Chapter 4) that make climate change-related knowledge regionally detailed and more easily accessible to citizens (although these sources can be of uneven quality). It is also important for citizens to contact local agencies or private groups directly for available information.

Step 2, *Conduct inventory of infrastructure and other assets*, will be led by planners, but citizens have an important role in ensuring that all assets, physical, economic, environmental, social, cultural and historical, are fully included in inventories. These can then be presented in lists or tabular form for review and use throughout the adaptation process.

Citizens also need to engage in Step 3, *Characterize risk of climate change impacts on infrastructure and other assets*. Based on the inventories of assets to which citizens will contribute in Step 2, citizens can provide input to Step 3 by helping to provide local knowledge of existing risks, such as flooding, that may not be recorded in official documents.

Step 7, *Prepare and implement adaptation plans*, is perhaps the most important role for citizen stakeholders: weighing in on the merits of the final adaptation plan for a community. This also includes judging impacts on individuals and households, and supporting, disagreeing with, or suggesting changes in the proposed final plan.

Step 8, *Monitor and reassess*, provides another important role for citizens as climate and other factors change over time. It is important that citizens take on an oversight role in ensuring the continued effectiveness of adaptation planning and implementation.

## Public Officials

Public officials are elected and appointed officials who have leadership and supervisory roles. They play important roles in all of the adaption steps, but most directly in three steps (see Table 2.1): 1, 5, and 7.

Public officials have a significant role to play in Step 1, *Identify current and future climate hazards*. This step is fundamental to the rest of adaptation planning, and public officials should take the lead in making sure that the identification of hazards is fully carried out by local agencies, with input from other stakeholders. This includes ensuring proper coordination among agencies in identifying hazards. In this step and others, their role also includes ensuring that there is sufficient financing and technical capability to engage in climate change adaptation measures, both in local agencies and through regional, national, or international agencies.

Step 5, *Identify opportunities for coordination*, is critical in any town or city, and all public officials should engage in and direct coordination; such coordination helps to deal with inconsistencies in the allocation of responsibilities. There are many climate change impacts that will cut across departmental or sector responsibilities and coordination between departments is necessary. Public officials can take the lead in developing inter-agency coordinating mechanisms, including any needed city-specific planning regulations or guidelines. The allocation of leadership responsibilities, which will vary from community to community, can affect the types of adaptation measures that can be taken by agencies and how and when they should be carried out. Coordination can be undertaken with the establishment of special task forces, for example, that include representatives from different departments. These task forces can meet regularly and share information. They can involve not only departmental representatives, but also other stakeholders from civil society and private sectors.

Step 7, *Prepare and implement adaptation plans*, is where the oversight and leadership of public officials is essential to ensure that the process happens efficiently and effectively. Public officials can also help to ensure that adaptation measures are mainstreamed into agency activities, which will increase the effectiveness of the adaptation process both in the near term and over the longer horizon.

## Planners

Planners work in local government agencies, including, among other departments, those for housing, water, transport, environmental and social planning, and health. These professionals play key roles in each of the adaptation steps. In overview, they have a significant responsibility for creating the conditions that enable adaptations to take place. They are well placed to see and know how the impacts of climate change are likely to affect different parts of a community. In larger communities, planners are frequently referred to as urban planners; in larger and wealthier cities, they embody a high level of expertise. In smaller and poorer communities, their roles may need to be played, or at least supplemented, by expertise from regional, national, and international agencies and NGOs. Planners' contributions to the adaptation assessment steps include, but are not limited to, the inputs described here.

Step 1: *Identify current and future climate hazards*. For the planner, this step includes identifying what key climate change hazards are likely to occur, based on current hazards and available climate change-related information and scenarios. Examining future projections will be important in understanding how current climate-related hazards may change in frequency or severity. Planners can also contribute to the inputs of citizens and public officials to Step 1 by using their expertise to highlight: the scope and goals of adaptation planning; the roles and responsibilities of participants; governance structures; resource availability; and methods of improving stakeholder participation.

Step 2: *Conduct inventory of infrastructure and other assets*. Key infrastructure and other assets that are vulnerable to climate change need to be identified and mapped by planners with input from other stakeholders. Assets include not only physical infrastructure, but also economic, environmental, social, cultural, and historical assets, including those in especially vulnerable neighborhoods. An inventory should include an assessment of the current condition of assets and identification of maintenance and support needs. To help in planning and oversight, it is important that the information in Step 2 should be displayed in user-friendly ways, including easy-to-read maps.

Step 3: *Characterize risk of climate change impacts on infrastructure and other assets*. The contribution of planners to this step includes detailed cross-referencing of impacts, vulnerabilities and risks from climate change, including interrelated climate risks, with inventories of infrastructure and assets. This allows for a locally specific understanding of climate change risks; some areas in a community will be more exposed to climate change impacts than others, which should be taken into account in adaptation planning.

Step 4: *Develop initial adaptation strategies*. After assessing risks, planners, with input from other stakeholders, can identify what kinds of adaptation measures can be taken from among the range of possibilities that are available (see Chapter 6). For the planner, short-term adaptation measures can include immediate protection of critical assets and developing more detailed information about the impacts of climate change. Mid- and long-term measures may include larger infrastructure projects and the possible retreat to higher ground of all or parts of a community. In any event, it is necessary for planners to integrate climate change impacts in any existing plans for developing any new infrastructure, supporting existing neighborhoods, or extending developed areas. The work in this step contributes to long-term integrated adaptation planning.[4]

Step 5: *Identify opportunities for coordination*. Many necessary adaptation measures will cut across different sectoral responsibilities of local agencies. Public officials, as above, will take a leading role in supervising coordination; planners have an important role to play in identifying points where collaboration is necessary or beneficial and in carrying out the details of coordinating programs and policies for climate change. As with Step 4, this work contributes importantly to successful long-term integrated adaptation planning.

Step 6: *Link strategies to capital and rehabilitation cycles*. Planners will help to make sure that adaptation strategies are linked to, and mainstreamed into, the normal processes of asset replacement and rehabilitation. This can help to ensure that a community's resources are used to support adaptation in an efficient and effective way. It is also important that resources are not used for development that is likely to increase the community's vulnerability to climate change impacts in the future.

Step 7: *Prepare and implement adaptation plans*. Adaptation plans include scheduled projects and programs that reflect the needs of the community as a whole and its different sectors. Using methods such as the evaluation measures and the adaptation checklist (Chapter 7), planners contribute effectively to the development of adaptation plans and their integration into a community's other development plans.

Step 8: *Monitor and reassess*. After plan implementation, planners help to monitor: climate science; the levels of climate parameters; economic, demographic, and environmental conditions; and the relative success of adaptation measures, in order to consider adjustments in adaptation measures. Necessary adjustments may be indicated, for example, by climate parameters reaching certain levels, acting as 'triggers' for new adaptation measures. Because adaptation will continue to be a concern for decades to come, planners will help to develop specific programs and procedures for future monitoring and reassessment of adaptation measures.

## What to Know and Do

1. The information in this chapter provides the basis for citizens, public officials, and planners and other stakeholders to know about the steps of climate adaptation and the many roles that stakeholders play in the adaptation process. This knowledge can help stakeholders to see adaptation planning within the larger context of the sustainability of their towns and cities.
2. Although adaptation decisions are in significant part local, stakeholders should seek access to any national guidance that can provide helpful context and sources of information. Examples include the National Adaptation Programmes of Action (NAPAs) that are designed to 'provide a process for Least Developed Countries (LDCs) to identify priority activities that respond to their *urgent* and *immediate* needs to adapt to climate change—those for which further delay would increase vulnerability and/or costs at a later stage.'[5] Many developed countries have national climate assessments.[6]
3. Further, although smaller settlements are often disadvantaged when it comes to adaptation, they may have at least one advantage over larger cities. For smaller towns and cities, networks within the city may be relatively small, making it is easier to coordinate joint action. Stakeholders should be involved in such networks, both to develop contacts with

other stakeholders and, where opportunity offers, to develop or discover local knowledge useful in adaptation that may not be available in national or regional documents and databases.

4. In addition, stakeholders in coastal towns and cities should explore regional collaborations with other towns and cities. These can be useful for many purposes, including when there are regional concerns such as joint risks of flooding or the need to cooperate on wetland and other natural area preservation and reconstruction.
5. Throughout the planning process, stakeholders should be fully aware of the needs and opportunities for climate change adaptation, and help to ensure the timely and appropriate allocation of scarce resources to adaptation. Importantly, this includes ensuring that adaptation measures are designed not just for current conditions, but for expected future climates. In this endeavor, stakeholders should be aware of evolving national and local laws and regulations that affect adaptation planning.

CHAPTER 3

# Impacts and Vulnerabilities of Climate Change on Coastal Cities

This chapter discusses key elements of climate impacts and vulnerabilities on coastal communities. It provides information for Step 1, *Identify current and future climate hazards*, and also for later steps throughout the adaptation planning process. The topics discussed include: sea level rise, storm surge, rainfall intensity and flooding, higher temperatures, droughts, heat waves and other impacts. Other sections describe the characterization of impacts and sources of data on impacts and vulnerabilities. The chapter concludes with What to Know and Do: perspectives on how citizens, public officials, and planners and other stakeholders can deal with impacts and vulnerabilities.

## Sea Level Rise

Sea level rise is the most important element of climate change for low-lying coastal cities. On time scales relevant to current human activity, it is a permanent change, with all that that implies. The impacts of sea level rise include: land lost through erosion and submergence; higher levels of storm surge and flooding; the destruction of natural areas, including wetlands; the intrusion of salt water into aquifers (as is happening in southeastern Florida, USA, for example);[1] and the disruption or destruction of communities. Simply because of rising sea levels, storm surge and flooding will increase even without possible increases in storm frequency and intensity.

The causes of sea level change are shown in Figure 3.1. The primary contributors to increasing global mean sea level are ocean thermal expansion and glacier and ice sheet melting.[2]

Among these causes, the main source of uncertainty is the rate at which the ice sheets in Greenland and Antarctica are melting and will melt.[3] (Increases in water storage on land, including climate change-induced increases in groundwater and soil moisture and storage in dams, can decrease the speed of sea level rise to some extent.[4])

According to the IPCC, taking account of all these factors:

> Over the period 1993–2010, global mean sea-level rise is, with *high confidence*,[5] consistent with the sum of the observed contributions from ocean thermal expansion, due to warming, from changes in glaciers, the Greenland ice sheet, the Antarctic ice sheet and land water storage.[6]

Moreover, according to a recent IPCC report on the cryosphere: '**Global mean sea level (GMSL) is rising, with acceleration in recent decades due to increasing rates of ice loss from the Greenland and Antarctic ice sheets (*very high confidence*), as well as continued glacier mass loss and ocean thermal expansion.**'[7]

Local impacts on sea level, as shown in the figure, include vertical land motions, local ocean water mass density, and the 'fingerprints' of gravitational and other changes from the loss of ice mass. Relative sea level rise can vary substantially in different areas because of these and other local factors. For example, isostatic rebound in the northern part of the Gulf of Bothnia (between Sweden and Finland) is estimated at 90 cm in the 21st century.[8] Sea levels at the northeastern coast of the USA may rise in response to a possible slowdown of what is called the Atlantic meridional overturning circulation.[9]

> Rates of sea level rise over broad regions can be several times larger or smaller than the global mean sea level rise for periods of several decades, due to fluctuations in ocean circulation. Since 1993, the regional rates for the Western Pacific are up to three times larger than the global mean, while those for much of the Eastern Pacific are near zero or negative.[10]

Maps for projected relative sea level changes globally between 1986–2005 and 2081–2100 are provided in the IPCC Fifth

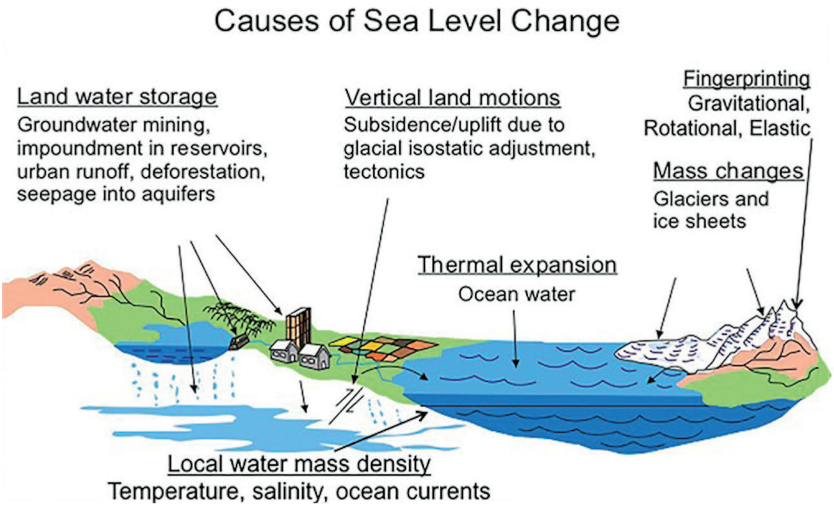



**Figure 3.1:** Causes of sea level change.

Source: NPCC 2015: 38.

Note: 'Fingerprints' refer to changes from surface mass loads of melting ice sheets, including gravitational, elastic, and rotational changes that impact local or regional sea level.

Assessment Report.[11] Globally, many urban areas face higher than average relative sea level rise due to subsidence and groundwater withdrawal.[12]

In terms of recent history, according to the IPCC: 'It is *very likely* that the mean rate of global averaged sea-level rise was 1.7 [1.5 to 1.9] mm/yr between 1901 and 2010 and 3.2 [2.8 to 3.6] mm/yr between 1993 and 2010. Tide gauge and satellite altimeter data are consistent regarding the higher rate during the latter period.'[13] Further: **'The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia (*high confidence*).'**[14]

Looking toward the future:

> There has been significant improvement in understanding and projection of sea level change since the AR4 [Fourth Assessment Report]. Global mean sea level rise will continue during the 21st century, *very likely* at a faster rate than observed from 1971 to 2010. For the period 2081–2100 relative to 1986–2005, the rise will *likely* be in the ranges of 0.26 to 0.55 m for RCP [Representative

> Concentration Pathway—see Chapter 4] 2.6, and of 0.45 to 0.82 m for RCP8.5 (*medium confidence*). Sea level rise will not be uniform across regions. By the end of the 21st century, it is *very likely* that sea level will rise in more than about 95% of the ocean area. About 70% of the coastlines worldwide are projected to experience a sea level change within ±20% of the global mean.[15]

It is possible that the IPCC's high-end estimates are too conservative—high-end estimates for New York City, for example, are close to 2 meters.[16]

In sum, rising seas are the most important problem of climate change for coastal settlements; impacts have been experienced globally, and some small islands have already disappeared, will do so during this century, or will become otherwise uninhabitable.[17] Moreover, the sea level rise discussed here will continue beyond 2100, so that yet further measures will doubtless be required after this century is over. Together with the need for locally focused data, which is not always easy to find, these considerations suggest that relatively conservative policies toward adaptation, together with continuous monitoring, are appropriate for coastal communities as risk management strategies.

## Storm Surge

Higher levels of storm surge are among the most significant impacts associated with sea level rise. Storm surge is defined as the abnormally high water levels (additional water above the normal tide, Figure 3.2) generated by severe storms, such as hurricanes and other cyclones. A surge forms when strong winds over the ocean combine with low pressure to drive water onshore.[18] The effects are increased by wave phenomena known as run-up (waves breaking and water flowing to the shore) and set-up (waves continually breaking and preventing water from flowing back to sea). (The effects of lower barometric pressure in a storm are minimal compared to other factors.[19])

As the sea rises, any given storm produces surge starting from a higher level than before. Consequently, it floods more land area

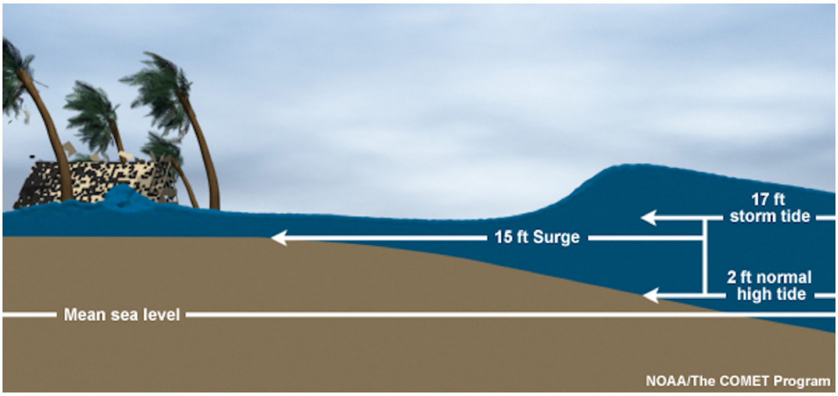



**Figure 3.2:** Storm surge and tide.
Source: NOAA n.d.a.

to a higher level than before with the resulting impacts on people, buildings, other infrastructure, and natural areas. (Wind damage from storms can also be a significant impact.) As a result of global sea level rise, storm surges that occur in the early 21st century are (using the global average) about 20 cm (eight inches) higher than they would have been in 1900. By 2100, storm surges will happen on top of significantly higher sea level.[20]

Storm surges can produce temporary sea levels much higher than normal high tide, resulting in extreme coastal and inland flooding. The combination of astronomical tide and storm surge is sometimes referred to as 'storm tide.' This is shown in Figure 3.2, with an example storm tide of 17 feet (5.2m) above mean sea level. Should sea level rise by two feet, this storm tide would be 19 feet (5,8m), with consequent greater flooding of land. (This assumes that future storms would have the same intensity as current storms; if intensity increases, as is sometimes projected, the storm tide would be still higher.[21])

A useful way for stakeholders to consider the consequences of rising sea levels and storm surge is shown in Table 3.1. This shows the change in the estimated recurrence intervals of the 10, 100, and 500 year storms for the lower tip of Manhattan, New York City, USA, with projected sea level rise as compared to the base period. The results show, for example, that the central range (the

**Table 3.1:** Coastal storms and floods for New York City, baseline (1971–2000) and estimated future storm recurrence intervals and flood heights.

| | Baseline | 2020s | 2050s | 2080s |
|---|---|---|---|---|
| 1-in-10 yr flood to recur, on average | ~once every 10 yrs | ~once every 8–10 yrs | ~once every 3–6 yrs | ~once every 1–3 yrs |
| Flood heights (m) associated with 1-in-10 yr flood | 1.9 | 2.0–2.1 | 2.1–2.2 | 2.3–2.5 |
| 1-in-100 yr flood to recur, on average | ~once every 100 yrs | ~once every 65–80 yrs | ~once every 35–55 yrs | ~once every 15–35 yrs |
| Flood heights (m) associated with 1-in-100 yr flood | 2.6 | 2.7–2.7+ | 2.8–2.9 | 2.9–3.2 |
| 1-in-500 yr flood to recur, on average | ~once every 500 yrs | ~once every 380–450 yrs | ~once every 250–330 yrs | ~once every 120–250 yrs |
| Flood heights (m) associated with 1-in-500 yr flood | 3.3 | 3.3–3.4 | 3.5–3.6 | 3.6–3.8 |

Source: NPCC 2010: 55–56; lowest and highest estimates are shown on p. 210.

Note: Converted from the original estimates in feet (one foot = 30.48 cm) to meters, rounded to one decimal place. The table shows, for flood frequencies and heights, the central range (middle 67%) of the results from a suite of GCMs and greenhouse gas (GHG) scenarios for the tide gauge at the Battery, in Lower Manhattan. Higher areas of New York City experience lower flood heights.

middle 67% of results in the analysis shown) of the estimated recurrence interval of the storm that was the 100-year storm in 1971-2000 is between 15 and 35 years in the 2080s, depending on the climate projection. That is, the floods now associated with the 100-year storm would recur between 3 and 6 times more frequently. The consequent higher flood levels are also shown. (Note that the recurrence intervals of storms are statistical estimates, not certain data, especially for larger storms such as the 100 and 500 year events.)

The actual effects of a given storm in generating surge will depend on storm size and intensity, forward speed, angle of approach, shape of the coastline and ocean bottom, and local features such as barrier islands.[22] These considerations can enter into the detailed engineering design of adaptations, depending on the type of adaptation and local conditions.

Unlike sea level rise, storm surge is temporary; but surge can produce immense damage during the event, and result in extended reconstruction periods. Moreover, some effects can linger for long periods, such as damage to ecosystems. Toxic waste sites, which are often located near coasts, can also be impacted by sea level rise and storm surge, releasing pollutants that can harm both the local settlement and the larger community. Local people may have good knowledge of these sites that can be taken into account in adaptation planning.

## Rainfall Intensity and Flooding

Heat drives the hydrologic cycle, and so the higher temperatures that the world will experience will have direct impacts on precipitation. Impacts can be from both higher (or lower) average or seasonal precipitation in particular localities, and also more extreme events, especially more intense storms. Unlike the impacts of sea level rise and increased storm surge, the impacts of precipitation changes can directly affect inland towns, as well as coastal towns and cities.

Expected precipitation changes from global climate change can be positive or negative, and are highly variable geographically, as shown in Figure 3.3. Precipitation scenarios under two Representative Concentration Pathways, the lowest and the highest, are shown as percentage changes.[23] Stakeholders will want to review

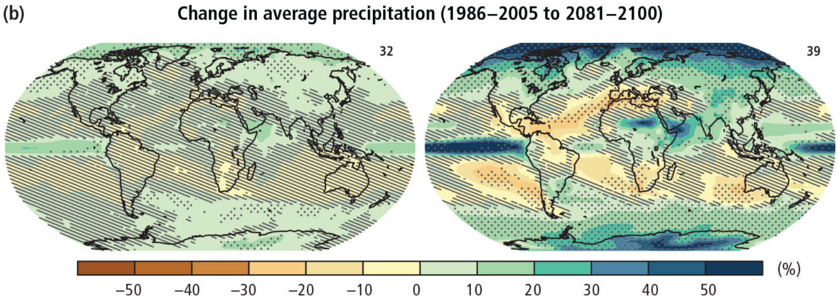



**Figure 3.3:** Change in average precipitation 2081–2100 relative to 1986-2005 in percentages.

Source: IPCC 2014c: 61, Figure 2.2 b ©IPCC. The required detailed IPCC legend for this figure and Figure 3.4, below (included here for economy of space) is: Coupled Model Intercomparison Project Phase 5 (CMIP5) multi-model mean projections (i.e., the average of the model projections available) for the 2081–2100 period under the RCP2.6 (left) and RCP8.5 (right) scenarios [see Chapter 4] for (a) [Figure 3.4, below] change in annual mean surface temperature and (b) [Figure 3.3, above] change in annual mean precipitation, in percentages. [The sea level illustrations in IPCC 2014c 61, Figure 2.2c, are not used here.] Changes are shown relative to the 1986–2005 period. The number of CMIP5 models used to calculate the multi-model mean is indicated in the upper right corner of each panel. Stippling (dots) on (a) and (b) indicates regions where the projected change is large compared to natural internal variability (i.e., greater than two standard deviations of internal variability in 20-year means) and where 90% of the models agree on the sign of change. Hatching (diagonal lines) on (a) and (b) shows regions where the projected change is less than one standard deviation of natural internal variability in 20-year means. {WGI Figure SPM.8, Figure 13.20, Box 12.1.} Note: WG1 = Working Group 1 of the IPCC.

available regionally focused estimates, as well as local knowledge from recent years.

Figures such as 3.3 and 3.4 (below) are provided for 35 subcontinental scale regions of the globe, and for the December–February and June–August seasons, in the IPCC's Fifth Assessment Report.[24] These may be helpful in planning where more local scenarios (see Chapter 4) are unavailable.

According to the IPCC, changes in precipitation will not be uniform:

> The high latitudes and the equatorial Pacific are *likely* to experience an increase in annual mean precipitation by the end of this century under the RCP8.5 scenario. In many mid-latitude and subtropical dry regions, mean precipitation will *likely* decrease, while in many mid-latitude wet regions, mean precipitation will *likely* increase under the RCP8.5 scenario …
>
> Extreme precipitation events over most mid-latitude land masses and over wet tropical regions will *very likely* become more intense and more frequent as global mean surface temperature increases.
>
> Globally, in all RCPs, it is likely that the area encompassed by monsoon systems will increase and monsoon precipitation is likely to intensify.[25]

The impacts of precipitation changes include effects from precipitation directly on a community and flooding from precipitation upstream on watercourses that run through or near a community. 'Heavy rainfall would impact urban areas through flooding, which in turn can lead to the destruction of properties and public infrastructure, contamination of water sources, water logging, loss of business and livelihood options, and increase in water-borne and water-related diseases ...'[26] Changes in extreme short-duration rainfall events can impact urban drainage and sewer systems, possibly leading to more combined sewer overflow events.[27] Flooding of urban drainage and water supply systems can cause additional health hazards and, in addition, intense storms may cause higher levels of wind damage.

Unlike temperature and sea level scenarios, which show increases over time, precipitation scenarios for a given location can show either increases or decreases, which puts pressure on planning for more flexibility. In this respect, the distinction between average and extreme precipitation is very important; for example, there may be more intense rainfall days while average precipitation remains relatively unchanged. Precipitation changes can require expensive adaptations, such as drainage system investments; there are also less expensive efforts, such as rain barrels.

**Table 3.2:** Baseline and estimated heavy rainfall days for New York City.

| 2080s: Number of days with rainfall at or above … | Baseline (1971–2000) | Low estimate (10th percentile) | Middle range (25th– 75th percentile) | High estimate (90th percentile) |
|---|---|---|---|---|
| 1 inch (2.54 cm) | 13 | 14 | 15–17 | 18 |
| 2 inches (5.08 cm) | 3 | 3 | 4–5 | 5 |
| 4 inches (10.16 cm) | 0.3 | 0.2 | 0.3–0.5 | 0.7 |

Source: NPCC 2015: 31.

An example of local information is from the New York City Panel on Climate Change (NPCC). Table 3.2, based on projections for New York City, shows the possibility of additional days per year with heavy rainfall. The table shows baseline values and estimates for the 2080s for New York City for days with 1, 2, and 4 inches of precipitation (2.54, 5.08, and 10.16 cm). Although the additional number of days for each level of precipitation seems modest, these are events that can cause considerable damage and thus even relatively small increases can be significant. As with many extreme events, more refined modeling in the future could result in better projections of the number of extreme rainfall days, which would then provide for more effective adaptation.

## Higher Temperatures

Higher temperatures not only drive the hydrologic cycle and sea level rise through thermal expansion and ice melt, they also have direct effects on health, on natural areas including wetlands, and on materials (e.g. for construction) and metals (such as bending of rail lines with inadequately designed expansion joints). Unlike sea level and storm surge, higher temperatures directly impact inland as well as coastal towns and cities. There

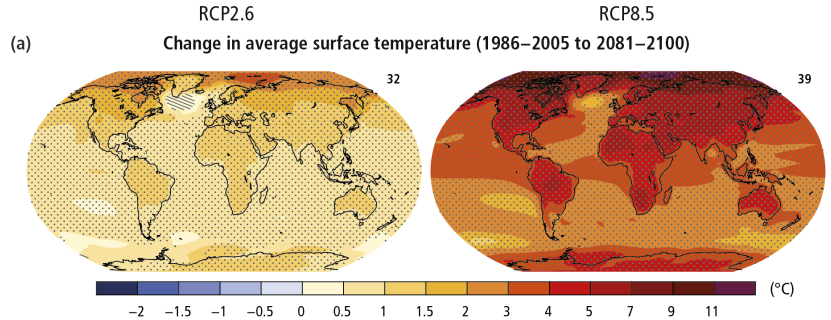



**Figure 3.4:** Change in average surface temperature (°C ) 2081–2100 relative to 1986–2005.

Source: IPCC 2014c 61, Figure 2.2a. ©IPCC See legend for Figure 3.3 for details.

are good general estimates of higher temperatures distributed around the globe. Temperature forecasts under two Representative Concentration Pathways, the lowest and the highest, are shown in Figure 3.4.[28] Stakeholders will want to review local knowledge from recent years, as well as available regionally focused estimates.

## Droughts

While perhaps counterintuitive, it is possible for some areas to have both more intense rain and more droughts: the latter from both increased evapotranspiration and increased (or inefficient) water use. Much of the information that relates to droughts requires local assessment because of the dependence of drought conditions on both hydrologic conditions and on local water management and use. Droughts can be widespread and cause extensive economic, social, and environmental damage. As described by the IPCC: 'Drought can have many effects in urban areas, including increases in water shortages, electricity shortages (where hydropower is a source), water-related diseases (through use of contaminated water), and food prices and food insecurity from reduced supplies.'[29] Impacts on food supply and prices may be particularly significant in small communities with local agriculture. The IPCC says that current observations of global-scale drought trends are uncertain because of lack of direct observations, definitional issues, and inconsistency in trends,[30] but that for the future, '[i]n presently dry regions, the frequency of droughts will *likely* increase by the end of the 21st century under RCP8.5'[31] (the highest RCP).

## Heat Waves

The higher temperatures that drive sea level rise and droughts also have direct impacts on coastal cities and towns. These impacts are from both higher average temperatures and more extreme temperature events. Unlike the impacts of sea level rise and increased storm surge, the impacts of higher temperatures directly affect inland towns, as well as coastal towns and cities. The impacts of heat waves particularly include impacts on health, including both sickness and death, particularly of older people, the very young, and health-compromised individuals.[32] 'Heat-related mortality has been recognized as an important public health challenge for many decades.'[33] And heat waves exacerbate impacts of temperature on natural areas and materials.

Extreme events such as heat waves are likely to become more common. An example of local information is from NPCC. Table 3.3, based on projections for New York City, shows the possibility of many more extreme heat days per year with projected global warming, with potentially serious impacts on coastal cities and towns. The table shows baseline values and estimates for the period of the 2080s for New York City for the number of days per year with temperatures at or above 90°F (32°C) and 100°F (38°C). It is striking that for the number of days per year with maximum temperature at or above 100°F (38°C), the high-end projection goes from 0.4 at the baseline to 20 in the 2080s.

## Other Impacts

In addition to the climate hazards discussed above, there are other impacts that must be taken into account in adaptation planning, including extreme events such as high winds, freezing rain, and

**Table 3.3:** Projected extreme heat days for New York City, 2080s.

| 2080s | Baseline (1971–2000) | Low estimate (10th percentile) | Middle range (25th–75th percentile) | High estimate (90th percentile) |
|---|---|---|---|---|
| Number of days per year with maximum temperature at or above 90°F (32°C) | 18 | 38 | 44–76 | 87 |
| Number of days per year with maximum temperature at or above 100°F (38°C) | 0.4 | 2 | 4–14 | 20 |

Source: NPCC 2015: 31.

lightning. Unlike sea level rise, storm surge, temperature, and some precipitation changes, for which quantitative estimates can be made, the future levels of many of these impacts are harder to characterize quantitatively, and indeed in one study they are listed under the category of 'qualitative changes.'[34] The NPCC researchers' estimates for New York City are in Table 3.4.

Such extreme events occur to a greater or lesser extent in different regions, and in many cases their impacts are not well recorded or are unlikely to be recorded in higher-level databases. These are hazards about which local knowledge can be very important and for which local record-keeping should be encouraged. Of the extreme events noted here, winds are among the most important hazards worldwide, causing considerable damages, 'although separating damages from flooding and winds is a complex matter on which few data are available.'[35] Much more data is needed on winds and other extreme events. As methods and models improve, better estimates of extreme events, which are of great importance in evaluating vulnerabilities and risks, can be achieved.[36]

**Table 3.4:** Qualitative changes in extreme events.

| Extreme event | Probable direction through the 21st century | Likelihood |
|---|---|---|
| Heat index | ↑ | Very likely |
| Ice storms/freezing rain | ↑ | About as likely as not |
| Snowfall frequency and amount | ↓ | Likely |
| Downpours (precipitation rate/hour) | ↑ | Likely |
| Lightning | unknown | N/A |
| Intense hurricanes | ↑ | More likely than not |
| Nor'easters | unknown | N/A |
| Extreme winds | ↑ | More likely than not |

Source: NPCC 2010: 57.

Note: The likelihood categories (except for 'unknown') are IPCC categories (see Appendix B of this volume), but the estimates are by the researchers. 'Nor'easters' are extra-tropical storms that affect the Middle Atlantic and New England coasts of the US. The United States Weather Service uses a heat index based on temperature and humidity.

## Characterization of Impacts

The impacts described in this chapter provide the main physical challenges of adaptation to climate change in coastal cities. These challenges can be described in three dimensions.[37] The first is the probability (likelihood) of a climate event happening. In the case of sea level rise, this is virtually certain. The second dimension is the extent to which a physical aspect of climate change, if it occurs, will have impacts on a community. This second dimension refers to a community's vulnerabilities: for coastal communities and sea level rise, for example, the impacts, including increased flooding, will be highly probable. Finally, the third dimension is the magnitude of the effects of an impact. For sea level rise, these can be small or large depending on the characteristics of the community at risk (Chapter 5).

Based on this three-dimensional conceptual approach, including climate hazard probability, impact probability, and magnitude of impacts, it is possible to generate a table for a coastal city or town such as Table 3.5, in which different elements of climate change, impacts, and importance are identified. The last column in Table 3.5 shows the initial assessment of the relative importance of immediate, mid-term, or longer-term adaptations (including any existing adaptations).

Table 3.5 provides an initial effort to organize information for the further analysis described in later chapters. It provides an initial overview for stakeholders, and also a beginning set of information for evaluation of adaptations and adaptation plans. There are different ways of structuring such tables; the entries below are examples, which will differ, perhaps substantially, from place to place. This is an aggregate table; for detailed planning later in the process, the elements can be divided into suitable parts and assessed separately. For example, the consequences of sea level rise on natural areas may require detailed examination separately from other consequences, such as impacts on infrastructure. In addition, data gaps and uncertainties in each area of the table can be identified. It is important to be as complete as possible in constructing such a table early in the process of adaptation planning.

## Sources of Data on Impacts and Vulnerabilities

Sources of data on impacts and vulnerabilities can be found at the international, national, and local levels. The best international source of scientific review and analysis is the IPCC, referred to in this chapter and in more detail in the next chapter on climate modeling. There are also excellent national and supranational institutions with websites presenting climate, economic, and demographic data, of which leading examples are given in the

**Table 3.5:** Example of climate change likelihoods, impacts, magnitude of impacts, and initial planning assessment.

| Climate change event | Likeli-hood of event | Strength and nature of impacts | Strength and nature of consequences | Initial evaluation of adaptation needs |
|---|---|---|---|---|
| **Sea level rise** | High or certain | Loss of land; higher storm surge; salt water intrusion; loss of natural areas | High economic losses; loss of communities; environmental costs | Immediate planning and early adaptation |
| **Higher tempe-ratures** | High or certain | Impacts on health, infrastructure, water shortages (drought), agriculture, oceans | Economic, environmental, social costs | If impacts are moderate, planning for mid-term adaptation (some cooling centers are available now) |
| **Changes in precipi-tation patterns** | Uncertain, but generally increased | Possibly more intense storms and winds; inland flooding | Economic losses; infrastructure costs | Planning for more resilient drainage and water storage systems; flexible adaptation pathways |

Source: David C. Major and Sirkku Juhola.

Note: The term 'likelihood' (or risk) refers, in a formal sense, to the probability of an event (NPCC 2010: 31). Uncertainty, as opposed to risk, describes a situation that cannot be characterized by a known probability distribution.

following and later chapters. In many areas there are regional research institutions and universities that have significant data relating to climate and adaptation. However, data from central and even regional sources can be overly general; for example, topographical and flood data may be based on gross topographic maps that do not accurately reflect facts on the ground, although this is changing with more satellite and *in situ* sensors.[38] As Gornitz notes, even at the most basic level of topographic information: 'Sufficiently reliable elevation data … are simply unavailable on a global scale.'[39] This will require local reconnaissance and planning. Thus, local data can be quite important in considering impacts and vulnerabilities. An example is the soil-sampling work of citizen scientists in Dar es Salaam, Tanzania, providing data to improve urban flood models.[40]

Some types of data, such as impacts on small communities, may only be available at the local, rather than the central, level. Local information includes both written or recorded data, such as tide or flood heights, especially from extreme events, and informal knowledge, such as local impacts on communities, natural areas, and water sources (e.g. what effects there are and may be on wells). There may also be analogous situations in nearby towns and cities that can be drawn upon.[41] Some local information, especially in developed cities, will be recorded formally and made available digitally; other information will be recorded, but not digitized for wider use; and some will not be collected formally at all, but rather may be known to community members.

Steps that can be taken to access local information, including that which is not formally recorded, include the following:

- Identify particularly vulnerable locations that might be affected by climate change impacts. These include coastlines that are at risk of flooding and erosion from sea level rise and storm surge.
- Engage stakeholders and local people to determine who might have knowledge about locations at the community level that have experienced flooding or other impacts in previous years. People may be able to pinpoint specific locations that were badly flooded, for example, and how high and how far inland the water reached.
- Document available local knowledge and make sure that it is used appropriately by local communities. This might mean taking recordings, making videos, or drawing maps of particular locations.

- Identifying local coping mechanisms. Local people may have done some local adaptations already, and will know how to cope with some impacts and vulnerabilities. This information can be used in the design of further measures.

The first three points relate primarily to adaptation steps 1 and 3, *Identify current and future climate hazards* and *Characterize risk of climate change impacts on infrastructure and other assets*, and the last point relates primarily to adaptation step 4, *Develop initial adaptation strategies*.

## What to Know and Do

The climate impacts and vulnerabilities that are the focus of this chapter provide the basis for initial work on adaptation planning. This fundamental work will be undertaken in large part by planners, with oversight and input from both citizens and public officials.

1. The identification of stakeholders and the development of stakeholder relationships is of great importance to the identification and assessment of impacts. This effort should cast a wide net to ensure that all those who might contribute are contacted. It includes the development of linkages to international, national, and regional data and to planning organizations, funders, and sources of scientific information.
2. Inventories of vulnerabilities and impacts should be developed early in the adaptation planning process, with significant refinement at later steps. Material on evaluating impacts on infrastructure[42] can be modified to assess impacts on other assets, including environmental, social, cultural, and historical assets. In addition, an inventory of current and planned adaptations should be made for ongoing integration into planning and evaluation activities.
3. Sources of data should be identified, both from central sources such as national weather bureaus and also locally available information as described earlier. Stakeholders should ensure

that all of the available information, including local knowledge, is included in the application of the adaptation steps. Efforts should also be made to develop procedures that will ensure that local data collected in the future is properly identified and made available for adaptation planning.

4. As telecommunications develop further, an interactive process can be foreseen where local information can be sent to higher-level databases, formatted according to protocols designed to ensure comparability. This in turn can provide for better higher-level planning for adaptation.

All of this work is in preparation for more detailed planning and evaluation, as described in the following chapters.

CHAPTER 4

# Using Climate Information

## Global Climate Models and Climate Scenarios

This chapter presents the scientific basis for developing future climate scenarios. The chapter includes a description of what Global Climate Models (GCMs) do and how they work, and a discussion of the development of regional scenarios from global model results. Finally, because this science is primarily done at large scientific centers, there is a discussion of how local stakeholders can keep up with the science to help them plan adaptations over time. The information in this chapter will assist stakeholders with step 1 of the adaptation assessment steps, *Identify current and future climate hazards*. This science is also fundamental to step 3, *Characterize risk of climate change impacts on infrastructure and other assets*.

### Global Climate Models

Recent decades have seen a dramatic increase in scientific understanding of climate change, from very early research, through the development of the Intergovernmental Panel on Climate Change (IPCC) and the growth of a large scientific community focused on the need for greater understanding of climate change and the need to develop adequate policy.[1] GCMs have been a principal scientific tool for examining the possible future scenarios of climate and suggesting appropriate mitigation and adaptation policies. The most recent IPCC reports utilize results from 39 GCMs, vetted for quality, from scientific centers worldwide.[2]

GCMs are large mathematical models, run on supercomputers, that simulate key physical processes that produce climate. The models do this by dividing the earth, ocean, and cryosphere (ice) into very large numbers of cells, with the number increasing as model resolution improves. The models use horizontal and vertical divisions for the cells (see Figure 4.1). Horizontally, the most detailed models now have cells 1 degree wide (110 km at the equator) or less, and models continue to reduce the size of cells to provide additional detail for climate simulations. Vertical slices cover the atmosphere up to some 10,000 meters and down to the bottom of the ocean. Each cell includes equations of physical variables that change over time, based on well-known physical laws; cells are connected as appropriate for the transfer of information from one cell to another.

To simulate the development of global climate over long periods, the models are driven ('forced' is the word that scientists use) with selected greenhouse gas (GHG) emissions trajectories. For the IPCC's Fifth Assessment Report (AR5), there are four 'Representative Concentration Pathways' (RCPs) ranging from stringent mitigation to high emissions. The RCPs include GHG concentrations (see Figure 4.2), aerosols (natural and human-generated particles that can reflect sunlight and therefore have a cooling affect), and land-use changes.[3]

Simulation runs with these complex models, driven by emissions scenarios, can take substantial computer time; a single simulation run of 100 years of future climate takes weeks on a supercomputer. Each simulation provides estimates of future temperatures, precipitation, and information that contributes to estimates of (for most models) sea level rise. Although the simulations are run at very short time scales, measured in minutes, and for some variables even in seconds, the outputs that are most generally used are monthly estimates.

For the IPCC reports, the models are all run with the same emissions trajectories to provide comparable results. The results are

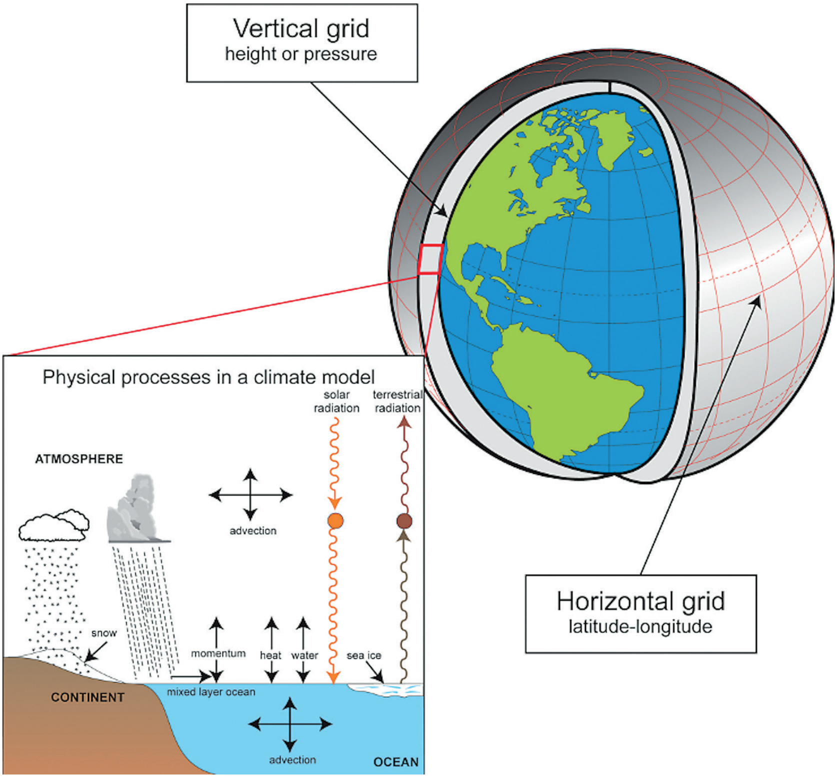



**Figure 4.1:** Global Climate Models.

Source: NPCC 2010 50 after NOAA.

Note: Advection = movement of atmospheric properties.

summarized, interpreted, and displayed graphically in the reports of the IPCC and other scientific bodies.

'Over the past several decades, climate models have increased in both complexity and computational power as physical understanding of the climate system has grown.'[4] And, as computers get faster, more information becomes available, and the models capture more events, it can be expected that climate forecasts will improve still further. However, it is important to note that at present there remain many challenges for further model development; the models still do not capture some physical elements appropriately, such as local storms and clouds. As one expert has written, 'for a system as complex as that determining Earth's

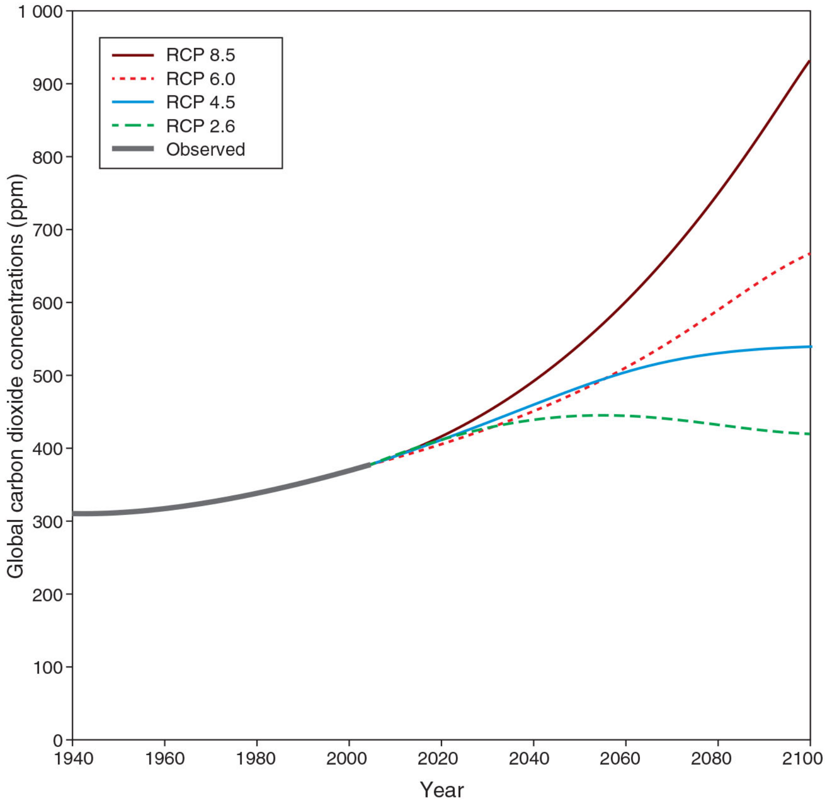



**Figure 4.2:** Representative Concentration Pathways for $CO_2$.

Source: NPCC 2015 Sec. 1.1.

Note: For detailed information on the components of RCPs, see IPCC 2014c: 57.

climate, one should always be prepared for surprises.'[5] Nevertheless, the GCMs provide vital outputs that constitute an important basis for planning both mitigation and adaptation.

For local and regional planning for adaptation, the outputs of the IPCC GCM simulations can be 'downscaled' as described in the next section.

## Regional Scenarios

The projections of climate change in the IPCC described in the previous chapter are central to its work.[6] They are global (and some large-region) projections, but they can be utilized to develop climate scenarios for local regions. This process is known as 'downscaling.' Such methods are essentially ways of reorganizing and utilizing GCM outputs to provide local guidance for adaptation. An example of the approach for New York City is given here; this illustrates many of the key elements involved. Scenario results are shown for temperature (Figure 4.3a) and precipitation (Figure 4.3b), which can be calculated directly from data produced by the GCMs, and for sea level (Figure 4.4), for which additional components are taken from research and datasets as shown in Figure 3.1 and NPCC 2015: table 2.1.[7]

The nature and extent to which local scenarios are required for adaptation planning will depend on the individual community, including its vulnerabilities, its resources, and the range of available adaptations, as discussed in Chapters 6 and 7 on adaptation and evaluation. For a large city like New York City (or a smaller community with complex infrastructure), significant detail is helpful in planning. This level of detail may not always be possible or needed for many small communities.

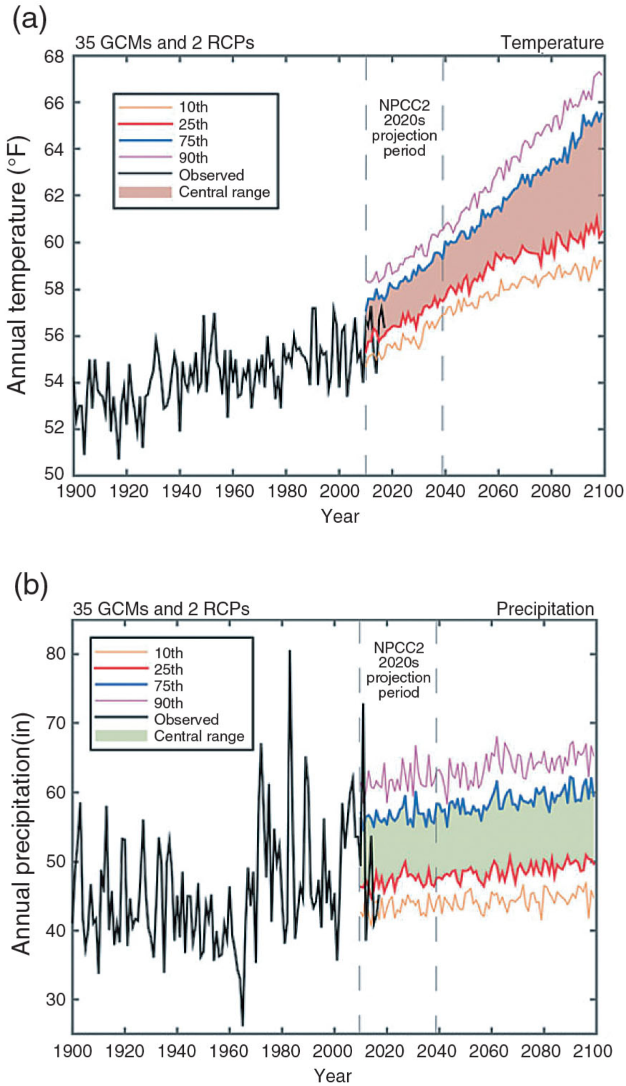
The downscaling procedure described here begins by selecting a suite of GCMs and RCPs from the IPCC GCM and RCP sets.[8] In the example for New York City (NYC), 35 GCMs (24 GCMs for model-based components of sea level) and 2 RCPs are used. The smaller number of GCMs for sea level rise reflects the fact that some GCMs do not produce the information on ocean-based variables that is needed for downscaling.[9] The two RCPs selected are 4.5 and 8.5, representing, respectively, a medium increase and the highest increase of the four IPCC RCPs. (NYC agencies wanted to consider high-end scenarios as an aid in planning.) For each model, the grid box that includes New York City is identified. The boxes for the different models are different because of the various spatial resolutions of the models.

Future scenarios must be presented for planning horizons relative to a baseline. The choice of baseline depends on data availability and how much change should be picked up in the scenarios as opposed to being included in the baseline. The baseline should be a mean value over a length of time in order to average out fluctuations. For this reason, the baseline for sea level rise can be shorter in general than those for temperature and precipitation because sea level has a smaller variation over time than the latter two climate variables. For most planning, a baseline calculated from data just prior to or at the beginning of the 21st century is appropriate if data are available. Taking these considerations into account, the baselines chosen for the NYC assessment are averages from 1971 to 2000 for temperature and precipitation and from 2000 to 2004 for sea level. As newer models and scenarios become available over time, the use of the same baselines provides for over-year consistency in planning.

Scenarios should be calculated for benchmark years chosen to represent the types of adaptation planning decisions that may be required for a city or town. For a large city such as New York City, where adaptations include very substantial infrastructure investments over a long period, projections were initially presented for the 2020s, 2050s, and 2080s; later projections include 2100; see Figures 4.3a, 4.3b, and 4.4 below.[10]

The scenarios are developed by taking the monthly outputs of each GCM for the model's grid box that includes New York City for the benchmark years. (These values are available from the Earth System Grid–Center for Enabling Technologies (ESG-CET) at http://pcmdi9.llnl.gov/, hosted at the US Lawrence Livermore National Laboratory in California.) The differences between the results for each benchmark year and the model's values at the baseline are added to the actual baseline data. This procedure (called the 'delta method') anchors the scenarios in real data for the area under study, and allows the results of different models to be used on a consistent basis. The combination of 35 GCMs and two RCPs produces 70 outputs for temperature and precipitation (24 x 2 = 48 for sea level rise). For each scenario, time period, and variable, the results constitute a 'model-based probability distribution.' That is, the results do not necessarily reflect the true (unknown) probability distribution of future events, but rather the range of model results.

The values for each planning horizon are actually averages around the benchmark year, a procedure that is used to deal with




**Figures 4.3a and 4.3b:** NPCC 2015 projected changes for (a) average annual temperature and (b) average annual precipitation and observations at Central Park (1900–2017). Colored lines represent the 10th, 25th, 75th, and 90th percentiles of model projections for RCPs 4.5 and 8.5 for 35 GCMs. The central range of projections between the 25th and 75th percentiles is shaded. Vertical dotted lines represent the range of the 2020s time slice from 2010 to 2039. Note the significant short-term natural variation in the observed data.

Sources: NPCC, 2019, sec. 2.2 and NPCC, 2015, p. 32.

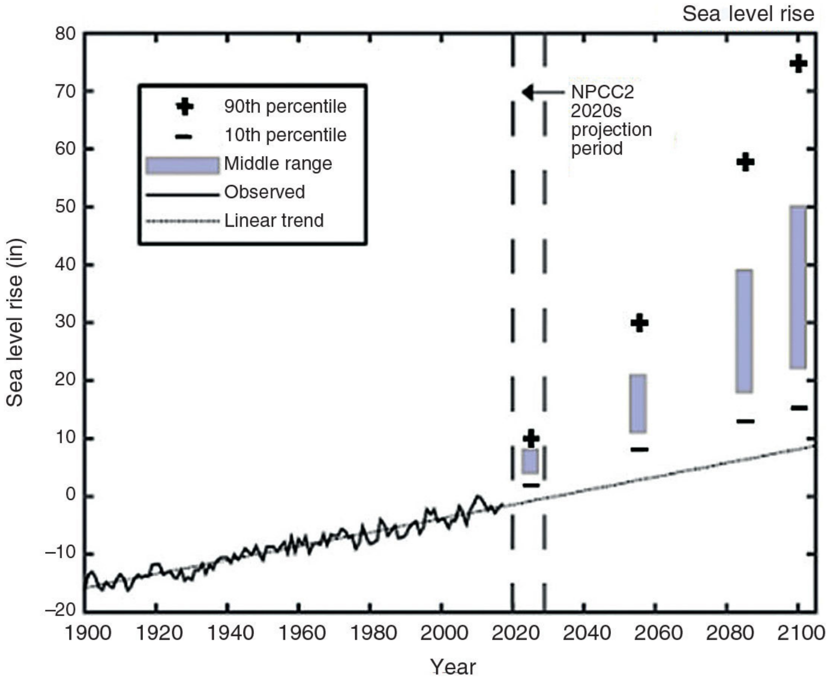



**Figure 4.4:** NPCC 2015 projected changes in sea level rise and observed sea level rise at the Battery in New York City from 1900 through 2017. The table key indicates the 10th, 25th, 75th, and 90th percentiles of model projections for RCPs 4.5 and 8.5 for 24 GCMs. The central range of projections between the 25th and 75th percentiles is shaded. Vertical dotted lines represent the range of the 2020s time slice from 2020 to 2029.

Sources: NPCC, 2019, sec. 3.2.3 and NPCC, 2015, p. 40.

the significant over-year variability of outputs of the GCMs. For temperature and precipitation, time slices are 30-year periods (ten for sea level) centered around a given decade, for example, the 2050s is 2040–2069. For 2100, a different procedure is used because most models do not project beyond 2100.[11] The time slice for sea level is shorter because sea level varies less than temperature and precipitation.

Results are shown here for temperature (Figure 4.3a) and precipitation (Figure 4.3b), which can be calculated directly from the GCMs, and for sea level (Figure 4.4), for which additional components are taken from research and datasets.[12] Based on similar methods, useful information on extreme events can be developed, although this information is likely to be less accurate than average estimates because of the additional assumptions that must be made.[13]

For these figures, it might in some cases be preferable to show the highest and lowest outputs, not just those from the 10th through the 90th percentile; this is a judgement that should be discussed with stakeholders.

These downscaled scenarios can be very useful for local planning guidance in various ways. For example, long-lived infrastructure would be planned in relation to a wider range of forecasts, as opposed to shorter-lived projects which can be planned for the smaller divergence that is characteristic of near-term scenarios as opposed to long-term scenarios.

As noted in Chapter 3, local factors can be very important in sea level rise scenarios. For example, isostatic rebound will be significant in some northern areas: Helsinki, Finland, will have an estimated 40 cm of isostatic rebound in the 21st century.[14] These figures can be relied on for local planning in those areas, and are readily available. On the other hand, some local factors may develop on which information may not be readily available to local planners. For example, the slowing of ocean circulation patterns in the Atlantic due to warming could increase sea level in the northeastern United States in the 21st century. One study estimates an increase in sea level for New York City due to ocean circulation changes (in addition to global sea level rise) of 15, 20, and 21 cm for scenarios with low, medium, and high rates of emissions, respectively.[15] The significance of local sea level effects for planning emphasizes the importance of recent local experience with regard to sea level and storm surge and flooding.

With local, national, or international resources, some local downscaling is possible and probably will become more common in the future. As mentioned, the nature and extent to which local scenarios are required for adaptation planning will depend on the individual community, including its vulnerabilities, its resources, and the range of available adaptations. An ongoing positive development is that the spatial resolution of GCMs has become continuously finer and thus will more readily facilitate locally based work. On the other hand, downscaling, as in the example shown, requires baseline data, which might not always be available. Other methods are possible, including the more resource-intensive approach using small-scale models called Regional Climate Models (RCMs) in addition to GCMs.[16] RCMs are driven by GCM outputs and include more spatial detail. However, RCMs are computationally intensive, and in practice they have tended to be coupled to only a small number of GCMs, and for only a small number of model years. As a result, RCM simulations can under-sample the range of possible outcomes as the climate system evolves and experiences climate variability.

Overall, scenarios such as those shown here can be seen as the 'demand' side of the planning equation; adaptations are the 'supply' side. These are methods where a significant level of expertise is required; even if scenarios are available, expertise will be helpful in evaluating their quality and applicability.

## What to Know and Do

Adaptation to climate change will be a continuing effort for many years, so it is important for large and small coastal cities and towns to keep up with general trends in climate change, mitigation, and adaptation.

1. The objective is to ensure that changes in scientific knowledge can be integrated with adaptations, scheduling, and local knowledge and conditions to the extent possible, using the adaptation steps provided in this volume. Fortunately, the technological revolution of connectedness via the internet, computers, and cell phones enables local people to be increasingly aware of what information is available.
2. As planning progresses, it will be important for planners to keep up with improvements in climate science and modeling. There are many areas of progress that can improve adaptation planning. As one example, an assessment could consider how an entire temperature distribution may change, rather than

applying a delta-method of uniform change to the historical distribution.[17] In addition, projections are beginning to consider compound extreme events, a diverse topic that includes multivariate extremes (e.g. simultaneous drought and heat), as well as spatio-temporal correlation of extremes (e.g. whether the probability of back-to-back coastal storms may increase in a changing climate.)[18] Although such compound and cascading events remain challenging to model, they can be analyzed using sensitivity analysis. For example, the existence of particularly serious compound events can be assumed, and their impacts and their consequent implications for planning and risk management evaluated.

3. The best overall global review and assessment of scientific information on climate change, including modeling and sectoral analysis, can be found in the work of the IPCC. The IPCC, often referred to in this volume, is the premier international body for assessing the science related to climate change. By way of background, the organization was set up in 1988 by the World Meteorological Organization (WMO) and UN Environment Programme (UNEP) to provide policymakers with regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation. The IPCC's First Assessment Report was published in 1990; the most recent is the Fifth Assessment Report (AR5), with volumes published from 2013 to 2015.[19] These reports are developed from the work of hundreds of scientists, with multiple rounds of review. There is an overview of the AR5 results in the *Synthesis Report*.[20] The IPCC will continue to be a key source of information on climate change.
4. In addition to the IPCC's focus on global climate change, there is significant information on regional change. In the IPCC's *Climate change 2014: impacts, adaptation, and vulnerability*, there are ten chapters (21–30) dealing with climate change for different world areas by continent and by special regions (e.g. chapter 29, 'Small islands'). These chapters provide information on observed and projected climate change, impacts, vulnerabilities, and adaptation by region. While this

information is somewhat more general than the detailed information that would be ideal for planning, it provides guidelines and insights that will be helpful to many communities. Regionally downscaled climate scenarios, as described above, are the best option, and these can best be obtained, if available, from national climate science agencies or other research establishments.

5. Current information on climate change is available on several important websites, including those of the US National Oceanic and Atmospheric Administration (NOAA), http://www.noaa.gov/, the US National Aeronautics and Space Administration (NASA) https://www.nasa.gov/, the UK Met Office, http://ukclimateprojections.metoffice.gov.uk/, and the UN Framework Convention on Climate Change (UNFCCC), unfccc.int/. These websites, which are updated regularly, are somewhat more popular in orientation than the reports of the IPCC. More regionally focused scientific information will be increasingly available from local and national sources such as universities. In Africa, for example, there is the website of the Intergovernmental Authority on Development (IGAD) Climate Prediction and Applications Centre (http://icpac.net/) for the Greater Horn of Africa, as well as others.[21] The models used in the AR5 report are listed in the IPCC's *Climate change 2013: the physical science basis* (p. 747), and model details can be obtained from the corresponding modeling centers.

CHAPTER 5

# Coastal Cities and Towns

## Characteristics and Challenges

The purpose of this chapter is to help communities identify key characteristics of their settlements relevant to their adaptation choices. Following a concise note on coastal cities and towns worldwide, the following elements relevant to both large and small communities are considered: physical characteristics; demographic, economic, environmental, social, cultural, and historical characteristics; governance; adaptive capacity; barriers to implementation; and environmental justice. This information provides part of the basis for adaptation planning (including step 4, *Develop initial adaptation strategies*), both locally and by those who would aid communities, whether national and regional governments or aid agencies. It also helps to identify similarly situated communities elsewhere from which lessons can be learned. The chapter concludes with perspectives on what to know and do about these subjects. Much of the information discussed in this chapter will be developed in adaptation assessment step 2, *Conduct inventory of infrastructure and other assets*.

### Coastal Towns and Cities

A useful way of framing the importance of coastal cities and towns of all sizes is that their populations are included within available estimates of total population numbers within given distances from coasts. These estimates vary considerably, but all show large percentages of world population near coastal areas. One estimate is that close to 40% of the world's population lives within 100 km of the sea (and three quarters of all large cities are located on the coast).[1] Such populations are not necessarily all resident in settlements close to or on the coasts, although it is reasonable to assume that most are. These population estimates reinforce the importance of confronting the challenges and opportunities of climate adaptation planning for coastal towns and cities.

Large coastal cities, rich and poor, are frequently written about in climate and other contexts, and there is extensive information for some about their characteristics.[2] Much less is known about smaller coastal towns and cities worldwide. There do not even appear to be reliable estimates of how many of these there are in the world.[3] Thus, the development of further information on the topics of this chapter is a continuing need for adaptation planning in the decades to come.

## Physical Characteristics

It is important for citizens, public officials, and planners to know and review the physical characteristics of their community so as to help to understand the types of adaptations required and their costs. This information will also help to deal with engineering and other firms that might work on adaptations for the community. The principal physical characteristics of interest are listed here and in Table 5.1; these provide a checklist for stakeholders to ask questions, help in planning, and provide oversight. Knowledge of the physical situation also helps stakeholders to consider the basic division of responses into protection and retreat.[4]

*Topography of land on or near the shore*. Topographical features, such as slopes, angles, and distances on or near the shore, are perhaps the most important physical characteristics of interest in adaptation planning. In addition, many coastal settlements (including some of the largest cities, such as Buenos Aires, New

**Figure 5.1:** A house on an eroded coastal dune in northwest Denmark. Source: David C. Major.

York, Rotterdam, and Shanghai) are estuarine, that is, located on the coast at the mouths of rivers, and the situation of possible riverine flooding with sea level rise poses an additional challenge for adaptation planning. Some communities are located on bluffs above the water, and thus are relatively safe from the immediate impacts of sea level rise (although there may be increased erosion over a long period from increased storm surge with sea level rise). Those located on eroding dunes, even if high, can be in immediate danger (see Figure 5.1).

Settlements located on a narrow beach before a cliff are at great risk because floods cannot dissipate beyond the settlement. Other settlements, perhaps the majority, are located on beaches with a low slope, so that surges will reach far inland. In such cases, there is an issue of whether retreat is possible or is blocked by other settlements, natural features, or infrastructure. Other factors which can impact storm surge are the width and slope of the continental shelf. A shallow slope will potentially produce a greater storm surge from a given sea level than a steep shelf.[5]

*Isostatic rebound*. This refers to a change in elevation resulting from the lingering impacts of the last ice age. It occurs as the earth slowly expands from the compression of large ice sheets. In some northern areas, isostatic rebound increases the height of the land, in some cases by a significant amount (90 cm per century in the northern part of the Gulf of Bothnia between Sweden and Finland).[6] In other cases, isostatic effects can result in a drop in elevation, as for instance in the New York City (NYC) area, where, relating to the isostatic rise in Canada and because of the geological structure of the northeast, there is a drop of several centimeters in a century.[7] This was relatively significant in the past, but will be relatively unimportant in the future as sea level rises more rapidly.

*Subsidence*. This refers to processes that result in the loss of land height, increasing relative sea level. Groundwater withdrawal can cause subsidence, as in Venice and other cities.[8] In some cases, such as the southern Chesapeake Bay area of the eastern USA, groundwater withdrawals (as well as isostatic adjustment) can create immediate and significant problems of adaptation.[9] As another example, settlements built on marshy lands can sink with sediments deposited on them from rivers and from the weight of infrastructure. An opposite effect to subsidence can occur in places where tectonic plates converge (as near Mendocino, CA), which can result in a small local uplift.[10]

*Groundwater*. Communities that use groundwater as a source of municipal water supply must be concerned with infiltration of sea water into aquifers, as is happening in southeastern Florida, USA.[11] This situation depends on the degree to which the aquifer is 'confined,' that is, protected by clay or other layers that keep sea water out. Whether such protection will continue with sea level rise is a matter for engineering and scientific investigation.

*Exposure to large storms such as hurricanes*. (These storms are also known as cyclones and typhoons depending on the area of the Earth where they occur.[12]) Wind and rain damages can occur far inland, but a significant part of immediate coastal damage is caused by surge, which will only increase with sea level rise. In the eastern USA, extra-tropical cyclones are referred to as Nor'easters.

*Interior flooding from rainfall*. Such flooding can result from hurricanes and other large storms and other precipitation directly on a coastal settlement. It can also occur from precipitation in river basins upstream of a settlement, as rainfall in the Himalayas can add to floods in cities, including coastal ones, in Bangladesh.

*Limestone or other porous rock*. This affects whether barriers can be built successfully. As in southeastern Florida, USA, where the base is porous limestone, a Dutch-style barrier would be ineffective because sea water would infiltrate through the limestone.[13]

*Other physical considerations*. Other more general changes, such as those resulting from shifts in ocean circulation patterns, will physically impact communities, but are at a larger scale than individual settlements. Information on these should be obtained from scientific agencies and publications.[14]

**Table 5.1:** Physical characteristics checklist for stakeholders.

| Characteristic | Example | Observations relating to the examples |
|---|---|---|
| Slopes and angles | Low-sloping beach | Large area flooded |
| Isostatic rebound | High rebound | More time to adapt |
| Subsidence | Settlement on marshland | Immediate needs |
| Hurricanes/ cyclones/typhoons | Located in hurricane area | Significant infrastructure needs |
| Groundwater | Infiltration | New water sources needed |
| Interior flooding | From upstream rivers | Infrastructure needs, emergency evacuation |
| Porous base rock | Seawater infiltration | Barriers ineffective |

Source: David C. Major and Sirkku Juhola.

Note: Filled in here with examples.

A more general physical categorization that may be helpful for decision-making is the Köppen–Geiger climate classification system.[15] This system categorizes areas of the world in terms of temperatures and precipitation. The categorizations will of course change with climate change, but knowledge of the current situation is helpful to stakeholders in cases where detailed, settlement-level information is not available.

Table 5.1 is a checklist for physical characteristics for stakeholders, with examples of each type and observations on adaptations relating to them.

## Economic and Demographic Characteristics

It is important for citizens, public officials, and planners to know and review the economic and demographic characteristics of their community, to help in understanding the types of adaptations required and their costs, and also to deal with engineering and other firms that might work on adaptations for the community. This information enables stakeholders to contribute more effectively to the adaptation process.

Many wealthier towns and cities have good economic and demographic information. However, of the coastal towns and cities in the world, probably the majority are poor, without good local economic information of the sort presented in government reports. Nonetheless, local people will have some important types of information, such as land ownership and numbers of families. Such information or its lack will be important in helping localities to consider the possibilities of adaptation from local resources, or alternatively from national and international governmental aid and non-governmental organization (NGO) resources. Ideally, income per capita would provide such a guide, but this is rarely available for poor localities; national or regional information may provide a rough framework for decision-making. Relatively wealthy towns are also likely to have economic information on housing and infrastructure (private, public, and commercial) at risk. This information will provide a guide to the potential benefits of adaptations. In some cases, physical metrics, such as number of buildings or kilometers of roads and the proportions of these that have been subject to flooding, will be helpful if economic values and estimates are not available. Demographic information will be important in planning such measures as emergency evacuation. It is important to note that, in the Global South, many coastal megacities have extensive informal housing areas built on some of the most risky land areas. Accurate information on the demographics of these districts is seldom available from databases.

It is important to emphasize that economic data do not provide direct information on environmental issues or, unless very detailed, on distributional and justice issues. On these latter, the Human Development Index (see UN Development Programme 2018) may be helpful, although this is at the national level. For this reason, it might not take into account regional differences in a country. Table 5.2 provides a framework for economic and demographic data.

**Table 5.2:** Economic and demographic characteristics checklist for stakeholders.

| Characteristic | Description | Notes |
|---|---|---|
| **Data availability** | Moderate | Local demographic data |
| **Population** | 10,000 | |
| **Households** | 2,000 | |
| **Gross national income/capita (national or regional if local information unavailable)** | 8,000 (national) | PPP figures for 2015<br>Lowest category<br>(see table notes) |
| **Information on income distribution** | Not available | |
| **Human Development Index (national)** | 0.65 | Medium (2014)<br>(see table notes) |
| **Infrastructure (previously flooded)** | Unpaved roads<br>20 km (12) | Local knowledge |

*Contd.*

**Table 5.2.** *(Continued)*

| Characteristic | Description | Notes |
|---|---|---|
| **Housing units (previously flooded)** | 2,000 (1,600) | Local knowledge |
| **Rules for environmental justice** | None available | |
| **Commercial structures (previously flooded)** | 200 (180) | Local knowledge |
| **Key economic sector(s)** | Tourism (20,000 international beach visitors/year) | Sector threatened by sea level rise and storm surge |

Notes: Filled in with examples for a hypothetical small coastal town in a developing country. Gross national income (GNI) per capita at purchasing power parity (PPP) values for 2015 are given in the following categories by the World Bank (see World Bank n.d.a). PPP categories in thousands of PPP $:<8.22; 8.22–18.81; 18.81–30.84; 30.84–48.40; >48.40. The Human Development Index, produced by the UN Development Programme (see UNDP 2018), is composed of three elements, representing health, education, and standard of living. The health dimension is assessed by life expectancy at birth, the education dimension is measured by mean years of schooling for adults aged 25 years and more and expected years of schooling for children of school-entering age. The standard of living dimension is measured by GNI per capita (see UN Development Programme 2018). The categories of HDI for 2014: <0.550 Low; 0.550–0.699 Medium; 0.700–0.799 High; >8.00 Very High.

## Environmental, Social, Cultural, and Historical Characteristics

It is important for citizens, public officials, and planners to review the environmental, social, cultural, and historical characteristics of their communities. This information helps to provide an understanding of the types of adaptations required, what they might cost, and what trade-offs might be required with economic and other goals. These categories are listed in Table 5.3,

**Table 5.3:** Environmental, social, cultural, and historical characteristics checklist for stakeholders.

| Characteristic | Description | Notes |
|---|---|---|
| **Environment** | Wetlands (200 ha.) | Under pressure from pollution and development |
| **Social** | Local and newly arrived ethnic groups | Potential for conflict in adaptation decision-making |
| **Cultural** | Religious structures and shrines | Importance of preservation where possible against sea level rise |
| **Historical** | 19th-century buildings in old town area | Attraction to tourists |

Source: David C. Major and Sirkku Juhola.

Note: Filled in with examples for a hypothetical small town in a developing country.

which provides a checklist for stakeholders to ask questions, help in planning, and provide oversight. Each of these characteristics is multidimensional, and defining these dimensions is a part of adaptation planning in which both official knowledge and local knowledge will be important.

Environmental areas, for example, can be important in themselves for ecological reasons; as areas of natural beauty; or they may also have direct economic effects, such as revenue from tourism. They also can act to modify or attenuate some of the impacts of climate change on coastal cities. For example, mangrove forests on a coast can modify the impacts of cyclones and storm surges on coastal communities, and other green areas such as parks and city forests can attenuate the impacts of storm surge and interior flooding. Social characteristics will also vary, with often deep roots in local as well as national societies; the same multidimensionality holds also for cultural and historical characteristics. Table 5.3 will thus normally have more rows than those shown here, and these more detailed rows will often be important in decision-making.

**Figure 5.2:** The Rapa Nui National Park on Easter Island. At this UNESCO World Heritage site, the monuments are in danger from rising seas and storm surge (Rapa Nui is the Polynesian name of Easter Island).

Source: Dale F. Simpson Jr.

These characteristics are discussed in more detail below, in the section on 'Environmental Justice,' and in Chapter 7, in the sections on environmental and social objectives and reconciling objectives.

Many of these environmental, social, cultural, and historical characteristics will be well-known, such as the possible loss of the famous statues of Easter Island (Rapa Nui), a Chilean territory in the Pacific, Figure 5.2, and the Stone Age village of Skara Brae, in the Orkney Islands of Scotland, UK, Figure 5.3.[16] However, there are many more instances that are of great importance to local communities, but are not well-known to the outside world. In such cases, stakeholders have the added responsibility to make these endangered characteristics known to all those, including foreign aid agencies, involved with adaptation.

In addition to the range of characteristics of coastal cities and towns discussed above, there are other challenging aspects of

**Figure 5.3:** The Stone Age village site of Skara Brae in the Orkney Islands, Scotland, UK.

Source: John Lord. Published under CC BY 2.0.

adaptation planning. Four of particular significance are discussed here: governance; adaptive capacity; barriers to implementation; and environmental justice.

## Governance

Governance is a concept that is related to collective decision-making in society. It reflects the complex ways in which social decision-making takes place. Whatever the details in a particular society, good governance is crucial to achieving sustainable and equitable adaptation outcomes. Urban climate governance comprises the ways in which public, private, and civil society actors and institutions articulate climate goals, exercise influence and authority, and manage urban climate planning and implementation processes.[17] Adaptation strategies at the city level tend to address the specific climate vulnerabilities and impacts that are particularly relevant to the city in question, focusing on land use, traffic, environment, social issues, equity, infrastructure, rescue services, and public safety.[18]

A first feature of governance that is of great importance is the number and type of stakeholders who are engaged in decision-making. Stakeholders include not only public authorities, that is, city or regional and national governments, but also other stakeholders from the public and private sectors, as described in detail in Chapter 2. (See also 'Working with Others' in Chapter 8.) The importance of stakeholders reflects the fact that to some extent the concept of governance has moved away from an older style of government-dominated decision-making based on command and control principles to a system with more participatory and innovative multi-level arrangements.[19] However, planning often does remain hierarchical, even with public participation included.

A second important element of governance is the level at which decision-making takes place. In the urban context, this can mean including the supra-national, national, and sub-local levels, although the majority of adaptation decisions need to be taken, or at least approved, at the local level. At the local level, while responsibility for adaptations may be shared among agencies, with suitable arrangements for cooperation and coordination, it is also possible that a separate department could be established that cuts across sectoral divides, especially in cases where adaptation is of very high priority. This is an approach that might help with the continuing challenges of getting climate change on the agenda and searching for resources.[20] International networks can be important to support work on climate issues,[21] and there are national level requirements that will need to be considered. Finally, sub-local city networks may be involved in the decision process.

A third important feature of governance is the range of instruments that are used in adaptation. The types of governance instruments that are used can have a significant impact on the extent to which climate adaptation is successful for coastal towns and cities. These instruments can include regulations such as permits used in controlling land use planning related to adaptation. Other instruments may be information policies, such as information campaigns related to climate impacts. There may also be economic instruments, including taxation of certain types of activities relating to climate impacts. A detailed study of environmental laws and regulations to determine their applicability to adaptation has been undertaken for New York City, which illustrates the wide range of available and possible instruments to guide adaptation planning.[22] In cities and towns where no binding regulations exist, organizations may engage with climate change simply because adaptation is essential to the continuation of their activities.[23]

## Adaptive Capacity

A crucial component in enabling and supporting adaptation to climate change in coastal cities and towns is adaptive (or planning) capacity. The concept of adaptive capacity in relation to climate change impacts is defined by the IPCC as 'the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.'[24] (This can extend to the capacity of coastal towns and cities to deal with mitigation, as well as adaptation.) While there will be some positive impacts of climate change in some cities, such as taking advantage of warmer mean temperatures, for example in agriculture, in most cities the negative consequences will far outweigh the positive ones.

There are many elements that enter into a city or town's capacity to support adaptation to climate change. One way of characterizing these is shown in Table 5.4, where the elements are given as: economic resources, technology, information, skills, existing infrastructure, institutions, and equity. An alternative way of considering these elements is to think of them as different types of capital:[25] learning capital (relating to technology, information, and skills), social capital (relating to institutions and equity, as well as cultural factors), and financial capital (relating to economic resources). To these types of capital can be added natural capital.[26] These elements need to be evaluated by stakeholders to help determine: the extent to which capacity is adequate for adaptation

**Table 5.4:** Determinants of adaptive capacity.

| Determinant | Contribution(s) to capacity |
|---|---|
| **Economic resources** | These resources provide for more personnel, better planning processes, and more adaptation options |
| **Technology** | Advanced technology permits more precisely defined and operated adaptations, such as temporary flood barriers and system control measures |
| **Information** | Access to scientific and other information permits better planning and adaptation scheduling |
| **Skills** | Skilled personnel contribute effectively to better adaptation planning |
| **Existing infrastructure** | Well-constructed and flexibly operated existing infrastructure can make additional adaptations easier to design and implement |
| **Institutions** | Well-structured institutions permit more effective planning processes, including the ability to integrate stakeholder concerns |
| **Equity** | Equitable distribution of resources helps a larger proportion of the population to contribute to the planning process |

Source: Adapted from Smit & Pilifosova in IPCC 2001: ch. 18, sec. 5.2.

planning; the extent to which capacity limits the choice of adaptations; and the extent to which capacity indicates the need for outside assistance. While the determinants are interconnected, it is helpful at least initially to examine each separately. The determinants of adaptive capacity for climate change also relate directly to other types of planning.

Adaptive capacity can differ markedly among cities and towns; one Europe-wide study showed, for example, that capital cities tend to have the highest capacity, and regions that have smaller cities have lower capacity.[27] Globally, the large wealthy cities noted in Chapter 1 have high capacities, as do many smaller cities and towns in wealthy countries. On the other hand, there are megacities as well as very large (and unknown) numbers of smaller cities and towns in the Global South that have relatively little adaptive capacity. In that regard, especially in the Global South, there is striking variability in adaptive capacities within cities and towns. For example, well-off suburban estates can be observed where citizens are rich and well-educated, and have access to information (e.g. early warning), while in the poorer (often informal housing) areas, the citizens lack financial resources, have weaker social capital, lower educational levels, and little access to information. With regard to larger cities in the Global South, a study examining six African cities (Douala, Lagos City, Dar es Salaam, Accra, Addis Ababa, and Mombasa, all coastal except Addis Ababa) found that implementation of adaptation was hindered by a variety of factors, including lack of knowledge and the capacity of institutions.[28] The challenges encountered in these cities are formidable and are well set out in the list of policy recommendations derived from the analysis: strengthen city administrations' financial capacity to invest; improve local authorities' skill and knowledge; foster partnerships among public and private stakeholders in implementation; facilitate the adoption of feasible technology and green infrastructure; promote good governance; and integrate climate change adaptation strategies with the urban development plan and disaster risk management.[29]

With regard to adaptive capacity overall, what matters most is the relationship between capacity and adaptation needs. In some cases, local knowledge in small cities and towns will play an important role, even though some other determinants of adaptive capacity are not strongly represented. Especially in poorer communities, there may be more capacity than seems apparent using current methods of analysis because of the existence of traditional arrangements and knowledge. These arrangements and knowledge may not always be helpful in themselves under rapidly changing climate conditions, but they should certainly be taken into account by external planning groups.

Education and training ('skills' in Table 5.4) are central to improving adaptive capacity, and are especially relevant in developing areas. The many resources available include both general learning resources and specifically tailored measures. An example of the former is the *UN CC: learn | resource guide for advanced learning on climate change and cities*,[30] in which learning modules (3) Vulnerable groups in urban areas, (5) Integrating climate change into local planning learning, and (6) Mobilizing financial resources are especially relevant to the adaptation planning discussed in this guidebook. An example relating to module 5, undertaken under the umbrella of the Durban Charter,[31] is a learning exchange between the coastal city of Durban, South Africa, and the deep-water port of Nacala, Mozambique[32] (see Figure 2.2).

An important issue in considering climate change adaptation for poorer towns and cities is whether deficiencies in adaptive capacity should first be overcome before adaptation proceeds.[33] However, a more nuanced and preferred approach is to move ahead with a combination of improved adaptation capacity, removal of barriers (see next section), and adaptation planning. Climate impacts on coastal settlements are becoming so severe, and the challenges of obtaining funding so significant, that adaptation efforts, undoubtedly helped by outside agencies, should go forward wherever possible. As one author puts it:

> Local climate change adaptation in developing countries, therefore, cannot separate from socio-economic development and capacity enhancement. A coordination mechanism for inter-policy is necessary to manage the trade-offs between multiple priorities.[34]

## Barriers to Implementation

Barriers to the implementation of adaptation measures can either prevent the use of some climate change adaptations or affect the extent to which they can be implemented. 'Generally defined, barriers to adaptation are challenges, obstacles, constraints or hurdles that impede adaptation.'[35] There can be barriers that affect each of the capacity elements shown in Table 5.4 (or alternatively the various 'capitals'), or several of these capacity elements at once. Barriers can be seen as the reverse of adaptation capacity: removing barriers increases capacity; in this regard, barriers are sometimes listed, as in a recent IPCC report, as 'constraints' on adaptation.[36]

While there is no generally accepted list or typology of barriers to implementation, and they are usually at least in part context-specific, there are general categories that are helpful guides in considering the situations of particular cities and towns. Among the barriers that are most relevant for coastal cities and towns are institutional, social, informational, and financial barriers.

First, institutional barriers include inadequately defined responsibilities for adaptation planning and inadequate coordination among agencies. Some coastal cities and towns will have dealt effectively with these in the course of their experience with a range of public decision-making; others will be burdened by them. These are among the most intractable barriers; as adaptation methods and experience increase, it should be possible to deal more effectively with them.

Second, there are social and cultural barriers that govern how individuals respond to climate impacts and how they act on these to adapt.[37] They may be prevented from acting effectively as stakeholders. Such barriers can include pressures on groups that are discriminated against and that therefore cannot take appropriate courses of action with regard to climate impacts and adaptations. These barriers are difficult to deal with effectively in project and program planning; planning overviews by outside agencies may help.

Third, there are information barriers, including the unavailability of region- or locally- specific climate change information. However, such barriers will increasingly be overcome with the rapid spread of digital communications even to remote areas.[38]

Finally, there are very often financial barriers that hinder the implementation of adaptation in coastal cities and towns both large and small. These will continue to be challenging, although it is to be expected that aid from developed nations will increasingly be directed toward adaptation as well as mitigation.

In sum, barriers to implementation are elements that present challenges, although increasing concern with adaptation to climate change will allow many to be confronted. There is nonetheless 'a need for research that focuses on the interdependencies between barriers and considers the dynamic ways in which barriers develop and persist.'[39] In some cases, external groups, such as NGOs and aid agencies, can be useful in dealing with barriers to implementation. And the orderly application of the adaptation steps provides a consistent approach that helps to identify and overcome barriers.

## Environmental Justice

The concept of environmental justice is a reminder that it is not only the totality of climate change adaptation that is important to communities, but also the way in which protection against climate impacts is distributed within the community. A useful definition of environmental justice that relates to the environment as a whole, not just climate change adaptation, is: 'Environmental justice (EJ) is the fair treatment and meaningful involvement of all people … with respect to the development, implementation and enforcement of environmental laws, regulations and policies.'[40]

With regard to climate change, the concept of meaningful involvement ensures that all members of the community have the opportunity to be involved as stakeholders in the planning and implementation of adaptation measures.[41]

The need for considering environmental justice in climate adaptation can arise from inequalities in neighborhood conditions and local adaptive capacities within communities. In many cases, less advantaged members of a community may live in low-lying, flood-prone areas that are particularly vulnerable to climate change. These areas may include toxic waste sites of various kinds, which when flooded pose serious health problems. While there is relatively little organized information on flood-prone toxic sites in poorer countries, a study for the USA of riverine and coastal flood-prone areas indicates the potential for frequent and serious impacts.[42] Because resources in general are not equally divided in society, it is likely that people in such neighborhoods will have fewer resources to respond to climate change; they may therefore require more assistance in adaptation than other groups.

Consideration of environmental justice in adaptation planning is not only a matter of fairness,[43] but has a practical impact as well. Over the long periods during which climate adaptation will be required, fairness will be an important component of long-term sustainability in communities. In this volume, some special attention has been devoted to the least advantaged cities and towns, and environmental justice is an element of this.

While information on income distribution is not always available for coastal towns and cities, information on other factors, such as the quality of housing, roads, flood vulnerabilities, and healthcare in different areas of a city, is normally available or discoverable, and this information can guide concerns for fairness in adaptation to climate change.

## What to Know and Do

This chapter focuses on the key information needed to develop adaptation strategies: the physical, economic, demographic, environmental, social, cultural, and historical aspects of coastal cities and towns. Included in the discussion are governance, adaptive capacity, barriers to implementation, and environmental justice.

1. This information is integrated with climate scenarios, the range of adaptation methods, and types of evaluation to develop plans. These elements are directly relevant to towns and cities both large and small. Stakeholders play an important role in evaluating this information and taking it into account in planning: they can provide more detailed input and provide an overview of the completeness and adequacy of available information. This role thus includes suggestions for needed additional information, including information that may be relevant to particular parts of the community.
2. It is important to identify what are the strongest capacities in a town or city, and what are the capacities that are lacking. For example, a city might possess solid information, but might not have enough staff to develop adaptation strategies. This suggests the need for outside assistance, perhaps from national

or international organizations. Financing will also often be lacking, in which case outside assistance will be needed and should be sought.

3. Further, some action may be helpful when there are organizational and governance barriers to the development and implementation of adaptation measures, even with adequate information. These include inappropriate organizational culture and the lack of clear roles and responsibilities in a town or city. Such barriers can sometimes be at least partially overcome once they have been acknowledged, perhaps as a result of stakeholder involvement and the engagement of outside, especially international, sources of assistance.

CHAPTER 6

# The Range of Adaptations to Climate Change

This chapter presents a range of adaptations available for coastal cities and towns confronted by the challenges of climate change. The chapter begins with a description of the main types of adaptation, classified into management, infrastructure, and policy types, with examples of each; continues with sample adaptation pathways over time for two types of coastal towns; and then concludes with a discussion of what stakeholders—citizens, public officials, and planners and others—should know about the engineering, planning, and design of adaptations. The material in this chapter is central to step 4, *Develop initial adaptation strategies*, and relates to other steps as well.

## Types of Adaptations

One big advantage of adaptation planning today is that many if not most adaptation methods, such as those listed below, have already been employed in some form for current issues of coastal flooding and other impacts. They can then be employed with some confidence for climate change adaptation, with the crucial differences that they must be properly designed for future conditions and properly scheduled over the planning horizon to meet changing impacts.

The grouping of adaptations below into three types, management, infrastructure, and policy, provides a convenient way of discussing the range of adaptations, although many adaptations bridge more than one of these categories. (For example, an adaptation that is primarily a managerial adaptation may require some amount of infrastructure, and some policy changes.) In addition, some adaptations may be particularly relevant to different planning periods: the short, medium, and long terms. Adaptations can also be related to the resource-poor or resource-rich situations of coastal settlements, and can be both public and private. More broadly, adaptations respond to impacts by protection, accommodation, and retreat.[1] A final plan will likely include all three of these types of adaptation.

### *Management adaptations*

These are adaptations that can usually be implemented with relatively minor infrastructure changes, and thus are important in near-term adaptation, as well as throughout the planning horizon. Some management adaptations are low-technology and can be implemented in almost all coastal communities. There is therefore great potential, at least in the near term, for adaptation measures related to current operations and management to deal with sea level rise, storm surge, and other impacts of climate change. Planners, with their detailed knowledge of agencies and sectors, will have an important role to play in management adaptations, with oversight from citizens and public officials. Some principal types of management adaptations follow.

*Emergency evacuation plans*. These can be implemented in almost all communities; they can be complex in developed cities, requiring, for example, the use of highly developed public transportation; or relatively simple, such as pathways to natural or artificially higher ground in rural areas such as in Bangladesh.[2] The emergency evacuation plans (and the refuges that accompany them) against storms and coastal flooding in India and Bangladesh are perhaps the most successful and cost-effective adaptation measures against current and future climate risk anywhere in the

Global South. These methods were remarkably successful in 2019 when Cyclone Fani hit both countries. In India, 'the authorities whisked more than a million people to safety, executing an evacuation plan that they have been perfecting ever since [the] disastrous storm in 1999,' and 'Indian officials transmitted millions of text messages, broadcast warnings over public address systems and sent fleets of buses to take vulnerable people to hundreds of cyclone shelters that had been stocked with water and food.'[3] Similar success was reported in Bangladesh.[4] It should be noted that these evacuation plans and the refuges need to be assessed and evolved over time as climate continues to change, with possibly more intense storms and further sea level rise.

*Communications about climate impacts*. Communications methods can be used to inform citizens about recommended or required behaviors relating to climate impacts, such as water-saving measures during droughts and local flood proofing against higher storm surge. A drought management plan,[5] for example, will normally include both operational measures and procedures for communication with users. Such communication also includes information on cooling centers where citizens can go on the expected greater number of very hot days. The New York State (US) Department of Health, for example, has a website, https://www.health.ny.gov/environmental/weather/cooling/, which lists cooling centers in those counties that provide them.

*Joint system operations*. Plans should be in place for joint operation of a town or city's transportation, water, energy, and communications systems in emergencies. An example is managing transportation systems to control travel and congestion during flood emergencies so as to avoid further risks to lives and assets.[6]

*Transportation management*. Prepositioning of rolling stock and other assets upon storm warning and the expected higher surges resulting from climate change is very important in preventing damages; this was done very successfully by New York's Metropolitan Transportation Agency prior to Hurricane Sandy in 2012.[7] Other management adaptations for transportation include revising travel routes to reflect expected flooding; improving pumping capacity for tunnels and other areas; and increasing back-up emergency equipment so that service can be maintained as long as possible.

*Water systems*. Short-term adaptations include drought management schemes with provision for water supply for essential uses. Longer-term system adaptations include changing reservoir systems management to reflect expected increased temperature and precipitation effects from climate change on water quality and quantity.

*Drainage systems*. An important system management adaptation is better maintenance of drains and gutters to clear these systems so as to reduce the extent and duration of flooding. This is particularly important under conditions of climate change because of the expected increase in the intensity of rainfall in many areas.

## *Infrastructure adaptations*

These are the adaptations that involve constructed facilities; existing ones are inventoried as part of adaptation assessment step 2. They can range from small to very large; the larger ones generally take significant planning time, and thus tend to be appropriate for implementation later in the planning horizon (barring emergencies). Infrastructure adaptations are sometimes classed as 'hard' and 'soft,' the former being barriers such as sea and flood walls and surge barriers, and the latter being adaptations such as reconstructed wetlands that reduce the impacts of sea level rise and storm surge.

*Sea walls*. These are probably the most famous type of constructed barrier. They are used to protect ocean and estuarine shorelines against both normal sea and tidal levels, as well as estimated storm surges (see Figure 1.3). The best-known sea walls are the dikes of the Netherlands, the protective system of which includes land below sea level.[8] Sea walls in general are permanent installations, often quite large, although some are relatively small and some emergency barriers (such as sand bag walls) can be included under this heading. There are a variety of names for different types of sea walls, such as dikes, but all have the same protective purpose. Related types of shoreline armoring include groins, jetties, breakwaters, bulkheads, and piers.

*Flood walls*. These are a common type of constructed facility, including walls of various heights and design. Like sea walls (with which they are sometimes grouped), they are used to protect populations and properties. They are usually differentiated from sea walls because they may be along river banks or elsewhere away from the sea coast, but these definitions are very flexible. Flood walls (sometimes referred to also as levees and other terms) have been widely implemented for current conditions, and there is extensive engineering and planning experience with them. The examples of flood wall types shown in Figure 6.1 illustrate the detail in which engineering and planning guidance is available for many adaptation types.

A relatively new type of flood barrier is a temporary (but regularly used) barrier that is erected in a predesigned setting ahead of flood warnings. Figure 6.2 shows the temporary walls used for the Whitney Museum of American Art in New York City, which is located in a flood-prone area near the Hudson River. There are other temporary barriers, the modern version of sandbags, that can be used for a single flood or for several years while permanent infrastructure is completed. These include wire mesh barriers with heavy duty fabric liners, and plastic tubes. The former are filled with sand or gravel and the latter with water.[9]

*Surge barriers*. These are constructed facilities built across harbors to block storm surge. They may have movable gates or other mechanisms to enable ships to enter harbors. The best-known ones are quite large, such as those in London, Rotterdam, and Venice.[10] However, they have also been implemented for current conditions in some smaller cities, such as the New Bedford, MA, USA, hurricane protection barrier, shown in Figure 6.3. If properly designed, they can block storm surges with sea level rise; however, they do not block the wind and rain damages that accompany cyclones and other large storms. They require long-term planning and careful evaluation of all impacts. Other places where barriers have been proposed are New York City and Jakarta.[11]

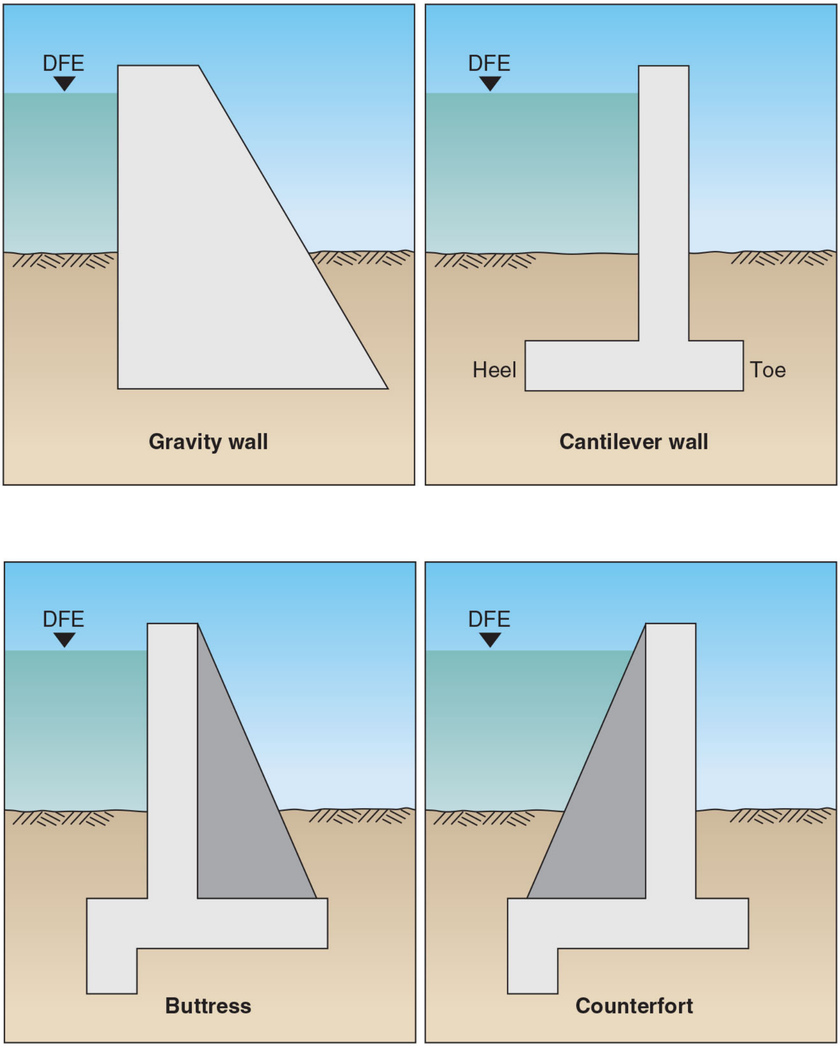



**Figure 6.1:** Types of flood walls.

Source: FEMA 2012: ch. 5.

Note: DFE stands for design flood elevation, the elevation of the highest flood that a flood wall is designed to protect against.

*Raising and relocating buildings, roads, and other facilities.* Buildings and key elements within them (such as electrical equipment) can be raised or relocated to higher ground. These


**Figure 6.2:** Temporary flood barriers for the Whitney Museum of American Art, New York City. The photo shows the structure and method of emplacing the barriers.

Source: Gregory Weithman.

measures can both accommodate climate change impacts and defend against them, depending on design. Raising a road, for example, can both accommodate risks and, if designed as a barrier,

**Figure 6.3:** New Bedford, MA, USA, hurricane protection barrier, completed in 1966. The barrier is located in New Bedford and Fairhaven Harbor, approximately 50 miles south of Boston. The project protects about 1,400 acres (567 hectares) in the towns of New Bedford, Fairhaven, and Acushnet.

Source: Jesse Costa/WBUR; for details on the barrier, see U.S. Army Corps of Engineers, 2015.

defend against them, whereas relocating electrical equipment is primarily an accommodation. Such adaptations have been undertaken to respond both to currently experienced conditions and to climate change; an example is a case study of private adaptation of this type in New York City.[12] Figure 6.4 shows a road that has been raised in Miami Beach, Florida, a city that has an aggressive infrastructure program for both current and future flooding.[13] In general, it is important to note that procedures such as placing electrical equipment on floors higher than expected floods are much cheaper when designed into structures from the start, rather than being fixed after structures have already been completed. This relates to step 6, *Link strategies to capital and rehabilitation cycles*.


**Figure 6.4:** A raised road in the city of Miami Beach, Florida. The elevation acts as a defense against flooding.

Source: Graham Major-Ex.

**Figure 6.5:** Floating Pavilion, Rotterdam.

Source: Rotterdam Climate Initiative. Published under CC BY 2.0.

*Floating structures*. These can range from small houses (such as in the famous floating villages of Tonle Sap in Cambodia)[14] to larger structures such as the Floating Pavilion (Figure 6.5) in

Rotterdam.[15] Within their design ranges, they adapt to rising water levels. They are generally more appropriate for protected waters rather than the open sea.

*Urban drainage systems*. These systems can be expanded or upgraded to deal with increased interior flooding because of expected more intense (and possibly also increased) precipitation levels due to climate change. Measures such as green roofs (Chapter 1) can be employed to attenuate rainwater flows, reducing the immediate flood impact of intense rain on drainage systems.

*Water systems*. Water systems can be impacted by many elements of climate change, including sea level rise, storm surge, droughts, and floods. Infrastructure adaptations, many of them requiring extensive planning and long lead times, include increased physical linkages between parts of a system to provide redundancy, relocation of groundwater wells away from coastal areas with groundwater subject to salination, and possibly increased storage capacity.

*Wastewater treatment systems*. These can be upgraded, potentially at high cost, to ensure that rising sea levels do not block tide gates and prevent gravity outflows into coastal waters from the systems. This is likely to require additional pumping (and therefore more energy use).

*Refuges*. These are buildings constructed to protect populations that often are designed to house schools or other facilities on the second floor.[16] Figure 6.6 shows a cyclone shelter in Bangladesh that is also a primary school. These refuges act as endpoints to emergency evacuation routes.

*'Soft' adjustments*. These include a range of adaptations to coastal flooding, including beach nourishment, dune raising and re-planting, and restoration of saltmarshes. These are often designed to attenuate the effects of floods rather than to act as direct barriers, such as flood walls. They also include: new wetlands, piers and slips, oyster beds, artificial islands, artificial reefs, and offshore piers.[17] An example is shown in Figure 6.7, an artist's conception of an artificially constructed barrier islands proposal for the southern tip of Manhattan, New York, USA, 'optimized to decrease the velocity of currents and waves associated with storm surges, while respecting navigation lanes.'[18]

**Figure 6.6:** Uttar Seral Government Primary School, Agulchara, Barishal, Bangladesh. The building is also a cyclone shelter.

Source: © Mahfuzul Hasan Rana World Bank 2013.

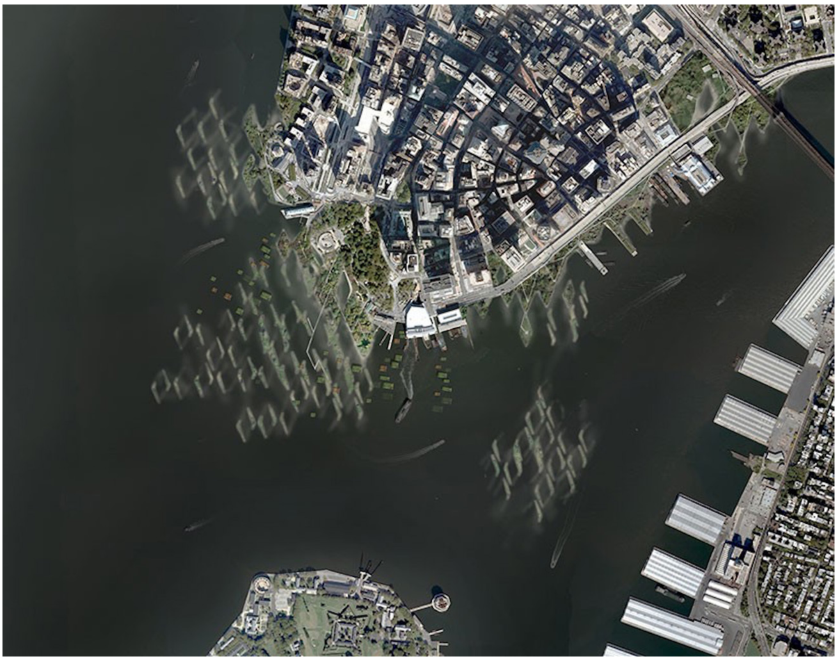


**Figure 6.7:** Proposal for reshaped coastline of Lower Manhattan with barrier island formation.

Source: © 2010 Guy Nordenson and Associates, Catherine Seavitt Studio, and Architecture Research Studio. Source: Nordenson et al., 2010, *On the Water: Palisade Bay*, 165.

## *Policy adaptations*

Policy adaptations change the framework of adaptation. Such changes can be within a town or city, between two or more settlements, or between a town or city and the regional and national governments. On the one hand, they may seem simple to introduce, but on the other they may require lengthy political processes to implement. Thus, some may be appropriate for near-term adaptations, and others for longer-term adaptations.

*Legislation*. National (or state) legislation can impact climate change adaptation for cities and towns through requiring planning efforts and possibly also the use of specified climate scenarios. Legislation at the national level regarding climate change has tended to focus on mitigation, rather than adaptation, as the former lends itself to national requirements such as automobile mileage standards or cap-and-trade systems, while the latter, encompassing a range of settlements, is likely to be more complex.[19]

*Zoning*. Local zoning changes can impose restrictions on construction design and types in areas at risk. These can include policies that are incorporated both in new construction and in retrofits to existing infrastructure. In the city of Helsinki, Finland, for example, minimum base heights for construction based on updated sea level scenarios and guidelines are required, although construction is decided on a case-by-case basis.[20] Changes in construction materials may be required to better withstand the effects of higher temperatures; other measures might include integrating 'green' designs such as green roofs on buildings, especially those that house key infrastructure, to reduce the building's energy needs while ensuring proper functioning. These roofs thus are both adaptation (holding rainwater to lessen flooding) and mitigation (reducing emissions).

*Land use changes*. These, related to zoning and other forms of regulation, enable areas at risk to be reserved for parks and other low-density uses that can survive flooding with minimal damage. Parks can absorb floodwaters from storm surge and intense precipitation and absorb the impacts of surge-related wave action;[21] having parks in areas at risk rather than buildings and other infrastructure can be an important adaptation to the impacts of climate change.

*Financial incentives*. As flooding in coastal areas becomes more frequent and economic and social damages increase because of climate change, one policy is to use financial incentives to buy out residences and other buildings in flood-prone areas and prevent rebuilding and thus future damages. A riverine program, which has characteristics relevant to coastal communities, is in Nashville, TN, USA. The city uses a voluntary program to buy out people in flood zones by paying market rates for houses. The city razes the house and prohibits future development; the 'acquired land becomes an absorbent [flood] buffer.'[22] A mixture of federal, state, and local funds is used. It is to be expected that such programs, which can be very cost-effective, will increase for coastal areas.

*Managed retreat*. Managed retreat is an important adaptation method that involves the movement of populations (and sometimes infrastructure) from existing locations to higher or better-protected areas.[23] It reduces or eliminates the impacts of sea level rise and increasing flooding from storms, while attempting to maintain continuity in settlements. Retreat can also mean complete relocation, as, for example, from an island to a mainland site or even to another nation.[24] A well-thought-out plan for managed retreat is for coastal communities in São Tomé and Príncipe. Relocation to higher ground was requested by coastal populations themselves after experiencing heavy flooding: 'The essence of this strategy, which the government is currently piloting, is to effectively manage voluntary population retreat from coastal areas at risk to safer, higher ground.'[25]

Managed retreat is relevant to both wealthy and poor communities, but it is to some extent forced in the latter because of lack of resources for accommodation and defense, one of the many elements of adaptation impacted by income inequality. One study provides helpful overall guidance for considering managed retreat:

> A preferred approach is for retreat to be integrated into the pursuit of broader social goals (the strategy) and its implementation tailored to context-specific goals (the management). This

> reorientation is needed to innovate, deploy, and refine socially viable and equitable approaches to retreat.[26]

*Joint system operations*. These policies call for long-term joint operations of water, energy, transportation, and communications systems with neighboring administrative and political units. For example, arrangements can be made for safe placement of transportation assets in neighboring communities ahead of expected storm surges.

*Joint or coordinated construction*. These policies call for cooperation in infrastructure design and construction among neighboring settlements so that protections are consistent. For example, flood walls should be at similar heights, without gaps between them. An inland place where this has been a serious issue is on the Mississippi River in the USA: 'Every time they build a levee or raise one, it hurts everybody without a levee.'[27] This can also be true also for coastal protection against storm surge in adjoining areas.

*Storm warning systems*. Policies can be adopted to ensure that a settlement is connected to or has access to national or supranational storm warning systems.

*Flexible adaptation pathways*. All of these adaptation methods, and their many variants, provide important sources of information to enable stakeholders to participate fully in the adaptation process. In the development of adaptation plans, they should be considered within the context of flexible adaptation pathways. This means that, to the extent possible, adaptations and combinations of adaptations should be planned to maximize the possibilities of adjustment and re-planning as experienced and expected climate conditions change. This useful concept is illustrated in Figure 6.8.

As an example, a community would build enough of an adaptation—say, a sea wall of a certain height—to match the estimated (and uncertain) change in sea level over a certain time period, rather than building a larger project all at once. While this is not always possible, it will work in many cases. For example, if a sea wall is to be built, it could be built on a smaller scale at first, but designed so as to reserve land and include foundations strong enough for future expansion. Flexible adaptation pathways can be

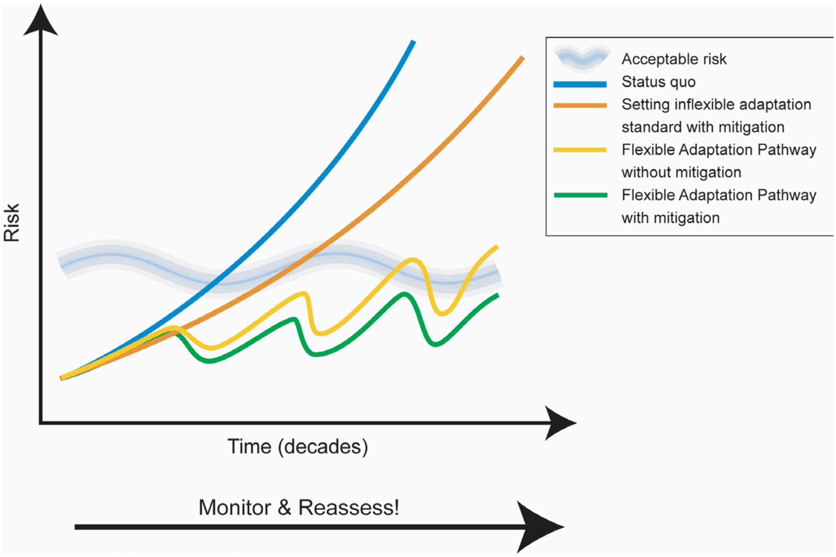



**Figure 6.8:** Flexible adaptation pathways. The wide, blue-gray line represents some level of acceptable risk. The solid lines represent different approaches to adaptation (see the figure keys), from keeping the status quo (which crosses the risk level soonest), to flexible adaptation with mitigation, which provides the potential for staying below the target risk level. This possibility depends on adaption technology, the accuracy of scenarios, and costs.

Source: Major & O'Grady 2010: 243; after Lowe et al. 2008.

expected to be of increasing importance in adaptation planning as experience with the method is gained. A discussion of adaptation pathways in the New Zealand context, but with wider relevance to the material discussed here, is in Britton et al. 2016.[28]

## Sample Adaptation Pathways

This section provides two sample adaptation pathways (i.e. trajectories over time) for typical smaller coastal cities and towns. The aim is to help stakeholders consider the actions that might be taken in the short, medium, and long terms so that they are efficient, effective, and consistent.[29] The two pathways are: (1) for a small, poor, coastal settlement with minimal infrastructure; and

(2) for a relatively wealthy, small, coastal city in a developed country. These two types are representative of a significant proportion of coastal cities and towns, while the analytic method is relevant to large cities as well. Some of the latter already have significant reports on adaptation, as noted in Chapter 1. In each of the examples, there is an assessment of adaptation challenges and opportunities and a suggested adaptation pathway based on them.

This work is part of steps 4 and 5 of the adaptation assessment steps: *Develop initial adaptation strategies* and *Identify opportunities for coordination*. This discussion is especially useful considering that most adaptation work to date does not assess 'the processes of implementation or the effects of adaptation actions.'[30]

### *(1) A small, poor, coastal settlement with minimal infrastructure*

This type of coastal settlement has the characteristics (Chapter 5) of a relatively small and poor population and minimal infrastructure and represents a significant fraction of all coastal communities.

*Assessment of adaptation challenges and opportunities*. Small, poor coastal communities such as this example, with minimal existing protection, provide one of the most challenging situations for adaptation. From an economic standpoint, it may be difficult to justify substantial adaptations; on the other hand, from a social and cultural standpoint, these may be justified. Such communities may have been in existence for a long time, and the members will typically have significant experience with local history and conditions. In this regard, stakeholders will include informal local councils and elders. In many cases, there will have been some raising of structures and the community members may have experienced temporary evacuation. It is assumed in this example that the community may for economic reasons (e.g. fishing) be built in an area with gradual slopes, that is, without the natural protection of cliffs. In addition, it is assumed that it will be difficult for the community to access aid from national or regional governments.

*Adaptation pathways*. The option discussed by Gornitz, of 'staying put and holding the line as long as possible,' may not realistically be available.[31] This will likely be true of most such communities, and certainly true of low-lying island communities. Adaptation thus involves a measured element of retreat, using local knowledge of flooding and other impacts and minimizing disruption. In the short term, some moderate, locally constructed adjustments are appropriate. These include raising dwellings (of limited use in cases of strong storms), together with some improvements in evacuation pathways. Where storms are significant, early warning may be possible with new technology, including cell phones. In the medium term, retreat and relocation are probably the most appropriate options. With regard to these methods of adaptation, issues of governance, including property rights, compensation, and technical assistance, will be critical and difficult to resolve in countries with weak institutions. A sample adaptation pathway for this small, poor settlement with a population of perhaps 10,000 is shown in Table 6.1.

### *(2) A wealthy, small town in a developed country*

*Assessment of adaptation challenges and opportunities*. This small city is in a coastal area with a relatively narrow beach and a fairly rapid inland rise to originally forested land. The town has fully paved streets, comfortable houses and public buildings, and a modest harbor for small boats, with a protective breakwater. There is well-managed bus and rail transit service to larger metropolitan areas, as well as highway access. It is subject to cyclones, both tropical and extra-tropical. The well-managed city has excellent contacts with local universities and state and national science agencies. Key stakeholders are the elected town council and citizens who are used to attending public meetings on important questions. Water supplies are from inland reservoirs. There is a stable tax base and orderly borrowing facilities for infrastructure management. The main climate impacts are the impacts of rising sea levels, higher storm surges, and potentially more intense inland rainfall.

*Adaptation pathways*. The city has had flooding from storm surge beyond historical experience and so adjustments and adaptations are required for a system that is fairly well adapted to historical

**Table 6.1:** Adaptation pathway for a small, poor coastal community with minimal infrastructure.

| Time period | Actions | Costs/Notes |
|---|---|---|
| **1. Immediate** | Improve evacuation plans | Based on local knowledge; inexpensive |
| **2. Short term (1–5 years)** | Some locally constructed adjustments; join early warning systems if available; review retreat and refuge options | Some outside assistance required for refuges |
| **3. Medium term (5–15 years)** | Retreat and relocation of some buildings/roads; possibly moderate protection for some buildings/roads | Moderate costs, some local; institutional and property issues; access current science regarding sea level rise and storm surge to consider flexible pathways |
| **4. Long term (15–50 years)** | Plan and implement full retreat | High cost; complex institutional and property issues |

Source: David C. Major and Sirkku Juhola.

Note: The sample community is located on a gently sloping area, impacted by both sea level rise and storm surge. The time periods are defined conventionally here and in Table 6.2; they will vary depending on a community's resources, timing of hazards, and other climate change challenges and opportunities. An alternative approach, benchmark years, is discussed in Chapter 7.

experience. The city is in somewhat the circumstances of the large cities worldwide that have taken the lead in adaptation planning, except that it does not have a large scientific and engineering establishment of its own. However, it can draw on experienced firms for assistance, as well as local universities and agencies for science guidance. The main problem is to determine an effective and fiscally efficient series of adaptations that will protect the city over decades.

Unlike the poor community in the previous example, it is able to exercise the option in Gornitz of 'staying put and holding the line as long as possible.'[32] This settlement is likely to be able to deal effectively with the levels of sea level rise currently expected over this century, except if the highest estimates are the reality. There will, however, be some managed retreat in the immediate beach areas, such as at Herring Cove Beach in Provincetown, MA, USA.[33] In the long term, it may be that a surge barrier will be needed across the harbor, although this will depend on the pace of sea level rise and on whether softer measures will suffice. A surge barrier might be relevant as part of a long-term, staged response to rising sea levels and flooding, especially if rising sea levels and enhanced flooding proceed at the higher end of projections.

A sample adaptation trajectory for this wealthy settlement with a population of perhaps 30,000 is shown in Table 6.2.

The important differences in the two example settlements in this section are: (1) the level of wealth, and thus of the ability to work with universities, agencies, and contracting firms in a stable institutional environment; and (2) the resulting difference in whether ultimately retreat will be required. In the two cases described here and others, adaptation timing should ideally be flexibly integrated into the overall town or city planning framework, and linked to best estimates of sea level rise, changes in storm characteristics and frequency, increases in salinity of groundwater and other impacts.

It will be of great importance to follow the relative success of mitigation attempts worldwide in the coming decades through contacts with scientific groups (possibly via websites)—if warming can be kept to below 2°C, this will be an important element of planning for adaptation. (An IPCC report deals with keeping warming to 1.5°C.[34]) Even communities that are quite poor today, like the community in the first example, are likely to be able to access such information in the coming decades. Information of this kind will be essential in considering flexible adaptation pathways over time.

**Table 6.2:** Adaptation pathway for a wealthy coastal community with good infrastructure.

| Time period | Actions | Costs/Notes |
|---|---|---|
| **1. Immediate** | Install any needed updated signs/directions for evacuation<br>Review adaptation plans | Based on regional/national criteria |
| **2. Short term (1–5 years)** | Design and install additions to current flood walls | Contracts with experienced engineering/construction firms |
| **3. Medium term (5–15 years)** | Initial planning for soft harbor infrastructure and partial beach retreat | Science contacts with and advice from state/national universities and agencies<br>Work with neighboring municipalities<br>Access current science regarding sea level rise and storm surge to consider flexible pathways |
| **4. Long term (15–50 years)** | Implement soft infrastructure and limited retreat options<br>Consider planning for a possible surge barrier | Relatively high costs met by borrowing |

Source: David C. Major and Sirkku Juhola.

Note: The example community has experience in contracting for engineering, planning, and construction work.

## What to Know and Do

1. The descriptions of adaptation measures and sample pathways that are the focus of this chapter provide an important part of the information that stakeholders require to participate fully in the adaptation process. Stakeholders will want to have a good general sense of the range of adaptations that are available (with suitable redesign and scheduling) and some typical possible adaptation pathways. Familiarity with these will help

stakeholders to interact effectively with engineering firms and donors within the planning horizon for a coastal town or city. A knowledge of the range of adaptations will help stakeholders to judge what the possibilities are for adaptation within the available resources in the immediate future and later as climate change continues.

2. This information is part of the beginning of step 4 in the adaptation steps: *Develop initial adaptation strategies*. The information in this chapter, together with the information on evaluation in Chapter 7, provides a basis for asking questions, contributing to planning, and providing oversight. This information also provides insights into when expert knowledge is needed.
3. In addition, judgements on the need for adaptation at particular times involve some social decisions on the part of stakeholders, such as the willingness of a community to endure flooding for a short period of time versus the disruption that may be caused by immediate implementation of adaptations. Stakeholders should nonetheless be clear that adaptations will be required; there is some but not necessarily extensive flexibility on when, depending on social as well as economic decisions. In addition, stakeholders will want to ensure as far as possible that public and private adaptations are compatible.
4. Stakeholders should continue to be aware of important design, technological, and case study availability changes in the years to come. In addition to design improvements in the many available adaptations, the technological framework for adaptation will change in the coming years in ways that will assist effective adaptation planning, including improved visualizations of prospective adaptations. Better smartphones and increased internet access will enable many more communities and settlements than now to access information about climate, adaptation planning, and available resources. In addition, as adaptation proceeds, there will be more case studies that stakeholders can examine for lessons and techniques that can be borrowed.

CHAPTER 7

# Evaluation of Projects and Programs

This chapter describes methods of evaluating and planning potential adaptations to climate change. Evaluation is central to four of the adaptation assessment steps: step 4, *Develop initial adaptation strategies*; step 5, *Identify opportunities for coordination*; step 6, *Link strategies to capital and rehabilitation cycles*; and step 7, *Prepare and implement adaptation plans*. Citizens, public officials, and planners all have important roles to play in the evaluation process and these steps. The chapter begins with an overview of methods for evaluating the appropriateness of adaptations, and continues with sections on: scheduling adaptations over time; finance, cost constraints, and planning time lags; adaptation checklists; and examples of adaptation costs. A discussion of what to know and do about these key subjects concludes the chapter.

## Evaluation

Evaluation involves the assessment of the benefits and costs (or positive and negative effects) of adaptation projects and programs on the objectives of adaptation: economic, financial, environmental, social (including environmental justice) and cultural and historical objectives. Evaluation is especially relevant to step 4 of the adaptation assessment steps, *Develop initial adaptation strategies*, as well as to the steps that follow step 4.

*Benefit-cost analysis*. The best-known evaluation technique is economic benefit-cost analysis (BCA; also called cost-benefit analysis), which has been developed over many years. The earliest known use of the approach that required that project benefits exceed costs was embodied in the US Flood Control Act of 1936.[1] Following World War II, standard economic BCA methods were developed and, by the early 1960s, were widely accepted.[2] This was followed by the development of methods for assessing non-economic as well as economic objectives.[3] Straightforward economic BCA continues to have relevance in adaptation, but these wider approaches to evaluation (often called multi-objective or multi-criteria approaches) can be of great importance in adaptation planning, which often requires taking into account a range of objectives; see 'Reconciling objectives,' below.

At the project level, BCA consists of identifying the stream of benefits and costs over time for each scale of the project (such as the height of a flood wall) and bringing these back to present value by means of an interest rate (discounting). The next step is to choose the project scale that yields the maximum net benefits. In the context of adaptation to climate change for coastal cities, one large class of benefits is the damages from flooding that would be prevented by adaptation. Other economic benefits can accrue from the prevention of salinization of groundwater supplies, the avoidance of healthcare costs, and other impacts. The benefit-cost approach has been widely used by the World Bank and other agencies for project analysis.[4]

*Benefit-cost analysis in practice: example*. The Multihazard Mitigation Study presented a BCA of US Federal Emergency Administration Hazard Mitigation grants.[5] (Note that 'mitigation,' as used in that study, is more generally understood as adaptation.) These included a set of grants to raise streets and structures in Freeport, Long Island, New York, USA, a coastal town with an estimated 2016 population of 43,279, to prevent flooding under existing conditions.[6] The approach would be the same for future climate change conditions, with the addition of climate scenarios for forecast years (step 1, *Identify current and future climate hazards*) and the estimation of future damages for those years. The analysis

**Table 7.1:** Costs, benefits, benefit-cost ratios, and ranges for HMGP grant activities in Freeport, NY, USA.

| Activity in Freeport, NY | Total costs (2002 $m) | FEMA costs (2002 $m) | Best estimate benefits (2002 $m) | Best estimate benefit-cost ratio | Benefit-cost ratio range |
|---|---|---|---|---|---|
| Building elevation | $2.36 | $1.77 | $13.5 | 5.7 | 0.18–16.3 |

Source: Adapted from Multihazard Mitigation Council 2005: 107.

Note: HMGP = US Federal Emergency Management Agency Hazard Mitigation Grant Program.

for building elevation is given in the table. The total costs were US$2.36 million; the grants for raising private structures required local matching funds of 25%; the match for raising private buildings was paid by the owners. The study examined a wide range of values of benefits and costs, and concluded that the total Freeport benefit-cost ratio best estimate for this adaptation to coastal flooding was 5.7, with a range of 0.18–16.3 (Table 7.1). This provides some sense of what might be required in the future in small and medium-sized coastal settlement areas such as Freeport, or in specific areas of larger cities.

The benefit-cost approach has proven its utility as a framing method, and where benefit and cost estimates are good, relatively robust conclusions can be drawn about economically optimal adaptation design. On the other hand, the approach can be misused or used ineffectively; the quality of the work must be judged on a case-by-case basis. This is an important area for stakeholder oversight. Nor should the method be used as a sole decision criterion in most adaptation situations, where objectives other than the economic one (such as saving lives, preserving communities, protecting the environment, and attaining economic justice) are important.

*Financial analysis*. The financial analysis of an adaptation project can be significantly different than the economic analysis of a project. Financial analysis is concerned with the actual monetary flows of a project, both in terms of outlays for the project and payments for the outputs of the project. It is designed to show whether an adaptation is financially worthwhile for the agency undertaking it, rather than to capture the true economic benefits and costs of the adaptation, which may differ. For example, if an adaptation prevents $10,000 of flood damages per year, but the agency undertaking the project can collect only $6,000 per year from those who enjoy the benefits, the economic benefits exceed the financial returns. This circumstance can lead to projects that are economically sound, but not financially feasible, one of the many elements of evaluation that stakeholders must monitor. Gittinger, in the standard World Bank study cited above, provides both economic and financial analyses of a bank project in Africa.[7] It should also be noted that there are some attempts to estimate the monetary values of natural services (such as water purification by a marsh).[8]

*Environmental objectives*. Environmental objectives vary significantly in different places; in relatively poor countries, environmental issues may be closely linked to livelihoods, whereas in wealthier countries, they may be more closely linked to quality of life. In any event, suitable metrics for these objectives (such as number of hectares of wetland preserved) need to be identified for adaptation planning. Stakeholders will play an important role in oversight for environmental planning, especially in ensuring that any national environmental laws and regulations are observed. Many countries have environmental laws and regulations, although their observance in some countries is sporadic.

One of the first such laws was the US National Environmental Policy Act (NEPA), Public Law 91-190.[9] In Section 102B of that law, it is required that methods and procedures be identified and developed to 'insure that presently unquantified environmental amenities and values may be given appropriate consideration in decision-making along with economic and technical considerations.' Furthermore (102C), there should be included:

> … in every recommendation or report on proposals for legislation and other major Federal actions significantly affecting the

> quality of the human environment, a detailed statement by the responsible official on
>
> (i) the environmental impact of the proposed action,
> (ii) any adverse environmental effects which cannot be avoided should the proposal be implemented,
> (iii) alternatives to the proposed action,
> (iv) the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and
> (v) any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented.

This and similar laws in other countries require that environmental objectives be considered in adaptation and other projects, and that trade-offs with other objectives, such as economics, must be considered.[10] This multiple objective approach to decision-making is central to sustainability and important to adaptation planning.

The European Union has extensive laws and regulations dealing with the environment. Among the data to be collected and analyzed under Regulation (EC) No. 401/2009 are data on climate change and adaptation to climate change. This is done with a view toward, among other things, providing the EU with the objective information necessary for effective environmental policies.[11]

*Social objectives, including environmental justice. and cultural and historical objectives*. Social and other objectives can be significant parts of adaptation to climate change in coastal towns and cities. These settlements are often well-developed though not necessarily wealthy communities; taking social and other objectives into account in adaptation planning can be important both for the community and for society as a whole. For somewhat larger settlements, where perhaps there is no cohesive overall community, environmental justice may suggest the protection of all or part of the settlement because of the existence of poorer sub-communities. These objectives, while important, may be expensive to attain and will certainly in many cases require outside assistance. There is some ethical justification for this because these often poor and small communities have on the whole added little to global warming and the consequent impacts of sea level rise and other climate variables. Stakeholders from outside the community may need to be involved in these issues.

*Interest rates*. In detailed studies, the interest rate is a key element in assessing future benefits and costs from climate change. The present value of such effects can change greatly depending on the value of the interest rate. The interest rate embodies judgements about the future as compared to the present, that is, it is an inter-temporal weighting assigned to future events expressed as a percentage. In a pure economic model, the interest rate serves to allocate resources properly over time. There are several correctives to this relating to climate change adaptation. First, the true interest rate, because of market imperfections and income distribution considerations, is not known. Second, there will generally be different weights on the future as compared to the present for different objectives, as, for example, economic versus environmental objectives. Finally, the great uncertainties of climate change suggest that ordinary discounting is probably not a sufficient criterion for decision-making.[12]

In fact, the limitations of standard BCA for climate change have been addressed in significant part through discussions of the interest rate. There are advocates for low social rates of discount, as well as more standard economic rates.[13] Higher interest rates have the effect of postponing action on climate change, as future benefits are more heavily discounted. Stern argues that the risks of inaction are quite high (and largely uncertain or unknown) when compared to the costs of action (about 1% to 2% of gross domestic product for several decades).[14] The use of higher interest rates may carry the implicit assumption that actions are reversible, which they are not likely to be in transformative conditions such as climate change.

It may be best to utilize several interest rates (that is, to do sensitivity analysis) to consider what adaptation proposals appear to be good under a range of assumptions. An important World Bank report on the economics of adaptation to climate change suggests the use of sensitivity analysis on the interest rate.[15] On the other hand, one clear use of a specific interest rate is when funds for an adaptation are borrowed. In such a case, the financial benefits must be sufficient to pay off the loan at the cited interest rate. It is also important to note that methods for integrating a social rate of discount (i.e. a socially determined interest rate, rather than a market rate) with shadow pricing (an estimate of true opportunity cost) for private sector investments foregone due to public investment have long been available.[16] However, these methods are complex and have not been widely used.

*Using analogs*. Because of the large number of coastal cities and towns, and the fact that adaptation planning is a relatively recent phenomenon, there is not a large library of benefits and costs (or positive and negative effects) on various objectives, and thus for many coastal settlements adaptation planning will include uncertain estimates. (On the other hand, for some objectives, local knowledge will be quite exact.) Nonetheless, in some cases, analogous information from other studies will be available; this is called the 'value transfer method' by Costanza et al. for economic values.[17] Some information will also be available for such objectives as protecting wetlands and keeping communities together.

*Reconciling objectives*. Stakeholders will be deeply involved in the discussion of multiple objectives and the evaluation of potential adaptations in terms of them, with the knowledge that achieving different objectives will often involve difficult decisions on trade-offs. There are well-developed graphical and mathematical methods for organizing data on positive and negative effects on different objectives that will aid in evaluating trade-offs among objectives.[18] Particularly in the case of complex decisions, these methods will be helpful for stakeholders, especially in the context of 'Questions for Stakeholders Throughout the Planning Process' in Chapter 8. On the one hand, some adaptation decisions will be relatively straightforward and contribute on a net basis to several objectives, such as protecting both physical assets and a community. There may be a large number of potentially worthwhile investments of this type available in the near term, partly because so little has been done in the past that directly confronts the impacts of climate change. However, more generally, objectives will conflict rather than be complementary for many potential adaptations. For example, strengthening existing flood walls in fairly well-developed settlements may be worthwhile from an economic standpoint. However, there may be environmental costs such as impacts on coastal flow patterns, wetlands, and aquifers, which would suggest softer infrastructure methods. It is also possible that there may be few new environmental costs because earlier costs have already been incurred through implementation of the lower existing flood walls. There are many other possible cases of trade-offs among objectives, including very high costs for community or historical preservation that cannot be generated by the resources available to local settlements. An example is the costly potential relocation of the small Native American coastal community of Shishmaref in Alaska, USA, described below in the section on costs.[19]

## Scheduling Adaptations over Time

Scheduling of adaptations is an important component of adaptation planning. In most cases, it would not be appropriate, even if financially feasible, to implement all adaptations at once. They should track the development of climate impacts, constrained by financial and institutional resources. It is careful scheduling that enables coastal towns and cities to plan climate adaptations within the context of long-term sustainability.

*Benchmark years*. Benchmark planning years are useful tools for organizing the many dimensions of adaptation. The number of benchmark years chosen for a particular city or town depends on: the capacity of the planning entity; the seriousness of vulnerabilities and impacts over time; and the availability of scenarios. One useful starting approach is to choose three benchmark years.[20] Forecast climate variables and impacts at the benchmark years are compared to those variables in a suitable base period to guide planning. To take an example, for a base year of 2015 (or, more generally, a base period to smooth out short-term fluctuations), the benchmark years might be 2025, 2050, and 2090. This choice can be thought of as follows. The first benchmark year provides a relatively near-term target that is nonetheless sufficiently far off that some implementation activities can take place by that date. Such adaptations could include, for example, the development and implementation of an evacuation plan and system operation changes for transportation management. The second benchmark year provides time for planning and implementing structural measures, as well as more complex policy and management measures; and the third benchmark year provides a distant marker for long-range planning that includes provision for flexible adaptation pathways. Depending on the problem, intermediate benchmark planning years can also be selected.

The benchmark years provide a convenient way of organizing information for stakeholders. An example is given in Table 7.2.

**Table 7.2:** Benchmark years, forecast sea level rise, and typical adaptations.

| Benchmark planning year | Forecast sea level rise above base year 2015 | Forecast storm surge | Forecast storm surge with sea level rise | Typical adaptations |
|---|---|---|---|---|
| **2025** | 5 cm | 60 cm | 65 cm | Evacuation plan; system management changes |
| **2050** | 40 cm | 60 cm | 100 cm | Soft and hard infrastructure; regional agreements |
| **2090** | 1 m | 60 cm | 160 cm | Provision for large-scale infrastructure |

Source: David C. Major and Sirkku Juhola.

Here, the benchmark years are 2025, 2050, and 2090, and the assumed base year is 2015. The climate scenarios are for sea level rise and storm surge compared to the base year, and examples of possible adaptations are given. The example numbers in the table assume that sea level will rise, but that storms will have the same intensity throughout the planning period; thus, the same surge is added to sea level rise at each benchmark year to estimate the general impact of sea level rise on flood heights; for a specific storm, tide conditions should be added.

There are several complications and some fine-tuning that relate to the simple presentation in the table. First, in calculating vulnerabilities and impacts for the example in the table, the duration of flooding may be important, as well as the maximum flood height. Second, for adaptation planning generally, marginal costs will be relevant in choosing adaptations to meet the impacts foreseen at the benchmark years. If adaptation targets can be exceeded cheaply, probably this should be done. (In any case, the evaluation methods described earlier in this chapter should be applied to the choice of adaptations.) An alternative approach to benchmarking, by time period, that may be particularly helpful early in the planning process, is shown in Tables 6.1 and 6.2.

*Adaptation design and scheduling*. An important issue in scheduling adaptations is the relationship of the design of adaptations, their expected lifetimes, and the proposed years of their implementation. In much standard practice, a project design is optimized and put on the shelf until funds are available. However, to take an example, if a project has a 20-year lifetime, and future conditions differ from present conditions as they will with climate change, the project will no longer be correctly designed if its implementation is delayed by planning or financing lags. For example, a project with a lifetime of 15 years and a target date of implementation of 2020 should be designed to cover expected conditions in 2035. However, if its implementation is delayed and it is brought on line only in 2030, the project will no longer be the correct one—it should be redesigned for 2045 conditions. A further consideration is that provision should be made for the replacement of an adaptation—the use of the concept of flexible adaptation pathways, explained in Chapter 6.

A more complex issue is that, when benefits are reasonably well-estimated, it may pay to postpone some adaptations if benefits—that is, flood damages prevented—are rising over time—thus saving expenditures for potentially more worthwhile current investments.[21] This is an issue that may require some expert help. An example from an analysis of present and future storm surge damages in Copenhagen, Denmark, together with the costs of dikes and sluices to prevent present and future flooding, indicates that from a purely economic view, the optimal construction time of the dikes and sluices is 2035, assuming a construction time of five years.[22]

## Finance, Cost Constraints, and Planning Time Lags

*Finance*. Financing for adaptation to climate change is an essential component of planning, with the objective of getting the most favorable terms over the planning horizon. The time dimension of support depends on climate scenarios and the integration of scheduled adaptations with them.

Financing can come from various sources. Locally, there is in-person labor, both individual and community; mutual funding; and possibly also micro-lending to a local community.[23] In more developed areas, this lending could come from local banks. Other sources include municipal bonds, again something that would be appropriate in more advanced areas, but not available to poorer, less organized communities. Grants, loans, and technical assistance are often available from regional, national, or foreign aid entities. Some types of adaptation (e.g. surge barriers) will need significant financing, and these and other expensive works may be beyond the means of all but the most favored communities, although foreign aid may make some possible.

Some innovative financial arrangements for adaptation to climate change have been developed. As an example, the Seychelles has committed to the creation of 400,000 $km^2$ of new marine protected areas to improve resiliency of coastal ecosystems in return for a restructuring of its external debt. This debt swap enables the Seychelles to redirect a portion of their current debt payments to fund designated nature-based solutions to climate change. The Nature Conservancy brokered this public–private agreement between the Seychelles Government and its creditors; it is said to be the first debt swap designed explicitly for climate adaptation. This debt restructuring could serve as an important example of financing for other coastal adaptations to climate change for both settlements and ecosystems.[24]

Another innovative and potentially large funding source (albeit taking time to adjudicate) for adaptation planning and implementation in the Global South relates to environmental justice, and the fact that many communities that have contributed little to global warming will be among the most affected by it. This approach is exemplified by the Torres Straits Islanders' claim to the United Nations against Australia. The Torres Straits Islands are part of the state of Queensland, Australia, and the islanders claim that Australia's failure to undertake adequate mitigation efforts and its failure to fund adequate coastal protection measures constitute a violation of their rights to culture, family, and life.[25] It is possible that many more such claims will be made in the future.

In all financing decisions, stakeholders have a significant role to play, especially in ensuring transparency and buy-in. In particular, the issue of inadequate government supervision at higher levels must be taken into account. It should be noted also that loans may be difficult to pay back; communities may begin to withdraw from the coast, and the town or city that took the loan in effect will no longer exist in its original form.

*Cost constraints*. Cost constraints relate to all of the adaptation assessment steps, but especially to steps 4 to 7. They describe a situation, extremely common, where there is not enough funding from public and private sources to build all worthwhile projects that a community might deem necessary for climate adaptation and other purposes. There are several approaches to this situation. The ideal alternative from a community's point of view is to attempt to expand the resource base by bringing in international aid agencies or agencies of the national or regional governments, where these are effective enough to contribute. This alternative will, of course, often not be possible. One good way to avoid at least some of the impact of resource constraints in dealing with climate change, and particularly rising sea levels, is to carefully implement the use of flexible adaptation pathways.

The approach of economic theory to resource constraints is that they should be implemented by scaling back the least beneficial parts of each desired project so that the 'best' core of each project can be implemented.[26] (This is technically referred to as applying an internal 'shadow price' to resources, meaning that each dollar expended is valued for planning purposes at more than a dollar when comparing benefits to costs.) This is a useful idea that can be applied to the various objectives—social, environmental, and economic, of a project. When there are some projects that appear to be absolutely necessary if the community is to survive, this can mean not just scaling back all projects, but actually not doing some things at all. These are difficult decisions to which stakeholders must contribute.

*Planning time lags*. These relate to all of the adaptation assessment steps, but especially to steps 4 to 7. It takes time to plan and to plan well. There are time requirements for complex designs embodying engineering and other standards; there are simple bureaucratic delays; and there are approval delays. Taken together, these can add up to many years. Time lags will differ as to type of adaptation. Better signage on escape routes may be implemented quite quickly; flood walls may take a medium amount of time; and complex structures such as surge barriers can take many years. Lags can also differ by source of funds and planning aid; it is possible, in countries with inadequate and, for various reasons, inefficient domestic bureaucracies, that adaptations undertaken with external assistance may be implemented more quickly than those undertaken domestically.

In every case, planning should take such lags into account, on the same principle discussed in the section on scheduling: design should be for the actual expected date of implementation, rather than for the date at which planning starts (the common approach in the past). With regard to lags, stakeholders can play an important role by ensuring that, to the extent possible, lags are due to genuine planning issues and not to simple bureaucratic delay.

The issue of lags relates not only to planning, but also to the adoption and implementation of plans. For example, a comprehensive planning effort for climate change (Plan 4C) has been developed for Cartagena, a World Heritage coastal city in Colombia.[27] However, the adoption of the plan and implementation of its recommendations have according to some reports been delayed by administrative and financial issues.[28] Stakeholders have a role here in contributing to more rapid progress. As is the case with all lags, this calls for openness and transparency, which stakeholders can help to bring about. This also calls for a realistic knowledge of the extent of delays in any given situation, which can in part be known through experience. Table 7.3 shows example adaptations, requirements, and planning time to implementation.

**Table 7.3:** Example adaptations, requirements, and planning time to implementation.

| Adaptation | Requirements | Planning time to implementation |
|---|---|---|
| **Signage for evacuation** | Legal, design standards | 1 year |
| **Sea walls (larger than existing)** | Engineering design, model/ mathematical testing, environmental review, financing | 5 years |
| **Harbor surge barrier for small city** | Engineering design, model/ mathematical testing, review of 'soft' alternatives, environmental review, financing, higher-level approvals | 30 years |

Source: David C. Major and Sirkku Juhola.

## Adaptation Checklists

The adaptation checklist (Table 7.4) is a guide for adaptation planners; it will encompass all of the significant elements of

**Table 7.4:** Adaptation checklist.

| Checklist element | References and comments | Adaptation assessment steps |
|---|---|---|
| Climate scenarios for benchmark years (sea level rise, storm surge, heat, wind, precipitation) | | 1 |
| Benchmark years | | 1 |
| Included in inventory | | 2 |
| Vulnerability study | | 3 |
| Site in relation to future sea level rise, storm surge | | 4 |
| Designed for specific future year | | 4, 7 |
| Designed in reference to other adaptations | | 4, 5 |
| Key elements (e.g. electrical) above future sea level rise, storm surge estimates | | 4, 7 |
| Economic analysis | | 4, 7 |
| Environmental analysis | | 4, 7 |
| Social analysis (including environmental justice); cultural and historical analysis | | 4, 7 |
| Financial analysis | | 4, 7 |
| Can be designed more conservatively or with more co-benefits at relatively little cost? | | 4, 7 |
| Flexible adaptation if scenarios change | | 4, 7 |
| Relation to rehabilitation and replacement cycles | | 6 |
| Funding available for date of implementation | | 7 |
| Monitoring program designed | | 8 |

Source: David C. Major and Sirkku Juhola.

adaptation planning at the project level if the planning methods described have been followed. The table includes the checklist element, references or comments as appropriate, and the relation of the element to the adaptation assessment steps. The checklist has three functions. First, it is a checklist for project planners, designed to ensure that the full range of analysis that is appropriate to adaptation is applied to each project. Second, it provides an essential component for in-agency review of project plans, helping to indicate to supervisors that these are complete. Finally, it is a key, publicly available aid to oversight by citizens and public officials (see 'Questions for Stakeholders Throughout the Planning Process' Chapter 8).

The main adaptation steps that relate to each element in the checklist are given; however, it should be remembered that the adaptation process is an integrated one, so that, broadly speaking, all the steps have some relevance to each element. Moreover, the full checklist may not be relevant for all situations, such as a simple evacuation plan, but it can nonetheless serve as a target for all adaptation planning. For smaller and simpler adaptation problems and efforts, the adaptation checklists may be correspondingly simpler than the full list shown. The column for references/comments allows the designers and reviewers to trace the sources of information and the pathway to design.

## Examples of Adaptation Costs

The examples of adaptation costs given here relate especially to adaptation assessment steps 4 to 7. These costs are approximate guides to economic costs; costs (negative impacts) relating to other objectives will also be important.

Available cost examples are mainly from developed nations and special situations, such as islands. Informal adaptation methods are less well documented in terms of costs. The development of many more cost examples will be an important product of continuing adaptation assessment for coastal towns and cities. Cost examples are given here for special cases, low-cost adaptations, and

**Figure 7.1:** The village of Shishmaref, Alaska.
**Source:** Bering Land Bridge National Preserve.

medium-cost adaptations. Very high-cost adaptations, of which one example is given, will relate almost exclusively to large cities.

*Special cases*. Shishmaref is a well-settled Inupiat (Native American) community (see Figure 7.1) of about 600 people on an exposed barrier island in the US state of Alaska.[29] The only practicable solution to maintaining this community, because of the severity of current and future climate change impacts, including flooding and erosion, is to move the community to nearby sites on the mainland, about 5 miles (8 km) away. A 2004 estimate of the cost of relocation, $180 million, far exceeds what would be possible for the community to raise on its own and would of course be higher since that estimate was made. Such funding would have to come from government and private sources for social, cultural and environmental reasons, including environmental justice, as the community is poor and has contributed almost nothing to global warming and rising seas. On the other hand, this level of

**Figure 7.2:** A shoreline in Kiribati.

Source: Government of Australia, Department of Foreign Affairs and Trade. Jodie Gatfield AusAID, attribution 2.0 Generic (CC BY 2.0).

expenditure for each such community is clearly unlikely, even in rich countries. Most relocations are more likely to involve a measure of retreat over continuous space, not from islands to the mainland.

Another special case is that of the island nation of Kiribati in the South Pacific. The estimated elevation of the islands is less than 2 meters above sea level.[30] Figure 7.2 shows a shoreline in Kiribati. Seriously threatened by sea level rise, the government is said to have purchased 6,000 acres (2,428 h) of land in Fiji as a future refuge for the islanders for US$9.6 million.[31] This is just the cost of land; total resettlement costs will be much higher.

*Low-cost adaptations*. Some adaptations with low costs will include evacuation planning and route marking. In such cases, the costs may not be monetized, or they may be included in agency operation costs and therefore not broken down separately. Other low-cost adaptations will include modest flood walls and raising of small houses and other structures. In some cases, it will be helpful to stakeholders to have these costs broken down by person-hours of work, rather than in money terms.

*Medium-cost adaptations*. Table 7.5 has examples from the northeastern United States, including both hard and soft infrastructure. Because the examples are from the same geographical area, they are broadly comparable. The costs shown are from reports; only some of the adaptations have been implemented. Some of the projects, especially the earlier ones, focused on then-current climate impacts, rather than on the future impacts of

**Table 7.5:** Medium-cost adaptations and one proposed high-cost adaptation from the northeastern United States.

| Adaptation | Climate (current or future) and/or other variables | Location and report year | Estimated cost |
|---|---|---|---|
| Reconnecting a salt marsh | Adapt to development | Long Island, New York Sound (Connecticut shoreline) (2003) | Total cost $60,000–141,000 for 10 acres |
| Wetlands restoration | Sea level, storm surge | Jamaica Bay-Elders West, New York City (2010) | $10 million for 40 acres |
| Wetlands restoration | Sea level, storm surge | Soundview, New York City (2010) | $5 million for 4 acres |
| Sea wall repair | Sea level, storm surge | Roosevelt Island, New York City (2001) | $6,222,000 |
| Beach nourishment | Sea level, storm surge | Coney Island, New York City (1995) | $9,000,000 |
| Beach nourishment | Sea level, storm surge | Westhampton Beach, Long Island, New York (1996) | $30,700,000 |
| Surge barrier | Storm surge | New Bedford, MA (1966) | $18,600,000 |

*Contd.*

**Table 7.5.** *(Continued)*

| Adaptation | Climate (current or future) and/or other variables | Location and report year | Estimated cost |
|---|---|---|---|
| Temporary flood barriers and other adjustments (2013) | Sea level, storm surge | Whitney Museum, New York City (2013) | Approx. estimate $20,000,000 |
| Storm surge barriers | Sea level, storm surge | New York/New Jersey Harbor (2009) | $9.1 billion for three-barrier system |

Sources: Aerts et al. 2009: 75; Leichenko et al. 2011: 39; Pogrebin 2013; Whitney Museum of American Art n.d.

Note: Costs are as of the report dates given in the table, not indexed to a current year.

climate change. (Note that beach nourishment, widely used in the past, is less likely to be used with climate change.) One high-cost project, a proposed surge barrier for New York and New Jersey, is included for comparison.

For each of these cases, details are given in reports on which the table is based, and stakeholders can consult these where the examples appear to have particular relevance to their communities. As an example of the type of information available, the New Bedford, MA, surge barrier can be considered:

> Construction of the New Bedford Hurricane Protection Barrier … was completed in January 1966, costing $18.6 million. The project required the relocation of power cables, modification of sewerage and drainage facilities, and acquisition of a small boat yard, several buildings, and about 36 acres [14.5 h] of land. The city maintains the project, with the exception of the navigation gates and the barrier extending across New Bedford and Fairhaven Harbor which are operated and maintained by the Corps [U.S. Army Corps of Engineers].[32]

Another example, this one from the private sector, is the temporary flood barrier system at the Whitney Museum of American Art in New York City (Figure 6.2). A new museum building was constructed near 14th Street and the Hudson River for US$422 million. The additional cost for the temporary flood barrier system and other flood protection measures such as loading dock doors was about 5% of building costs. All of the systems are in place or can be erected quickly with notification of significant hurricane or other flooding danger.[33]

A final issue about costs is what should be done about indexing for the benefit of stakeholders. It is possible to bring dollar amounts, for example, up to current dollars using the sophisticated Engineering News-Record (ENR) indexes, and it is also possible to convert dollar amounts to other currencies using on-line calculators.[34] Whether indexing and conversion should be done depends on when planning is undertaken, and whether the information lost in the indexing and conversion processes is less than the convenience gained for stakeholder evaluation. Relatively few areas have good construction indexes, such as the ENR indexes in the USA, and it is difficult to make cross-cultural comparisons given currency fluctuations and controls. These are detailed planning issues that stakeholders will confront in specific planning situations.

## What to Know and Do

The project planning elements that are the focus of this chapter (methods of evaluation, scheduling, financing, cost constraints, planning lags, adaptation checklists, and adaptation cost) are primarily components of three adaptation assessment steps: 4, *Develop initial adaptation strategies;* 5, *Identify opportunities for coordination;* and 6, *Link strategies to capital and rehabilitation cycles*. These three steps lead up to step 7, *Prepare and implement adaptation plans*. The project planning elements in the chapter help to integrate adaptation into everyday planning and management processes in coastal cities and towns.

1. There are many elements of the planning process to which stakeholders should contribute. Stakeholders have an important role to play in this work, providing input and oversight of the development of adaptation projects. Because of the potential complexity in developing projects and programs, and the need in many cases for outside expert assistance (e.g. in evaluation measures), it is particularly important for stakeholder involvement to be regularized on a planned schedule with opportunities for review, feedback, and further development.
2. As is true throughout the adaptation process, local information including both written or recorded data and informal knowledge will be one important input that stakeholders can provide to those developing projects and programs.
3. Stakeholder involvement provides the opportunity to recognize that not all risks are experienced or perceived in the same way by all those concerned; in this respect, broad stakeholder engagement can provide legitimacy and support for the measures chosen.
4. Further, while in the case of most coastal cities climate change adaptation will have a significant claim on resources, there will be many other demands for resources in addition to adaptation. It is therefore important for stakeholders to review the full range of priorities using participatory methods, and to help keep climate change adaptation needs to the fore.

CHAPTER 8

# Getting It Done

## Working Together to Develop and Finance Adaptations

The previous chapters cover the principal elements of adaptation planning in a series of guidelines and explanatory sections. In this chapter, elements of planning that deserve particular additional attention are discussed, including plan formulation, questions for all stakeholders to ask at each step of the adaptation process, working with others, and monitoring and reassessing adaptations. A discussion of what to know and do about these key subjects concludes the chapter. The material in this chapter emphasizes and reflects the important fact that effective adaptation planning is a participatory process.

### Plan Formulation

Assessment step 7*, Prepare and implement adaptation plans,* is the culmination of the preceding steps. An adaptation plan is a group of properly scheduled projects and programs that reflect the needs of a community's different sectors. These plans are evaluated with regard to the extent to which they achieve community objectives, have extensive involvement by all stakeholders, and include implementation responsibilities. They are undertaken with a view toward later monitoring and reassessment (step 8).

Adaptation plans need to be examined using the evaluation methods of Chapter 7. Planners should review the details of separate projects and examine how these projects interact, whether with complementarity or competition, and how the design, scale, and schedule of each one should be modified if necessary. This is a second round of evaluation, with the additional step of examining the interactions among projects and whether changes are needed to ensure the most effective attainment of adaptation objectives. Fortunately, much of the work of plan formulation can be undertaken during earlier stages of planning. This is because project studies will often be done with an eye toward the final plan, and scaled and scheduled accordingly. Two excerpts from an interactive adaptation planning tool developed in Australia are particularly apt in summaries of important elements of plan formulation:

> Having identified a suite of adaptation options, you now need to select options to include in your plan, and discard those that may be maladaptive or which are not suitable for the purposes of your … stakeholders.
>
> And, you can also identify options that will achieve short term as well as long term outcomes, and work on sequencing when these options should be implemented and identifying thresholds … for implementing various actions.[1]

In developing plans, there may be simple decisions in many cases. For example, there may be an existential threat of climate-related flooding that requires an immediate focus on adaptation measures to preserve the lives and property of a community without detailed regard to the longer future. On the other hand, plans can be complex. The long future must be considered, as must the balance of objectives and the relationship of adaptations to other challenges facing cities and towns, including the economy, housing, roads, parks, and other sectors that must be integrated with climate adaptations.

There are no generally available overall mathematical models for the formulation of plans. However, for some components, there are highly developed models that will be useful, such as the SLOSH model for estimating surge heights from hurricanes.[2] Such models can be used in conjunction with orderly methods and procedures, such as benefit-cost analysis, not necessarily imbedded in mathematical models. A useful source of guidance is the long history of river basin planning, in which plan formulation that integrates a set of interacting projects is a standard procedure.[3]

With regard to objectives, alternative plans may be formulated based on alternative objectives, including economic, financial, environmental, social, cultural and historical objectives, all of which must be discussed with stakeholders. It should be noted that in some cases it might be possible to obtain the same level of climate protection with different combinations of structural and/or non-structural measures, and decisions between them will depend on the objectives and financing of the plan.

In all cases, scheduling is of great importance to the design of plan components; moreover, scheduling should be linked to flexible adaptation pathways to allow for adjustments in the plan, including cost savings, as different possible futures unfold. What will ultimately be done will depend, in significant part, on longer-term issues of how well climate change is controlled worldwide.

All stakeholders contribute to step 7. Planners contribute effectively to the development of adaptation plans and their integration into a community's development plans. Citizen stakeholders weigh in on the merits of the final adaptation plan (and alternatives) for a community. This includes judging impacts on individuals and households, and supporting, disagreeing with, or suggesting changes in the proposed final plan. Finally, the oversight and leadership of public officials is essential to ensure that the final process occurs efficiently and effectively. Public officials can also help ensure that adaptation planning is mainstreamed into activities of all public agencies, which will increase the effectiveness of the adaptation process both in the near term and over the longer horizon.

When a plan is selected, there should be a plan checklist as detailed in Table 7.4 for projects. This should include a full description of the way in which the plan is expected to reduce the impacts of climate change on a city or town, or, more generally stated, how it is to achieve the objectives of the plan. In addition, as experience with the Sustainable Development Goals (SDGs) accumulates and a consistent set of targets and indicators is identified, reporting on the impacts of climate change adaptation on these can be a regular part of managing climate change adaptation in coastal towns and cities.[4]

Implementation, including financing, also needs to be planned and described. Implementation responsibilities can be local, regional, national, or international, and should include private implementation by individuals and firms. Full implementation details can be elaborated with regard to the near and medium terms, with plans for the longer term in less detail, including provision for changes in implementation responsibilities should climate futures and other factors change.

Finally, the chosen plan should include indicators for monitoring and reassessment (step 8), in particular, the plan

> … should include an agreed process and time frames for when to update the plan. This will ensure that there is due consideration of new data, that risk assessments are updated, and that new innovative mechanisms and approaches to adaptation can be incorporated.[5]

To this it should be added that regularly planned reviews and updates will permit increasingly effective planning capacity, especially in poor communities, to be brought to bear on adaptation planning over time.

## Questions for Stakeholders Throughout the Planning Process

One of the best ways of working together on climate change adaptation is through shared questions at different points of the planning process. The most important questions, organized here (Table 8.1) by the adaptation assessment steps, are suitable for asking within all of the meetings and discussions on adaptation planning, whether they are among experts or with a wide range of stakeholders. The material available for review when asking and

**Table 8.1:** Stakeholder questions.

| |
|---|
| **Step 1: Identify current and future climate hazards** |
| What are the sources and extent of data on existing climate hazards, including local knowledge, local agency records, and state and national and international records? What are the key lacks, and how can they be made good? |
| What climate scenarios for the future are available? Are these for regions, or are they locally focused? What is the scientific quality of the scenarios? |
| What data and scenarios will become available in the next few years, and how might this new information affect current plans? |
| What stakeholders have been involved in this and the following adaptation steps? Should others be included? |
| **Step 2: Conduct inventory of infrastructure and other assets** |
| Have key infrastructure and assets, including environmental, social, cultural, and historical assets, that are vulnerable to climate change been fully identified and mapped? |
| Does the inventory include an assessment of their current condition and identification of maintenance responsibilities? |
| Have the elements and assets been categorized by distance from the water and height above mean sea level or other suitable markers? |
| In addition to written inventories, is there local knowledge from which to draw? |
| **Step 3: Characterize risk of climate change impacts on infrastructure and other assets** |
| How has what is known about climate risks been related to inventories of infrastructure and other assets to characterize specific risks? |
| How will risks change, including costs and social and environmental impacts, in relation to the growth of income and population, as well as climate change? |
| Which risks are of immediate importance? |

*Contd.*

**Table 8.1.** *(Continued)*

| |
|---|
| **Step 4: Develop initial adaptation strategies** |
| What is the range of adaptations considered for the initial strategies? Should additional strategies be considered? |
| Have all relevant objectives been taken into account? |
| What were the success criteria for selecting the initial strategies: costs, lives saved, and/or environmental and social impacts? |
| What were the sources of technical/engineering assistance used in planning? Should additional experts be consulted? |
| **Step 5: Identify opportunities for coordination** |
| Which adaptation measures can and/or should be coordinated with other local sectoral planning, neighboring communities, and regional and national efforts? |
| How have the designs of these adaptation measures been adjusted to take into account the benefits and costs (or positive and negative impacts) of coordination? |
| **Step 6: Link strategies to capital and rehabilitation cycles** |
| Among existing infrastructure and other asset categories, which current and future projects/programs can be adapted to climate change? |
| What information is available on capital and rehabilitation schedules and costs? |
| How recently has this information been compiled, and is further information needed? |
| Which current infrastructure and other assets can be adapted to climate change in the course of replacement and rehabilitation? |
| What estimates have been made of adaptation costs during replacement and rehabilitation, compared to later add-ons? What further estimates should be made? |

**Table 8.1.** *(Continued)*

| |
|---|
| **Step 7: Prepare and implement adaptation plans** |
| What arrangements have been made for detailed public review of plans, including costs, financing, and scheduling? This includes ensuring that stakeholders are fully aware of the needs and opportunities for climate change adaptation, and can contribute to ensuring the timely and appropriate allocation of scarce resources to adaptation. |
| How will the results of these reviews be reflected in plans? |
| What are the details of scheduling and finance for each project/program? |
| How has scheduling flexibility been incorporated in the plan to enable adjustments to new climate scenarios and changes in population and income? |
| **Step 8: Monitor and reassess** |
| What arrangements have been made to monitor the success of measures after implementation and make adjustments, if necessary? |
| Has the monitoring program been fully funded in the relevant agencies? |
| When will public reviews of monitoring and reassessment plans be undertaken? Is there a planned schedule, such as every three years? |

Source: David C. Major and Sirkku Juhola.

discussing these questions will include the detailed adaptation checklists developed for each proposed adaptation project and program (Chapter 7) and for the final proposed plan, as well as other information from earlier in the planning process. This approach will contribute greatly to transparency and full analysis and review, leading to more effective final adaptation programs and their scheduling and monitoring.[6]

## Working with Others

Adaptation to climate change is a relatively new issue for citizens, public officials, and planners and the many other actors involved

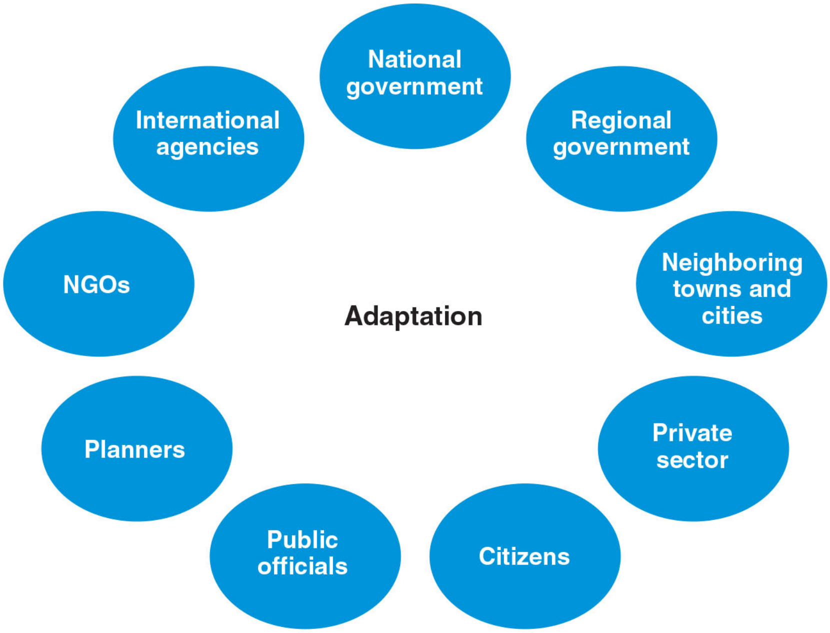



**Figure 8.1:** Actors in adaptation.
Source: David C. Major and Sirkku Juhola.

(summarized in Figure 8.1), and there is a need to adapt institutions to deal effectively with it. As with various aspects of adaptation, there is a wide variety of capacity in coastal settlements to do this. Well-managed communities both large and small will have the capacity to modify existing organizational arrangements, such as placing adaptation planning in an existing department, or developing intra-departmental arrangements that will provide for the participation of a wide variety of stakeholders. Many smaller communities, on the other hand, will not have developed organizations of the same complexity, but may have customary patterns of decision-making. This is an area in which examples from successful efforts from elsewhere can be helpful.

*Outreach*. One type of organizational method is finding out how to reach out to individuals to help them in their own climate adaptation efforts. These are ideally, but not always, coordinated with overall adaptation plans. A good example of this type of organized outreach deals with adaptation of dwellings to the higher levels of

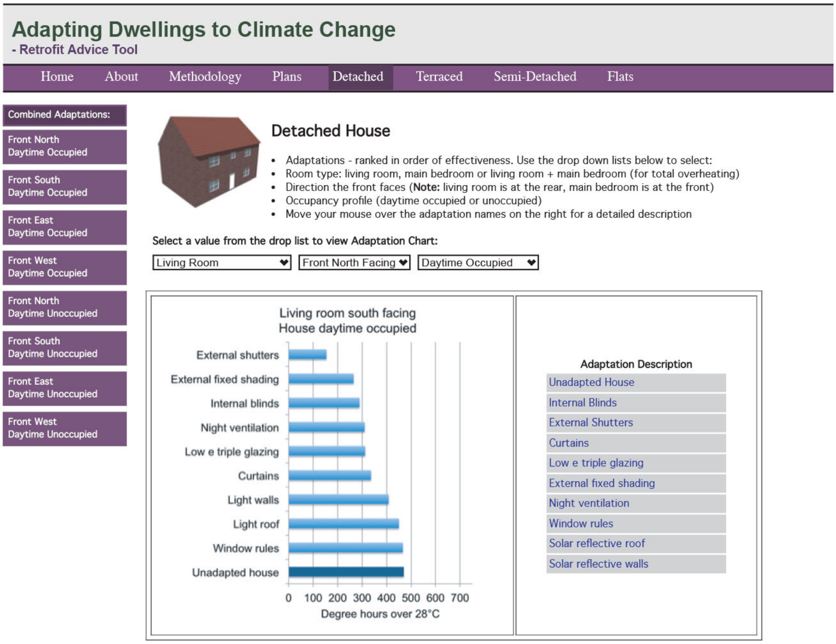



**Figure 8.2:** Adapting dwellings to climate change.

Source: © Stephen Porritt, Paul Cropper, June Wang, Li Shao, see IESD 2016.

future temperature that will occur. This example (Figure 8.2) is from London, which is considered to be at significant risk from climate change already.[7] A digital database has been developed that allows homeowners to describe the characteristics of their dwellings and then to find suggested adaptations and estimates of cost for adapting to warmer temperatures.[8] An example is shown in the figure for a detached house with rooms facing in specified directions, and whether these rooms are occupied during the day. This is a type of organizational outreach that can be adapted to other cities and for other climate impacts.

A second example of this type of organizational outreach is from the Nordic countries. University researchers, working with the insurance industry, produced an online database for Nordic house owners.[9] This allows the users to select the location of one's house in the Nordic countries and. through downscaled climate scenarios, the database provides estimated climate change impacts from temperature and precipitation. The database then provides suggested adaptations for different types of houses and building materials. This type of database is rather general for most coastal communities, and needs to be adapted to include flooding and sea level rise potentials, but it is indicative of what may be expected as adaptation planning becomes more effective. The lesson is that good possibilities exist for this type of outreach, but that further work is required.

*Organization*. The first example relates to stakeholder involvement in a report on the Metro East Coast area, centered on New York City, for the first US National Assessment of the Potential Consequences of Climate Variability and Change for the United States.[10] This report was undertaken under the leadership of Columbia University, in cooperation with other universities, and supported by the US National Science Foundation and other grantors. The US Global Change Research Program, which provided overall guidance for the studies, emphasized the importance of stakeholder involvement at the regional level. In the Metro East Coast study, important stakeholders were involved from the outset. Methods of stakeholder involvement included linking each sectoral chapter of the report (e.g. water or energy) to specified agencies and organizations, and holding regular meetings of the research team at the offices of stakeholders.[11] This is an example where guidance from a national agency successfully helped to ensure the integration of stakeholder information, concerns, and research into work produced in an academic setting and presented in the final report.

The second example is from follow-on work to the Metro East Coast study undertaken by Columbia and other universities for the NYC Department of Environmental Protection (DEP). New York City was one of the first large cities to develop and describe in detail extensive adaptation plans and programs. The purpose of the DEP work was to assist the department in integrating climate change considerations into its planning, management, and investment decisions.[12] The DEP set up a Climate Change Task Force composed of representatives of all of its operating and planning bureaus, together with experts from Columbia University and other universities and engineering firms. The Task Force held monthly meetings on a range of adaptation issues for more than a year and later evolved into a Department-wide Climate Change Program. The Task Force was an example of an innovative non-statutory (but approved) group, which was a useful method of approach at the start of adaptation planning; it provided important input from knowledgeable professionals to begin an agency's adaptation efforts.

*Financing*. The financing of adaptations can be one of the most difficult elements of successful adaptation to climate change. As with planning as a whole, outreach is important in financing. Some very wealthy communities will be able to plan for desired adaptations and then largely self-finance, which is the case of Miami Beach, Florida, USA, which is spending US$400+ million on raising roads, pumps, and other adaptations to cope with sea level rise and flooding.[13] However, many communities will want and need outside assistance, and in this case, it is best to engage early in outreach to financing sources to ascertain what might possibly be financed, rather than to design a 'best' program and then look for financing. (Although that can also sometimes work.)

For poorer communities, in addition to self-financing through in-person labor and local funding, external sources may include micro-lending banks. For wealthier and more developed cities and towns, external assistance might come from local banks or tax-exempt municipal bonds. Grants, loans, and technical assistance are often available from regional, national, or foreign aid entities. In each case, the coastal city or town should be in contact with a range of potential sources at or near the beginning of the planning process, to ensure that any funding constraints are taken into account in the design of adaptation programs.

*Linking adaptation plans to the Sustainable Development Goals*. An additional element of working with others is linking a town or city's adaptation plans to the SDGs discussed in Chapter 1.[14] For the 17 SDGs, there are a total of 169 targets, which are the operational sub-goals of the SDGs. Each of the targets has one or more indicators, 232 in total, some used for more than one target, that show how well that target has been met in a country. An example for SDG 13, 'Take urgent action to combat climate change and its

**Table 8.2:** SDG 13 target and indicators example.

| Target | Indicators |
|---|---|
| 13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries | 13.1.1 Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population<br>13.1.2 Number of countries that adopt and implement national disaster risk reduction strategies in line with the Sendai Framework for Disaster Risk Reduction 2015–2030<br>13.1.3 Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies |

Source: United Nations 2016. From un.org © 2021. United Nations. Reprinted with the permission of the United Nations.

impacts,' is in Table 8.2, which shows the first target for this SDG, as well as its indicators. The complete list of targets and indicators for SDG 13 are shown in Appendix C.

Taking as an example an adaptation plan for a single coastal settlement, adaptation planners could report a definite and perhaps significant contribution to Target 13.1. The elements of the plan could be, for example, newly developed evacuation routes, as well as new flood barriers. The plan would be a contribution to both elements of the target; as it would protect against both climate-related hazards and existing natural disasters (e.g. existing storms). The task of adaptation planners relates to reporting at the first level, the targets, with a subsequent connection to the second level, the national indicators, that would be reported by national agencies. Linking adaptation planning to the SDGs is thus a way of developing interaction between the local and national levels; it is also something that outside aid agencies may typically have an interest in supporting. Climate adaptation planning may impact many of the SDGs, such as SDG 11, 'Make cities and human settlements inclusive, safe, resilient and sustainable,' as well as others.

## Monitor and Reassess

Monitoring and reassessment (step 8) are important long-term components of adaptation planning. There is a need to ensure that adaptation plans are monitored and assessed in order to see how well they perform, especially given uncertainties in how climate change (and other changes such as population and income) will occur. By continuing to monitor and reassess, making adjustments in adaptation strategies as appropriate, communities will be able to increase the effectiveness of adaptation programs.

Monitoring and reassessing adaptation plans should be done on a regular basis. These procedures should be undertaken at least every few years for the most part, but also when specific events occur that require changes. Some automated monitoring, on the other hand, may be continuous. Plans may need to be adjusted to reflect not only changes in climate, but also in other environmental conditions, population, economic factors, and technology. The exact components of monitoring depend on types of adaptations, schedules, and existing and new monitoring systems. It is important to recognize that monitoring will take place with constantly improving methods.

Monitoring and reassessment will, for example, help ensure that evacuation plans are up to date, warning systems are working, and dams or flood walls have integrity. The adaptation checklists discussed earlier will be important in developing monitoring programs and will provide baselines against which to assess progress. How do we know that adaptations are working? Some cases may be complex, requiring careful testing (such as groundwater contamination); others may be more straightforward. For example, even without long time records, the effectiveness of a flood barrier can be estimated by considering the change in flood area for a storm that is similar to one that occurred before the barrier was erected, adjusted for sea level change.

The importance of monitoring is suggested by the data on sea level rise in the 20th century, as shown for global sea level rise in Figure 8.3. This illustrates the constant change of a crucial climate parameter and the need for monitoring and reassessing adaptation measures.

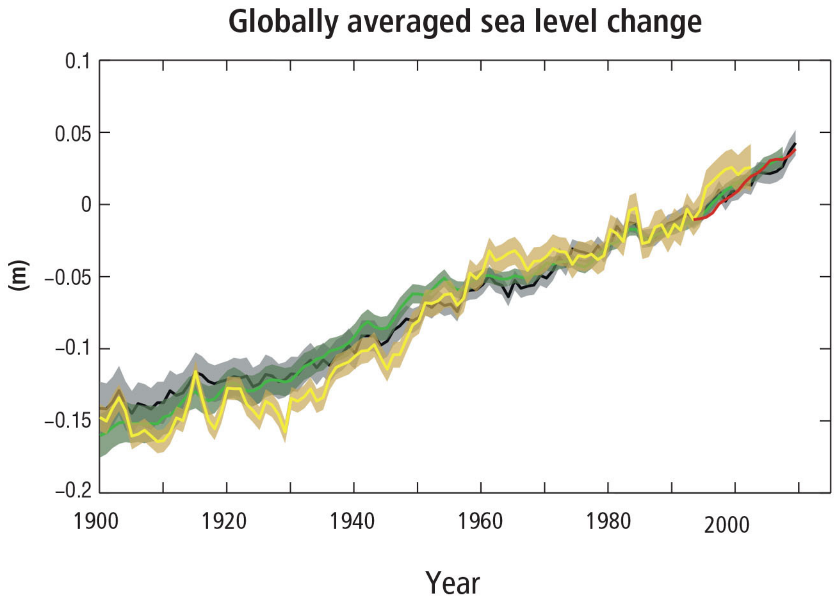



**Figure 8.3:** Global mean sea level change, 1900–2010.

Source: IPCC 2014c: 41 ©IPCC.

Note: the colored lines indicate different data sets, with all data sets aligned to have the same value in 1993, the first year of satellite altimetry data. See IPCC 2014c, 41 for details.

Similar information is often available locally, ranging from automated tide gauges to locally recorded flood heights. In

**Table 8.3:** Categories of variables for monitoring.

| | |
|---|---|
| **Categories of variables for monitoring** | Physical climate change variables<br>Risk exposure vulnerability and impacts<br>Adaptation measures<br>New research within each of these categories |
| **Additional categories** | Organizational changes<br>Financing changes<br>Population growth<br>Urban area growth<br>Economic changes<br>Contributions to the SDGs |

Sources: Jacob et al. 2011: 129; David C. Major and Sirkku Juhola.

developed communities, many of the monitoring systems (such as tide gauges) will be in place or can be modified from existing systems.

Monitoring of climate variables will often be at both local and higher levels; data may be collected locally and stored or made available nationally. Monitoring should also include appropriate elements not directly related to climate (Table 8.3).

Citizens, public officials, and planners all have roles in step 8. As climate and other factors change over time, it is important that citizens provide an oversight role in ensuring the continued effectiveness of adaptation planning. Planners will play a key role in setting up and maintaining monitoring systems, and public officials should be concerned with providing adequate resources for monitoring and reassessment procedures.

## What to Know and Do

Working with others, the element of adaptation planning that is the focus of this chapter, relates to all of the adaptation steps. All stakeholders have important roles to play in this work.

1. It is important that organizational arrangements be reviewed at the start of planning, and that attention be paid to any need to modify these arrangements (e.g. by bringing in more stakeholders) as planning progresses. There have already been cities and towns that have confronted the need for new organizational arrangements, several examples of which are described in this chapter. Stakeholders should seek out and consider such examples.
2. Methods of working with all stakeholders, including information dissemination, should be reviewed and adopted. These include making information from each step of the planning process fully available to all, and developing or modifying digital methods of communication, such as those described in this chapter, to help individuals with their own adaptations.
3. The questions for stakeholders should be fully integrated into each step of the planning process.

4. Begin early in the planning process to develop contacts with potential funding sources. These will differ depending on the circumstances of each city and town, from sophisticated borrowing methods to micro-lending, but in each case early discussions will be important in achieving sustainable adaptation goals.

CHAPTER 9

# Future Prospects

There are many possible futures for climate and the Earth, and there is little certainty as to which one will become reality. If the increase in global temperature can be held to 1.5°C above pre-industrial levels, as is discussed in an IPCC Special Report[1] (which the move to clean energy will help), then relatively reasonable adaptation measures will be adequate for many coastal cities as the world moves toward sustainability.[2] If, on the other hand, temperatures rise more rapidly, the comment of the IPCC becomes all too relevant: 'Adaptation can substantially reduce the risks of climate change impacts, but greater rates and magnitude of climate change increase the likelihood of exceeding adaptation limits (*high confidence*).'[3]

There is a wide range of changes and events that could occur to shift the trajectory of the future. On the positive side, there are renewable energy sources like wind and solar, which can help with the comprehensive decarbonization of the energy system. There are also technologies to remove carbon dioxide from point sources or from the atmosphere that still have issues of cost and scale, as well as geoengineering methods to reflect a portion of the sun's rays back into space. Should these technologies come to fruition, the outcome in the best case could be better than currently expected.[4] This will also likely be true if population growth slows. However, there are worst-case scenarios of permafrost melt and the melting of the icecaps.[5] If such events occur, reasonable adaptation measures may suffice for a time, but in the long run many coastal settlements will be abandoned. In this respect, communities will need to move forcefully in future years to keep up with knowledge of the then-current science and technology.

In these circumstances of great uncertainty, reasonable and flexible adaptations appear appropriate for the near and medium terms for many coastal communities. (Of course, for some coastal settlements, it is already too late for anything but retreat.[6]) The pressure for adaptation, and the forms that it will take, will change depending on the success of the world in limiting climate change. In any event, the world will have to focus on appropriate scheduling of movement toward a non-carbon economy, and adaptations should be undertaken with due consideration of this.[7]

In terms of governance and organization, the Paris Agreement of December 2015 may blossom into great effectiveness, or it may fail to achieve its objectives.[8] It is possible to be hopeful about this, especially because organizationally, the issue is not necessarily one that relies on nation-states alone. Various cities and companies can achieve greenhouse gas emissions reductions even without the leadership of national authorities.[9] In addition, the Sustainable Development Goals (SDGs) (Figure 9.1) may provide an overarching framework for effective adaptation.

Whatever the long-term climate outcome, there will certainly be likely improvements in implementing effective adaptations. These include: better climate modeling; improved experience with plan formulation, including stakeholder contributions; improvements in communications; the development of more well-designed flexible adaptation pathways; additional information on costs; and the linking of adaptation programs to the SDGs. In sum, the implementation of all of the adaptation steps should improve with experience, leading to more effective adaptation planning for coastal towns and cities and a better future for all, including the most vulnerable.

All things considered, the issue of adaptation for coastal cities is one of risk management writ large. Looking further ahead, it is difficult to judge whether the future will be good or really bad, and how far individual cities' and towns' adaptation measures will


**Figure 9.1:** UN Secretary-General Ban Ki-moon poses with 17 staff volunteers to help promote the SDGs, Vienna, April 27, 2016.

Source: Dean Calma / IAEA.

be able to contribute to safe and sustainable living environments in the long run. But the best public policy approach under these circumstances is to move ahead rapidly both with mitigation and adaptation, including adaptations that contribute to mitigation. The amounts of resources required are small relative to the risks. It is to the adaptation part of this policy that this volume is designed to contribute.

APPENDIX A

# List of Planning Tables

Throughout the text, tables are used to provide guidelines for planning. To provide a convenient reference for these planning tables, they are listed in this Appendix. To encourage their use (and adaptation or adjustment as needed) in actual planning, especially for readers using the print version of this volume, the tables are available for digital download on the following website: https://www.helsinki.fi/en/researchgroups/urban-environmental-policy.

Table 2.1: The most important roles of citizens, public officials and planners in the adaptation assessment steps, identified by checkmarks.

Table 3.5: Example of climate change likelihoods, impacts, magnitude of impacts, and initial planning assessment.

Table 5.1: Physical characteristics checklist for stakeholders.

Table 5.2: Economic and demographic characteristics checklist for stakeholders.

Table 5.3: Environmental, social, cultural, and historical characteristics checklist for stakeholders.

Table 5.4: Determinants of adaptive capacity.

Table 6.1: Adaptation pathway for a small, poor coastal community with minimal infrastructure.

Table 6.2: Adaptation pathway for a wealthy coastal community with good infrastructure.

APPENDIX B

# Intergovernmental Panel on Climate Change Likelihood Categories

In the IPCC's *Climate change 2014: synthesis report* section entitled 'Communicating the degree of certainty in assessment findings,' the IPCC provides an overview of how the Panel's findings, characterized by different degrees of uncertainty, are presented.[1] In the case of those with well-defined outcomes in which the IPCC has high or very high confidence, the following likelihood (or 'probability') categories are used, several of which are employed in this volume with reference to specific IPCC findings. These categories may be helpful for local planners in communicating the levels of uncertainty of aspects of climate change.

| | |
|---|---|
| Virtually certain | 99–100% probability |
| Extremely likely | 95–100% |
| Very likely | 90–100% |
| Likely | 66–100% |
| More likely than not | >50–100% |
| About as likely as not | 33–66% |
| Unlikely | 0–33% |
| Very unlikely | 0–10% |
| Extremely unlikely | 0–5% |
| Exceptionally unlikely | 0–1% |

APPENDIX C

# Sustainable Development Goal 13

## Take Urgent Action to Combat Climate Change and Its Impacts

Table C.1 shows the complete targets and indicators for SDG 13, as an example. Targets and indicators for other SDGs can be found in United Nations, *Report of the Inter-Agency and Expert Group on Sustainable Development Goal Indicators* (E/CN.3/2017/2), 2016, annex 3, Revised list of global Sustainable Development Goal indicators. Regarding SDG 13, the *Report* adds: Acknowledging that the UN Framework Convention on Climate Change is the primary international, intergovernmental forum for negotiating the global response to climate change.

**Table C.1:** Targets and indicators for SDG 13.

| Targets | Indicators |
|---|---|
| 13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries | 13.1.1 Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population<br>13.1.2 Number of countries that adopt and implement national disaster risk reduction strategies in line with the Sendai Framework for Disaster Risk Reduction 2015–2030<br>13.1.3 Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies |
| 13.2 Integrate climate change measures into national policies, strategies, and planning | 13.2.1 Number of countries that have communicated the establishment or operationalization of an integrated policy/strategy/plan which increases their ability to adapt to the adverse impacts of climate change, and foster climate resilience and low greenhouse gas emissions development in a manner that does not threaten food production (including a national adaptation plan, nationally determined contribution, national communication, biennial update report, or other) |
| 13.3 Improve education, awareness-raising, and human and institutional capacity on climate change mitigation, adaptation, impact reduction, and early warning | 13.3.1 Number of countries that have integrated mitigation, adaptation, impact reduction, and early warning into primary, secondary, and tertiary curricula |

**Table C.1.** *(Continued)*

| Targets | Indicators |
|---|---|
| | 13.3.2 Number of countries that have communicated the strengthening of institutional, systemic, and individual capacity-building to implement adaptation, mitigation and technology transfer, and development actions |
| 13.a Implement the commitment undertaken by developed-country parties to the United Nations Framework Convention on Climate Change to a goal of mobilizing jointly $100 billion annually by 2020 from all sources to address the needs of developing countries in the context of meaningful mitigation actions and transparency on implementation and fully operationalize the Green Climate Fund through its capitalization as soon as possible | 13.a.1 Mobilized amount of United States dollars per year starting in 2020 accountable towards the $100 billion commitment |
| 13.b Promote mechanisms for raising capacity for effective climate change-related planning and management in least developed countries and small island developing states, including focusing on women, youth, and local and marginalized communities | 13.b.1 Number of least developed countries and small island developing States that are receiving specialized support, and amount of support, including finance, technology, and capacity-building, for mechanisms for raising capacities for effective climate change-related planning and management, including focusing on women, youth, and local and marginalized communities |

Source: United Nations 2016. From un.org © 2021. United Nations. Reprinted with the permission of the United Nations.

Note: Targets and indicators denoted by letters rather than numbers generally refer to means of implementation (see Weitz et al. 2016: 6).

# Endnotes

Note on endnotes here and throughout the volume: The IPCC's recommended volume and chapter citations are quite long, including the names of the very many authors and editors who have contributed to each volume or chapter. For ease of reference in this book, we use instead a short form, e.g. IPCC 2014c, as below and then the chapter or page citation, rather than the long full citation. Interested readers will find the complete citations in the references. In addition, the Synthesis Report for the Fifth Assessment Report was first published in 2015. However, in this volume the IPCC's recommended reference date, 2014, is used; it is cited here as IPCC 2014c.

## Chapter 1: Introduction and Overview

1 IPCC 2014c: 13; for a range of projections for the New York City area that includes a higher scenario, see NPCC 2015: 40. The Fourth US National Climate Assessment, 2017, vol. 1, section 12.5.1, uses as the highest scenario 250 cm (8.2 feet).

2 IPCC 2014a: 4; IPCC 2014c: 1.

3 IPCC 2014a: 364, 381; IPCC 2019a: Summary for Policymakers, section A.1.3.

4 Pielke et al. 2007: 597; Council on Foreign Relations 2013: 1.

[5] IPCC 2015: 29.

[6] See World Commission on Environment and Development 1987; UN 2015b.

[7] See, e.g., UNEP 2019a.

[8] For example, NPCC 2010; City of Copenhagen 2011; Helsinki Region Environmental Services Authority 2012; Rotterdam Climate Initiative 2013; New York City, Office of the Mayor 2014; UK Environment Agency 2014; NPCC 2014c; Sengupta 2019.

[9] IPCC 2014c: 2. There is now an enormous literature on global warming; the best scientific literature is in the IPCC reports cited throughout this volume. A key early public moment was the testimony of Dr. James Hansen (see Hansen 2009: xv) before a US Senate committee in 1988, that with 99% confidence, 'Earth was being affected by human-made greenhouse gases.' One of the best early books on global warming is Schneider 1989.

[10] US Environmental Protection Agency n.d.

[11] IPCC 2014c: 4 (emphasis in original).

[12] US NOAA 2016.

[13] IPCC 2014c: 2.

[14] IPCC 2013: 20.

[15] The UN Framework Convention on Climate Change (https://unfccc.int/) was adopted at the Earth Summit in Rio de Janeiro in 1992, and entered into force in 1994. The secretariat (UN Climate Change) is located in Bonn, Germany.

[16] UN 2015a.

[17] UN 2018b.

[18] IPCC 2014a: 4, 5. Two useful glossaries of climate change and adaptation terms are: IPCC 2018: Glossary; and Rosenzweig et al. 2018: app. A, Glossary, 775–782.

[19] Nordenson et al. 2010.

[20] A green roof is generally defined as 'a layer of vegetation planted over a waterproofing system that is installed on top of a flat or slightly-sloped roof' (US National Park Service n.d.). The US National Park Service website provides a full description of the characteristics of green roofs. A green roof has mitigation properties, reducing the need for heating and cooling in a building, and also adaptive properties, acting to hold precipitation for a time to ease strains on drainage systems.

[21] See also Jim 2015; and Ismail & Abdullah 2016.

[22] UNEP 2019b: XV.

[23] World Commission on Environment and Development 1987: 8.

[24] UN 2015b.

[25] UN 2016.
[26] In this regard, the Sendai Framework for Disaster Risk Reduction, which was adopted by the United Nations in June 2015, has as an important element mutual reinforcement with other international agendas, including SDGs and climate agreements. UN Office of Disaster Risk Reduction 2015.
[27] United Nations 2020. https://www.un.org/sustainabledevelopment/news/communications-material/.
[28] World Bank n.d.b.
[29] Pelling & Garschagen 2019: 327.
[30] Pelling & Garschagen 2019: 328.
[31] UN 2015b: para. 2.
[32] Dougherty-Choux 2015.
[33] UNEP 2014: 33.
[34] Schaeffer et al. 2013: 31.
[35] Schaeffer et al. 2013: 32.
[36] UN Environment Programme 2014: 31.
[37] Schaeffer et al. 2013: 25, fig. 4.7.

## Chapter 2: Adaptation Assessment Steps and the Roles of Citizens, Public Officials, and Planners

[1] Major & O'Grady 2010. For the reference to critical infrastructure, see p. 235.
[2] 'Interrelated' climate impacts can also be described as 'correlated and cascading' impacts.
[3] Extensive definitions of these and other terms can be found in IPCC 2018: Glossary.
[4] One approach developed to implement such planning under uncertain global and regional changes is Dynamic Adaptive Policy Pathways; see Haasnoot et al. 2013; Lawrence & Haasnoot 2017.
[5] UN Climate Change n.d. (emphases in the original).
[6] See, e.g., US Global Change Research Program 2017.

## Chapter 3: Impacts and Vulnerabilities of Climate Change on Coastal Cities

[1] Berry 2012.
[2] Dieng et al. 2017.

[3] Gornitz 2013: 186.
[4] Reager et al. 2016.
[5] See Appendix B for the meaning of IPCC probability categories. (emphasis in orginal).
[6] IPCC 2014c: 42.
[7] IPCC 2019b: Summary for Policymakers, section A.3 (bold and emphasis in the original).
[8] Ekman 1996.
[9] Yin et al. 2009.
[10] IPCC 2014c: 42.
[11] IPCC 2013: 1196, fig. 13.20. These figures are based on 21 GCMs and four Representative Concentration Pathways (see Chapter 4) and information such as isostatic adjustments. They can provide some planning guidance when more local information is not available.
[12] Bader et al. 2018: 51.
[13] IPCC 2014c: 42 (emphasis in the original).
[14] IPCC 2014c: 42 (bold and emphasis in the original).
[15] IPCC 2014c: 13 (emphasis in the original); see Chapter 4 for an explanation of RCPs.
[16] NPCC 2015: 40. The Fourth US National Climate Assessment, 2017, vol. 1, section 12.5.1, uses as the highest scenario 250 cm (8.2 feet).
[17] Gornitz 2013: ch. 8.
[18] US Climate Resilience Toolkit n.d.
[19] US NOAA n.d.a.
[20] US Climate Resilience Toolkit n.d.
[21] IPCC 2014c: 60.
[22] US NOAA n.d.a.
[23] IPCC 2014c: 59, 61.
[24] IPCC 2013: Annex of Global and Regional Climate Projections.
[25] IPCC 2014c: 60 (emphasis in orginal).
[26] IPCC 2014a: 555.
[27] IPCC 2014a: 555, 556.
[28] See IPCC 2014c: 61; discussion 58–60.
[29] IPCC 2014a: 555.
[30] IPCC 2014c: 53.
[31] IPCC 2014c: 69 (emphasis in the original).
[32] Rosenzweig et al. 2011: 410.
[33] Rosenzweig et al. 2011: 410.
[34] NPCC 2010: 180. For a similar table for the United Kingdom, see UK Met Office n.d.b.

[35] Major et al. 2013.
[36] See NPCC 2019: ch. 2.
[37] Major & O'Grady 2010: 254.
[38] See, e.g., Fu & Roemmich n.d.
[39] Gornitz 2013: 201.
[40] World Bank 2019.
[41] This point is made for costs in Leichenko et al. 2011: Annex III, 14.
[42] Horton & Rosenzweig 2010; Major & O'Grady 2010: annex A, 'Infrastructure Questionnaires.'

## Chapter 4: Using Climate Information: Global Climate Models and Climate Scenarios

[1] Early research includes Sellers 1969.
[2] IPCC 2013; IPCC 2014a; IPCC 2014b; IPCC 2014c.
[3] IPCC 2014c: 56–57.
[4] NPCC 2015: 26.
[5] Stevens 2017: 484.
[6] IPCC 2013: chs. 11–13; IPCC 2014c: 58–63.
[7] NPCC 2015: 39, table 2.1.
[8] NPCC 2015: chs. 1–2, annex 2.
[9] NPCC 2010: 211.
[10] Horton & Rosenzweig 2010: 171–172.
[11] NPCC 2015: 28.
[12] As shown in NPCC 2015: 39, table 2.1.
[13] See NPCC 2015: ch. 1 and annex 2.
[14] Ekman 1996.
[15] Yin et al. 2009.
[16] See UK Met Office n.d.a.
[17] A detailed explanation of statistical downscaling methods is in US Global Change Research Program 2017: 145–146.
[18] Zscheischler et al. 2018.
[19] IPCC 2013; IPCC 2014a; IPCC 2014b; IPCC 2014c, see note prior to endnote 1, Ch. 1.
[20] IPCC 2014c.
[21] See also Southern African Science Service Centre for Climate Change and Adaptive and Management (SASSCAL) (http://www.sasscal.org/); and West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL) (https://wascal.org/wascal-data-centre/).

## Chapter 5: Coastal Cities and Towns: Characteristics and Challenges

[1] UNEP 2019a.
[2] Hanson et al. 2011: 89–111; Hallegatte et al. 2013.
[3] Major & Juhola 2016.
[4] Gornitz 2013: 246–247.
[5] US NOAA n.d.c.
[6] Ekman 1996.
[7] NPCC 2010: 211; NPCC 2015: 36–37.
[8] Gornitz 2013: 45.
[9] Eggleston & Pope 2013.
[10] Gornitz 2013: 45.
[11] Berry 2012.
[12] US NOAA n.d.c.
[13] Berry 2012.
[14] See NPCC 2015: 39.
[15] Climate Change & Infectious Diseases Group 2019. See world maps of Köppen-Geiger climate classification. Available at http://koeppen-geiger.vu-wien.ac.at/ [last accessed March 12, 2019].
[16] Casey 2018; Dwyer 2018.
[17] Anguelovski & Carmin 2011.
[18] Revi et al. 2014.
[19] Spaargaren et al. 2006.
[20] A useful guide in this respect is: Center for Science in the Earth System et al. 2007: ch. 3.
[21] Bulkeley 2005.
[22] See Sussman & Major 2010: ch. 5, esp.88–89, table 5.1.
[23] Reviews of policy instruments are in Jordan et al. 2003: 201–222; Jordan 2005.
[24] IPCC 2014a: Glossary.
[25] Plummer et al. 2018.
[26] Costanza et al. 2006.
[27] Georgi et al. 2012.
[28] Leal Filho et al. 2018. An earlier study of the risks faced by Mombasa is: Awuor et al. 2008.
[29] Leal Filho et al. 2018: 35.
[30] UNITAR 2016.
[31] Durban Adaptation Charter n.d.

[32] See eThekwini Municipality 2017: 17.
[33] Fuchs 2010: Summary; Mycoo & Donovan 2017: Executive Summary.
[34] Le 2019: abstract.
[35] Eisenack et al. 2014: 387.
[36] IPCC 2014a: ch. 16, 911–919.
[37] Jones & Boyd 2011.
[38] Talbot 2013; Searcey 2017.
[39] Eisenack et al. 2014: abstract.
[40] US Environmental Protection Agency, Office of Environmental Justice n.d.
[41] See also World Bank 2011: ch. 5.
[42] Tabachi et al. 2018.
[43] For the idea of 'justice as fairness,' see Rawls 1999: ch. 1.

## Chapter 6: The Range of Adaptations to Climate Change

[1] Gornitz 2013: 246–247.
[2] Rahman & Islam n.d.
[3] Kumar et al. 2019.
[4] Manik & Schultz 2019.
[5] New York City, Department of Environmental Protection 2012.
[6] New York City, Office of the Mayor 2013: 17.
[7] New York City, Office of the Mayor 2013: 178–179.
[8] Netherlands Rijkswaterstaat, n.d.
[9] McGeehan 2019: A21.
[10] UK Environment Agency 2014; Netherlands Rijkswaterstaat n.d.; O'Sullivan 2016.
[11] Aerts et al. 2009; NCICD Program (Indonesia) 2014.
[12] Dunlap 2017.
[13] Flechas & Staletovich 2015.
[14] Rhodes 2017.
[15] Rotterdam Climate Initiative 2013: 8; see also Lisa 2013.
[16] As in Bangladesh: Yee 2013.
[17] Nordenson et al. 2010: 98–114.
[18] Nordenson et al. 2010: 164.
[19] Craig 2010: 15.

[20] Helsinki Region Environmental Services Authority 2012: 18.
[21] New York City, Office of the Mayor 2013: 198.
[22] Schwarz 2019.
[23] See Neal et al. 2005 and Hawai'i 2019 for discussions.
[24] Mele & Victor 2016; and UN 2018a.
[25] SISRI n.d.: 3.
[26] Siders et al. 2019: 761.
[27] Smith 2019.
[28] Britton et al. 2011: ch. 3.
[29] Two useful detailed studies of adaptation pathways are: Barnett et al. 2014 and Lawrence et al. 2019.
[30] IPCC 2014c: 106.
[31] Gornitz 2013: 246.
[32] Gornitz 2013: 246.
[33] Bidgood 2016.
[34] IPCC 2018.

## Chapter 7: Evaluation of Projects and Programs

[1] US Congress, Flood Control Act of 1936, Public Law 74–738, 74th Congress, 2nd Session, 1936.
[2] Eckstein 1958; Krutilla and Eckstein 1958.
[3] Maass et al. 1962; Marglin 1967; Dasgupta et al. 1972; Major 1977.
[4] Gittinger 1972 is a classic World Bank example.
[5] Multihazard Mitigation Council 2005.
[6] Multihazard Mitigation Council 2005: 61–67, 107.
[7] Gittinger 1972.
[8] Costanza et al. 2006.
[9] US Congress, National Environmental Policy Act (NEPA), Public Law 91–190, 1969.
[10] A case study of trade-offs between an environmental objective of preserving an ecologically significant area and economics is in Major 1977 69–74.
[11] Eur-lex 2009.
[12] An interesting and helpful discussion of what the author calls the 'standard' cost benefit analysis of climate change and why it might not be adequate for the analysis of climate change is in Weitzman 2009.
[13] Nordhaus 2007: 201–202; Stern 2007.

[14] Stern 2009: 90.
[15] Margulis et al. 2008: 9.
[16] Dasgupta et al. 1972.
[17] Costanza et al. 2006. On the use of analogs, see Leichenko et al. 2011: 14.
[18] See the references in endnote 3 to this chapter, and especially, for graphical presentations of the methods, Marglin 1967, and Major 1977.
[19] Mele & Victor 2016.
[20] An example is in NPCC 2010: 53, 55. The interpretation of benchmark years given here is based on the use of benchmark years in a large-scale water resources plan; see Major & Schwarz 1990: 26.
[21] Marglin 1967: 74–79.
[22] Hastrup Clemmensen et al. 2015: ch. 5.
[23] The best-known microfinance institution is the Grameen Bank (http://www.grameen.com/).
[24] Nature Conservancy, Africa n.d.; the details of the swap are on p. 2. See also Cornish 2018.
[25] Client Earth n.d.; and Albeck-Ripka 2019.
[26] Marglin 1967: 69–71; Major 1977: 43–47.
[27] Cartagena de Indias 2014.
[28] Ortiz 2017.
[29] Mele & Victor 2016.
[30] UN 2018a.
[31] Goldberg 2013.
[32] US Army Corps of Engineers 2015.
[33] Whitney Museum of American Art n.d.; Pogrebin 2013.
[34] Engineering News Record n.d.; an example currency converter is: https://www1.oanda.com/currency/converter/.

## Chapter 8: Getting It Done: Working Together to Develop and Finance Adaptations

[1] CoastAdapt n.d.: sec. 4.
[2] US National Hurricane Center n.d.
[3] Major & Stakhiv 2018.
[4] Major et al. 2018: 205–208.
[5] CoastAdapt n.d.: sec. 4.

[6] Questions relating to the plan formulation process, reflecting the content of the section, 'Questions for Stakeholders Throughout the Planning Process' of this chapter, are in CoastAdapt n.d.
[7] City of London 2015.
[8] IESD 2016.
[9] VisAdapt 2017; Johansson et al. 2015.
[10] Rosenzweig & Solecki 2001.
[11] Rosenzweig & Solecki 2001: 5.
[12] Rosenzweig et al. 2007.
[13] Weiss 2016.
[14] See also Major et al. 2018: 205–208.

## Chapter 9: Future Prospects

[1] IPCC 2018.
[2] Obama 2017.
[3] IPCC 2014c: 67, (emphasis in original).
[4] Porter 2017.
[5] US National Snow and Ice Data Center n.d.; US NASA 2015.
[6] Heffernan 2012.
[7] Figueres et al. 2017; Ocko et al. 2017; Rockström et al. 2017; Shindell et al. 2017.
[8] UN Framework 2015a; see also UN 2018b.
[9] Bloomberg 2017.

## Appendix B: Intergovernmental Panel on Climate Change Likelihood Categories

[1] IPCC 2014c: 37, Box introduction 2.

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# Index

Page numbers in *italic* denote figures and in **bold** denote tables.

*Climate Change Adaptation in Coastal Cities* is a guidebook that presents a framework for climate adaptation planning for coastal cities, large and small. It is focused on the central roles of citizens, public officials, and planners. The book is designed to help all stakeholders in coastal cities understand and develop effective adaptation measures in a sustainable way. Guidance is provided from initial assessments of climate impacts to final planning.

The book sets out methods of adaptation to climate change for many types of coastal communities. Adaptation is seen as a process that should take into account all coastal assets, including economic, environmental, social, cultural and historical assets, with due attention to disadvantaged communities.

Numerous tables are presented to guide planning, and examples of adaptation challenges and opportunities are provided from both developed and developing coastal cities and towns. The volume is copiously illustrated, with extensive up-to-date references with additional sources of information.

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