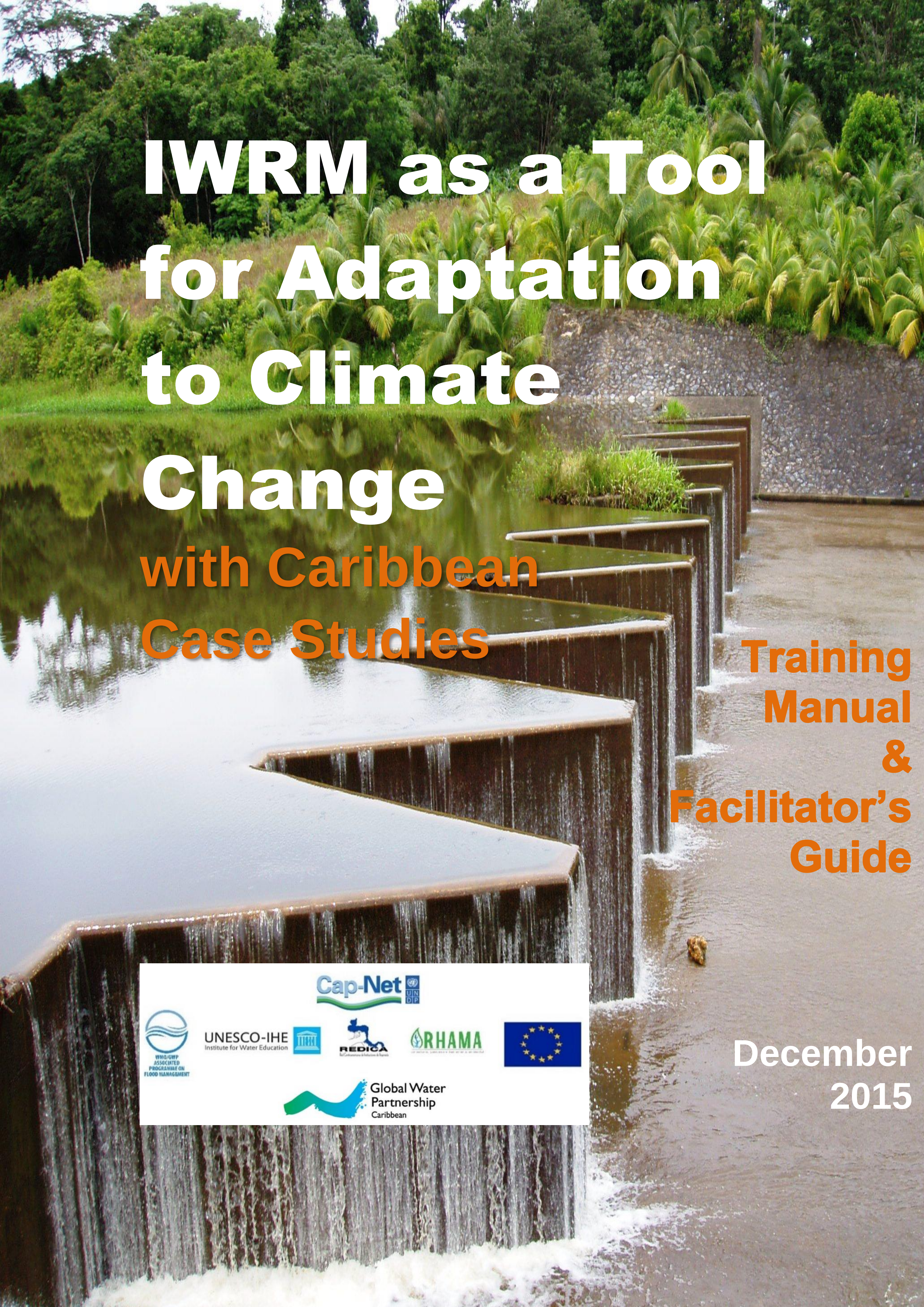

IWRM as a Tool for Adaptation to Climate Change

with Caribbean Case Studies

Training Manual & Facilitator's Guide

December 2015

Foreword – Paul Taylor

While the causes of climate change are primarily from our use of energy, the impacts will be felt mainly through water. Climate change is expected to impact on countries in different ways, bringing more intense storms, increases or decreases in the annual rainfall, and floods and droughts. Undoubtedly, changes in one of our most important resources will affect people, economies and the environment, perhaps in a dramatic way.

As we look at our current knowledge of climate change, it is clear that we are still in a state of uncertainty. For most countries there is still much debate as to how climate change will manifest itself and what the effects will be. Despite this uncertainty there is pressure to act now and to allocate resources for climate change adaptation.

These training materials are intended to increase our understanding about climate change and to explore what we can do now. There are actions that can be taken to prepare for a more variable climate and we can make a case to our policy makers to prepare for change. The most important immediate action concerns the way we manage our water resources. Improving our management of water today will prepare us to adapt tomorrow. Improved understanding of our water resources will allow more efficient and flexible allocation systems and better investment in infrastructure, both to improve access to water and reduce risks from climate change. We can act now and these training materials can help us to identify those actions.

Other materials are available from Cap-Net that cover more specific issues of climate change, such as hydro-climatic disasters, urban flood management and community management of floods.

Our collaboration with the World Meteorological Organisation and UNESCO-IHE provides the framework within which this programme takes place and we are grateful for their support.

Paul Taylor
Director, Cap-Net
2009

2nd Foreword – Themba Gumbo and Jacob Opadeyi

The world today confronts a water crisis with critical implications for peace, political stability and economic development. Starting to manage water resources more effectively and efficiently will enable humanity to better respond to today's problems and to the surprises and troubles expected in a warming world.

Climate change related storms, floods and drought particularly affect the poor, who typically have limited resilience and adaptive capacity to climate-related hazards and natural disasters.

On 25 September 2015, the 193-Member United Nations General Assembly formally adopted the 2030 Agenda for Sustainable Development, along with a set of bold new Sustainable Development Goals (SDGs: 17 goals and 169 targets), hailed as a universal, integrated and transformative vision for a better world. Among these Goal 13 relates to taking urgent action to combat climate change and its impacts. Target 13.1 of the SDGs specifically pronounces improving education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning.

The adaptation solutions to climate change are also the paths to a safer, healthier, cleaner and more prosperous future for all closely interlinked with sustainable water management. To see this and to understand what needs to be done requires a sharp and sustained focus on education, training and public awareness in all countries and at all levels of government, society and enterprise.

The Caribbean Small Island States are particularly not only highly vulnerable to the negative impacts of climate change but are mostly water-scarce. It is therefore necessary that the capacity of the region to mitigate the effect of climate change be enhanced using regional case studies and examples.

This revised and customised training manual by Caribbean WaterNet on integrated water resources management (IWRM) as a tool to adaptation to climate change is an important addition in empowering the relevant societies and stakeholders in shaping a climate-resilient and equitable future.

Themba Gumbo
Director, Cap-Net UNDP
2015

Jacob Opadeyi
Coordinator, Caribbean WaterNet
2015

Foreword – Patricia Shako

The Global Water Partnership-Caribbean (GWP-C) has been partnering with Cap-Net and Caribbean WaterNet in rolling out the Cap-Net training package on "IWRM as a tool for adaptation to the Caribbean". This partnership is under the GWP-C Water, Climate and Development Programme (WACDEP) which speaks to building climate resilience in the Caribbean water sector, through *inter alia* capacity building for water resources professionals and other stakeholders.

In moving forward with training activities, Cap-Net/Caribbean WaterNet and GWP-C wanted to ensure that the training material was as up to date and as relevant to the Caribbean as possible. Thus, GWP-C has worked with Cap-Net/Caribbean WaterNet and researchers from the University of the West Indies and the University of Guyana to supplement the Cap-Net manual with Caribbean case studies, tools, resources, photos, and references. This version of the manual also includes the most recent climate information from the Intergovernmental Panel on Climate Change (IPCC) reports. Caribbean specific information has been included within the main text but also presented and easily extracted through the use of specially coloured text boxes. Apart from these additions and updates, all other text, diagrams, and information remain identical to the original Cap-Net document.

GWP-C intends on using this updated manual in partnership with Cap-Net/Caribbean WaterNet to roll out further training throughout the Caribbean. GWP-C is pleased to have collaborated with Cap-Net/Caribbean Water Net on this venture and look forward further collaboration to build climate resilience in the Caribbean Water Sector. For more information on GWP-C training activities and the WACDEP, please visit our website at www.gwp-caribbean.org.

Patricia Shako
Regional Coordinator
Global Water Partnership-Caribbean
2015

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Many people have contributed to the development of this training manual and facilitator's guide. The partnership between Cap-Net, APFM, UNESCO-IHE, REDICA and Rhama has been very fruitful and we would like to acknowledge the team for preparing this training package. The team consisted of Joachim Saalmueller of APFM, Erik de Ruyter van Steveninck of UNESCO-IHE, Lilliana Arrieta of REDICA, Carlos Tucci of Rhama, Hamed Assaf of the American University of Beirut, Ashvin Gosain of the Indian Institute of Technology, and Kees Leendertse of Cap-Net who acted as team leader. We would like to thank Edwin Hes of UNESCO-IHE for sharing the role play presented in the facilitator's guide. Most valuable feedback has been received from the participants of training courses held in various regions.

The 2015 Caribbean Version of the Cap-Net Manual was funded by the Global Water Partnership-Caribbean (GWP-C) under its Water, Climate and Development Programme (WACDEP). Contributors to this manual include Dr. Adrian Cashman, Ms. Anuradha Maharaj, Ms. Tara Mackey, and Ms. Jeanel Georges (Centre for Resource Management and Environmental Studies); Ms. Joyce Peters; Dr. Paulette Bynoe and Dr. Jacob Opadeyi (University of Guyana); Ms. Lena Dempewolf, Ms. Candi Hosein, and Dr. Natalie Boodram (GWP-C).

Photos

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Natalie Boodram, Tara Mackey, and Jeanel Georges provided photos for the Caribbean 2015 Manual.

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Introduction

This training manual and facilitator's guide is intended to introduce general concepts and the practical application of Integrated Water Resources Management (IWRM) as an instrument for adaptation to climate change. The target audience for the manual is twofold: participants in courses on the subject will be provided with conceptual and practical knowledge, and capacity builders will find assistance to conduct short training courses on IWRM and adaptations to climate change. The manual is built in such a way that it will be instructive and at the same time informative for the target group of such courses – mainly water managers and climate change adaptation policy developers. The format and contents of the manual are flexible enough to be adapted to different purposes and as such they could also be used for educational programmes and awareness campaigns. Teachers and moderators/facilitators are encouraged to adapt the materials to their particular regional or local contexts, tailoring the adaptation strategies and actions to each set of unique conditions as needed.

The document is structured in two main sections: a training manual and a facilitator's guide. The first part, the training manual, provides concepts, strategies, developments and guidance on the use of IWRM principles and functions, particularly at the watershed level, for adaptation to climate change manifestations and impacts. It argues that IWRM principles and concepts are instrumental when climate change adaptation is being strategized.

To address this, the manual is structured according to seven topics:

- Introduction to IWRM and climate change;
- Drivers and impacts of climate change;
- Strategy development and planning for adaptation;
- Impacts of climate change on water use sectors;
- Dealing with uncertainties;
- Measures for adaptation; and
- Adaptation to climate change in water management.

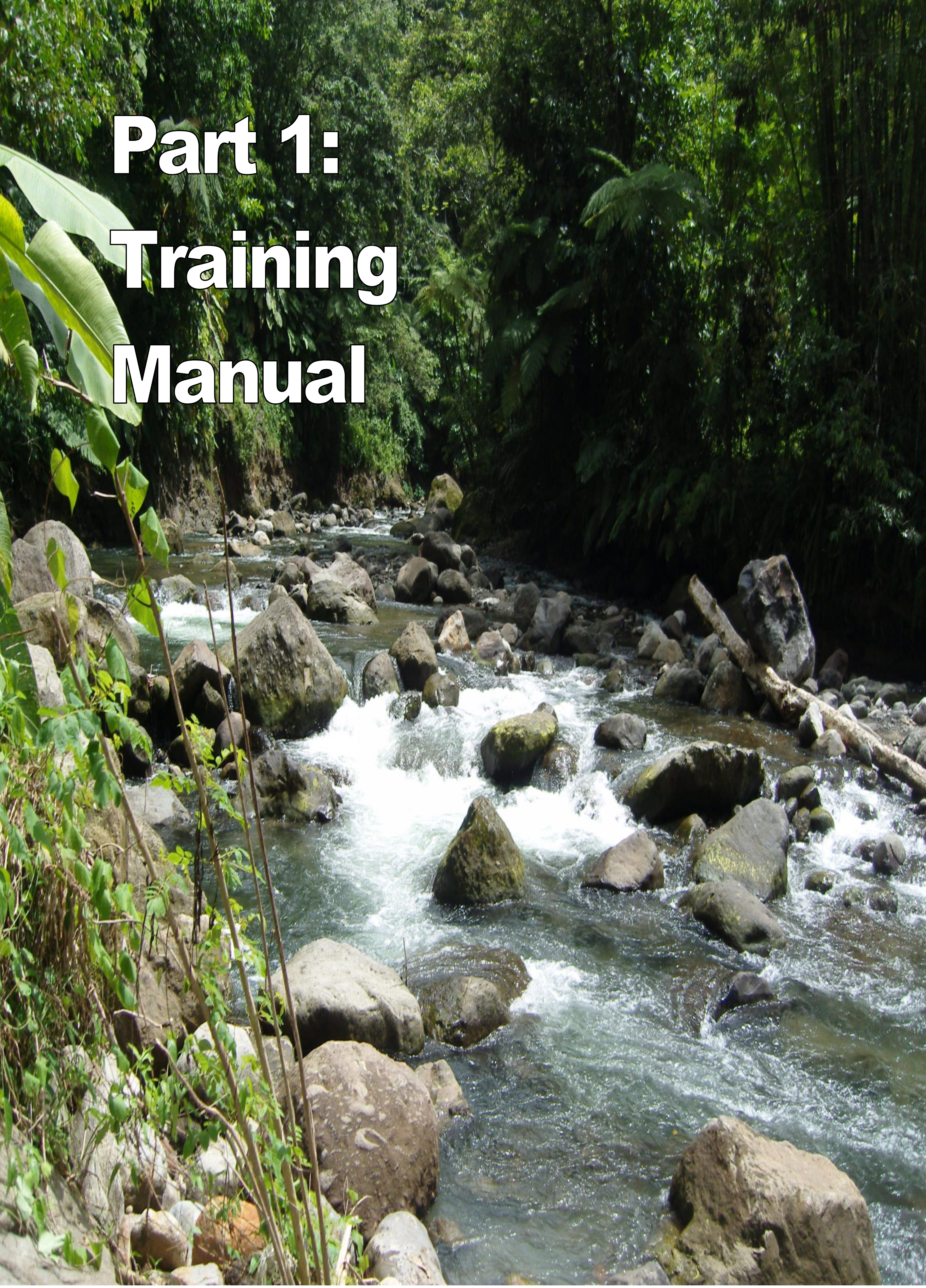
For each of the chapters presented, goals are provided and throughout the document the user is challenged with questions and statements that should trigger reflection on the applicability of the concepts and strategies to their own situation. Additional reading resources are recommended at the end of each chapter.

The second section of the document consists of a facilitators' guide. It aims to provide capacity builders with practical guidance for the organisation and conduct of courses or educational programmes on the subject. A sample course outline is provided to help in structuring a course on IWRM and climate change adaptation; but it is to no extent a blueprint for the organisation of such a course. The facilitators' guide furthermore presents session outlines for the proposed course schedule that contain learning objectives, brief summaries of each session, materials to be used and suggested timelines for interactive group work, exercises and discussions. The guide also includes references to useful websites and other resources. Practical guidance for the conduct of a course is provided, including tips for planning a workshop and the use of icebreakers. We also recommend that the course organiser refers to the Cap-Net planning of short training courses tool posted on the Cap-Net website.

The combined training manual and facilitator's guide is also available on CD-ROM, including supporting materials such as presentations for the sessions, resource materials that can be used as background reading, references and case studies.

The development of the training manual has largely benefited from the inputs received from participants in several courses in different regions. The exchange between participants and the course developers has been very enriching in that it clearly pointed out weaknesses and adaptability of materials. The package is intended to stimulate interactions between participants to contribute to a better understanding of the use and effectiveness of application of IWRM concepts and principles when strategizing climate change adaptation.

Part 1: Training Manual



1. INTRODUCTION TO INTEGRATED WATER RESOURCES MANAGEMENT AND CLIMATE CHANGE

Goal

The goal of this chapter is to introduce the concept of Integrated Water Resources Management (IWRM) and its principles, in both global and Caribbean contexts, and to provide a preliminary overview of the ways that implementing IWRM can address challenges resulting from climate change.

1.1 Introduction

Water sustains life - it is a basic human need and right. Each person requires a minimum of 20 to 40 litres of water per day for drinking and basic hygiene purposes. However, only 0.5 percent (Fig 1.1) of the global freshwater resources is available for direct human use (WWBCSD (World Business Council for Sustainable Development) 2005). Furthermore, the world's freshwater resources face increasing demands from population growth, economic activity and, in some countries, improved standards of living. Additionally, sustainable development includes maintaining healthy ecosystems and biodiversity, which require sufficient water. Lack of equal access to water, competing demands and conflicts over rights of access is leading towards an impending water crisis.

According to the United Nations, access to safe drinking water and basic sanitation is essential for the achievement of the Millennium Development Goals (MDGs) Goal 6 of the recently proposed Sustainable Development Goals (SDGs) advocates the availability and sustainable management of water and sanitation for all as it is a fundamental requirement for effective primary health care and a precondition for success in fighting poverty, hunger, child mortality, gender inequality and environmental damage (UN 2006).

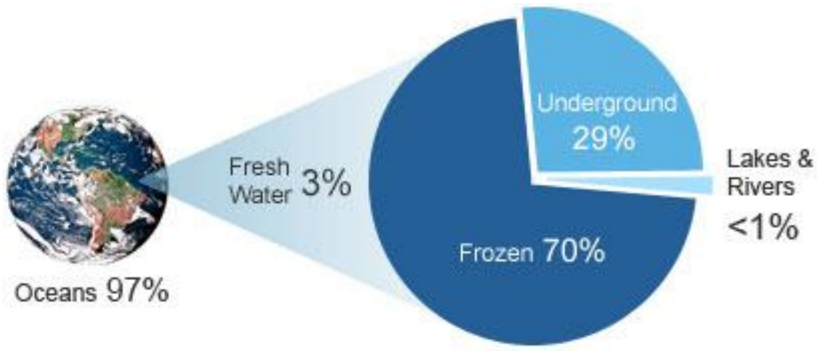


Figure 1.1: Availability of freshwater for human use
Source: "The Water Problem," Zulfiquer Ahmed Amin, Global Policy Forum, October 8, 2007

Many people argue that the world faces an impending water crisis. Box 1.1 below provides a few supporting facts.

Box 1.1: Interdependency and the need for IWRM

- 1.1 billion people still do not have access to safe water.
- Today, more than two billion people are affected by water shortages in over 40 countries.
- Four out of 10 people around the world still use sanitation facilities that do not meet basic requirements for health.
- Two million tonnes per day of human waste are deposited in watercourses.
- Each year, unsafe water and a lack of basic sanitation kill at least 1.6 million children below the age of five years.
- Half the population of the developing world are exposed to polluted sources of water that increase the incidence of disease.
- Ninety percent of natural disasters in the 1990s were water-related.
- The increase in global population from six billion to nine billion will be the main driver of water resources management for the next 50 years.
- High irrigation demands and river pollution from agriculture reduce the amount of available freshwater for drinking or industrial use.
- Contaminated municipal and industrial wastewater pollutes rivers and threatens ecosystems.
- Leaving river water untapped to protect fisheries and ecosystems means that less can be diverted to grow crops. IWRM recognises this interdependency of water uses.

Source: (Cap-Net 2006, WWBCSD (World Business Council for Sustainable Development) 2005)

Small Island Developing States (SIDS), such as those in the Caribbean region, face some unique challenges in managing their water resources and therefore stand to benefit greatly from IWRM for reasons outlined in Box 1.2 below.

Box 1.2: The need for IWRM in the Caribbean

- Average rainfall records for the Caribbean over the past 100 years show a consistent reduction in precipitation (IPCC 2013).
- The Caribbean region is home to some of the most water scarce nations on the planet.
- The Caribbean region has the least water available per capita compared to other SIDS regions (The Caribbean Environmental Health Institute (CEHI) 2006).
- These SIDS are particularly vulnerable to water resource stresses due to their limited size, human and natural resources, and need for socio-economic development.
- Rapid growth, urbanisation, tourism and commercial requirements in the Caribbean region, according to UNDESA (2013), has led to a population increase from 17 to 41 million between 1950 and 2010. Population density has increased by more than 100 percent during the same period (United Nations Department of Economic and Social Affairs (UNDESA) Population Division 2013).
- Access to centralised wastewater service systems which collect and treat wastewater is low, ranging from three percent in St Vincent to 30 percent in Trinidad and Tobago.
- Poor and aging water distribution systems contribute to high percentages of unaccounted for water: Jamaica 67 percent, Trinidad and Tobago 47 percent, and Barbados 50 percent.
- Increasing intensity of natural hazards such as droughts and storms can lead to a further deterioration of sanitation.
- Water resource provision is not a coordinated effort across responsible groups and in many cases is not considered a high priority (Cashman, Nurse, and Charlery 2010).

Cap-Net's Tutorial on Basic Principles on IWRM (2005a) notes that:

- Water resources are increasingly under pressure from population growth, economic activities and intensifying competition among users;
- Water withdrawals have increased more than twice as fast as population growth, and currently one third of the world's population lives in countries that experience medium to high water stress;
- Pollution is further aggravating water scarcity by reducing water usability downstream;
- Shortcomings in the management of water, a focus on developing new sources rather than managing existing ones better, and top-down sector approaches to water management result in uncoordinated development and management of the resource;
- More and more development means greater impacts on the environment; and
- Current concerns about climate variability and climate change demand improved management of water resources to cope with more intense floods and droughts, as well as changes in seasonality.

This impending water crisis presents challenges to the water sector, many of which are multifaceted in that they must address questions such as:

- How can people access water and sanitation?
- How can competition among various users be addressed without undermining economic growth objectives?
- How can the protection of vital ecosystems be ensured?

Failure to address these complex challenges pushes societies further away from meeting the goal of sustainable development in general, and sustainable management and development of water resources in particular. There is growing support for the ability of IWRM to meet these challenges (Box 1.3).

Box 1.3: Challenges and solutions in water supply and sanitation

Improving access to water can be difficult because responsibility for water resources management is usually shared by many different government departments in developing countries. No single department can take the lead, and they often have conflicting views. For example, agricultural departments are usually more interested in promoting irrigation and food production, while other ministries are more concerned with improving drinking water supplies and sanitation. Furthermore, existing wastewater treatment systems, whether centralized or decentralized, are likely to be less effective in providing adequate levels of treatment under climate change. Increases in ambient temperature may lead to warmer soil and water temperatures, thus lowering the effectiveness of sewage systems.

Improving access to water and sanitation requires:

- Commitment from developing country governments to make it a priority;
- Appropriate long-term financing;
- Arrangements to resolve the competing demands for water and other related environmental challenges;
- Increased advocacy on behalf of poor people to ensure that their demands are heard;
- Improved capacity of governments to facilitate service delivery to all citizens; and
- Improved responsiveness and accountability of government to meet the needs of all users, especially those of people living in poverty.
- Greater levels of wastewater reuse or recycling to create a climate-independent water source that is dependable, locally controlled and generally beneficial to the environment.
- Developing national water policies to ensure that greater attention is given to wastewater management within an Integrated Water Resources Management (IWRM) framework.

(United Kingdom Department for International Development 2006)

1.2 What is Integrated Water Resources Management (IWRM)?

IWRM is the sustainable development, allocation, and monitoring of water resource use in the context of social, economic, and environmental objectives (Cap-Net 2005b). The Global Water Partnership defines Integrated Water Resources Management (IWRM) as a process which promotes the coordinated development and management of water, land, and related resources in order to maximise economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. It is cross-sectoral and therefore in stark contrast to the traditional sectoral approach that has been adopted by many countries. It has been further broadened to incorporate participatory decision-making of all stakeholders.

IWRM is a paradigm shift. It departs from traditional approaches in three ways:

- The multiple goals and objectives are cross-cutting so that IWRM departs from the traditional sectoral approach;
- The spatial focus is on the watershed instead of on single water courses; and
- It entails a departure from narrow professional and political boundaries and perspectives, broadening them to incorporate participatory decision-making among all stakeholders (i.e. inclusion versus exclusion).

The basis of IWRM is that there is a variety of uses of water resources that are interdependent. The failure to recognise interdependency, coupled with unregulated use, can lead to water wastage and the unsustainability of water resources in the long term.

Integrated management does not segregate water users or take a sectoral approach as is done in many countries. Rather, water allocation and management decisions consider the impact of each use on the others. In doing so, the cross-cutting goals of social, economic, and environmental sustainability are considered collectively, and cross-sectoral policies are examined to shape more coherent, coordinated policies. In short, IWRM recognises that water is a scarce natural resource, subject to many interdependencies in conveyance and use.

Can you give examples from your own country where this interdependency of water uses exists?

The basic IWRM concept has been extended to incorporate participatory decision-making and will be discussed in more detail in Section 1.4, which deals with water management principles.

Different user groups (farmers, communities, environmentalists, and others) may influence strategies for water resource development and management. That brings additional benefits, as informed users apply local self-regulation in relation to issues such as water conservation and protection of catchments far more effectively than central regulation and surveillance can achieve.

The term 'management' is used in its broadest sense, in that it highlights the need to not only focus on the development of water resources, but also to consciously manage water development that ensures sustainable use for future generations (Cap-Net 2005b).

1.3 The water management framework

IWRM occurs in a holistic framework, dealing with:

- All water (spatial);
- All interests (social);
- All stakeholders (participatory);
- All levels (administrative);
- All relevant disciplines (organisational); and
- Sustainability (in all senses: environmental, political, social, cultural, economic, financial and legal) (Jaspers 2001).

The framework is so broad, that the aim of IWRM is to discard sector approaches and to create environmental, institutional, social, technical and financial sustainability through the creation of a platform for government and stakeholders for planning and implementation, and to deal with conflicts of interests.

At the core of the water management framework is the treatment of water as an economic good as well as a social good, combined with decentralised management and delivery structures, greater reliance on pricing and fuller participation by stakeholders (World Bank 1993). All of these principles and issues will be discussed in more detail in the following section (1.4).

What will a water management framework do?

1) Provide a framework for analysing policies and options that will guide decisions about managing water resources in relation to:

- Water scarcity;
- Service efficiency;
- Water allocation; and
- Environmental protection.

2) Facilitate consideration of relationships between the ecosystem and socio-economic activities in watersheds.

The analysis should take account of social, environmental, and economic objectives; evaluate the status of water resources within each watershed; and assess the level and composition of projected demand. Special attention should be given to the views of all stakeholders, which should take place through activities designed to facilitate participation.

Section 1.4 provides details on Principle 2 of the Dublin Principles, which highlight the benefits and challenges in attaining participation. Box 1.4 also indicates how participation can be operationalised by using consultative mechanisms, awareness building and education.

Stakeholder participation essentially involves four steps:

1. Identifying the key stakeholders from the large array of groups and individuals that can potentially affect, or be affected by, changes in water management;
2. Assessing stakeholder interests and the potential impact of IWRM planning on these interests;
3. Assessing the influence and importance of the identified stakeholders; and
4. Outlining a stakeholder participation strategy (a plan to involve the stakeholders in different stages of the plan preparation).

The results of the analyses at a watershed level would become part of the national strategy for water resources management. The analytical framework would provide the underpinnings for formulating public policies on regulations, incentives, public investment plans, environmental management, and the linkages among them. A supportive legal framework and adequate regulatory capacity are required, as well as a system of water charges to endow water entities with operational autonomy and some financial autonomy for efficient and sustainable service delivery.

Box 1.4: Participation is more than consultation

Participation requires that stakeholders at all levels of the social structure have an impact on decisions at different levels of water management. Consultative mechanisms, ranging from questionnaires to stakeholder meetings, will not allow real participation if they are merely employed to legitimise decisions already made, to defuse political opposition or to delay the implementation of measures that could adversely impinge upon a powerful interest group.

Participation will not always achieve consensus. Arbitration processes or other conflict resolution mechanisms will also need to be put in place.

Participatory capacity needs to be created, particularly amongst women and other marginalised social groups. This may not only involve awareness raising, confidence building, and education, but also the provision of the economic resources needed to facilitate participation and the establishment of good and transparent sources of information. It has to be recognised that simply creating participatory opportunities will do nothing for currently disadvantaged groups, unless their capacity to participate is enhanced.

(Cap-Net 2005a)

1.4 Water management principles

A decade and a half ago (at the International Conference on Water and the Environment, convened in Dublin, Ireland, in 1992), four main principles of water emerged that have become the cornerstones of subsequent water sector reform.

Principle 1: Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment.

This principle highlights that water is critical to sustaining life. However, freshwater is a finite resource because the hydrological cycle on average yields a fixed quantity of water per period, and the quantity of water resources cannot be adjusted significantly by human actions. Furthermore, as a resource, water is paradoxically both essential to development and vulnerable to its effects. Effective management of water resources – which seeks to ensure that the services that are in demand can be provided and sustained over time – requires a holistic approach that links social and economic development with the protection of natural ecosystems. Effective management does not dichotomise land and water uses but sees the integration of these uses across the whole of a catchment area or watershed.

The integrated approach to management of water resources demands a coordination of the range of human activities that create the demand for water, determine land uses, and generate waterborne waste products. Principle 1 also recognises the catchment area or watershed as the logical unit for water resources management.

Principle 2: Water development and management should be based on a participatory approach, involving users, planners, and policy makers at all levels.

Where water is concerned, everyone is a stakeholder. Accordingly, water development and management should be based on a participatory approach that draws on the principle of democratising decision-making and gives recognition to the input of multiple stakeholders, including users, planners, and policy makers at all levels (Box 1.5).

Real participation only takes place when stakeholders are part of the decision-making process. This can occur directly when local communities come together to make water supply, water management, and water use choices. Participation also occurs if democratically elected or otherwise accountable agencies or spokespersons can represent stakeholder groups; but even in this situation, access to information, consultation processes, and opportunities to participate should also exist.

Benefits of participation:

- Participation emphasises involvement in decision-making at the most feasible level (subsidiarity), with full public consultation and input from users in the planning and implementation of water projects - this leads to more successful projects in terms of scale design, operation and maintenance;
- Participation also helps to ensure that environmental resources are protected and that cultural values and human rights are respected; and
- Participation can help coordinate interests and increase transparency and accountability in decision-making.

Greater participation can also improve cost recovery, which is key to generating revenue and financing IWRM.

In Guyana, Water Users Associations have been established throughout the coastal region since 2006. The objective to the Waters Users Association is to promote proper drainage and irrigation structures and to assist farmers in playing a more integral role in managing their water supply. For example, farmers have received training and

Box 1.5: Determinants, conditions for effective participation, and challenges

As noted, real participation occurs only when stakeholders are actually part of the decision-making process. However, there are determinants, conditions, and challenges related to participation in most countries.

Determinants of the types of participation and conditions for effective participation

- The spatial scale (river basin or village water system) relevant to the particular water management and investment decision; and
- The nature of the political environment in which decisions take place.

Challenges to the participatory approach

Participation does not always achieve consensus as the following challenges reveal:

- Arbitration processes and other conflict resolution mechanisms are sometimes needed; Government intervention is sometimes needed to create an enabling environment for marginalised social groups such as people living in poverty, indigenous people, the elderly, and women;
- Governance framework at the macro-scale generally does not allow for participation because there are few legislative tools that provide for or encourage public participation;
- Merely the opportunity to participate is insufficient to provide the benefits of the participatory approach - disadvantaged groups must also have the capacity to participate, thus, capacity building is essential; and
- Information dissemination is sometimes insufficient to allow persons at the grassroots level to be involved in the decision making process - knowledge creates a vested interest in the success of the system.

(Cap-Net 2005a)

financial assistance to participate meaningfully in the management of secondary drainage systems, while the National Drainage and Irrigation Board continues to manage the primary drainage systems.

Associations are an example of the principle of local participation.

Principle 3: Women play a central part in the provision, management and safeguarding of water.

It is widely acknowledged that women play a key role in the collection and safeguarding of water for domestic use and, in many countries, for agricultural use. However, women are less instrumental than men in key areas such as management, problem analysis, and the decision-making processes related to water resources. Often the marginalised role of women in water resources management can be traced to social and cultural traditions, which also vary between societies.

In your country, are all stakeholders involved in decision-making on water supply, management and investment?

There is strong evidence that water managers must consider that there is an urgent need to mainstream gender in IWRM to achieve the goal of sustainable water use. Cap-Net and the Gender and Water Alliance (GWA) developed a tutorial for water managers entitled 'Why Gender Matters'. Some parts of the tutorial are covered in this section, but the manual users are advised to review the tutorial for a more complete understanding of the importance of having a gender-balanced approach in IWRM.

Basic linkages between gender and IWRM

There are three basic linkages between gender and IWRM issues:

1) Gender and environmental sustainability linkages
   - Women and men affect environmental sustainability in different proportions and by different means, as they have different access, control and interests.
   - Flood and drought events weigh heaviest on women because they lack the means to cope with disasters.

2) Gender and economic efficiency linkages
   - In many societies, women pay for drinking water but have mobility restrictions and payment constraints. Allowing users to pay smaller amounts more frequently and nearer to home makes water more affordable for them. (Water supply)
   - Technology choice affects affordability. Consulting female and male users may result in a more acceptable, user-friendly, and sustainable service. (Water supply)

- Lack of access to finance for poor people and for women farmers prevents them from developing more prosperous and water-efficient agricultural enterprises and limits their participation in agriculture to that of a subsistence activity. (Agriculture)

In your country, is a gender-sensitive approach being used in managing water resources? If not, why has this approach not been adopted?

3) Gender and social equity linkages
- Powerful groups of society, usually male-dominated, can exploit resources more systematically and on a large scale and can also drive industrial transformation of the environment; therefore, their potential to create damage is higher. (Environment)
- When water is not supplied by a piped system, the burden of water collection falls on women and children, who must expend considerable time and energy on this activity. (Water supply)
- Women rarely have equal access to water for productive use and are the first to be affected in times of water shortage. (Agriculture)
- Women and children are the most susceptible to waterborne disease due to their roles in water collection, clothes washing and other domestic activities. (Sanitation)

Box 1.6: The Rural Women's Network (Guyana)

An example of Principle 3 in action in the Caribbean is the Rural Women's Network (RWN) in Guyana which was officially launched in 1998 to aid in poverty reduction of rural women. RWN established a Steering Committee aimed at empowering and advocating on behalf of rural and hinterland women's development and promoting entrepreneurship.

The organisation networks with women's organisations, groups, and individuals from the ten administrative regions in Guyana and its mission is to empower rural women to improve their standard of living through training, cultural exchange, access to credit, and networking with a focus on capacity building. RWN's role is to improve the livelihood options and sustainability of rural women, families and communities and to transfer skills to rural women involved in small business management, poultry, hydroponics agriculture, food/fruit processing, and handicraft. RWN is mainly involved in training and capacity building of the members and provides a revolving (micro) loan fund and networking opportunities for its members.

Principle 4: Water has an economic value in all its competing uses and should be recognised as an economic good as well as a social good.

Many past failures in IWRM are attributable to ignoring the full value of water. The maximum benefits from water resources cannot be derived if misperceptions about the value of water persist.

Value versus charges

Value and charges are two distinct concepts. The value of water in alternative uses is important for the rational allocation of water as a scarce resource, whether by regulatory or economic means. Conversely, charging for water means applying an economic instrument to achieve multiple objectives, as follows:

- To support disadvantaged groups;
- To influence behaviour towards conservation and efficient water usage;
- To provide incentives for demand management;
- To ensure cost recovery; and
- To signal consumer willingness to pay for additional investments in water services.

When is water appropriate as an economic good?

Treating water as an economic good is imperative for logical decision-making on water allocation between competing water sectors, especially in an environment of water resource scarcity. It becomes necessary when extending the supply is no longer a feasible option. In IWRM, the economic value of alternative water uses helps guide decision makers in prioritising investments. In countries where there is an abundance of water resources, it is less likely to be treated as an economic good since the need to ration water usage is not as urgent as in water-scarce countries.

Why is water a social good?

Although water is an economic good, it is also a social good. It is particularly important to view water allocation as a means of meeting the social goals of equity, poverty alleviation, and safeguarding health. In countries where there is an abundance of water resources, there is an increased tendency to treat water as a social good to fulfil equity, poverty alleviation and health objectives over economic objectives. Environmental security and protection are also part of the consideration of water as a social good. Aesthetic and religious functions of water are often neglected, or at least not sufficiently considered in water management.

Applying the concepts

In the real world, in a situation of water scarcity, should water be provided to a steel-manufacturing plant because the manufacturer has the ability to pay more for water than thousands of poor people who have no access to safe water? Can you find any similar examples from the ground level in your country? How was such a situation solved?

1.5 Importance of IWRM for adaptation to climate change

Water is the first sector to be affected by changes in climate. Climate change leads to intensification of the hydrological cycle and subsequently has serious effects on the intensity of extreme events. Sea level rise, increased evaporation, unpredictable precipitation, and prolonged droughts are just a few manifestations of climate variability directly impacting on availability and quality of water.

Through management of the resource at the most adequate level, the organisation of participation in management practices and policy development, and assuring that the most vulnerable groups are considered, IWRM instruments directly assist communities to cope with climate variability. In 2001, the Intergovernmental Panel on Climate Change (IPCC) recognised the potential of IWRM to be used as a means of reconciling varied and changing water uses and demands, and it appears to offer greater flexibility and adaptive capacity than conventional water resources management approaches. It is critical that climate change in water governance be considered in the context of reducing vulnerability of poor people, in maintaining sustainable livelihoods and supporting sustainable development. The IPCC report makes recommendations on adaptation, vulnerability, and capacity enhancement; the main recommendation asserts that reducing the vulnerability of nations or communities to climate change requires an increased ability to adapt to its effects. Working to improve the adaptive capacity at the community level is likely to have a broader and more long-lasting effect on reducing vulnerability. Tailoring adaptation assistance to local needs requires the following actions:

- Addressing real local vulnerabilities;
- Involving real stakeholders early and substantively; and
- Connecting with local decision-making processes.

1.6 How can IWRM help address climate change?

As demonstrated earlier in this chapter, IWRM offers various tools and instruments that deal with access to water and protecting the integrity of the ecosystem, thus safeguarding water quality for future generations. In this way, IWRM can assist communities to adapt to changing climatic conditions that limit water availability or may lead to excessive floods or droughts.

Key water resources management functions are:
- Water allocation;
- Pollution control;
- Monitoring;
- Financial management;
- Flood and drought management;
- Information management;
- Watershed planning; and
- Stakeholder participation.

These functions are instrumental for integrated resources management and can be of help in coping with climate variability. For example:

- Water can be allocated to the most efficient and effective use to react to climate variability in a flexible manner.
- In monitoring water quantity and quality developments, management can pro-actively take action towards adaptation. For example, in 1963, the Barbados Water Authority established groundwater protection zones to guard against the contamination of the island’s unconfined aquifer system.
- Management of floods and droughts, as a key function of IWRM, allows for direct intervention in cases of extreme events such as the severe drought in March 2013 which affected the water supply in Kingston, Jamaica.
- Risk assessment and adaptation measures can be incorporated in watershed planning so as to mitigate against the combined effects of extremes in climate variability and unsustainable land management practices, for example, flash flooding and landslides related to deforestation in Pond Casse, Dominica (April 2013).

In brief, IWRM makes it easier to respond to changes in water availability. Risks can be better identified and mitigated in the process of watershed planning. When action is needed, stakeholder participation helps to mobilise communities and generate action. Water users can be stimulated to use the resource sustainably in the face of changing water conditions.

1.6 Integration of Climate Change in IWRM

Historically, at the core of water management has been its adaptive capacity and capability. Previously, management practices responded to particular situations or needs arising from changing circumstances that could be brought on by natural causes, institutional changes, political priorities, and other factors. From that perspective, adaptation and coping strategies for climate change are not new or devoid of basic water management practice principles.

Which interventions are more effective, with short-term or with long-term benefits? Why is that?

Management options for adaptation to climate change are not unique or specifically different from those already employed for coping with contemporary climate variability. The only substantive difference is whether one adopts a more conventional and incremental 'no-regrets' approach, or a more anticipatory and 'precautionary' approach. This is one argument for the use of IWRM as an instrument for adaptation. Perhaps more important is that IWRM is a response to the question "How to work through water management to achieve the Millennium Development Goals, or the more recent Sustainable Development Goals?" In this context, it has been rightly suggested that while energy habits are the focus of climate change mitigation, IWRM should be the focus of adaptation (Jonch-Clausen 2007).

How to incorporate the climate change dimension into national IWRM plans?

At the World Summit on Sustainable Development in 2002, countries committed to the development of national IWRM and water efficiency plans that were included in the Johannesburg Plan of Implementation (UN 2002). This has been instrumental in taking the development and implementation of IWRM forward in national agendas, and many countries have initiated or further strengthened national processes for the development of such plans.

The Cap-Net Training Manual and Operational Guide on Integrated Water Resources Management Plans (Cap-Net 2005a) presents the process in seven sequential steps as outlined in Figure 1.2 below.

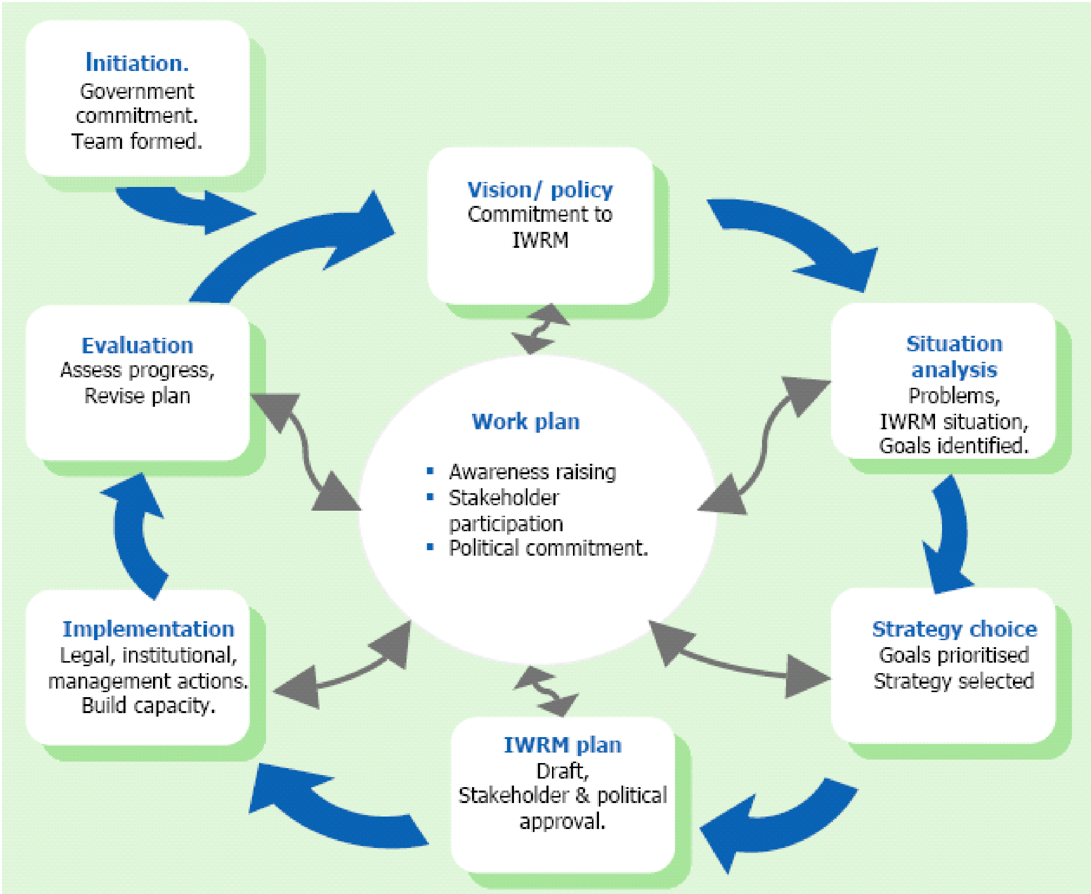


Figure 1.2: The IWRM planning cycle
(Cap-Net 2005a)

When viewing the IWRM planning process as instrumental for adaptation to changing climatic conditions, the following may be considered:

- In the 'initiation' step, climate change impacts need to be integrated into the planning process. In advocacy towards policy makers, the argument can be brought up that this will be instrumental for decision makers to advance demand management strategies, which otherwise might be politically difficult to implement.
- During the 'vision/policy' phase, climate change adaptation is an additional element, not a replacement of IWRM goals. The overall aims of IWRM will remain the same.
- In the 'situation analysis' step, the use of climate information and impact analysis needs be incorporated. Further, the adaptation/mitigation theme can be brought out to suggest that the IWRM process should reduce the risk of adaptation options negatively impacting on the mitigation targets, and vice versa.
- In the 'strategy choice' phase, the anticipatory or 'precautionary' approach can be introduced as the basis for strategies for IWRM.
- Consider the roles of local authorities and River Basin Organisations (RBOs) in adaptation strategies when drafting an IWRM plan.
- Legal frameworks, economics and health, and other variable conditional elements that have been analysed from the corner stone for implementation of IWRM and are decisive in how it contributes to climate change adaptation.

- During evaluation, results must be measured against indicators, taking into consideration the adaptation measures proposed in the plan.

Throughout the process, stakeholder involvement is essential so that the results of the impacts assessment and strategic choice are owned by the implementing agencies. The range of solutions and strategies has been broadened over time by improvements in technologies. What has changed is our understanding and implementation of the integrated ensemble of water management measures that conform to modern principles and policies. A catchment is composed of many users, who reside upstream and downstream of each other.

The integrated approach considers the catchment as a whole and considers the impacts that changes in the catchment or the distribution of water will have on the other users. Water resources managers no longer start with the presumption that certain structural measures (e.g. dams, levees) are the single best solutions. Rather, they begin planning by asking what the objectives of management are. These usually include factors such as social and community well-being, women's roles in water user groups, and environmental restoration. IWRM should be advocated as the encompassing paradigm for adaptation to contemporary climate variability, and it is the prerequisite for coping with the consequences of global warming, climate changes associated with it, and their repercussions on the water cycle.

1.8 Implementing IWRM

While there has been progress in a general understanding the meaning of IWRM, its importance in the context of scarcity, an acknowledgement of the main (Dublin) principles and a growing recognition of the need to use the right mix of economic and financial instruments, the actual implementation of IWRM is a challenging process.

There are several roadblocks to implementing IWRM, starting with entrenched sectoral interests, professional insecurities, and sociocultural myths (Box 1.7). These challenges are nevertheless not insurmountable. Overcoming the barriers to the implementation of IWRM requires an incremental approach to negotiating differences, cross-sectoral integration and instituting reforms (including policy and legal reforms).

Conflicts among professionals working in the various sectors, combined with a sense of vulnerability in adopting alternative approaches to water development and management that permeates professional groupings, calls for skills in negotiating win-win solutions and providing platforms for very different stakeholders to develop collaboration in implementing IWRM. These processes take time and require patience.

Box 1.7: Challenges and Achievements in the Implementation of IWRM for SIDS

Challenges:

- Governance arrangements within countries are weak;
- Supply-driven management;
- Fragmented and subsector approaches to water management;
- Lack of information;
- Inadequate technical competencies; and
- Low levels of investment in the water sector.

Achievements:

- National and sub-national IWRM road maps were prepared in Antigua and Barbuda, Barbados, Grenada, Saint Lucia, and Union Island in Saint Vincent and the Grenadines.
- Draft policy statements were developed in Antigua and Barbuda and Dominica, and support to dialogue and issue papers were produced in Cuba, Jamaica, Saint Kitts and Nevis, and Trinidad.

IWRM can only be successfully implemented if, among other reforms, there is a concerted effort to integrate perspectives and divergent interests of various water users in the management framework. Formal mechanisms and means of cooperation and information exchange should be established at different levels to achieve cross-sectoral integration. Past informal attempts have not been successful, and a formalised set of mechanisms should have the effect of ensuring commitment at the various levels. Uncertainties are part of a shift in the management paradigm and the process of implementation considers dealing with them (see Chapter 5).

Existing institutional and legislative frameworks have not been entirely responsive to the demands and requirements for implementing IWRM. Implementing IWRM will therefore require reform at most stages in the water planning and management cycle. Although there is an urgent need for reform, these changes can only take place incrementally – some occurring immediately and others taking several years of planning and capacity building. It will involve creating an enabling environment, and developing an institutional framework and management instruments for sustainable IWRM.

Box 1.8: Is there a water crisis, or are we on track to meet the target?

Water – Progress lagging: Target 10 of MDG7 is to halve the proportion of people without sustainable access to safe drinking water by 2015 (UN 2006). The share of people throughout the world with access to safe drinking water has continued to rise, reaching 83 percent in 2004 (up from 78 percent in 1990). However, on current trends, sub-Saharan Africa will not meet the target. This is due to factors such as high population growth rates, low government expenditure (particularly on operation and maintenance), conflict and political instability. Wide disparities between rural and urban areas persist in sub-Saharan Africa, where city dwellers are twice as likely as their rural counterparts to have access to safe water. There has been consistent progress towards achieving full access to improved drinking water services in the Caribbean region between 1990 and 2008. During this period, the proportion of the total population with improved access to drinking water has exceeded 95 percent for at least eight countries, with the largest increase being for Belize, where the proportion has increased from 75 percent in 1990 to 99 percent in 2008 (UNEP Caribbean Millennium Development Goals Report 2010).

Sanitation – Progress lagging: 1.2 billion people gained access to sanitation between 1990 and 2004. However, to meet the 2015 sanitation target, over 1.6 million people need to gain access to improved sanitation. The most serious problems are in sub-Saharan Africa and South Asia. In the Caribbean, eight countries have shown proportions of upwards of 95 percent of the population using sanitation facilities in 2008. GEF CReW statistics show that 85 percent of wastewater entering the Caribbean Sea remains untreated; 51.5 percent of households lack sewer connections and only 17 percent of households are connected to acceptable collection and treatment systems (www.gefcrew.org).

Key messages

- Sub-Saharan Africa remains the area of greatest concern. Over the period 1990–2004, the number of people without access to safe drinking water increased by 23 percent and the number of people without sanitation increased by over 30 percent.
- There are huge disparities between regions - while the percentage of people who have access to drinking water through a household connection is as low as 16 percent in sub-Saharan Africa, it is much higher in Eastern Asia (70 percent), North Africa (76 percent), and Western Asia (81 percent).

Source: (United Kingdom Department for International Development 2006)

Summary

Recently, IWRM has come up as the internationally and locally accepted management system to ensure sufficient water resources of adequate quality, not only for today but also for generations to come. The issue is particularly critical for SIDS, such as in the Caribbean region, given the challenges they face. The four principles of IWRM are:

- Freshwater is a finite and vulnerable resource;
- Water development and management should be based on a participatory approach;
- Women play a central role; and
- Water has an economic and a social value.

How can water management in your country help address climate change?

As water is the first sector to be affected by changes in climatic conditions, IWRM has an important role to play in addressing climate change issues. The key water resources management functions within an IWRM framework are instrumental for capacitating organisations and communities to cope with climate variability.

Suggested reading

Cap-Net (2005) Tutorial on basic principles of integrated water resources management.

Global Water Partnership (2000) TAC Background Paper No. 4: Integrated Water Resources Management. GWP: Stockholm, Sweden.

Global Water Partnership (2014) Integrated Water Resources Management in the Caribbean: the Challenges Facing Small Island Developing States. Technical Focus Paper. GWP: Stockholm, Sweden.

UN (2009) Water in a Changing World.

UN Conference on Sustainable Development. 2014. UN General Assemblies Open Working Group Proposes Sustainable Development Goals. Press Release. 22 July 2014 NY

WCBSD. 2007. Water facts and trends. Water and Sustainable Development Program.

WHO-UNICEF (2000) Global Water Supply and Sanitation Assessment 2000 Report. World Health Organisation and United Nations Children's Fund. http://www.who.int/water_sanitation_health/monitoring/globalassess/en

WHO-UNICEF (2006) Meeting the MDG Drinking Water and Sanitation Target. The Urban and Rural Challenge of the decade.

2. DRIVERS AND IMPACTS OF CLIMATE CHANGE

Goal

The aim of this module is to familiarise participants with the drivers and physical science basis of climate change, as well as to help them understand potential impacts on the water cycle and the consequences for water use and ecosystem functioning.

2.1 Understanding drivers and the physical science basis of climate change

The climate observations outlined by Working Group 1 in the Fifth Assessment Report (AR5) as adopted in 2014, provide new evidence and reiterate the reality of the climate change phenomena with growing evidence of climate change from observations of the atmosphere and the surface. Atmospheric warming is unequivocally evident from observed increases in global average air temperatures, ocean temperatures, widespread melting of snow and ice, and a rising global average sea level. Concerning the attribution of the observed increase in global average temperatures since the mid-20th century, the AR5 states that this is "very likely due to the observed anthropogenic increase in greenhouse gas (GHG) concentrations and it is extremely likely that human activities account for more than half of the observed increase in global mean surface temperature (GMST)" (IPCC 2013).

There is no doubt that this climate change is going to have impacts on water and many other sectors that are sensitive to climate variability and change. Therefore, it is imperative to develop a good understanding of some of the basic aspects of climate change and how it is detected before considering the impacts of such change.

The following YouTube links provide a better understanding of the physical science of climate change and explanations to help you better understand the terms and concepts that this chapter seeks to explain:

https://www.youtube.com/watch?v=6yiTZm0y1YA
https://www.youtube.com/watch?v=gDcGz1iVm6U

2.1.1 Climate variability and climate change

How do you differentiate between climate variability and climate change?

The global climate system is composed of the atmosphere, the hydrosphere (liquid water, of which three percent is freshwater and needed for survival, refer to Figure, 1.1, Chapter 1) (UN 2003), the cryosphere (ice and snow), the lithosphere (soil and rock) and the biosphere (plants and animals, including humans). The climate of a particular place is dependent on the complex nonlinear interactions between these components under the effects of solar radiation, the rotation of the earth and its orbital motion around the sun (refer to Chapter 5 - Box 5.1: Drivers of Climate).

The climate is usually defined in terms of a statistical description (mean and variability) of variables, such as temperature and precipitation, over a period of time ranging from a few years to millions of years. The World Meteorological Organization (WMO) recommends 30 years as the minimum period for averaging these variables to ascertain variability (WMO 2003).

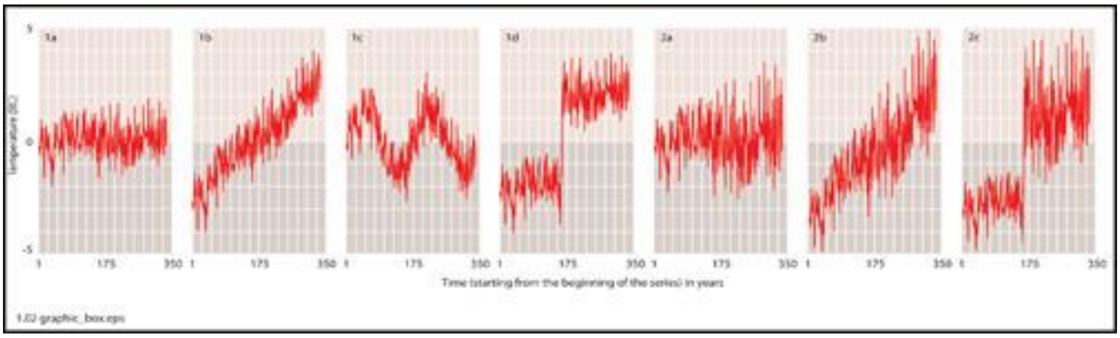


Figure 2.1: Climate variability and climate change
(WMO 2003)

Figure 2.1 illustrates a number of (notional) temperature time series under climate variability and climate change. Example 1a shows an example of climate variability - temperature fluctuates from observation to observation around a mean value. Examples 1b to 1d combine variability with climate change. Example 1a indicates an increase of variability with no change in the mean. Examples 1b and 1c combine increased variability with climate change.

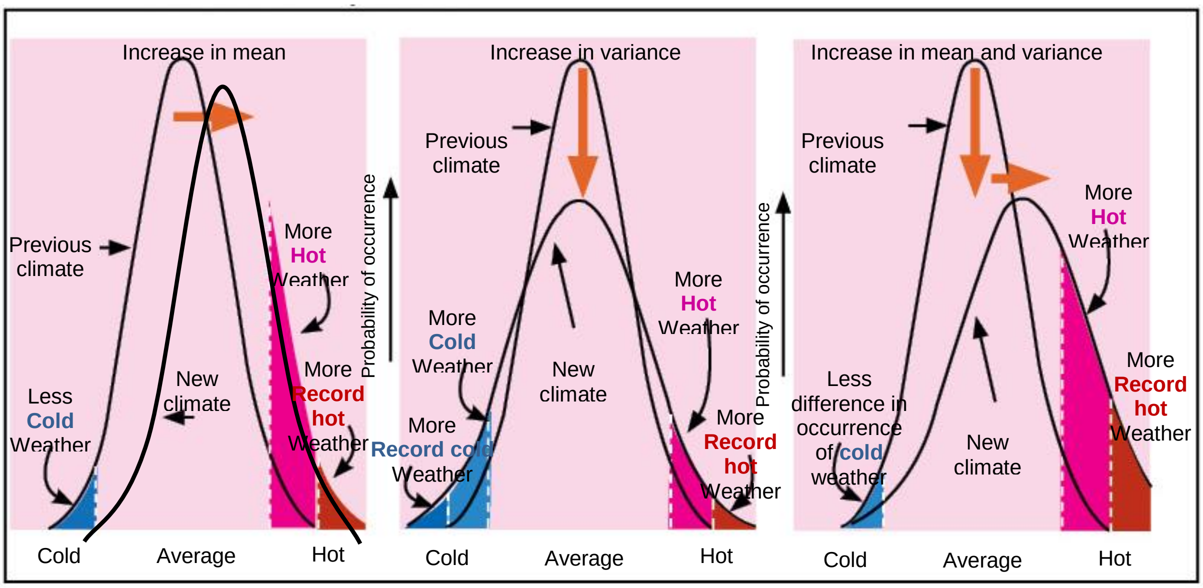


Figure 2.2: Climate variability and climate change – illustrated in the form of probability distributions for temperatures
(WMO 2003)

It is important to stress that no individual weather event can be attributed to climate change and that instrumental records for such events are not long enough to characterise the severity of future events. Figure 2.2 indicates through simple statistical reasoning how increased variability and mean in different combinations will affect temperature extremes.

Can you define weather and climate?

Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or as a result of persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1 defines climate change as 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes (IPCC 2007a).

2.1.2 Greenhouse gas concentrations, radiative forcing, and observed and projected temperature change

Water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and chlorofluorocarbons (CFCs) are the major greenhouse gases available in the atmosphere; there are a few other gases, which appear in trace amounts only. The earth's surface emits radiation. This emitted radiation is absorbed by greenhouse gas molecules and re-emitted in all directions, causing a warming of the earth's surface. Any change in the greenhouse gas content of the atmosphere triggers change in the global climate by modifying climate variables such as temperature. It is this enhanced greenhouse effect, attributed to the anthropogenically induced atmospheric changes from GHGs and aerosol concentrations, which are causing the global heat content to increase, resulting in climatic changes.

The Atmospheric Lifetimes, or residence times, for the various GHGs according to the IPCC AR5 Report (Myhre et al. 2013) are as follows:

- Water vapour: typically 10 days (controlled by the hydrological cycle)

- Carbon Dioxide (CO_2):
    - Source: Fossil fuel burning, deforestation
    - Anthropogenic increase: 30 percent
    - Average atmospheric residence time: 500 years

- Methane (CH4):
    - Source: Rice cultivation, cattle & sheep ranching, decay from landfills, mining
    - Anthropogenic increase: 145 percent
    - Average atmospheric residence time: 7-10 years

- Nitrous Oxide (N_2O):
    - Source: Industry and agriculture (fertilisers)
    - Anthropogenic increase: 15 percent
    - Average atmospheric residence time: 140-190 years

- Chlorofluorocarbons (CFCs): in excess of 50 years

It must be noted that the approximate value of 100 years is given for the adjustment time of CO_2 in the atmosphere, but the actual adjustment is initially faster but slower later on, which means that even drastic reductions in present emissions will not impact atmospheric CO_2 levels for approximately 100 years.

Figure 2.3 below presents the variations of deuterium (δD) over 650,000 years in Antarctic ice, which is a proxy for local temperature, and the atmospheric concentrations of the greenhouse gases carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) in air trapped within the ice cores and from recent atmospheric measurements. Both natural and human-made factors can be responsible for the changes in the greenhouse gas content of the atmosphere. The natural greenhouse effect may be caused by changes in CO_2 and CH_4 concentrations in the atmosphere that have been associated with transitions between glacial and interglacial episodes (shaded bands in Figure 2.3), vegetation, and weathering of rocks, among other factors.

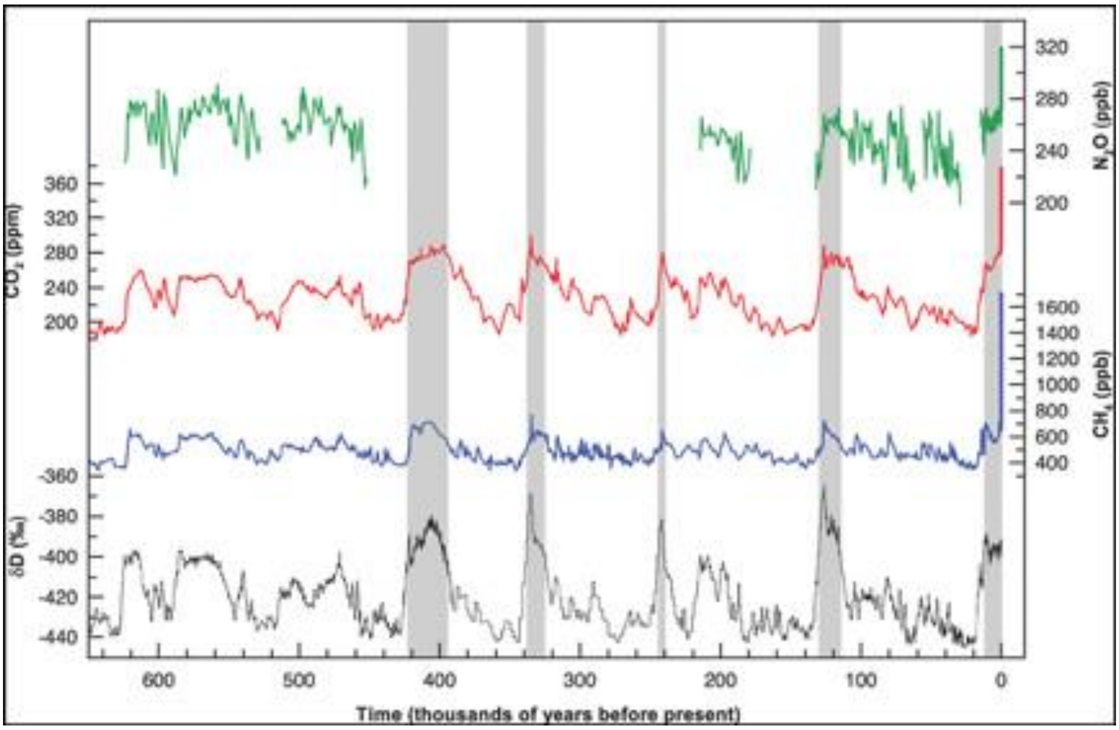


Figure 2.3: Variations of deuterium (δD) in Antarctic ice, and of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) in air trapped within ice cores. Shaded bands indicate current and previous interglacial warm periods
(Solomon et al. 2007)

The enhanced anthropogenic activities (Bindoff et al. 2013) that have increased the amount of CO_2 and other greenhouse gases since the 18th century include burning of fossil fuels, forest clearing, and industrial processes. The CO_2 concentration in the atmosphere has risen from 270 ppm to 395 ppm (upper limit measured for October 2014 by the Mauna Loa Observatory) in the past two hundred and fifty years (Figure 2.3), mainly due to the combustion of fossil fuels. This exceeds the natural variation (established through ice cores) over the past 650,000 years (180–300 ppm) (IPCC 2007b). The average annual growth rate in CO_2 concentration between 1995 and 2005 was 1.9 ppm y^{-1}, which is significantly higher than the 40-year average since 1960 (1.4 ppm y^{-1}), when the continuous record of atmospheric measurements began (Forster et al. 2007).

CO_2, methane, and nitrous oxide concentrations have far exceeded the natural range over past 650,000 years - most of the increase has been measured post-industrial revolution:

- CO_2 from 280 ppm to 380 ppm;
- Methane from 715 ppb to 1775 ppb; and
- Nitrous oxide from 270 ppb to 320 ppb.

Radiative forcing

There is a balance between incoming solar radiation and outgoing terrestrial radiation. Any process that alters the energy balance of the earth-atmosphere system is known as radiative forcing (RF). Some of the major causes that may trigger radiative forcing include variation in the earth's orbit, solar radiation, volcanic activity, and atmospheric composition (Forster et al. 2007). Figure 2.4 depicts the radiative forcing by the atmospheric concentrations of CO_2, CH_4, and

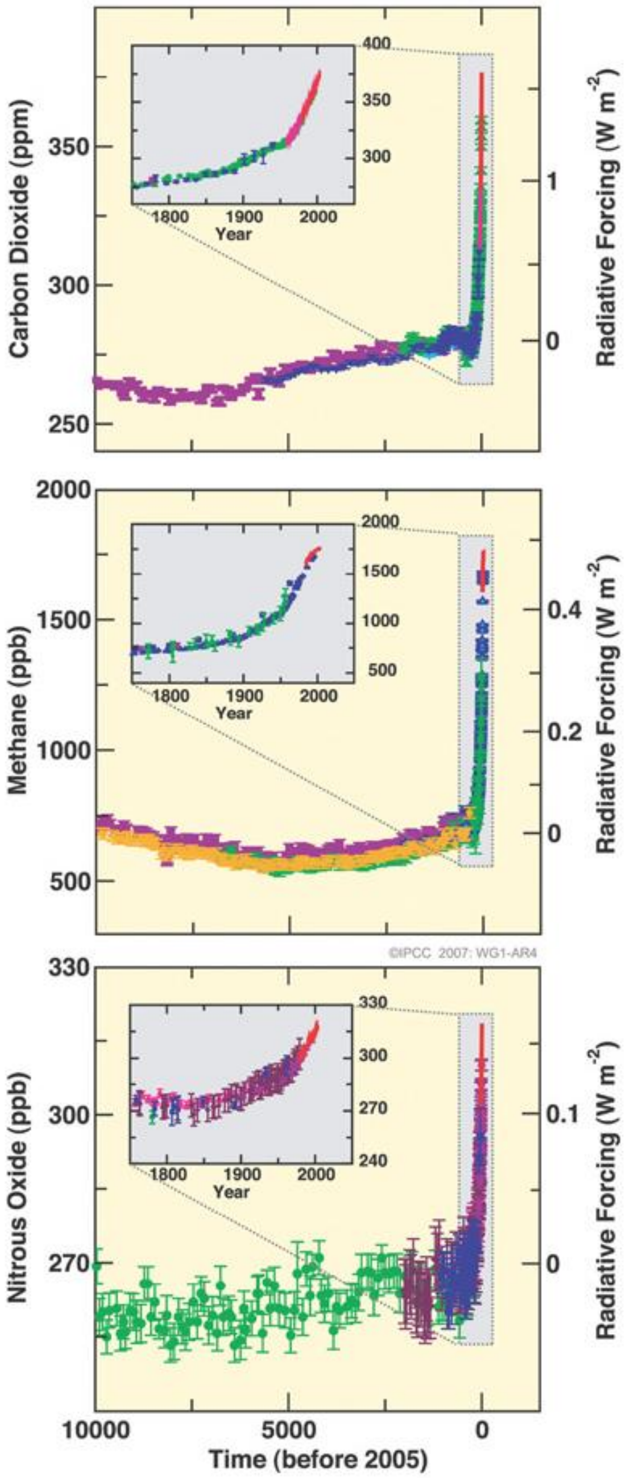


Figure 2.4: Atmospheric concentrations of carbon dioxide, methane and nitrous oxide over the last 10,000 years (large panels) and since 1750 (inset panels)
(IPCC 2007c)

N_2O over the last 10,000 years (large panels) and since 1750 (inset panels). Measurements are shown from ice cores (symbols with different colours for different studies) and atmospheric samples (red lines).

In Figures 2.5 and 2.6, AR5 provides global average radiative forcing estimates and ranges for anthropogenic agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU) in a comprehensive way (IPCC 2013).

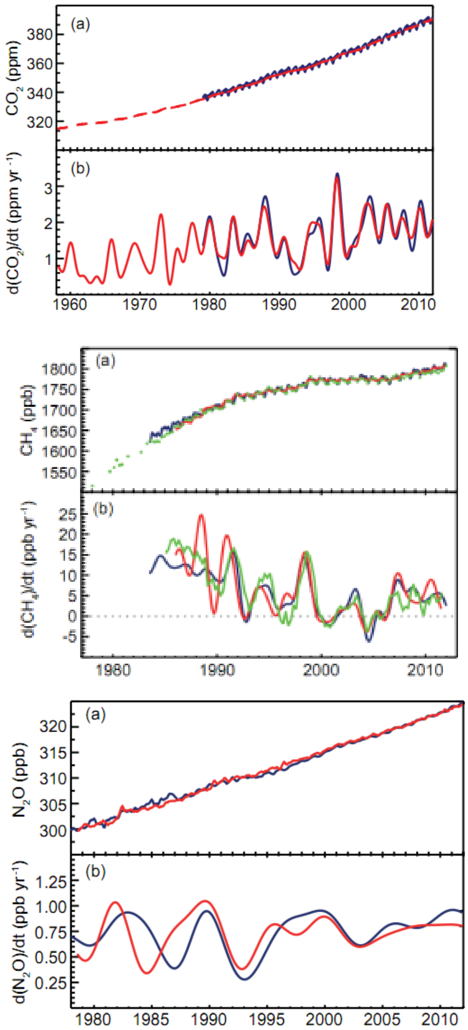


Figure 2.5: Globally averaged atmospheric concentrations of carbon dioxide, methane and nitrous oxide over the last 30- 50 years. *(IPCC 2013)*

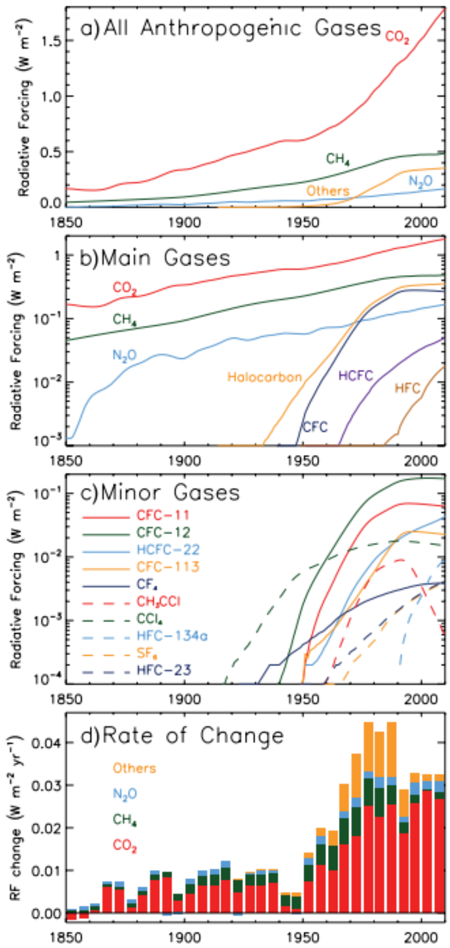


Figure 2.6: (a) Radiative forcing (RF) from the major well mixed greenhouse gases (WMGHGs) and groups of halocarbons from 1850 to (b) as (a) but with a logarithmic scale, (c) RF from the minor WMGHGs from 1850 to 2011 (logarithmic scale). (d) rate of change in forcing from the major WMGHGs and groups of halocarbons from 1850 to 2011.
(IPCC 2013)

The net anthropogenic radiative forcing and its range are also shown. These require summing asymmetric uncertainty estimates from the component terms, and cannot be obtained by simple addition. Additional forcing factors not included here are considered to have a very low LOSU. Volcanic aerosols contribute an additional natural forcing but are not included in this figure due to their episodic nature.

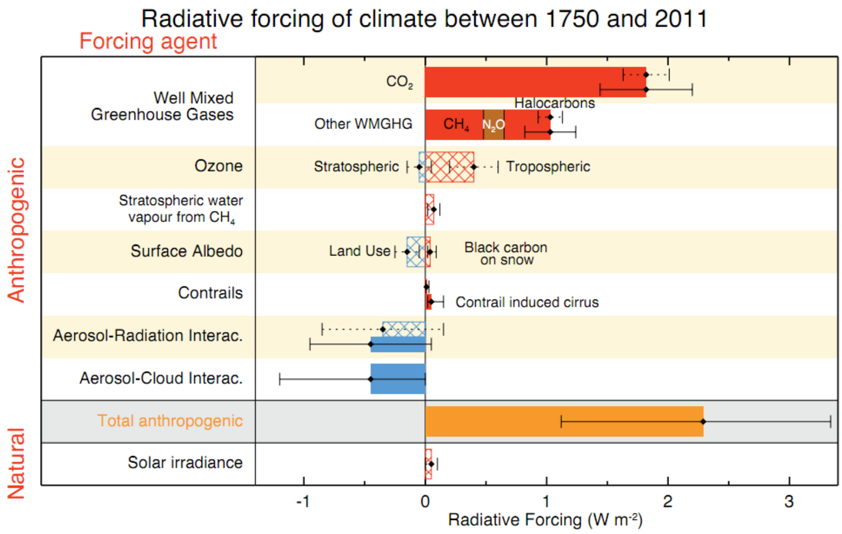


Figure 2.7: Global average radiative forcing (RF) estimates and ranges between 1750 and 2011 for anthropogenic carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU)
(IPCC 2013)

Figure 2.7 above presents the 'climate forcing' mechanisms that 'force' the climate to change by imposing a change in the planetary energy balance. The linkage of radiative forcing to other aspects of climate change is illustrated. Human activities and natural processes cause direct and indirect changes in climate change drivers. Radiative forcing and non-initial radiative effects lead to climate perturbations and responses. Climate change may also be attributed to natural and anthropogenic factors. The coupling among biogeochemical processes leads to feedbacks from climate change to its drivers. An example of this is the change in wetland emissions of CH_4 that may occur in a warmer climate (also see Box 5.1). The potential approaches to mitigating climate change by altering human activities (dashed line) are topics addressed by Working Group III of the IPCC (Figure 2.8).

What are the causes for radiative forcing? Which gas mainly accounts for radiative forcing per year?

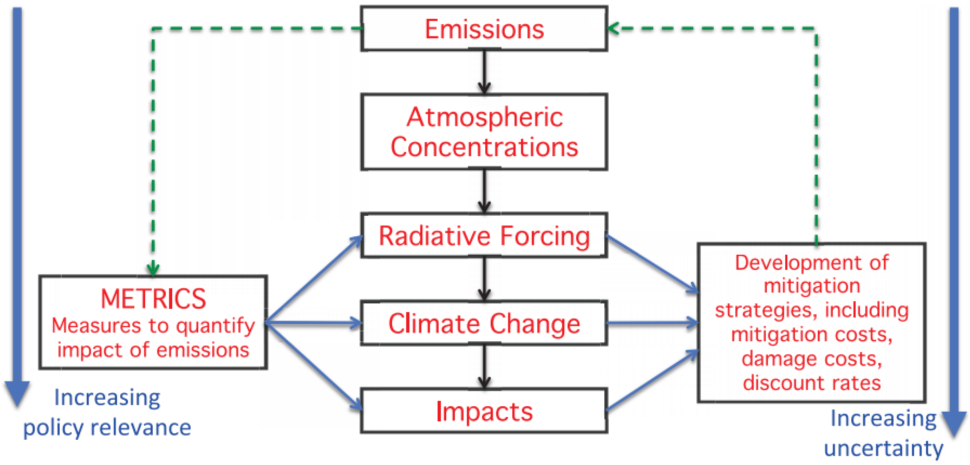


Figure 2.8: Diagram illustrating how RF is linked to other aspects of climate change assessed by the IPCC Components of the Climate Change Process
(IPCC 2013)

Box 2.1: El Niño Southern Oscillation (ENSO) phenomenon

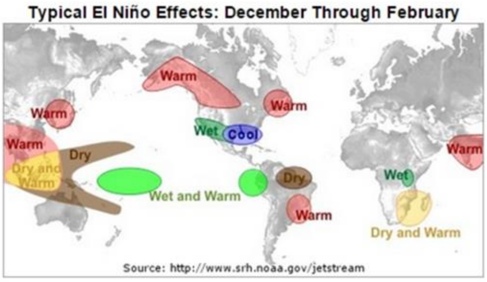
Climatic variations occur even in the absence radiative forcing. The Caribbean for example is routinely affected by the El Niño Southern Oscillation (ENSO) phenomenon. This is a natural phenomenon that occurs as a result of fluctuating atmospheric and oceanic conditions in the Pacific Ocean. The warming conditions of El Niño (an ENSO warm event) in the Pacific are accompanied by lower sea level pressure (SLP) in the eastern Pacific and a higher pressure in the western Pacific, while the reverse occurs during La Niña, otherwise known as an ENSO cold event. Together, they are known as the Southern Oscillation (SO). These events occur approximately every three to five years and typically last 9 – 12 months, although that timeframe is not fixed.

In terms of Caribbean SIDS, ENSO has a particular effect with respect to precipitation. The direct effect is due the Caribbean's location between the low sea level pressures in the Eastern Pacific and the resulting high sea level pressures in the equatorial Atlantic. As a result, drier conditions exist as a result of an El Niño event, and wetter conditions exist due to a La Niña event. Higher sea surface temperatures (SST) accompany El Niño events and peak approximately two to four months after an event – this is the indirect effect.

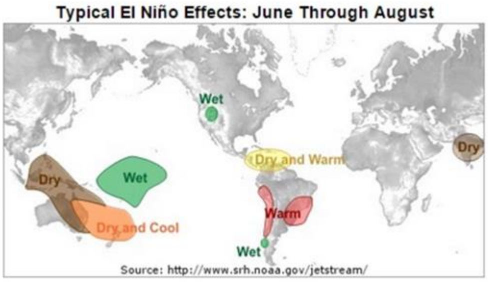
Overall, El Niño results in drier rainy seasons for the Caribbean, which has implications for water management. Islands that are already suffering from extremely dry conditions, such as Antigua and Barbuda and Barbados, face even more severe water shortages during these times.

El Niño events also result in fewer storms, while La Niña events are associated with an increased storm frequency in the Caribbean (IRI 2014).

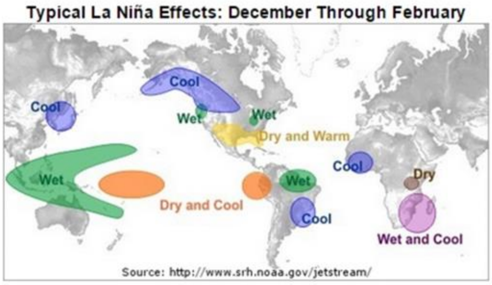
Typical El Niño Effects: December Through February



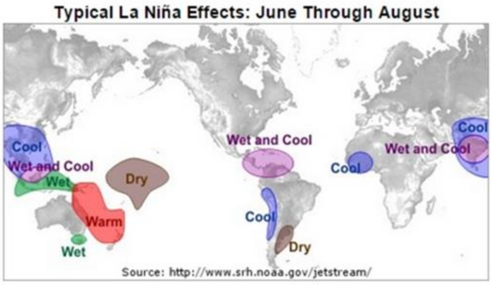
Typical El Niño Effects: June Through August



Typical La Niña Effects: December Through February



Typical La Niña Effects: June Through August



Observed and projected temperature change

Anthropogenic climate change is manifested in the increase of the earth's average surface temperature as a result of increases in the concentrations of greenhouse gases in the atmosphere, which absorb, reflect and partially re-radiate terrestrial long wave radiation, preventing it from leaving the earth's atmosphere.

All ten of the warmest years have occurred since 1997, with 2010 and 2005 effectively tied for the warmest year.

From examining long-term global mean temperature records, it has become clear to – and accepted by – the scientific community that the global mean temperature has increased by 0.6˚C over the 20th century, as shown in Figure 2.9 below. It is important to note that this change is not homogenous across the globe and is not linear. The records also show that the warmest year on record (until 2006) since scientific temperature observations began some 140 years ago was 1998, with surface temperatures averaging 0.55˚C above the 1961–1990 annual average. The second, third, fourth, and fifth warmest years on record are 2002, 2001, 2004, and 1995, respectively. Eleven of the 12 years between 1995 and 2006 rank among the 12 warmest years in the instrumental record of global surface temperature (since 1850).

The historical temperature record for the Caribbean region has been shown to match global records (Karmalkar et al. 2012). Global Climate Models (GCMs) have been downscaled for the Caribbean region to produce Regional Climate Models (RCMs) so that temperature and rainfall variability can be viewed for much smaller areas. The UK Hadley Centre's Regional Climate Modelling System, called PRECIS (Providing Regional Climates for Impact Studies, www.metoffice.gov.uk/precis/intro) has been applied to the Caribbean region. It is a dynamic downscaling technique that increases the resolution of the GCM to 50 km (Hall et al. 2013, Campbell et al. 2011, Karmalkar et al. 2012). This is one of the few RCMs run over the region and captures the bimodal nature of precipitation within the region. Projected temperature increase for the region for the period 2071-2100 is projected to be 1-4 ˚C, regardless of the scenario used (Campbell et al. 2011).

The projected temperature change with respect to emissions scenarios is depicted in Figure 2.9 Solid lines are multi-model global averages of surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. Shading denotes the ±1 standard deviation range of individual model annual averages. The orange line denotes the experiment where concentrations were held constant at year 2000 values. The grey bars at the right indicate the best estimate (solid line within each bar) and the likely range assessed for the Sixth Special Report on Emission Scenarios (SRES; see section 2.1.4).

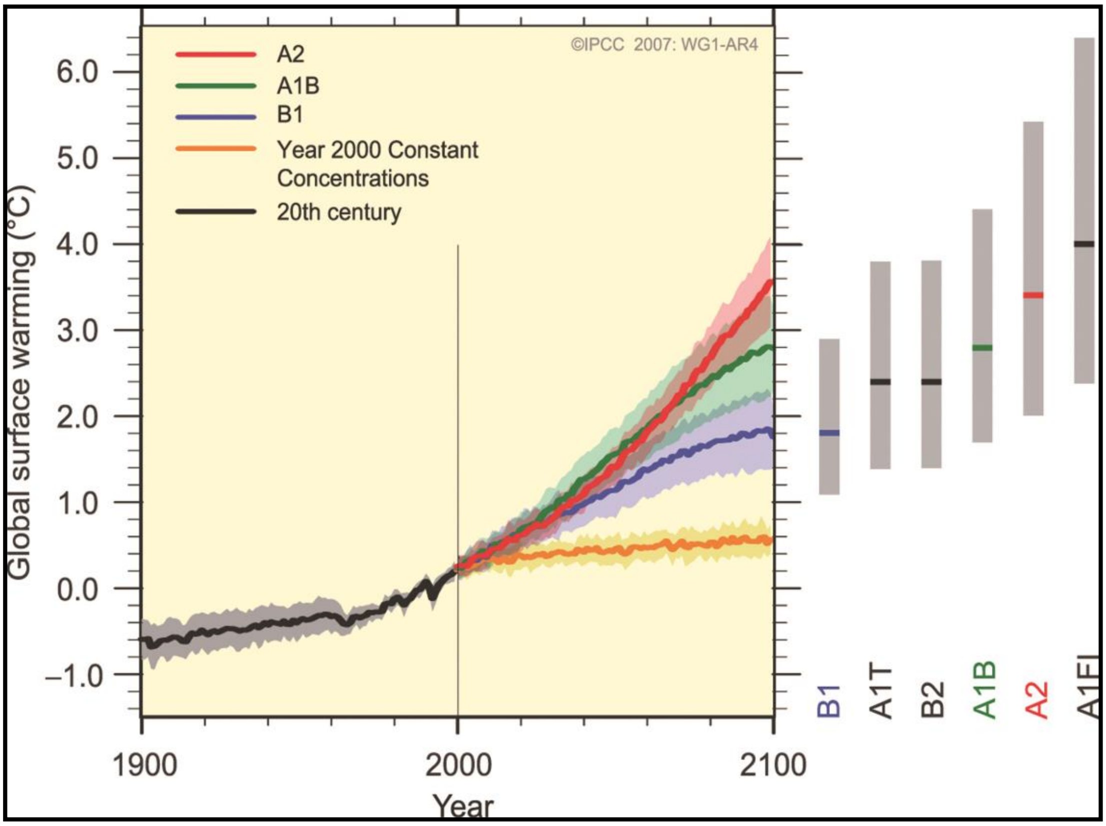


Figure 2.9: Solid lines are multi-model global averages of surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulations
(IPCC 2007c)

The PRECIS model projections for the Caribbean region show a general tendency for drying in the main Caribbean watershed by the end of the 21st century, with possibly wetter projections for the northern Caribbean between November and April. However, irrespective of the scenario modelled, the region is expected to become warmer. The warming is modelled to be greater under the A2 scenario. This is consistent with projections for other parts of the globe with the warming projected far exceeding natural variability (Figures 2.10 and 2.11 below).

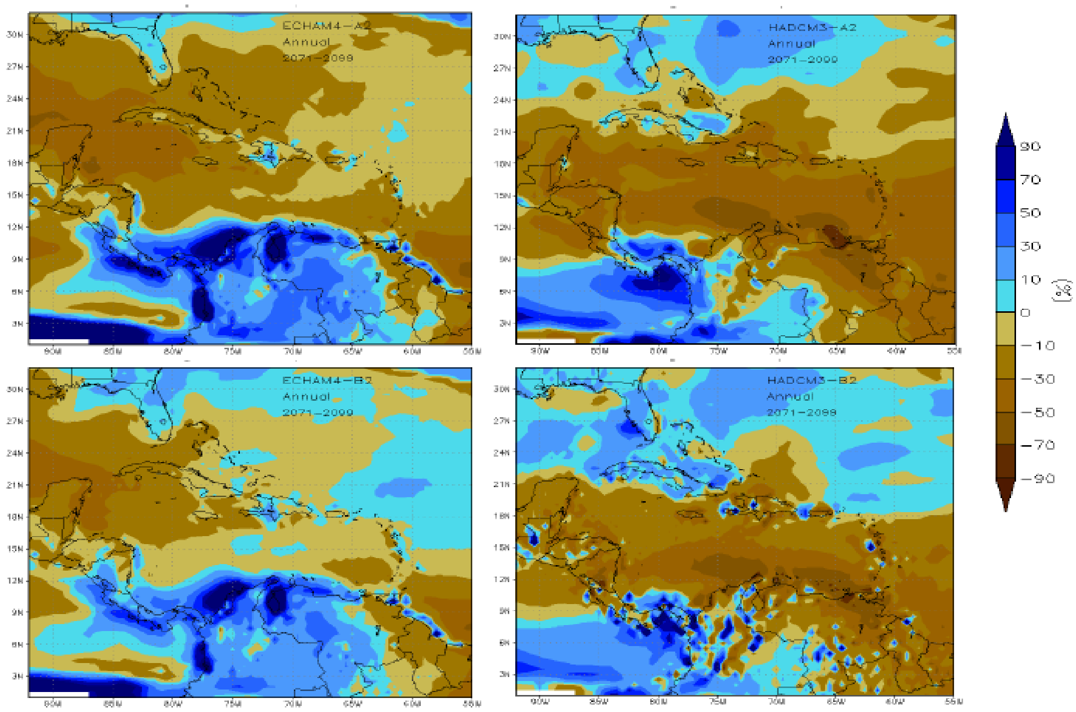


Figure 2.10: Mean changes in the annual rainfall for 2071-2099 for the Caribbean with respect to 1961-1990, as simulated by PRECIS_ECH and PRECIS Had for SRES A2 and SRES B2
(ECLAC 2010)

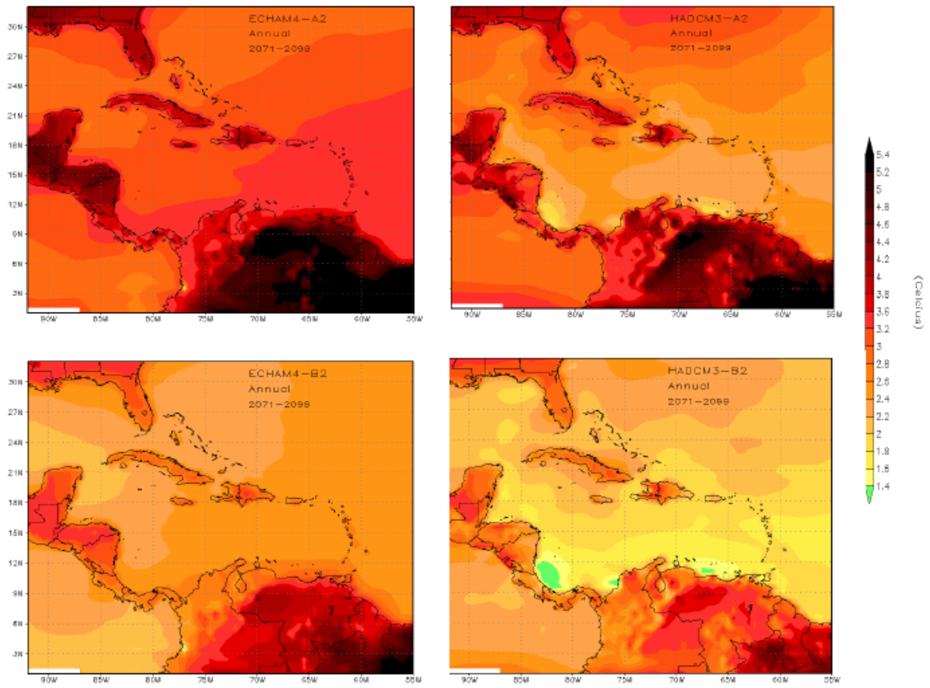


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Figure 2.11: Mean changes in the annual ,ean surface temperature for 2071-2099 for the Caribbean with respect to 1961-1990, as simulated by PRECIS_ECH & PRECIS_Had for SRES A2 and SRES B2 (ECLAC 2010)

2.1.3 Calibrating confidence and uncertainty

The IPCC has devised approaches to develop expert judgments, evaluating uncertainties, and communicating confidence and uncertainty in findings that arise in the context of the assessment process (Manning et al. 2004). It is proposed to use language that minimises possible misinterpretation and ambiguity to avoid uncertainty. However, terms such as 'virtually certain' or 'likely' can engage the reader effectively, but may be interpreted very differently by different people unless some calibration scale is provided. Therefore, three forms of language were used to describe different aspects of confidence and uncertainty and to provide consistency across the AR4 (see Box 2.1).

The IPCC Guidance Note on Uncertainty (2010) defines a common approach to evaluating and communicating the degree of certainty in findings of the assessment process. Each finding is grounded in an evaluation of underlying evidence and agreement. In many cases, a synthesis of evidence and agreement supports an assignment of confidence, especially for findings with stronger agreement and multiple independent lines of evidence. The degree of certainty in each key finding of the assessment is based on the type, amount, quality, and consistency of evidence (e.g. data, mechanistic understanding, theory, models, and expert judgment) and the degree of agreement. The summary terms for evidence are limited, medium, or robust. For agreement, they are low, medium, or high. Levels of confidence include five qualifiers: very low, low, medium, high, and very high, and are typeset in italics, e.g. *medium confidence*. The likelihood, or probability, of some well-defined outcome having occurred or occurring in the future can be described quantitatively through the following terms: virtually certain, 99–100 percent probability; extremely likely, 95– 100 percent; very likely, 90–100 percent; likely, 66–100 percent; more likely than not, >50–100 percent; about as likely as not, 33–66 percent; unlikely, 0–33 percent; very unlikely, 0–10 percent; extremely unlikely, 0–5 percent; and exceptionally unlikely, 0–1 percent.

Assessed likelihood is typeset in italics, for example, *very likely*. Unless otherwise indicated, findings assigned a likelihood term are associated with high or very high confidence. Where appropriate, findings are also formulated as statements of fact without using uncertainty qualifiers.

Box 2.2: Communicating confidence and uncertainty

Qualitatively defined levels of understanding

<table>
<tr><td rowspan="4">Level of agreement or consensus</td><td>High agreement
limited evidence</td><td>.....</td><td>High agreement
much evidence</td></tr>
<tr><td>.....</td><td>.....</td><td>.....</td></tr>
<tr><td>Low agreement
limited evidence</td><td>.....</td><td>Low agreement
much evidence</td></tr>
<tr><td colspan="3">Amount of evidence (theory, observations, models)</td></tr>
</table>

Quantitatively calibrated levels of confidence

Terminology	Degree of confidence in being correct
Very high confidence	At least 9 out of 10 chance
High confidence	About 8 out of 10 chance
Medium confidence	About 5 out of 10 chance
Low confidence	About 2 out of 10 chance
Very low confidence	Less than 1 out of 10 chance

Likelihood scale

Terminology	Likelihood of the occurrence/ outcome
Virtually certain	> 99 percent probability of occurrence
Very likely	> 90 percent probability
Likely	> 66 percent probability
About as likely as not	33 to 66 percent probability
Unlikely	< 33 percent probability
Very unlikely	< 10 percent probability
Exceptionally unlikely	< 1 percent probability

(Manning et al. 2004)

2.1.4 Emission scenarios

In 1992, IPCC released a set of six global emission scenarios (IS92a to f) known as IS92 scenarios. These are based on possible emissions of greenhouse gases under a wide range of assumptions of future population and economic growth. The IS92a scenarios (also known as the 'business as usual' scenarios) were the most widely used by scientists until they were updated in 2000 by IPCC and published through the SRES (IPCC 2000).

> **Are you aware of any signs of climate change? How certain are you that these are caused by climate change?**

The SRES scenarios are formulated in a fundamentally different way from previous scenarios, with a different range for each projection, called a 'storyline'. Four storylines have been defined, namely A1, A2, B1, and B2. These describe the possible ways the world population, land use changes, new technologies, energy resources, and economic and political structure may evolve over the next few decades (Anandhi 2007). These world future influences are represented in two dimensions: one represents economic or environmental concerns and the other represents the global or regional development patterns (Figure 2.12 below). For the A1 storyline, several emission scenarios were formulated, but the overall 'scenario families' were confined to four. The A1 storyline has three marker scenarios, namely A1B, A1F1 and A1T, whereas the others only have one each.

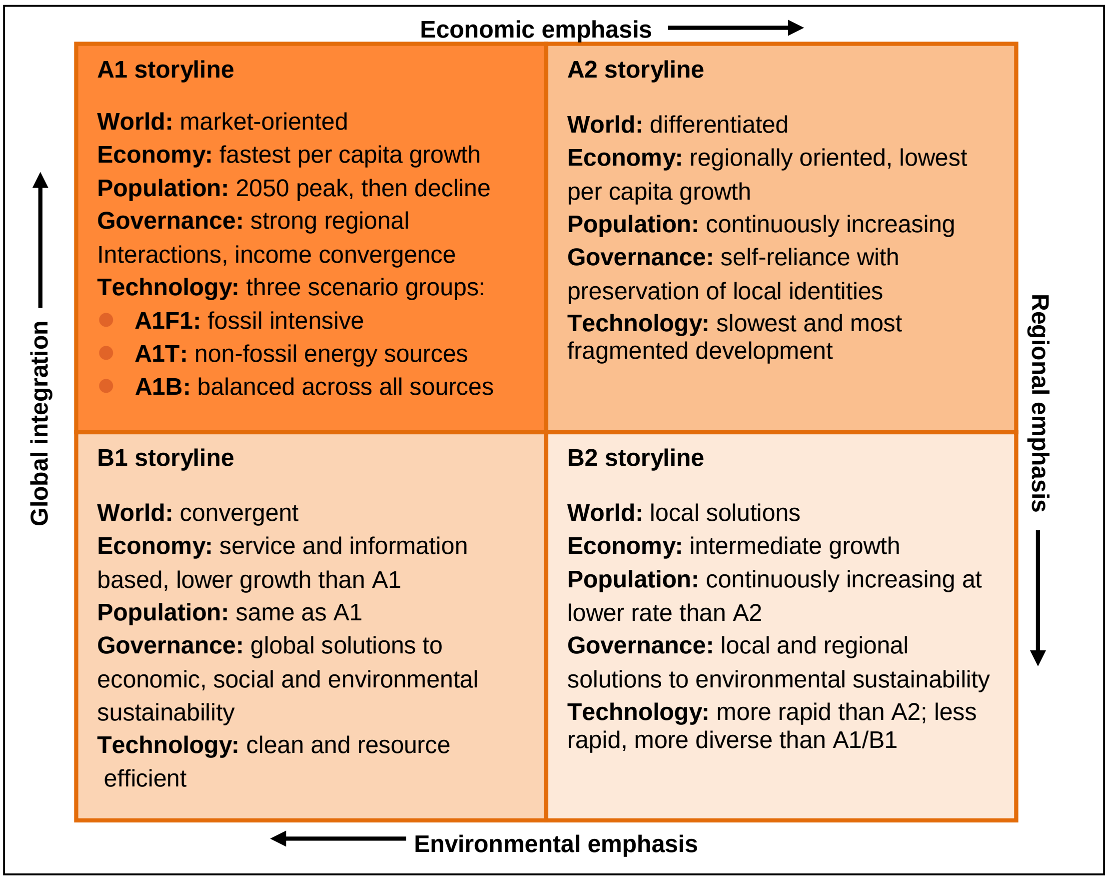

Figure 2.12: Scenarios considered by the IPCC in their Third Assessment Report of 2001

A1 storyline: This storyline designates very rapid growth with increasing globalisation, an increase in global wealth, with convergence between regions and reduced differences in regional per capita incomes. It also assumes materialist consumerism, with rapid technological change and low population growth. There are three variants within this family for sources of energy: a balance across all sources (A1B), fossil intensive (A1F1), and non-fossil fuel (A1T).
A2 Storyline: In this storyline a heterogeneous market-led world with rapid population growth but less rapid economic growth than A1 has been considered. The underlying theme is self-reliance and preservation of local identities.
B1 Storyline: This storyline assumes a world of dematerialisation and the introduction of clean technologies. The emphasis is on global solutions to achieve economic, social, and environmental sustainability.
B2 Storyline: In this storyline, population increases at a lower rate than in A2 but at a higher rate than in A1 with development following environmentally, economically, and socially sustainable locally oriented pathways.

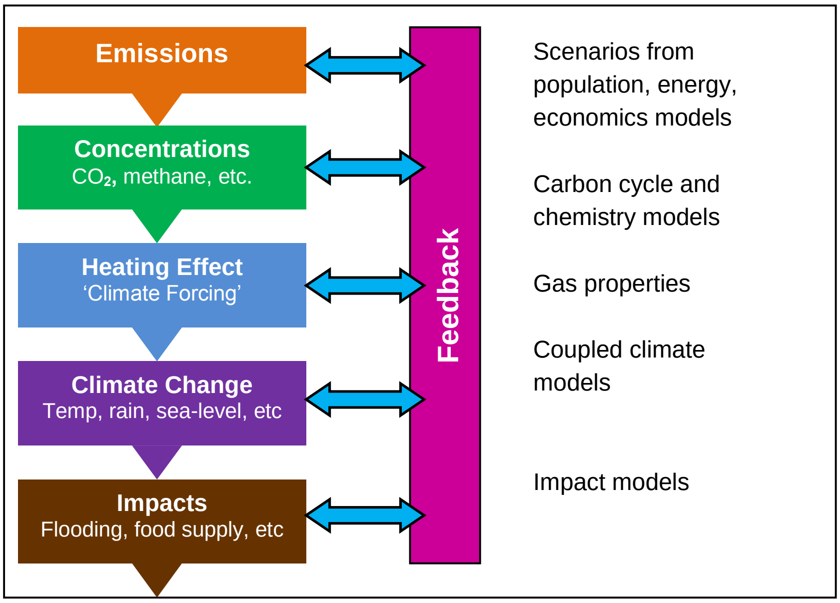

Figure 2.13: From greenhouse gas emissions to climate change impact
(Saunby 2007)

It is essential to remember that these emission scenarios are based on assumptions of future driving forces such as demographic, socio-economic, and technological development that may or may not be realised. As depicted in Figure 2.12, these emission scenarios are transformed into concentration scenarios, which are finally used for climate models to compute climate projections. There are uncertainties involved at every step, starting from emissions down through to the adaptation level, and at every successive stage the extent of uncertainties increases. It will be difficult for any government to invest in adaptation measures with such levels of uncertainties (see Chapter 5).

Which SRES scenario do you think is most relevant in your region and why?

However, there are projections of how much of a reduction in temperature is needed to allow for CO_2 levels to stabilise. In the Caribbean Region, the Caribbean Community Climate Change Centre (CCCCC) launched the "1.5 Stay Alive" campaign to educate the public on the immediate threat to their livelihoods in the region.

Figure 2.14: CCCCC's 1.5 Stay Alive campaign logo
(Caribbean Community Climate Change Centre 2014)

In the AR5, an additional set of scenarios has been developed and modelled to gain a better understanding of the future under various gas emission trajectories. These are referred to as Representative Concentration Pathways (RCPs), representative of possible future emissions scenarios with a pathway or trajectory of greenhouse gas concentrations over time.

The RCPs are an integrated assessment of concentration and emission scenarios chosen from existing literature that provide a holistic assessment of future gas trends through integrated scenarios of socioeconomic and climatic projections. They are a combination of "…more consistent short-lived gases and land use changes" (IPCC 2013). Four RCPs have been developed: RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5. The numbers in each RCP indicate the amount of radiative forcing produced by greenhouse gases in 2100. Figure 2.15 on the following page compares the SRES scenarios to the developed RCPs. The graph shows that the RF for the SRES and RCP scenarios are similar over the timeframe, the results of which can be used in climate envelope modelling studies.

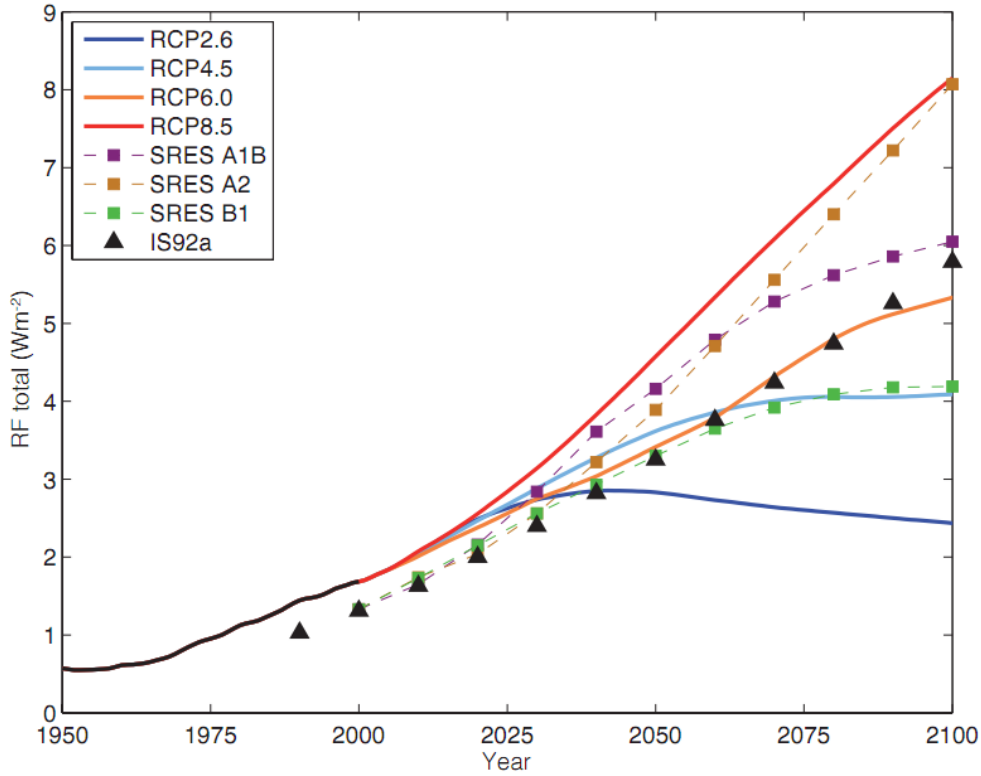

Figure 2.15: Historical and projected total anthropogenic RF (W m^{-2}) relative to preindustrial periods (about 1765) between 1950 and 2100. Previous IPCC assessments (SAR IS92a, TAR/AR4 SRES A1B, A2 and B1) are compared with the Representative Concentration Pathway (RCP) scenarios (IPCC 2013)

The four RCPs are based on the 21st century peak or stabilisation value of the RF derived from a reference model which expresses the RF in W $^{m-2}$. Figure 2.16 below highlights the various RCPs selected based on RF factor.

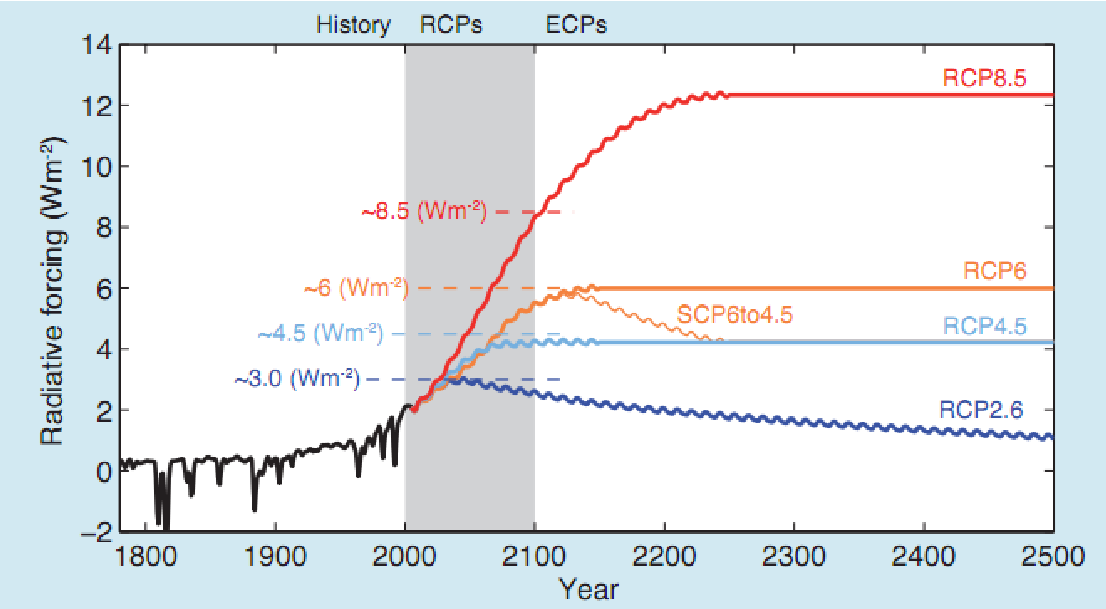

Figure 2.16: Total RF (Anthropogenic plus natural) for RCPs and extended concentration pathways (ECP): for RCP 2.6, RCP4.5, and RCP 6 and RCP 8.5, as well as supplementary extension RCP6 to 4.5 with an adjustment of emissions after 2100 to reach RCP4.5 concentration levels in 2250 and thereafter. (Note: there is substantial uncertainty in current and future RF levels for any given scenario)
(IPCC 2013)

2.2 Understanding observed and projected impacts on the water cycle

2.2.1 Observed changes and trends in the water cycle

Climatic changes have impacted natural and human systems across all continents and oceans. The evidence of impact is much more prominent and comprehensive in natural than human systems (IPCC 2013). The AR5 report highlights the importance of differential risks based on differences in vulnerability and exposure due to a multitude of inequalities that are the result of uneven developmental processes. Figure 2.17 highlights the changes to physical and biological systems attributed to climate change.

The quality and quantity of freshwater available to SIDS to feed biological systems and for ecosystems services production are being affected by changing rainfall patterns, which in turn alter the freshwater systems (CDKN 2014). Figure 2.18 gives us an idea of the impacts specific to SIDS with the following Figure 2.19, expressing the levels of confidence of impact to specific human and natural systems.

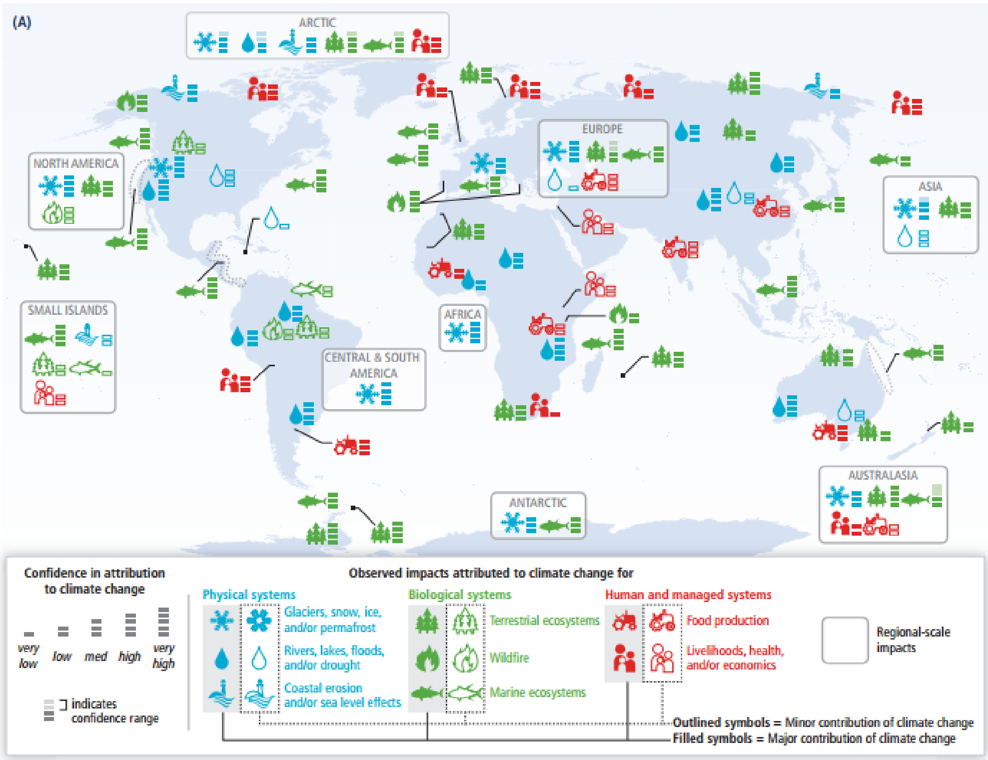

Figure 2.17: Global patterns of impacts in recent decades attributed to climate change based on studies since AR4. Impacts are shown at a range of geographic scales. Symbols indicate categories of attributed impacts, the relative contribution of climate change (major or minor) to the observed impact and confidence in attribution.
(Field et al. 2014)

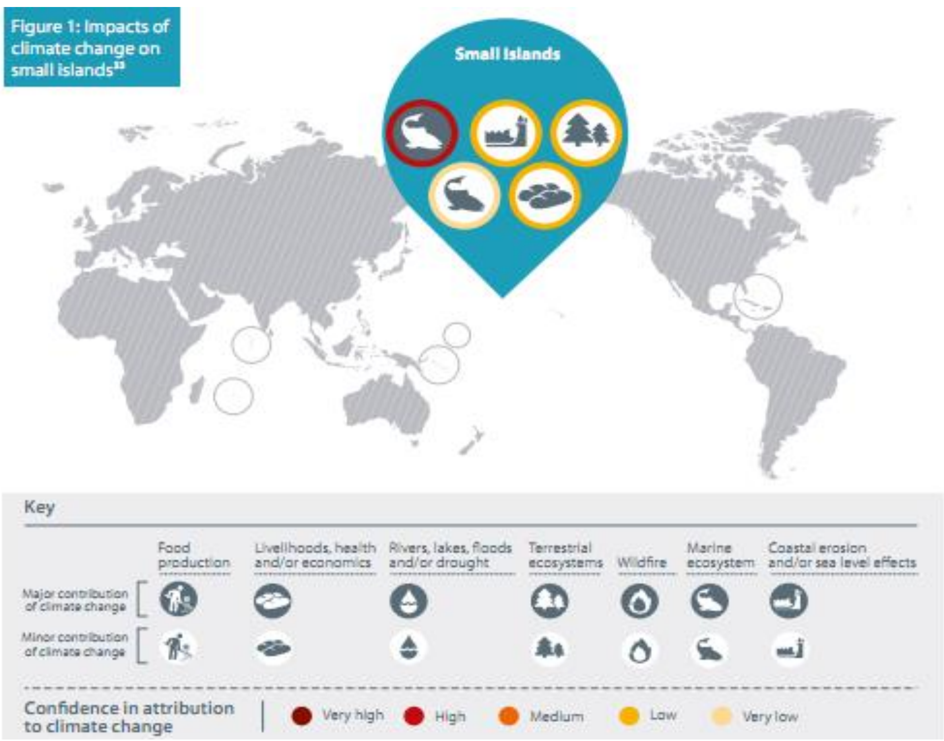

Figure 2.18: Impact of climate change specific to SIDS.
(CDKN 2014)

Freshwater resources	• Increased water scarcity in Jamaica, beyond increase due to water use (*very low confidence*, minor contribution from climate change)	
Terrestial ecosystems	• Tropical bird population changes in Mauritius (*medium confidence*, major contribution from climate change) • Upward trend in tree-lines and associated fauna on high-elevation islands (*low confidence*, minor contribution from climate change)	
Coastal erosion and marine ecosystems	• Increased coral bleaching near many tropical small islands, beyond effects of degradation due to fishing and pollution (*high confidence*, major contribution from climate change) • Degradation of mangroves, wetlands, and seagrass around small islands, beyond degradation due to other disturbances (*very low confidence*, minor contribution from climate change) • Increased flooding and erosion, beyond erosion due to human activities, natural erosion, and accretion (*low confidence*, minor contribution from climate change) • Degradation of groundwater and freshwater ecosystems due to saline intrusion, beyond degradation due to pollution and groundwater pumping (*low confidence*, minor contribution from climate change)	
Food production and livelihoods	• Increased degradation of coastal fisheries due to direct effects and effects of increased coral reef bleaching, beyond degradation due to overfishing and pollution (*low confidence*, minor contribution from climate change)	

Figure 2.19: Climate impacts for Small Island States
(CDKN 2014)

Cryosphere

Changes in systems and sectors related to accelerated melting in the cryosphere have been documented in glacial floods, ice, and rock avalanches in mountain regions, run-off in snow and glacial watersheds, Arctic mammals, Antarctic Peninsula fauna, *permafrost*-based infrastructure in the Arctic, relocation of ski centres to higher elevation areas, and impacts in indigenous livelihoods in the Arctic (high confidence). The changes in systems and sectors parallel abundant evidence leading to the assessment that the cryosphere is undergoing accelerated melting in response to global warming, including sea ice, freshwater ice, ice shelves, the Greenland ice sheet, glaciers, snow cover, and permafrost (*very high confidence*).

Hydrology and water resources

Recent evidences show that areas most affected by increasing droughts are located in arid and semi-arid regions due to the already warm and dry climate (*high confidence*). In the last 20 years, there are documented increases in flash floods and landslides due to intensive and heavy rain in mountain areas during the warm season (high confidence. Box 2.3 below highlights some of the effects that are already being

Box 2.3: Recent Flash Flooding Case Studies in the Caribbean Region

- Increasing occurrence of flash flooding: In April of 2003, the Caribbean Disaster Emergency Management Agency (CDEMA) initiated a Level 2 response to major flooding and subsequent landslide activity in Dominica. The Situation Report from CDEMA stated that the Pond Casse area experienced "… an extended period of moisture and instability" associated with a trough system. This system left behind severe damage to roads, bridges and other infrastructure in the area. The incident also left behind two fatalities (CDEMA 2013).
- The World Bank (2014) reported the December 2013 flash floods that affected the islands of Saint Vincent and the Grenadines, and St Lucia. Torrential rainfall and landslide activity left its trail on the damaged infrastructure, concentrated in the areas with the highest poverty levels. The incident also occurred during the peak of the tourist season and affected agriculture as well in both countries, leading to economic contractions.

felt in various islands in the Caribbean region.

Coastal processes and zones

Widespread coastal erosion and wetland losses are occurring under current rates of sea level rise, but at present, these are mostly the consequences of anthropogenic modification of the shoreline (*medium confidence*). In many low-lying coastal areas, development in conjunction with sea level rise (SLR) over the last century has exacerbated the damage to fixed structures from modern storms, which would have been relatively minor a century ago.

SIDS are particularly vulnerable and many islands of the Caribbean identify with the issue of sea level rise and the need for integrated coastal zone management (ICZM). Coastal zones are major income earners, tourism being the main economic driver in the region. Dominica, for example, is already experiencing coastal erosion (Bell Hall Beach Portsmouth) resulting in 4213.89 m^2 loss of beaches. Suriname has an extensive low-lying coastal region, housing the majority of its population and is central to economic activity. Nevis has also taken this emerging threat into consideration and has identified that even a 0.5 m rise in sea levels will result in 40 percent of their major beach resorts (Jessups, Oualie, and Pinney's Beach) becoming inundated. The stakes are high for these countries, especially with regards to the coastal inundation threat to tourism-based infrastructure, but also to ecotourism activities (such as sea turtle nesting sites in Antigua and Barbuda) (Simpson et al. 2012).

Simpson et al (2010) documented that the impacts of SLR will not be uniform among the CARICOM nations, with some countries projected to experience severe impacts from even a 1 m SLR. Based on available information, the Bahamas, Suriname, Guyana, Trinidad and Tobago and Belize are anticipated to suffer the greatest economic losses and damages in absolute economic terms. A second critical observation is that while the absolute size of economic losses is generally much greater in larger CARICOM economies, the proportional impacts (losses compared to the size of the national economy) are generally higher in the smaller economies of St. Kitts and Nevis, Antigua and Barbuda, Barbados, St. Vincent and the Grenadines, and Grenada. The capacity of the economies in these countries to absorb and recover from proportionately higher economic losses is expected to be lower. Impacts from a 1 m SLR in the CARICOM nations include:

- Nearly 1,300 km^2 land area lost (e.g. five percent of the Bahamas, and two percent in Antigua and Barbuda);
- Over 110,000 people displaced (e.g. five percent of population in the Bahamas, and three percent in Antigua and Barbuda);
- At least 149 multi-million dollar tourism resorts damaged or lost, with beach assets lost or greatly degraded at many more tourism resorts;
- Damage or loss of five power plants;
- Over one percent of agricultural land lost, with implications for food supply and rural livelihoods (e.g. five percent in Dominica, 6 percent in the Bahamas, and five percent in St. Kitts and Nevis);
- Inundation of known sea turtle nesting beaches (e.g. 35 percent in the Bahamas and St. Kitts and Nevis, 44 percent in Belize and Haiti, and 50 percent in Guyana);
- Transportation networks severely disrupted;
- Loss or damage of 21 (28 percent) of CARICOM airports;

- Lands surrounding 35 of 44 ports inundated; and
- Loss of 567 km of roads (e.g. 14 percent of road network in the Bahamas, 12 percent in Guyana, and 14 percent in Dominica).

Marine and freshwater biological systems

Many of the observed responses in marine and freshwater systems have been associated with rising water temperatures (*high confidence*), matched with changes in volume and timing of precipitation, increased evapotranspiration, and resulting reductions in groundwater recharge leading to increased low-flow episodes in rivers and increased water stress on biological systems. Climate change, in tandem with other human impacts, has already caused substantial reductions in habitat availability and reductions in flow-dependent species as well as impacting estuarine ecosystems (increased pollution levels) (Quesne et al. 2010). The documented poleward movement of plankton by 10 degrees in the North Atlantic is larger than any documented terrestrial study. Observations indicate that lakes and rivers around the world are warming, with effects on thermal structure, lake chemistry, abundance and productivity, community composition, phenology, distribution, and migration (*high confidence*).

Increases in higher and more frequent storm flows have also resulted in the removal of riparian and bottom dwelling organisms, changed the structure of habitats (widening floodplains) as well as decreases in shading from near channel vegetation, thereby increasing shallow water temperatures (Quesne et al. 2010).

Terrestrial biological systems

The overwhelming majority of studies examining global warming impacts on terrestrial species reveal a consistent pattern of change (*high confidence*). Responses of terrestrial ecosystems to warming across the northern hemisphere are well documented by phenological changes, especially the earlier onset of spring phases. Climate change over the past decades has resulted in population decrease and disappearance of certain species (*medium confidence*) and movement of wild plant and animals poleward and upward in elevation (*medium confidence*). Some evidence of adaptation is found in migratory species (*medium confidence*).

Agriculture and forestry

In North America and Europe, there is a lengthening of the frost-free growing season and an advance in spring-summer crop phenology, which may be attributed to recent warming (*high confidence*). Viniculture appears to be highly sensitive, with a documented improvement of quality related to warming. Reductions in precipitation, on decadal scales in the Sahel, are responsible for lower crop yields (*high confidence*).

Do you know of any examples of impacts of climate change on the water cycle? What do you expect for the future?

In the Caribbean region, agriculture is considered particularly vulnerable to climatic changes and it is expected that rural farming communities will be most affected (Trotz and Lindo 2013). In the region, agriculture and farming are particularly vulnerable due to the high dependency on weather and limited technology. An added impact is that of hurricanes and storms and their impact on agriculture dependent economies. In this regard, the damage and loss to the agricultural sector in Jamaica due to major climatic events between 1994 and 2010 is estimated to have amounted to J$14.4 billion.

Jamaica's agricultural sector recorded losses around J$8.5 billion (Selvaraju et al. 2013). Ivan also extended its destruction to 90 percent of the nutmeg trees in Grenada, threatening the livelihood of approximately 6,500 nutmeg farmers (Barker 2012).

2.2.2 Projections of future climate change impacts on the water cycle

It is expected that climate change is likely to alter the hydrologic cycle in ways that will result in substantial impacts on water resource quantity as well as quality. Precipitation, which is the main component of hydrology, is expected to change in intensity and spatial distribution. A brief summary of potential impacts on the most important water resource elements as brought out by IPCC in AR5 is given below (Parry et al. 2007). In Chapter 4, more details will be presented on regional differentiation.

Specific to the Caribbean region, aside from the downscaled projections of changes in temperature and precipitation previously mentioned in Chapter 2 for the Caribbean region, observations of change have been noted with regards to minor shifts in wet and dry season, as well as from anecdotal data comparisons.

Precipitation changes

An increase in global average precipitation and evaporation as a direct consequence of warmer temperatures has been predicted (Figure 2.11). Evaporation will increase with warming because a warmer atmosphere can hold more moisture, and higher temperatures increase the evaporation rate. An increase in global average precipitation does not mean that it will get wetter everywhere and in all seasons. In fact, all climate model simulations show complex patterns of precipitation change, with some regions receiving less and others receiving more precipitation than they do now. Changes in circulation patterns will be critically important in determining changes in local and regional precipitation patterns.

Figure 2.20 presents the range of winter and summer temperature and precipitation changes up to the end of the 21st century across recent models (15 – red bars) and pre-AR3 models (7 – blue bars). Coupled Atmosphere-Ocean General Circulation Model (AOGCM) projections under the SRES A2 emissions scenarios for 32 world regions is expressed as rate of change per century. Mauve and green bars show modelled 30-year natural variability. Numbers on precipitation plots show the number of recent A2 runs giving negative/positive precipitation change.

In determining climate change scenarios for the Caribbean region, however, the absolute change in temperature and percentage change in precipitation for the period 2071–2100 relative to the simulated baseline (1961-1990) under the A2 and B2 SRES scenarios was computed. The model results show that with the exception of the far northern latitudes, i.e., Florida, the Bahamas, and northern Cuba, annual rainfall is projected to decrease by about 25-50 percent under the A2 and B2 SRES scenarios over the Lesser Antilles and the Central Caribbean watershed (A2 Scenario), in comparison to the largest change (drying) located in the Netherland Antilles for the B2 Scenario. The northern edge of the Caribbean is projected to become wetter under both scenarios (about 25 percent for A2 and between 0-25 percent for the B2 projections).

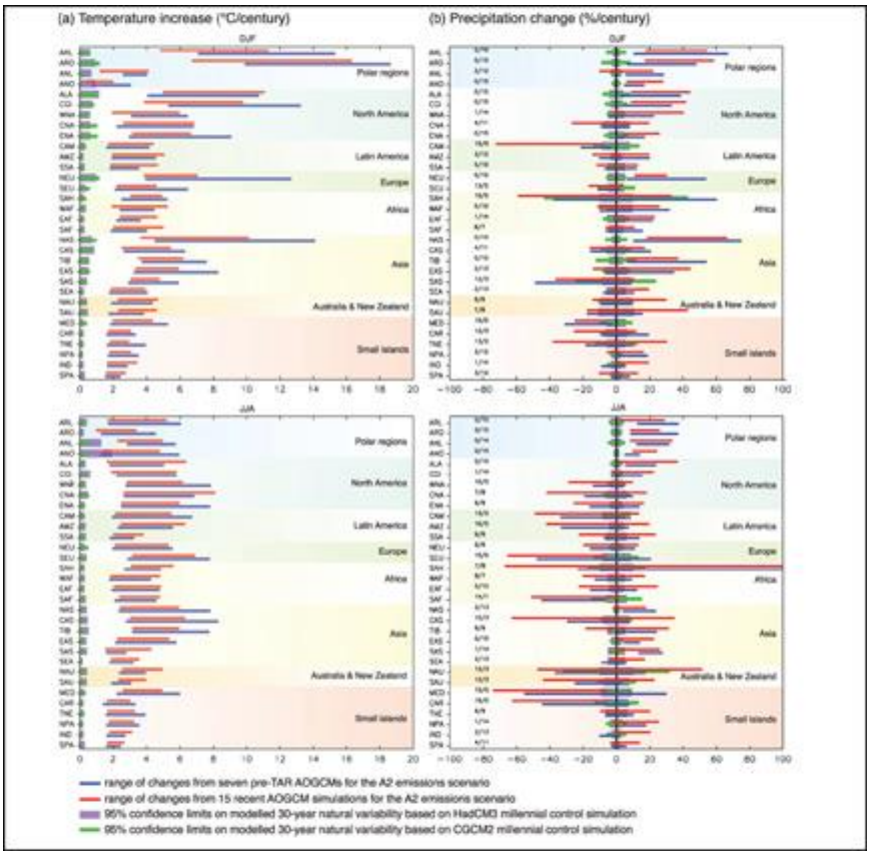

Figure 2.20: Regional temperature and precipitation changes to the end of the 21st century (various models)
(Parry et al. 2007)

Changes in precipitation frequency and intensity

It is also expected that, in addition to changes in global average precipitation, there could be more pronounced changes in the characteristics of regional and local precipitation due to global warming. On average, precipitation will tend to be less frequent but more intense, implying greater incidence of extreme floods and droughts.

The observed rainfall trends for the Caribbean region (last 100 years: 1900-2000) has shown a consistent reduction in rainfall (CDKN 2014) (noting that intraregional variability considerations excluded). Rainfall is projected to decrease under the low emissions scenario (RCP 4.5) by about five to six percent.

Changes in average annual run-off

Run-off changes will depend on changes in temperature and precipitation, among other variables. Most of the hydrological modelling studies have found that although there is a global average increase in precipitation, there are substantial areas where large decreases in run-off due to higher temperatures occur, which lead to higher evapotranspiration losses. Thus, the global message of increased precipitation clearly does not readily translate into regional increases in surface and groundwater availability.

Impacts of sea level rise on coastal zones

Some of the key impacts of sea level rise in coastal areas include (1) lowland inundation and wetland displacement, (2) altered tidal range in rivers and bays, (3) changes in sedimentation patterns, (4) more severe storm surge flooding, (5) increased saltwater intrusion into estuaries and freshwater aquifers and (6) increased wind and rainfall damage in regions prone to tropical cyclones.

Projected sea level rise for the Caribbean is in the range of 0.5-0.6 m (CDKN 2014). This poses a significant threat to the region since smaller islands such as the Bahamas and Anguilla will be significantly affected as they lie just above sea level. However, due to the high spatial variability, assigning a regional value for sea level rise to the Caribbean should be taken with some amount of caution (Maul 1993). Additionally, natural subsidence and subsidence due to petroleum and natural gas extraction, groundwater pumping, and sediment compaction will cause a further 15-20 cm increase in relative mean sea level, which is greater than the global average.

Impacts from a combination of SLR and one in 100 year storm surge in the CARICOM nations include (Simpson 2010) over one million people at risk to flooding (for example 22 percent of population of the Bahamas, 13 percent of Belize's population, and 12 percent of that of Antigua and Barbuda);

- Over 50 percent of major tourism resorts at risk to damage in Antigua and Barbuda, Belize, Haiti, St. Kitts and Nevis, St. Vincent and Grenadines, and the Bahamas;
- Flooding risk at all of the airports in Antigua and Barbuda, Belize, Dominica, Grenada, Haiti, St. Lucia, and St. Vincent and Grenadines, and the majority of airports in all other countries with the exception of Barbados; and
- Flooding damage to road networks (for example 27 percent in the Bahamas and 16 percent in Belize).

Water quality changes

Although the IPCC did not find evidence for a climate-related trend in water quality (Kundzewicz et al. 2007), a number of impacts can be expected to occur. Thus, more intense rainfall generally results in increased run-off and subsequently in an increase in the concentration of suspended solids (and turbidity) in rivers and lakes. If this run-off is accompanied by the transport of pollutants (e.g. fertilisers, pesticides, stormwater overflows), water quality will deteriorate. Fiji is one of the SIDS that has acknowledged the effect of climatic change to water quality and its impact on health, noting that some of the largest existing disease burdens are climate sensitive (Narayan 2012). The January 2012, floods in Fiji were exacerbated by land-use changes and resulted in increases in the intensity of water runoff leading to the distribution of water purification tablets to the local populous (OCHA 2012).

On the other hand, high river discharges will reduce the concentrations of dissolved chemicals. Water quality will consequently improve, although the total pollutant load will not change. During drought periods, water quality can deteriorate because of the opposite effect - reduced dilution of pollution. Changes in river flows will also affect the level of salt intrusion in estuaries: During low flows, salt concentrations in rivers will increase further inland, exacerbated by sea level rise. This will have repercussions for the production and supply of water for drinking, irrigation, industrial processes, and so on.

Higher water temperatures, an increase of up to 2°C since 1960, have been observed in lakes and rivers (see Rosenzweig et al. 2007 for an overview). This has resulted in earlier summer stratification and shallower thermoclines, depletion of nutrients in surface waters, and increased nutrient concentrations in deeper water layers (cf. 4.2.2: Lake Tanganyika). In addition, harmful algal blooms seem to be linked to increasing water temperatures and increased respiration, and the resulting lowered oxygen concentrations in warmer waters will accelerate oxygen depletion, resulting in anaerobic conditions with their resulting impacts on aquatic production and fisheries.

There is no evidence yet of climate change impact on water levels in shallow lakes (Rosenzweig et al. 2007). However, if lowering occurs during prolonged dry periods, re-suspension of bottom materials will be enhanced. This will decrease water transparency and could result in the release of nutrients (e.g. phosphate), enhancing eutrophication and/or the release of toxic compounds present in bottom sediments.

Groundwater changes

In many communities, groundwater is the main source of water for irrigation, and domestic and industrial demands. Generally, there are two types of groundwater resources – renewable and non-renewable. Renewable groundwater is directly tied to near-surface hydrologic processes; it is thus intricately tied to the overall hydrologic cycle and could be directly affected by climatic change. In many places, because of increasing demands, the overdraft of renewable groundwater aquifers occurs because the rate of withdrawal exceeds the rate of recharge. Thus, climate change could directly affect these recharge rates and the sustainability of renewable groundwater.

All CARICOM member states rely primarily on groundwater, surface water, rainwater harvesting, or a combination of these to meet their water demands in their most intensive sectors. The impact of droughts on groundwater systems tends to be slower in most cases when compared to the surface water systems. Therefore, if restrictive management practices are not put in place, over-extraction of groundwater may occur (Farrell, Trotman, and Cox 2010). An indirect effect of groundwater extraction is also on land subsidence and therefore the increased impact of sea level rise as previously mentioned.

Climate change impacts on ecosystems

Projected risks due to critical climate change impacts on ecosystems for different levels of global mean annual temperature change (ΔT) are shown in Figure 2.21 below; these are relative to the pre-industrial climate and are used as a proxy for climate change. The red curve shows observed temperature anomalies for the period 1900–2005. The two grey curves provide examples of the possible future evolution of the global average temperature change, with time exemplified by Working Group I simulated, multi-model mean responses to (i) the A2 radiative forcing scenario and (ii) an extended B1 scenario, where radiative forcing beyond 2100 was kept constant at the 2100 value. White shading indicates neutral, small negative or positive impacts or risks; yellow indicates negative impacts for some systems or low risks; and red indicates negative impacts or risks that are more widespread and/or greater in magnitude. Illustrated impacts take into account climate change impacts only and omit effects of land-use change or habitat fragmentation, over-harvesting or pollution (e.g. nitrogen deposition).

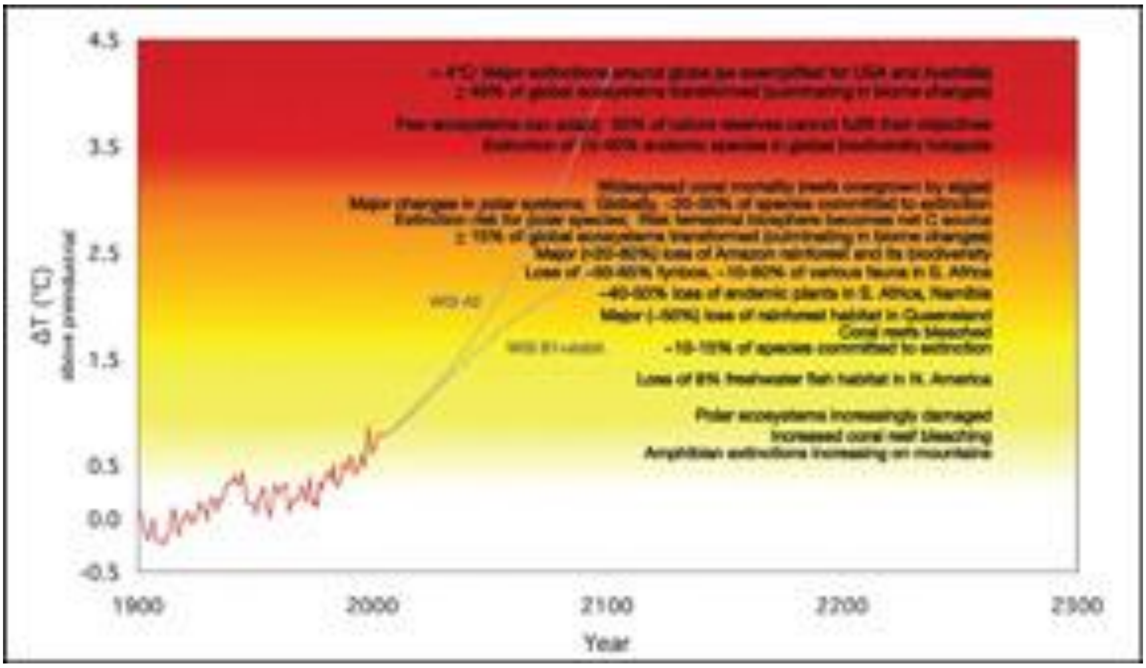

Figure 2.21: Projected risks due to critical climate change impacts on ecosystems
(Fischlin et al. 2007)

For the Caribbean Region, a comprehensive report on the impact of climate change on the marine and coastal ecosystems of the Caribbean Region was done in 2008. In this report Cambers et al. (2008) highlight that the high biodiversity found in the Caribbean coral reefs is as a result of the strong influence of the adjacent seagrass beds and mangrove forests. Therefore, any negative impact on these areas would cascade into the seascape. Unhealthy corals may also be unable to keep up with the pace of sea level rise and may therefore be unable to carry out their coastal protection functions.

2.2.3 Impacts on ecological processes

To understand the impacts of climate change on ecological processes, and therefore on ecosystems, biodiversity, food security, spread of diseases, and so on, it must be realised that the increased concentrations of greenhouse gases in the atmosphere have both direct and indirect effects. Thus, increased atmospheric CO_2 levels will affect physiological processes like photosynthesis, respiration, growth, and water use in plants. However, via increased temperatures, changed precipitation patterns, sea level rise, and changes in water quality, among others, various ecological relevant functions and processes are affected as well. Figure 2.22 below summarises some major climate change impacts on ecological processes and the consequences for the structure and functioning of ecosystems. Changes in phenology and distribution patterns are elaborated below.

The small size of the Caribbean islands leaves limited room for species to adapt to the traditional drivers of habitat loss and now the coupled climatic changes (Maharaj and New 2013). Species distribution modelling is limited by the lack of data in the Caribbean region; however, its application to the Caribbean island of Trinidad through a research-facilitated initiative has allowed for exploration in this arena. New datasets led to a study entitled "SD modelling analyses that investigate the potential response of a group of high conservation value tree species across the island of Trinidad during

2050 under an SRES A2 emissions future" (Maharaj and New 2013). The results show that the majority of the species fall into the category of 'losers'; which is defined by a future suitable habitat range of less than 50 percent of the present range.

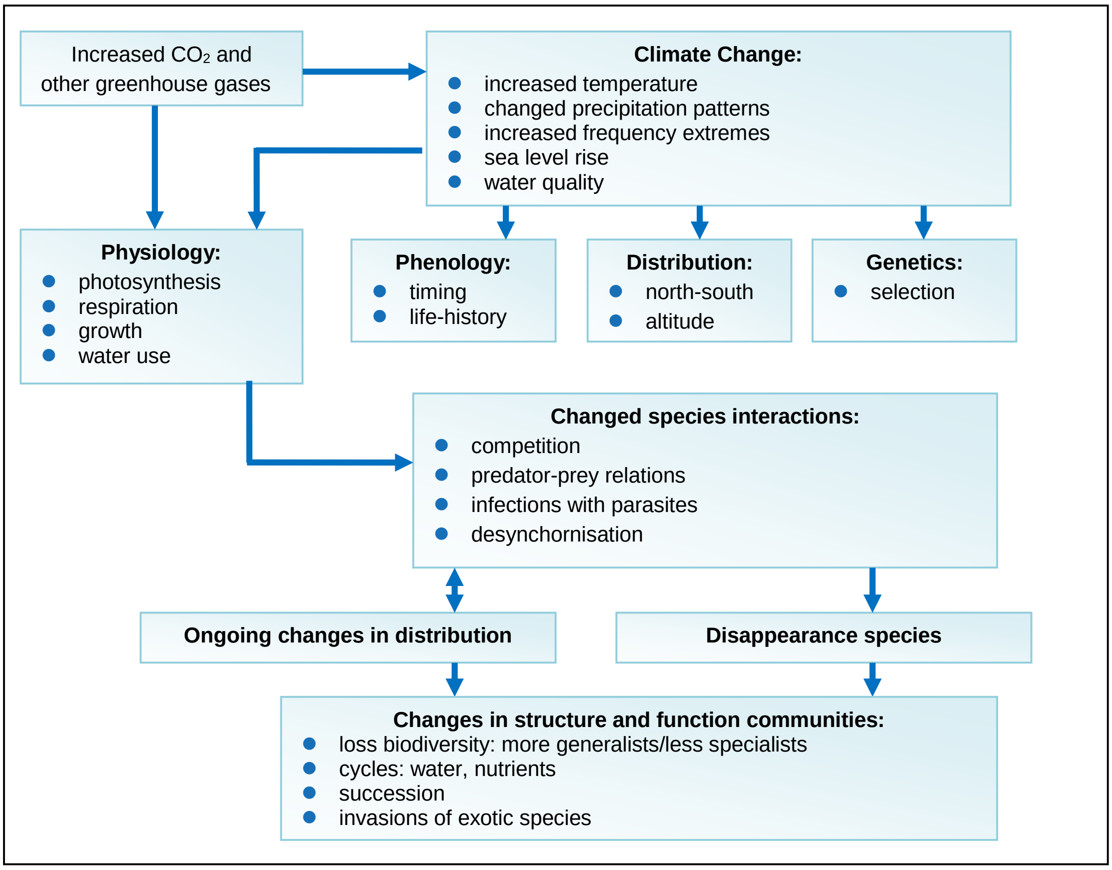

Figure 2.22: Impacts of greenhouse gases and climate change on ecological processes *(Hughes 2000)*

Phenology

Phenology is concerned with the dates of first occurrence of natural events in their annual cycle (e.g. the date of emergence of leaves and flowers, the first flight of butterflies, and the first appearance of migratory birds). Such events are often triggered by climatic events (e.g. temperature) and therefore can be used as proxies for climate change. However, many species depend on each other (e.g. in complex food webs, for pollination, in mutualistic relationships, and so on), and therefore life cycles of many species are synchronised. Thus, if climate change will affect the life cycles of different species differently, and if dependent species will not be able to adapt to the new situation, functional relations within ecosystems might be seriously hampered. For example, in temperate aquatic ecosystems (freshwater, marine), the spring bloom of phytoplankton is followed somewhat later by the development of zooplankton that feed on the algae. Various authors (such as Rosenzweig et al. 2007) have observed an advancement of the spring algal bloom (up to four weeks). Moreover, although zooplankton phenology is also affected, in many cases, the zooplankton has not responded in the same way the phytoplankton has. In the North Sea, shifts of over six weeks in seasonal cycles of plankton communities, including fish larvae, have been observed. Responses, however, varied between different functional groups (Edwards and Richardson 2004). Thus, populations of predators are at risk when their appearance does not correspond with the availability of their main food.

This is not only true for food web relations, but also for flowers that depend on insects for pollination, for example.

Temperature changes in the Caribbean region are expected to affect mangrove phenology (even though studies on the many species of mangrove are limited) and the effect that air temperature has on the reproductive capacity of mangroves. The flowering of *Rhizophora spp.* generally occurs year round; however, climate change effects on pollinating agents, such as wind, insects, birds, and bats may affect the successful pollination of flower buds. There is an additional risk of attack on developing propagules by insects and fungi, and the development of morphogenetic defects (Cambers et al. 2008).

How important is the impact of climate change on ecosystems compared to other stressors (e.g. population growth, pollution, or fragmentation)?

Distribution patterns

Different species are adapted to specific environmental conditions. If environmental conditions change, species can react in different ways - they can adapt to the new environment, migrate to a more suitable environment (and become locally extinct), or become completely extinct. When dealing with climate change, temperature and atmospheric CO_2 concentrations are the major direct factors that will change. These changes might be accompanied by changes in precipitation, storm frequencies, sea level rise, water quality, and so on, including their variability on time and spatial scales. An additional problem is that there are so many non-climate drivers that result from human activities. Thus, human population growth resulting in land use changes, land degradation, deforestation, urbanisation, pollution, among others, will affect the survival of species in a complex way, with many interactions and feedback mechanisms.

Box 2.4: Examples of range shifts (polewards and to higher elevations) and changes in population densities in relation to changes in climatic conditions

- Extension of southern species to the north;
- Changes in intertidal communities in the Pacific and around the British Isles;
- Kelp fish communities and offshore zooplankton communities off the southern California coast;
- Decline in krill in the Southern Ocean;
- Occurrence of subtropical plankton species in temperate waters;
- Changes in geographical distributions of fish species;
- Northward shifts in the distribution of aquatic insects and fish in the UK;
- Replacement of cold-water invertebrate and fish species in the Rhône River by thermophilic species;
- Bird species that no longer migrate out of Europe during the winter;
- Poleward expansion of distribution ranges (Table 1.9 in Rosenzweig et al. 2007);
- Extension of alpine plants to higher altitudes; and
- Spread of disease vectors (e.g. malaria, Lyme disease, bluetongue) and damaging insects.

(Rosenzweig et al. 2007)

The global distribution of biomes (e.g. tropical rain forest, temperate forest, savannah, tundra, desert) mainly depends on a combination of water availability (or annual precipitation) and average temperature. Therefore, major shifts in the present distribution of global vegetation components are expected to occur under a changing climate. Of course, such shifts have occurred in the past on geological time scales. It is predicted that a rise in mean annual temperature of 3°C corresponds to a shift in isotherms of 300–400 km in latitude (in the temperate zone) or 500 m in elevation (Hughes, 2000), the effect of which could result in the disappearance of unique vegetation types and the species that depend on them.

Trends in algal blooms and plankton distribution patterns are projected to be influenced by effects of climatic changes on estuarine inflows and salinity. Periods of decreased inflow and increased salinity can increase the frequency and magnitude of certain algal blooms (eg. *P. parvum*) (Pagou and Hallegraeff 2013).

What consequences will changes in ecological processes have for food production and health?

Summary

It is crucial to understand the physical science basis of the climate change and the associated drivers before looking into their possible consequences. Water, as a life-giving resource and as the one that will be impacted the most by climate change, needs special attention. Water managers need to understand how climate change is going to impact water resources and ecosystems and how this may affect water use. However, they should also be aware of the uncertainties before they can make justified decisions. This chapter also highlights the additional vulnerabilities faced by SIDS and the

Caribbean region due to their physical and economic characteristics. Chapter 4 sets out in more detail the impacts of the climate change phenomena on water.

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3. STRATEGY DEVELOPMENT AND PLANNING FOR ADAPTATION

Goal

The aim of this module is to present participants with the basic principles and steps of adaptation planning, as well as to provide a basic introduction to adaptation economics and the challenges and opportunities of adapting to climate change in the water sector.

3.1 Introduction

In the previous chapter, participants were provided with a basis for understanding the concepts of climate change and climate variability along with the observed and potential impacts on water resources and ecosystems. This chapter continues to build on those concepts, but with a slight shift of focus on how to address the impacts of climate change. Essentially, there are two response strategies: adaptation and mitigation. Adaptation is 'the process of adjustment to actual or expected climate and its effects' whereas mitigation, in this context, is 'a human intervention to reduce the sources or enhance the sinks of greenhouse gases' (IPCC 2014a). Although these terms are distinct by definition, there is a strong link between adaptation and mitigation, which causes the line between the two strategies to appear blurred. For example, with a solar-powered desalination plant, the use of desalination is an adaptive response to water shortages while the use of solar energy mitigates the emission of greenhouse gases. Increasingly, it is being recognised that adaptation and mitigation strategies should not be exclusive options but rather a complementary effort. However, the focus of this chapter will be on adaptation.

The typologies of adaptation are constantly evolving. Two of the more recent concepts are incremental adaptation and transformational adaptation (IPCC 2014a). However, the most commonly discussed types of adaptation can be broadly classified as follows:

- Purpose dependent: autonomous or planned adaptation
- Time dependent: anticipatory or reactive adaptation
- Agent dependent: public or private adaptation

Adaptation strategies should be selected and planned as practicably as possible as there is an inherent degree of uncertainty in managing the drivers and risks of climate change impacts. Thus, in planning for adaptation, there is a need to adopt a risk-based approach. Risk management is defined as plans, actions, or policies to reduce the likelihood and/or consequences of risks or to respond to such consequences (IPCC 2014a). Figure 3.1 shows how risk management is achieved through the efforts of both adaptation and mitigation. As adaptation benefits are immediate for the most vulnerable impacts, mitigation limits warming in the long-term, thus reducing the consequences in the future.

Climate change adaptation and mitigation efforts must be applied as complementary – not exclusive – options. The reasons for this lie in the recognition that even if the global community successfully manages to mitigate climate change by reducing greenhouse gas emissions, the climate is still expected to warm for several decades, with all the projected implications for the water cycle. Therefore, mitigation is not enough. Yet adaptation alone is also not a sufficient answer to the problem, as adaptation options have limits, especially if certain levels of warming are exceeded.

Figure 3.1 illustrates this complementary approach for various degrees of warming and the net benefits expected from it.

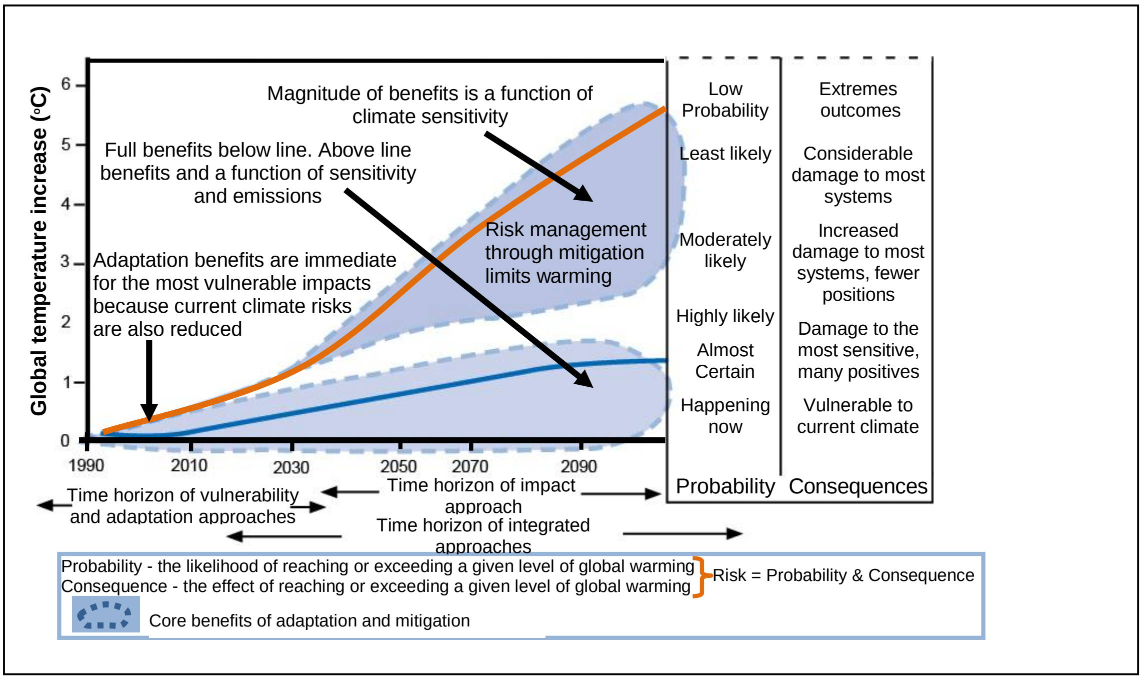

Figure 3.1: Risk management through adaptation and mitigation
(IPCC 2007c)

With regards to adaptation strategies in water-related developments and measures, IWRM is the key process that should be used in the water sector and hence for achieving the water-related SDG. However, the potential impacts of climate change and associated increasing climate variability need to be sufficiently incorporated into IWRM plans. IWRM should form the encompassing paradigm for coping with natural climate variability and the prerequisite for adapting to the consequences of global warming and associated climate change under conditions of uncertainty.

Adaptation should lead to harmonisation with the countries' more pressing development priorities such as poverty alleviation, food security, and disaster management. Management of land and water resources presents the major input in addressing all development priorities; therefore, IWRM planning processes must incorporate a dimension on climate change adaptation. The following subchapters outline the elements for guidance available from a range of key international institutions engaged in the adaptation debate. The need to address climate change and increasing climate variability is a comparably new issue in the global water debate. Although the increase in extreme events was identified as a new challenge for water managers in Agenda 21 of the 1992 UN Conference on Environment and Development (the Earth Summit) in Rio de Janeiro, this was not explicitly linked to climate change or increasing climate variability. Rather, it recommended a comprehensive set of measures for the water sector. The Implementation Plan of the 2002 World Summit on Sustainable Development (WSSD 2002) reiterates that these recommendations are still valid today.

3.2 International and regional obligations and guidance for adaptation

Internationally, adaptation and mitigation were recognised as major response strategies in the United Nations Framework Convention on Climate Change (UNFCCC) in 1992. Although the primary focus of the Convention was mitigation when it entered into force in 1994, the UNFCCC has shaped and supported global action on adaptation. The UNFCCC addresses adaptation through Article 4 by calling on Parties to "formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to mitigate climate change […] and measures to facilitate adequate adaptation to climate change". The various programmes and mechanisms that are implemented by Parties to the UNFCCC were decisions that were made at the annual Conference of the Parties (COP). The COP is the supreme decision-making body of the Convention and all States that are Parties to the Convention are represented at the COP, which meets annually in December. A series of programmatic elements on adaptation planning has been developed under the UNFCCC with inputs from various UN organisations and other international mechanisms. Figure 3.2 highlights some of the adaptation milestones under the Convention. The ones highlighted here are the National Adaptation Programmes of Action and the National Adaptation Plans.

It was with the publication of the IPCC's Third Assessment Report in 2001 that the need to address both adaptation and mitigation was given considerable attention. In 2001, a work programme was established to address the specific needs of developing countries, in particular the least-developed countries (LDCs). This work programme included, inter alia, the process of developing and implementing National Adaptation Programmes of Action (NAPAs), which provide a process for LDCs to identify priority activities that respond to their urgent and immediate needs with regard to adaptation to climate change. The rationale for NAPAs rests on the limited ability of LDCs to adapt to the adverse effects of climate change. In order to address the urgent adaptation needs of LDCs, a new approach was needed that would focus on enhancing adaptive capacity to climate variability, which itself would help address the adverse effects of climate change. The NAPA takes into account existing coping strategies at the grassroots level, and builds upon that to identify priority activities, rather than focusing on scenario-based modelling to assess future vulnerability and long-term policy at state level.

The steps for the preparation of the NAPAs include:

- Synthesis of available information;
- Participatory assessment of vulnerability to current climate variability and extreme events, and of areas where risks would increase due to climate change;
- Identification of key adaptation measures, as well as criteria for prioritising activities; and
- Selection of a prioritised shortlist of activities (see Chapter 5 for uncertainties and vulnerability indices).

As of November 2013, 50 LDCs completed and submitted their NAPAs to the UNFCCC secretariat (UNFCCC 2014).

Nearly a decade after the establishment of the NAPA process, the Cancun Adaptation Framework (CAF) recognised the need for LDCs to identify, develop, and implement medium and long-term adaptation needs, strategies, and programmes, respectively. Thus, CAF established a process for LDCs to formulate and implement National Adaptation Plans (NAPs). COP 17 in 2011 adopted initial guidelines which were further developed by Least Developed Countries Expert Group (LEG) to consist of the following four main elements:

- Laying the groundwork and addressing gaps;
- Preparatory elements;
- Implementation strategies; and
- Reporting, monitoring, and review.

These processes play an essential role in promoting the climate change adaptation agenda and therefore should play a role in inspiring adaptation actions in the water sector. These processes should also be considered when setting up national IWRM plans.

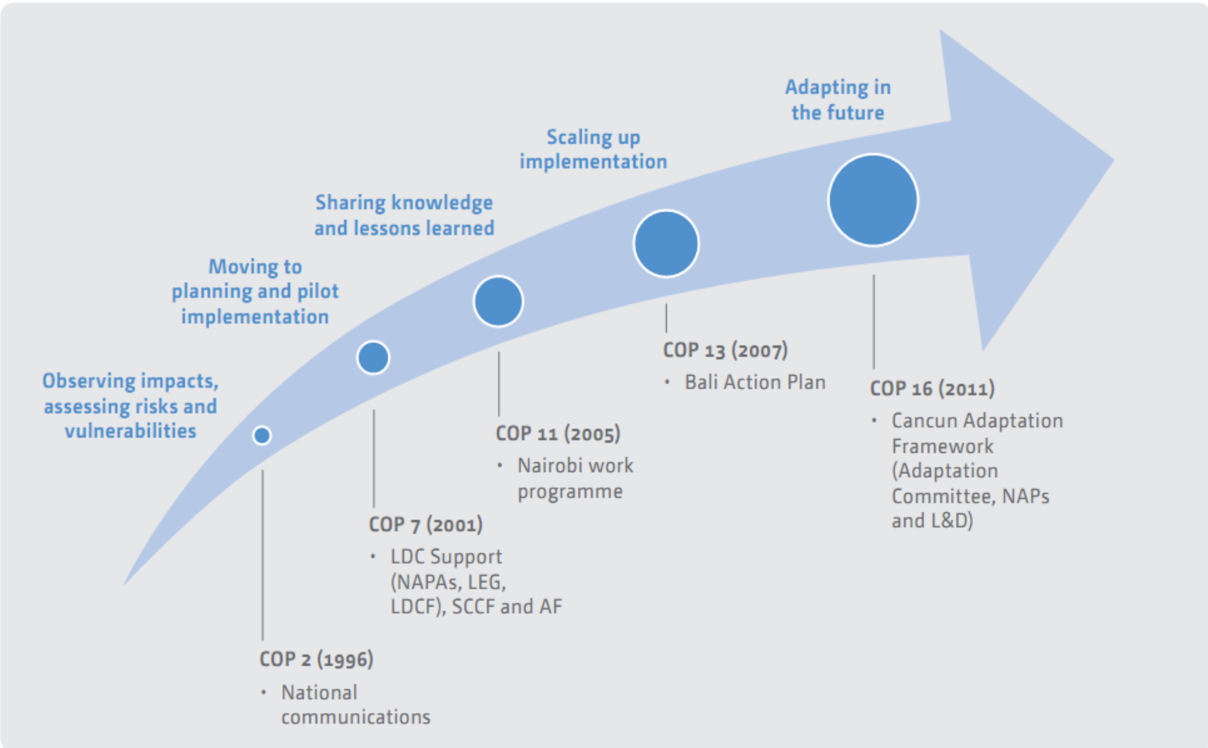

Figure 3.2: Adaptation milestones under the Convention

Regionally, the Caribbean Community Climate Change Centre (5Cs) developed an Implementation Plan (IP) for 2011-2021 to support climate resilient development in the Caribbean. The Heads of Government of CARICOM mandated the 5Cs to prepare an IP that would deliver the actions envisaged in the CARICOM Regional Framework, which articulated the strategic direction for the region’s response to climate change risks and provided a roadmap for action between 2009 and 2015. The IP was developed during the period of September 2010 to June 2011, with funding from the UK Department for International Development (DFID) and the Climate and Development Knowledge Network (CDKN).

The IP was prepared through an extensive consultation programme with over 200 stakeholders, including politicians, government officials, regional agencies, NGOs, private sector, and donor agencies.

3.3 Main elements based on guidance available Under UNECE

The United Nations Economic Commission for Europe (UNECE), under its Convention on the Protection and Use of Transboundary Watercourses and International Lakes, has embarked on a process to develop a guidance document on Water and Climate Adaptation (UNECE 2009). This document provides a good synthesis of the current policy debate on the issue and the requirements and broad steps involved in adaptation planning for the water sector. The steps involved in developing an adaptation strategy are outlined in Figure 3.3 below.

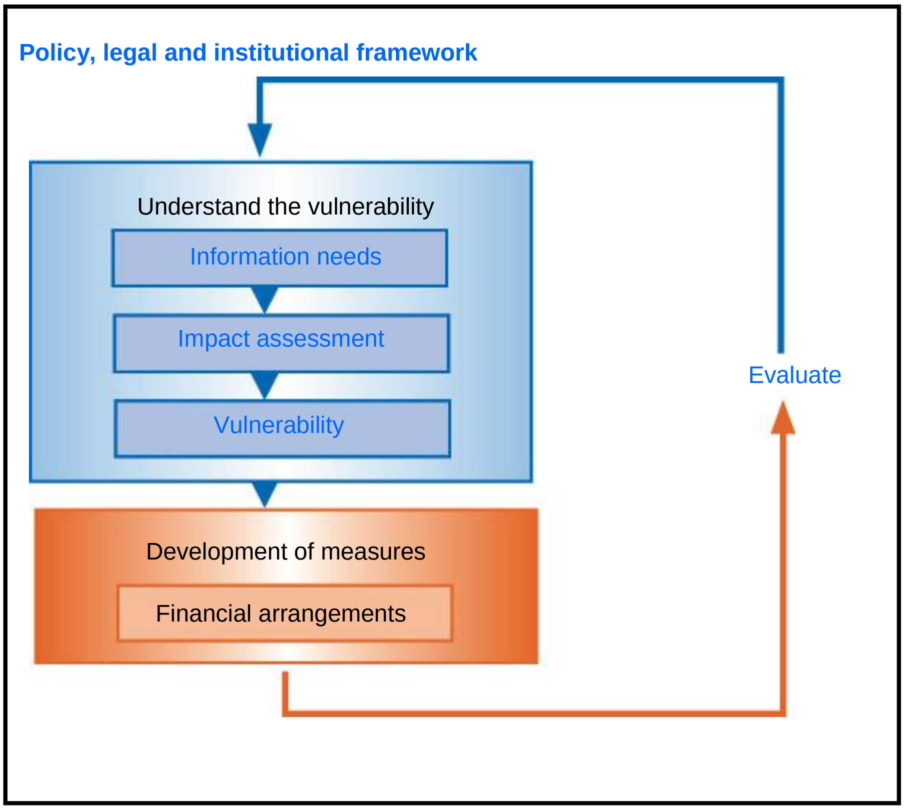

Figure 3.3: Development of an adaptation strategy
(UNECE 2009)

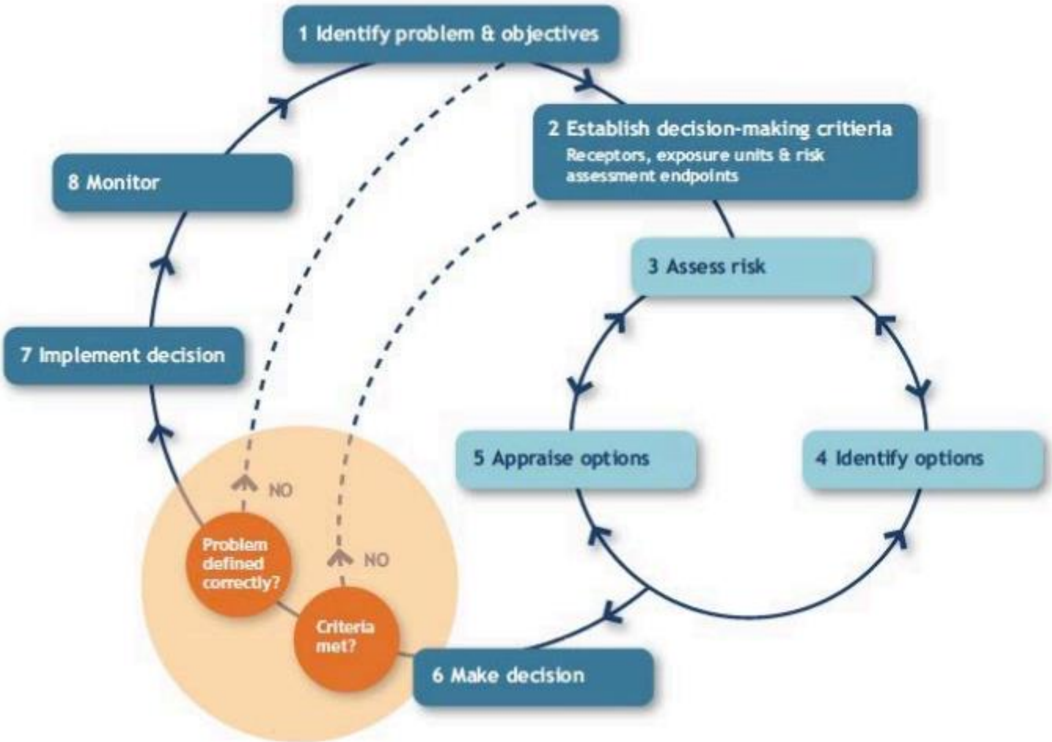

Figure 3.4: A generic framework for vulnerability and adaptation assessments
(Willows and Connell 2003)

The guidance document (UNECE 2009) proceeds to outline some major principles for adaptation planning, namely:

1. Climate change is a process characterised by a number of uncertainties and risks relative in particular to the magnitude, timing and nature of the changes. However, decision makers are not used to such uncertainty when dealing with other problems. To take this situation into account, various methods should be used. These include sensitivity analysis, risk analysis, simulation, and scenario development.

2. As climate change raises threats of harm to human health and the environment, the precautionary principle should be applied and preventive actions should be taken, even if some cause-and-effect relationships are not yet fully scientifically proven. According to the precautionary principle, uncertainty about the damage to be incurred should not serve as an argument to delay action. In the face of great uncertainty, a precautionary approach might even result in a more stringent emission-reductions target and/or adaptation response.

3. The following overarching principles should apply to any adaptation policy framework:
   - Adaptation to short-term climate variability and extreme events is a basis for reducing vulnerability to longer-term climate change;
   - Adaptation policy and measures are assessed in a socio-economic development context;
   - Following the principles of sustainable development adaptation policy and measures take social, economic, and environmental concerns into

consideration and ensure that the needs of the present generation are met without compromising the needs of future generations; and

- Adaptation policies/strategies are elaborated at different levels in society, including the local level.

4. Strong inter-departmental (inter-ministerial) and inter-sectoral cooperation with the involvement of all relevant stakeholders should be a precondition for decision-making, planning and implementation.

5. IWRM should be applied to ensure the multi-layered integration of management, in which existing approaches are distinct from one another and take into account the environmental, economic, political, and sociocultural conditions of the respective region.

6. No-regret and low-regret options should be considered as a priority. No-regret options are measures or activities that will prove worthwhile even if no (further) climate change occurs. For example, monitoring and early-warning systems for floods and other extreme weather events will be beneficial even if the frequency of the events does not increase as expected. Low-regret options are low-cost options that can potentially bring large benefits under climate change and will have only low costs if climate change does not happen. One example is accounting for climate change at the design stage for new drainage systems by making pipes wider.

7. The selection of scenarios and related methodologies and measures to deal with adaptation to climate change should take into consideration possible side effects of their implementation.

8. Measures to cope with the effects of climate change have to be taken into account at different scales, both in space and in time. Regarding the spatial component, measures should account for local issues as well as regional and watershed-wide issues. Regarding the time component, distinctions should be made between the strategic, tactical, and operational levels.

9. Estimating costs of a measure is a prerequisite for ranking a measure and including it in the budget or in a wider adaptation programme. The four major methods used for prioritising and selecting adaptation options are cost-benefit analysis, multi criteria analysis, cost-effectiveness analysis, and expert judgement. The costs of non-action that could lead to a number of environmental and socio-economic effects (e.g. lost jobs, population displacement and pollution) should also be considered.

While the above generic principles are necessary to guide adaptation policy, they do not say much about translating policy into action. As countries begin to report on their achievements in the UNFCCC context, they provide case scenarios on adaptation planning and practice, and it will be necessary to synthesise information gained from them. An example case is provided in the exercises for this chapter that shows one option of how to move from principles to practice in the form of an adaptation planning project in an arid developing country context. However, a best-practice model of an adaptation planning project in the Caribbean is the South Coast Boardwalk in Barbados. The Barbados Boardwalk is a coastal adaptation solution that was implemented by the Coastal Zone Management Unit (CZMU) in Barbados. The 1.2 km boardwalk not only serves as a popular attraction for residents and tourists, but also as a hazard-resilient infrastructure that provides shoreline protection against the impacts of climate change. In addition, a survey conducted in 2009 showed that the adaptation project resulted in an increase in beach volume by 26,000 m^3 (that is, an average of 20 m of beach width) and 50 percent of businesses in the area reported a one percent to five percent increase in monthly revenue attributed to the project (Development Effectiveness Overview 2013).

- **What is the role and potential of sectoral adaptation planning?**
- **Do you know examples of cross-sectoral adaptation planning?**
- **What do you think is the most adequate spatial level for adaptation planning?**

Figure 3.5: The Barbados Boardwalk
Source: http:www.barbados.org

3.4 Main elements based on guidance available under UNDP

UNDP, as a major international development partner, has developed the Adaptation Policy Framework (APF). The steps of the APF are depicted in Figure 3.6, below. Each step has a separate technical paper that specifies the requirements in detail. The APF process can be used for formulating and designing adaptation-related projects or for exploring the potential to add adaptation considerations to other types of projects. Projects can focus on any population scale, from village to national level. The following steps are part of the APF:

- Component 1: Scoping and designing an adaptation project involves ensuring that a project – whatever its scale or scope – is well integrated into the national policy planning and development process. This is the most vital stage of the APF process. The purpose is to put in place an effective project plan so that adaptation strategies, policies and measures can be implemented.
- Component 2: Assessing current vulnerability involves responding to several questions, such as: Where does a society stand today with respect to vulnerability to climate risks? What factors determine a society's current vulnerability? How successful are the efforts to adapt to current climate risks?
- Component 3: Assessing future climate risks focuses on the development of scenarios of future climate, vulnerability and socio-economic and environmental trends as a basis for considering future climate risks.
- Component 4: Formulating an adaptation strategy in response to current vulnerability and future climate risks involves the identification and selection of a set of adaptation policy options and measures, and the formulation of these options into a cohesive, integrated strategy.
- Component 5: Continuing the adaptation process involves implementing, monitoring, evaluating, improving, and sustaining the initiatives launched by

the adaptation project.

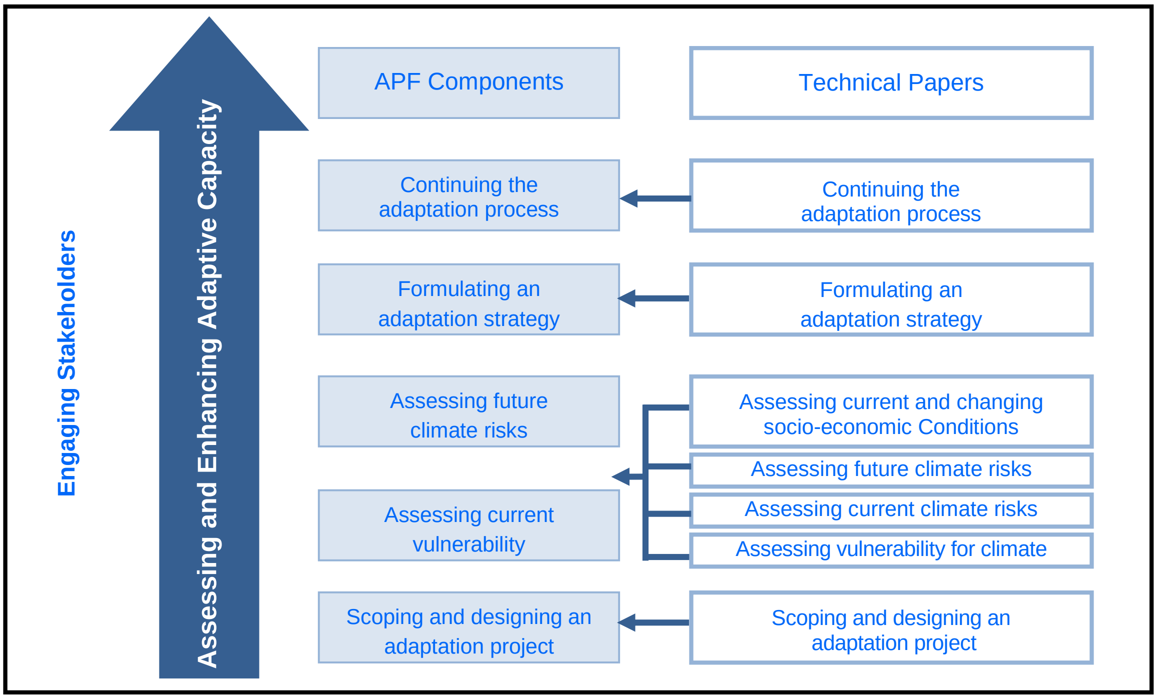

Figure 3.6: Components of the Adaptation Policy Framework (APF) (UNDP 2004)

The APF distinguishes four basic ways of focusing an adaptation project, namely hazards-based, vulnerability-based, adaptive-capacity, and policy-based approaches. Table 3.7 below provides definitions and examples of the four approaches for different institutional scales of application.

	Hazards-based approach	Vulnerability-based approach	Adaptive-capacity approach	Policy-based approach
	Increasing resilience to severe flooding and future climate risks	**Improving access to new markets and supporting livelihood diversification under future climate**	**Improving awareness in and the resilience of the business community to climate change, including variability**	**Reducing vulnerability to storm surges and sea level rise induced by climate change**
National	How can national meteorological services be changed to better monitor the evolution of future hazards?	How will recent changes in world markets affect aquaculture in Bangladesh (already at risk of inundation from sea level rise) under future climate?	Which business sectors will be most affected by climate change and why? What awareness raising is needed, and for whom? What fora should be involved?	What incentives or disincentives should be used to discourage the development of coastal zones vulnerable to sea level rise and storm surges induced by climate change?
Regional	How can flood early warning systems be made more effective under future climate for hard-to-reach communities?	How can access to new markets required by livelihood diversification activities be facilitated to moderate future climate?	How can regional businesses most effectively support livelihoods identified as being vulnerable to climate change, including variability?	Realignment or retreat? How to decide which areas are protected and which will become submerged under future climate?
Local	What techniques are most appropriate for effective local-level disaster preparedness planning under future climate?	How can credit schemes best support livelihood diversification in rural areas to reduce climate risks?	Which participatory visioning processes are most appropriate to identify threats and potential opportunities resulting from scenarios of climate change for members of local trade associations and businesses?	What stakeholder-led projects are most appropriate for investigating ways to mitigate flood damages in an urban area under future climate?

Figure 3.7: Identifying adaptation project focus according to scale of implementation (UNDP 2004)

3.5 Dialogue on climate change adaptation for land and water management

In April 2009, a set of key stakeholders who were engaged in the Dialogue on Adaptation for Land and Water Management, agreed on five Guiding Principles for Adaptation to Climate Change after a regional consultation process. Those principles, which were subsequently reproduced, "promote sustainable development while responding to the impacts of climate change" (Dialogue on Adaptation for Land and Water Management 2009). The principles include the following:

Guiding Principle No. 1 (Sustainable Development):
Adaptation must be addressed in a broader development context, recognising climate change as an added challenge to reducing poverty, hunger, disease and environmental degradation.

Guiding Principle No. 2 (Resilience):
Building resilience to ongoing and future climate change calls for adaptation to 'start now' by addressing existing problems in land and water management.

Guiding Principle No. 3 (Governance):
Strengthening institutions for land and water management is crucial for effective adaptation and should build on the principles of participation of civil society, gender equality, subsidiarity, and decentralisation.

Guiding Principle No. 4 (Information):
Information and knowledge for local adaptation must be improved and must be considered a public good to be shared at all levels.

Guiding Principle No. 5 (Economics and Financing):
The cost of inaction, and the economic and social benefits of adaptation actions, call for increased and innovative investment and financing.

For more detailed information, please consult the full statement (Dialogue on Adaptation for Land and Water Management 2009).

3.6 Economics of adaptation

A lot of debate has circled around the economic aspects of addressing the climate change issue, both on the cost and benefits of mitigating climate change and adapting to it. The most widely cited report is the Stern Review, published in 2006 by the British Government (Stern 2006). It implies the need to incorporate adaptive actions and appropriate policies in countries' development strategies, integrated into development plans and the adaptation funding and spending at regional, national, and local level, and not by setting up parallel processes, as stated in the Review:

> What would be the implications of separating climate change adaptations from the general development programmes and targets? Would that be possible in your country?

> "Taken together, all this implies that rather than treating adaptation as separate from development, it should be seen as an additional cost and complexity to delivering standard development goals. Specifically, adaptation has the same target outcomes as development, including sustaining or improving social protection, health, security, economic sufficiency – and so spending (whether

labelled adaptation or development) ought to be prioritised according to the expected impacts on these outcomes. The most effective way of achieving this is to integrate climate risk, and the additional resources required to tackle it, into planning and budgeting and delivering these development goals" (Stern 2006).

The Stern Review addresses the economic aspects of adaptation that are discussed in Chapter 5 of the report. While avoiding damage from climate change is considered a benefit of adaptation, the review is clear that there can often be a substantial residual damage (or risk). Figure 3.8 provides a substantially simplified model for the economics of adaptation. The relationship between the cost of climate change and increases in global mean temperature are shown here as linear, while in reality trends in cost for increasing temperature may be exponential.

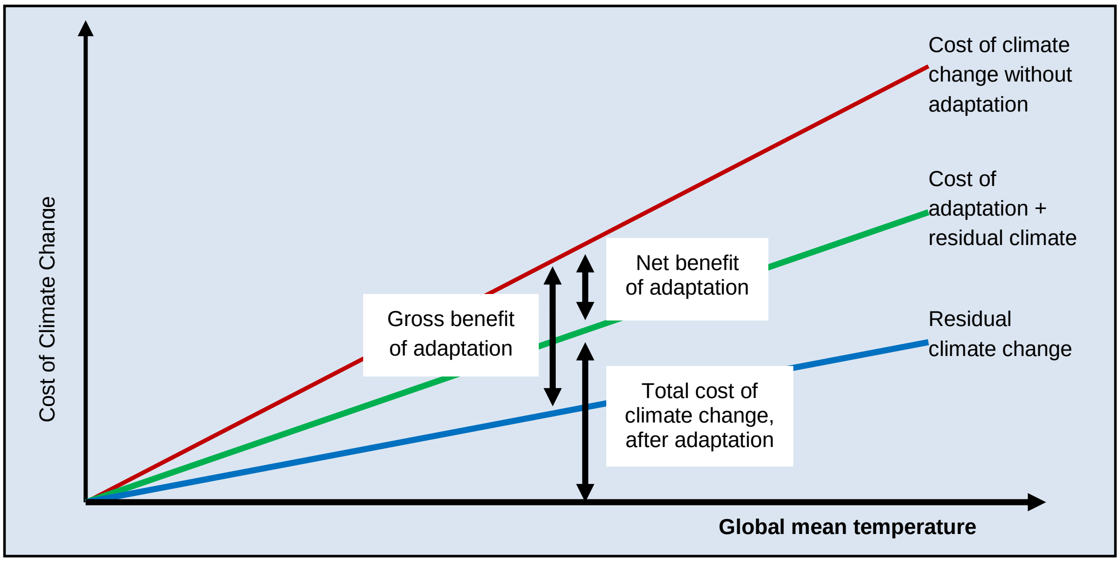

Figure 3.8: Cost and benefits of adaptation in relation to global mean temperature *(Stern 2006)*

The concept of 'net benefits' of adaptation is crucial to the model – that is, the damage avoided minus the cost of adaptation. The concept of net benefits as an indicator in policy design is already common practice in a number of climate-related development policies, such as integrated flood management: the net benefits of a flood management strategy are the overall benefits incurred by using the floodplain minus the cost of flood protection and the residual flood damages (WMO 2004). This implies that in planning decisions, there is a need to combine risk management (as a construct of probability and associated consequence) with a perspective on acceptable risk in view of benefits incurred. This perspective helps to avoid maladaptation in the sense of unnecessarily limiting development opportunities crucial for poverty reduction/livelihood generation.

What would the diagram in Figure 3.8 look like for an example of a flood defence project?

Box 3.1: The economic cost of climate change for Caribbean SIDS

For SIDS, the economic cost of adaptation to climate change is high due to the relative size of their economies (CDKN 2014). In 2011, the Economic Commission for Latin America and the Caribbean (ECLAC) carried out several assessments of the economic impacts of climate change for various countries in Latin America and the Caribbean.

With respect to tourism, climate change and climate variability will have a negative impact on the attractiveness of a destination, which will in turn have significant implications on the economies of countries that depend heavily on revenues from tourism. ECLAC estimated in 2011 for a sample of countries (i.e. the Bahamas, Barbados, Montserrat, and St. Lucia) the range of potential losses on tourism revenues from US$57 million (Montserrat) to US$15 billion (the Bahamas) under IPCC's A2 (high) scenario, and from US$45 million (Montserrat) to US$ 14 billion (the Bahamas) under IPCC's B2 (low) scenario by 2050 (Economic Commission for Latin America and the Caribbean 2011).

With respect to the agricultural sector, for St. Lucia it was estimated that a one percent increase in temperature is expected to cause an estimated 5.1 percent decrease in the growth of banana exports, and a one percent increase in rainfall is expected to cause an approximate 0.27 percent increase in the growth of banana exports (Economic Commission for Latin America and the Caribbean 2011). The value of cumulative yield losses for banana is expected to be near US$61 million by 2050 irrespective of the climate scenario (Economic Commission for Latin America and the Caribbean 2011). In their most recent release, ECLAC estimated the economic costs of climate change for Latin America and the Caribbean (albeit with a high degree of uncertainty) between 1.5 percent and 5 percent of the region's GDP (Economic Commission for Latin America and the Caribbean 2014).

ECLAC (2014) went on to report that a 2.5˚C increase in the world's temperature would cost the region approximately 2.5 percent of its GDP. However, it was estimated that the cost of adaptation would be 0.5 percent of the region's current GDP.

3.7 Challenges and opportunities for adaptation

Challenges

- **Insufficient monitoring and observation systems and data**
  Understanding the current status of water resources forms the baseline for detecting and establishing the significance of trends, for example in rainfall and run-off patterns or in soil moisture distribution. Insufficient monitoring and observation systems for ground and surface water resources – that is quantity and quality, prevailing rainfall patterns, and the status of the cryosphere – are an inhibiting factor for many countries in terms of water resources management and development, and consequently for adaptation planning. Insufficient data on changes in land use in watersheds make assessing hydrological changes due to climate variation very difficult. Even if this data is available, they may be treated as 'strategic resources' and may not be shared widely enough, or the institutional arrangements may not be robust enough to generate conclusive statements about the state of the resource. Therefore, water resources assessment – including the needs for operational monitoring programmes – should be seen as an indispensable (early) part of adaptation planning.

- **Lack of basic information**
  This represents perhaps the major current obstacle to adaptation planning as various countries can begin to afford investing in the collection of basic information. In the area of climate information, because of the aforementioned

deficiency in monitoring capacity, historical in situ climatological records are sparse and remotely sensed information can complement – but not replace – such records. Regarding climate prediction on seasonal to inter-annual timescales, only a few highly specialised centres are currently in the position to provide such products at the required quality, but not yet at the spatial and temporal scales in which water managers operate.

- **Settlements in vulnerable areas**

  Even outside of a climate change scenario, the issues posed by population growth (especially in developing countries) and the resulting pressure on limited land and water resources are enormous. Climate change is expected to exacerbate these problems by affecting the frequency and/or intensity of water-related hazards, such as floods, flash floods, mudflows, and landslides. Poverty and urbanisation are the major factors that continue to drive people into previously unoccupied vulnerable zones, as the land there is cheaper or it is the only land left to settle. Adaptation planning, therefore, must incorporate a development perspective.

- **Appropriate political, technological and institutional framework**

  Adaptation must not be understood as a process independent of a country's development, but as an integral part of it. While the weakness of institutional structures and institutional capacity remains a key challenge of the water sector in the developing world, there is an additional challenge posed by adaptation processes - the risk of side-lining established institutional structures. Consideration is needed in adaptation planning to strengthen and clearly define the role of competent authorities, NGOs, and the private sector in their pursuit of adaptation objectives. There is renewed need for a multidisciplinary cross-sectoral process that allows for a shift towards economically efficient, socially equitable and environmentally sustainable adaptation (and mitigation) options. The political discourse over recent years in devising climate change mitigation options has clearly demonstrated that need (e.g. use of biofuels).

- **Social equity in decision-making**

  The lack of stakeholder representation in decision-making is a major obstacle to more equitable solutions in water management in general, and the climate change nexus does not make issues less complex in that field. Vulnerabilities to the impacts of climate change have a vast potential for increasing inequities in societies, as the natural resource base may be further depleted and livelihoods – particularly in agriculture – are threatened by lack of investment and capacity building in the sector. While climate change is considered to be only one factor in determining migration decisions, the implications on intergenerational and gender equity can be vast. This is especially valid if rural communities are disrupted (e.g. where the male workforce is leaving to find work, leaving behind communities of the elderly, women and children). Therefore, developing a gender-sensitive perspective on the vulnerabilities of various groups and the different roles they can take in adaptation planning is required. An additional complicating element in equity in decision-making is that future generations are not represented in the process and that government has to take up that role.

Opportunities

- **Planning new investments for capacity expansion**

  Being able to predict impacts of climate change on water resources may help accelerate planning and investment decisions in new water resources development schemes. These schemes are urgently needed in areas that lack essential water infrastructure, as this lack has been an impediment to the development process in the past. In many areas, increasing storage and demand-side management options have been a challenging political and financial issue that should be revisited, especially in view of unfolding variability conditions in rainfall patterns. Such schemes may also be an element of economic stimulus packages that have large portfolios for infrastructure investment in support of the construction sector. Proposals that have completed the legally mandated planning cycle but that may have lacked funding or mainstream political support should now be the focus of attention to such investment to avoid inappropriate investment and maladaptation.

- **Maintenance and major rehabilitation of existing systems**

  Similarly, neglected aspects of water infrastructure maintenance (dam safety, drainage systems and channel maintenance, levee rehabilitation, among others) should undergo revitalisation through the reassessment of design procedures (such as the 'probable maximum precipitation' and 'probable maximum flood'), safety levels, and safety and monitoring programmes. This is an opportunity to strengthen infrastructure and public safety beyond the questions of climate change.

- **Operation and regulation of existing systems for optimal use and accommodating new purposes**

  The added complexity of climate variability and change offers a number of opportunities to reassess and optimise the operation and regulation of water infrastructure. This could include the requirements for minimum environmental flows and other ecological requirements related to water quality, seasonality of flow, vulnerability of upstream and downstream communities to rapidly changing flow rates, as well as the transboundary arrangements for water sharing, and so on.

> - **Which concrete challenges and opportunities do you find in your environment when it comes to climate change adaptation in the water sector?**
> - **Do you feel that it is justified to employ the climate change debate to facilitate improvements of current water resources management? What are the benefits and risks of taking such an approach? What role do principles of scientific integrity play under political pressure to deliver an adaptation strategy?**

- **Modifications in processes and demands (water conservation, pricing, regulation)**

  Increasing climate variability may also be an opportunity to establish smarter and more robust regulations on water conservation and pricing (although not by increasing regulation, *per se*). This has been a difficult task, even under the assumption of a stationary climate.

- **Introduce new efficient technologies**

  Expected changes in water availability may boost the development and application of innovative and efficient technologies for water resources development (e.g. desalination and reuse) as well as water resources conservation, such as wastewater treatment systems and irrigation efficiency improvements ('more crop per drop'). Such new schemes, however, require thorough testing to establish their respective merits and demerits to minimise the risk of conflicting objectives in the areas of climate change adaptation and mitigation.

Summary

Adaptation to present climate variability and extreme events forms the basis for reducing vulnerability to future climate change. An adaptation strategy has to be developed within the development context of the country or region in which it is to be implemented top avoid maladaptation. Adaptation happens at various levels within the society: national, regional, local, community, and individual. The adaptation process is as important as the adaptation strategy, especially in optimising available resources across sectors and engaging the broadest possible group of stakeholders.

Suggested reading

Cap-Net (2005) Integrated Water Resources Management Plans: Training Manual and Operational Guide.

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Web link

UNFCCC Climate Change Adaptation home page:
http://unfccc.int/adaptation/items/4159.php

4. IMPACTS OF CLIMATE CHANGE ON WATER USE SECTORS

Goal

The aim of this chapter is to familiarise the participants with the expected impacts of climate change in different regions and on selected water use sectors, as well as with methods to analyse and assess these impacts.

4.1 Projected climate changes by region

Although climate change is expected to increase global temperatures, its impact on water resources is more complex and varies across the world (see Chapter 2, Section 2.2). While some regions are expected to receive more precipitation, other regions will face increased water stress due to a significant reduction in net precipitation. The concept of water stress is widely used to convey concerns related to water resources. The way in which water stress is defined and measured has direct, and sometimes contradictory, implications on the perception of how serious an issue is in a particular region. For example, in tropical climates, most measures of water stress are based on average conditions and do not take into account seasonal variability, which could actually have a greater impact on resource availability. This demonstrates that reliance on a single indicator may give a misleading impression about water scarcity issues. The Falkenmark indicator is perhaps the most widely used measure of country- or region-specific water stress; categorised as no stress, stress, scarcity, and absolute scarcity (Table 4.1). It is defined as the fraction of the total annual runoff available for human use (see table below). The recent IPCC report (IPCC 2013) provides an overview of projected impacts on the water resources of different regions of the globe.

Index (m^3 per capita)	Category/Condition
>1,700	No Stress
1,000-1,700	Stress
500-1,000	Scarcity
<500	Absolute Scarcity

Table 4.1. Water barrier differentiation proposed by Falkenmark in 1989 *(Brown and Matlock 2011)*

Climate change projections are solely based on Global Climate Models or General Circulation Models (GCMs). Figure 4.1 below presents results from fifteen GCMs comparing changes of annual means of four hydro-meteorological variables (precipitation, soil moisture, run-off, and evaporation) for the period 2081–2100, relative to 1986–2005 under the Representative Concentration Pathway RCP8.5 (RCP 8.5 is somewhat higher than A2 in 2100 and close to the SRES A1F1 scenario - see section 2.1.4 Emissions Scenarios). The modelling results indicate projected increased water scarcities in several semi-arid and arid regions including the Mediterranean watershed, southwest USA, southern Africa, north-eastern Brazil, the Caribbean, and Central American countries. In contrast, precipitation is expected to increase in high latitudes (e.g. northern Europe) and some subtropical regions.

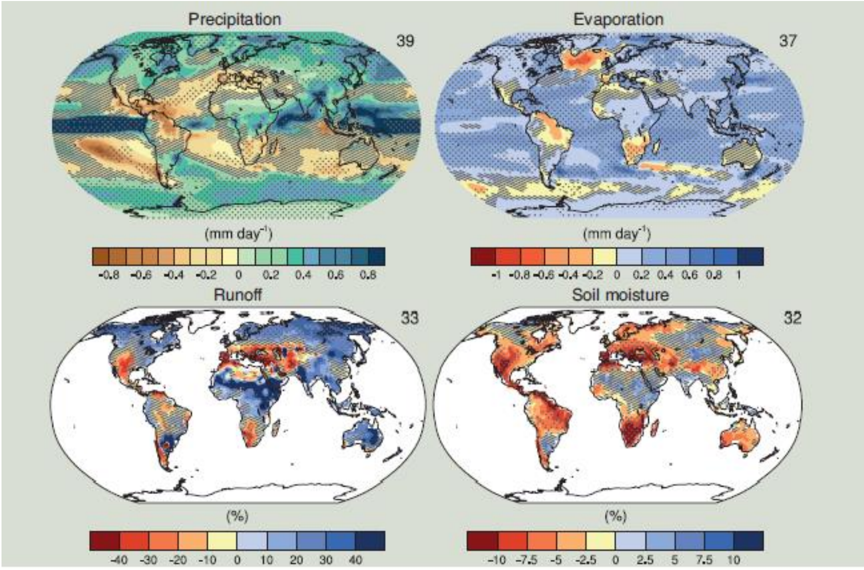


Figure 4.1: Annual mean changes in (a) precipitation (percent); (b) evaporation (percent); (c) run-off (percent) and (d soil moisture (percent). Changes are annual means: scenario A1B, period 2081–2100 relative to 1986–2005. The number of Coupled Model Intercomparison Project Phase 5 (CMIP5) models to calculate the multi-model mean is indicated in the upper right corner of each panel
(IPCC 2013)

Climate change is expected to increase the frequency and intensity of both floods and droughts in many parts of the world, as shown in modelling results presented in Figure 4.2 below, where stippling indicates statistical significance of an area to a projected change. Increases in drought are projected for the Mediterranean, Caribbean and Central America, Brazil, South Africa, and Australia while decreases are projected in high northern latitudes.

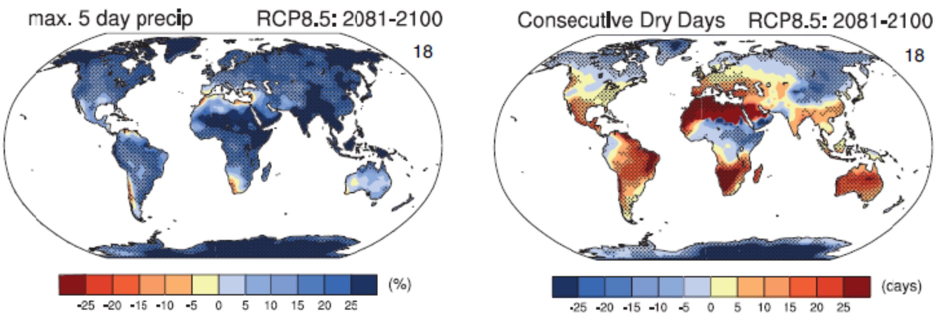


Figure 4.2: Global projections of precipitation intensity and dry days (annual maximum 5-day precipitation accumulation). Left: Percent change over the 2081–2100 period in the RCP8.5 scenario. Right: Projected change in annual CDD, the maximum number of consecutive dry days when precipitation is less than 1 mm, over the 2081–2100 period in the RCP8.5 scenario (relative to the 1981–2000 reference period) from the CMIP5 models.

The following is a brief summary of expected impacts of climate change in different regions (Bates et al. 2008).

Africa

Climate change is expected to exacerbate water scarcity conditions in northern and southern Africa. In contrast, eastern and western Africa are expected to receive more precipitation. Severe drought conditions in the Sahel have persisted for the past three decades. The Nile Delta is expected to be severely impacted by rising sea levels.

Asia

Climate change is expected to reduce precipitation in the headwaters of the Euphrates and Tigris. Winter precipitation is expected to decrease over the Indian subcontinent, leading to greater water stress, while monsoon rain events are expected to intensify. Maximum and minimum monthly flows of the Mekong River are expected to increase and decrease, respectively. The observed decline of glaciers is expected to continue reducing water supplies to large populations.

Australia and New Zealand

Run-off in the Darling Watershed, which covers 70 percent of the agricultural water demand in Australia, is expected to decline significantly. Drought frequency is expected to increase in the eastern parts of Australia. River run-off in the South Island is expected to increase. Southern areas are projected to have long-term drying during winter, and a long-term rainfall decline during spring. Precipitation change in northeast Australia remains uncertain (IPCC 2013).

Europe

In general, mean annual precipitation is projected to increase in northern Europe and decrease further south. The Mediterranean and some parts of central and eastern Europe will be more prone to droughts. Flood risk is expected to increase in eastern and northern Europe and along the Atlantic coast.

Latin America

The number of wet days is expected to increase over parts of south-eastern South America and central Amazonia. In contrast, weaker daily precipitation extremes are expected to increase over the coast of northeast Brazil. Extreme dry seasons are projected to become more frequent in central America, for all seasons. Glaciers are expected to continue the observed declining trend.

What are the expected changes in climate for your region and how do you expect water resources will be affected?

North America

Climate change will constrain North America’s already over-allocated water resources, especially in the semi-arid western USA. Water levels and water quality are projected to drop in the Great Lakes as a result of increased air temperature. Impacts may include increased phytoplankton, fish, and cyanobacteria biomass; solubilisation of accumulated phosphorous; and heavy metals with accelerated reaction rates. Other factors compounding water stress include salt water intrusion, and increased groundwater and surface water pollution. Shrinkage of glaciers is expected to continue. Delay and shortening of snow cover will decrease snow pack strategic storage capacity.

Small Island Developing States (SIDS)

Small Island States share similar vulnerabilities to climate change impacts, however, the specific impacts are expected to vary from one region to the next. The PRECIS model for the Caribbean region projects that by the end of the century, conditions during the primary rainy season, from May to November, will be significantly drier (see Figure 4.3) (Taylor et al. 2013). Under an intermediate low-emissions scenario, the Caribbean is expected to experience a five to six percent decrease in annual rainfall, compared to a one to nine percent increase in rainfall projected for SIDS in the Pacific and Indian Ocean regions. Wide variations in rainfall patterns are expected among islands within these regions: Equatorial islands in the Pacific Ocean are likely to experience increased precipitation, whereas sub-tropical islands are expected to get drier. Projections for northern Caribbean islands show increased rainfall during the latter part of the wet season whereas southern islands may experience drier conditions. Islands of the Indian Ocean are expected to experience an overall reduction in precipitation during both, the wet and dry seasons. These trends accelerate steeply under high-emissions scenarios (IPCC 2013).

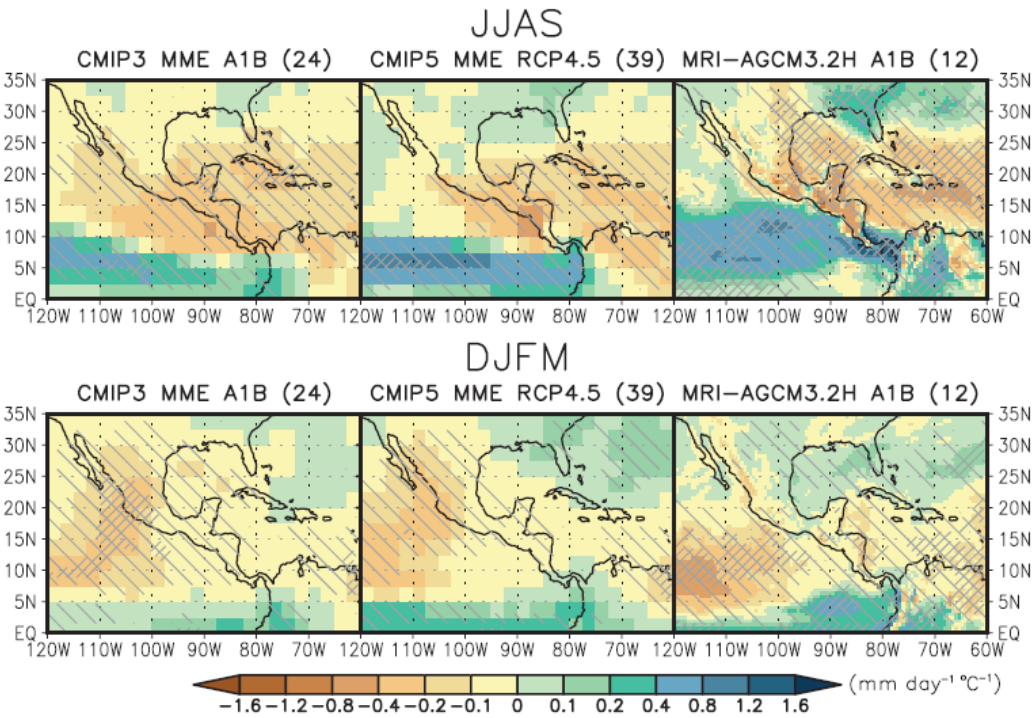


Figure 4.3 Maps of precipitation changes for Central America and Caribbean in 2080–2099 with respect to 1986–2005 in June to September (above) and December to March (below) in the SRES A1B scenario with 24 CMIP3 models (left), and in the RCP4.5 scenario with 39 CMIP5 models (middle). Right figures are the precipitation changes in 2075–2099 with respect to 1979–2003 in the SRES A1B scenario with the 12 member 60 km mesh Meteorological Research Institute (MRI)-Atmospheric General Circulation Model 3.2 (AGCM3.2) multi-physics, multi-SST ensembles. Precipitation changes are normalised by the global annual mean surface air temperature changes in each scenario. Light hatching denotes where more than 66 percent of models (or members) have the same sign with the ensemble mean changes, while dense hatching denotes where more than 90 percent of models (or members) have the same sign with the ensemble mean changes.
(IPCC 2013)

4.2 Impacts on water use sectors

Climate change impacts on water use sectors can be both positive and negative as discussed below.

4.2.1 Agriculture

Positive impacts of climate change could increase growth rates because of increased CO_2 concentrations and length of growing season. However, as agriculture is the largest water consumer, it will strongly be affected by variability in rainfall, temperature, and other weather conditions (Kabat and van Schaik 2003) and consequently to climate change. Additionally, the impacts on rain-fed agriculture *vis-à-vis* irrigated systems are not well understood (FAO 2007). More than 80 percent of global agricultural land is rain-fed and, when in arid and semi-arid conditions, production will be very vulnerable to climate change (Bates et al. 2008). In addition, although irrigated land represents only about 18 percent of global agricultural land, its yields are on average 2–3 times higher than those in rain-fed areas. Thus, global food production

Box 4.1: Effects of drought on Caribbean agriculture

The severe to extreme 2009-2010 drought that was experienced throughout most the Caribbean impacted harshly on the region's farming community, particularly since the majority of the countries relies on rain-fed agriculture (Farrell, Trotman, and Cox 2011). Banana production in Dominica was approximately 43 percent lower in 2010 than 2009; St. Vincent and the Grenadines experienced a 20 percent overall reduction in agricultural production (Farrell, Trotman, and Cox 2011).

In an attempt to cope with droughts, some farmers in Jamaica have turned to more short-term crops as an adaptation option. This action has resulted in an overall reduction of crop production and of seasonal earnings (Gamble et al. 2010). In addition to climate change induced drought, water available for agricultural purposes will also be further reduced by salt water intrusion of ground water wells, also resulting in reduced crop yields (CARDI 2012). The 2005 and 2006 floods in Guyana and ensuing impacts on agricultural productivity severely hindered Guyana's economic and social development process at the national and local levels (CARDI 2012).

depends both on precipitation and, increasingly, on the availability of water resources. Increased variability in the latter, in turn, will affect irrigated agriculture. At low latitudes, for example, early snowmelt can cause floods in spring leading to water shortages in summer. In addition, if reduced precipitation leads to an increase in the use of water for irrigation, the incidence of waterborne diseases might increase due to the use of insufficiently treated wastewater (Bates et al. 2008).

Obviously, too little water will directly and negatively affect agriculture production. On the other hand, extreme precipitation events could lead to excessive soil moisture, soil erosion, direct damage to plants, and a delay in farm operations, all of which disrupt food production (Bates et al. 2008). FAO categorises climate change impacts on food production into two groups: biophysical and socio-economic (Table 4.2 below) (FAO 2007). Altogether, overall food production might not be threatened, but regional and local differences will be considerable and those least able to cope (e.g. smallholder farmers in marginal areas) will be affected most severely.

Biophysical	Socio-economic
• Physiological effects on crops, pasture, forests, livestock (quantity and quality) • Changes in land, soil, water resources (quantity and quality) • Increased bush fires serving as a catalyst to land slippage e.g. Dominica 2010 • Increased weed and pest challenges • Shifts in spatial and temporal distribution of impacts • Sea level rise, changes to ocean salinity and acidity, which are damaging to fish habitat as evidenced by 2005 and 2010 coral bleaching events in the Caribbean • Sea temperature rise causing fish to inhabit different geographic ranges • Ciguatoxins may flourish when sea temperature thresholds are reached	• Decline in yields and production • Reduced marginal GDP from agriculture • Increased expenditure on food importation; the Caribbean Region currently spends over USD$ 3.5 billion annually to import food • Fluctuations in world market prices • Price increase of locally produced food items such as tomatoes and fruits; e.g. Antigua & Barbuda, Trinidad &Tobago during the 2010 drought event • Changes in geographical distribution of trade regimes • Increased number of people at risk of hunger and food insecurity • Migration and civil unrest

Table 4.2: Biophysical and socio-economic impacts of climate change on food production
(FAO 2007, Farrell, Trotman, and Cox 2011, CARDI 2012)

4.2.2 Fisheries

Some expected impacts of climate change on fisheries and aquaculture include stress due to increased temperature and oxygen demand, deteriorated water quality, and reduced flows. However, it is likely that human impacts (caused by population growth, flood mitigation, water abstractions, changes in land use, overfishing) will be greater than climate effects (see Bates et al. 2008). For example, O'Reilly et al. observed a decline in pelagic fisheries in Lake Tanganyika, which they attributed to a combination of the impacts of climate change and overfishing (O'Reilly et al. 2003). Lake Tanganyika is a large (mean width - 50 km, mean length - 650 km), deep (mean depth - 570 m, maximum depth -1,470 m) north–south trending rift valley lake that is an important source of both nutrition and revenue to the bordering countries of Burundi, Tanzania, Zambia and the Democratic Republic of Congo. Deep-water temperatures increased between 1920 and 2000 and the depth of the thermocline has decreased since 1940. This has been attributed to the effects of climate change resulting in increased ambient temperatures and reduced wind velocity causing a reduction of the mixing depth. Consequently, primary productivity in the (narrower) photic zone has decreased, as has the input of deep-water nutrients into this productive zone.

Small island communities are dependent on coastal fisheries for food security. Degradation of coral reef, mangrove and sea grass ecosystems as a result of increased sea water temperature and sea level rise will impact negatively on fisheries production. Coral reefs are sensitive to temperature and pH, therefore thermal stress and increasing CO_2 concentration are expected to increase the incidence of coral bleaching and reduce reef calcification rates resulting in compromised functioning and viability of living reef systems (Hoegh-Guldberg et al. 2007, Eakin, Lough, and Heron 2009). In addition, migration of some tropical species into deeper, cooler waters may reduce catch potential by as much as 40 percent (Cheung et al. 2010) and El Niño oscillations are expected to disturb pelagic fisheries of Pacific islands (Magrin et al. 2007). Aquaculture operations also stand to suffer losses as in the case of Ecuador, where rising sea levels and spread of disease have impacted negatively on fish farm production. Given the dependence of island communities on coastal ecosystems for subsistence fisheries, there is *high confidence* that coral reef ecosystem degradation will negatively impact island communities and livelihoods.

4.2.3 Water supply and human health

Climate change is affecting the social and environmental determinants of health such as clean air, secure shelter, and safe water, so much so that projections for 2030-2050 estimate an additional 250,000 deaths annually due to climate change. One of the greatest threats to human health is the lack of clean water. Despite progress made in the water supply and sanitation sectors, 1.1 billion people still lack an adequate water supply and 2.5 billion are without adequate sanitation (WHO, UNICEF, and WSSCC 2000). The majority of these people live in Asia and Africa (Figure 4.5 below). If water supply is stressed because of climate change, water availability for drinking and hygiene will be even further reduced. There is growing concern that more intense droughts and storms could lead to the deterioration of standards of sanitation and hygiene in island communities in the Caribbean and Pacific and Indian oceans (Cashman, Nurse, and Charlery 2010, McMichael and Lindgren 2011). The relationship between water scarcity and health has been seen in Jamaica, for example, where

What is the general condition in your region with respect to water supply and sanitation? Will this be affected by climate change?

there was a 16-20 percent increase in the total number of cases of oral rehydration/diarrhoea in children under the age of five years during the 2009/2010 drought (Barnett 2010).

Lowering the efficiency of sewerage systems could lead to higher concentrations of micro-organisms in raw water supplies. Concentrations of pollutants will increase because of reduced dilution. Increased salinity as a result of lower stream flows and drying up of groundwater resources could force people to use contaminated surface waters. Higher rainfall, on the other hand, will put more pressure on sewerage systems and will result in more overflows, thus increasing the risk of spreading diseases. The incidence of waterborne diseases is further increased as higher temperatures stimulate the spread of many diseases. Dengue fever is a major health concern for SIDS such as the Pacific and Caribbean islands. In the Caribbean, an increased incidence of the disease in Trinidad and Tobago has been significantly correlated with rainfall and temperature (Chadee et al. 2007, Koh et al. 2008). Moreover, increases in temperature could also introduce new diseases to previously unaffected areas. Overall, the incidence of diseases is expected to increase (Kabat and van Schaik 2003, Ludwig and Moench 2009).

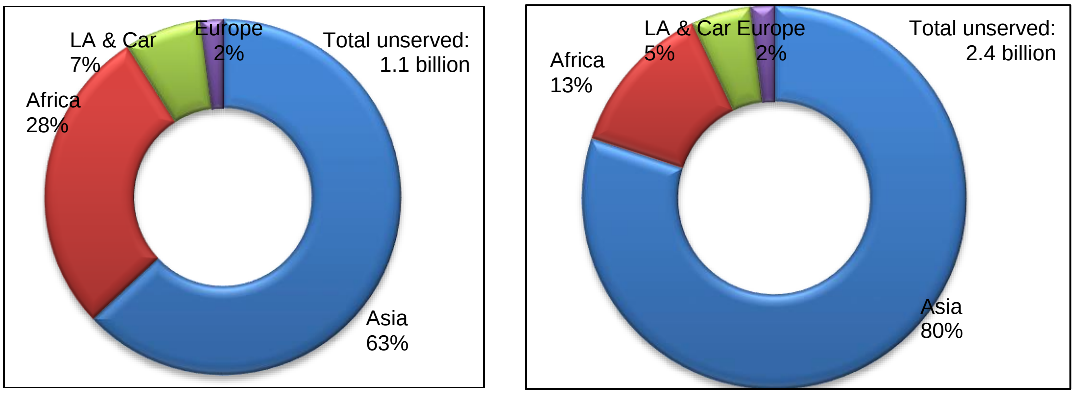


Figure 4.4: Distribution of the global population without access to an adequate water supply (left) and adequate sanitation (right)
(WHO, UNICEF, and WSSCC 2000)

Table 4.3 summarises climatic changes that, via their impact on water resources, affect human health (Kabat and van Schaik 2003).

Mediating process	Health outcome
Direct effects	
Change in the intensity of extreme weather events (e.g. storms, hurricanes, cyclones)	**Deaths, injuries, psychological disorders; damage to public health infrastructure**
Indirect effects	
Changed local ecology of waterborne and food-borne infective agents	**Changed incidence of diarrhoeal and other infectious diseases**
Changed food productivity through changes in climate and associated pests and diseases	**Malnutrition and hunger**
Sea level rise with population displacement and damage to infrastructure	**Increased risk of infectious diseases and psychological disorders**
Social, economic and demographic dislocation through effects on economy, infrastructure and resource supply.	**Wide range of public health consequences: mental health and nutritional impairment, infectious diseases, civil strife.**

Table 4.3. Mediating processes and direct and indirect potential effects on health of changes in temperature and weather
(Kabat and van Schaik 2003)

Other climate related effects on health may be experienced in the form of emotional and mental health stresses. Countries with weak health infrastructure - most often developing countries - will be the least able to cope without assistance.

Social impacts resulting from the 2010 drought in Kingston, St Andrews, Jamaica were determined to include mental and physical stress, which may have resulted in anxiety and even domestic violence. Additionally, some schools had to be closed during periods of water shortage, thus affecting students' education (Barnett 2010).

4.2.4 Energy

Although many other sectors and economic activities will be affected by climatic changes as well (e.g. urban infrastructure, tourism, transportation), the energy sector in particular is susceptible to climatic changes. Hydropower generation is sensitive to the amount, timing, and geographical patterns of precipitation, as well as to the direct impacts of (water) temperatures (Kabat and van Schaik 2003).

How will your energy sector be affected by climate change? Are there also positive impacts?

Thermal electric power plants are expected to increase their generation output in order to make up for the loss from hydropower plants; however, low flow river conditions mean that there may be less water available for cooling of thermal plants (Contreras-Lisperguer and de Cuba 2008). Moreover, during low flow periods, more user conflicts could arise (e.g. allocations for agriculture, nature). If water temperature is too high, it will no longer be suitable for cooling purposes. For example, the 1997/1998 La Niña drought resulted in a drop in hydropower generation of 48 percent in Kenya, resulting in very high economic costs for the country. In the Colorado River (USA), a 10 percent decrease in run-off is estimated to reduce power production by 36 percent (Kabat and van Schaik 2003).

Box 4.2: Renewable energy in the Caribbean in the face of climate change

Renewable energy resources on small islands have only recently been considered within the context of long-term energy security (Praene et al. 2012, Chen et al. 2007). In the Caribbean, the reasons for the slow uptake of alternative energy technology include a lack of resources and the appropriate regulatory framework. In 1998, the Caribbean Renewable Energy Development Programme (CREDP) was founded by 16 Caribbean countries in order to remove the barriers to the use of renewable energy and to foster its development and commercialisation. Currently, 13 countries are participating in the programme, exploring primarily wind and hydropower energy options.

Hydropower production decreases with decreased flows as has been the experience of some Caribbean countries that depend on hydroelectricity for their energy needs. During a period of drought, hydropower contribution to total electrical energy in St. Vincent and the Grenadines fell from 28 percent in 2009 to 8.1 percent 2010 (Farrell, Trotman, and Cox 2010). The Jamaica Observer newspaper reported that the recent 2014 drought resulted in a 15 percent reduction in the country's hydropower production.

4.2.5 Water infrastructure

Consider the following quotes:

"Water management is all about managing climate variability. Climate change and increased climate variability will only transform boundary conditions for water managers." (van Beek 2009)

"In view of the magnitude and ubiquity of the hydroclimatic change apparently now underway, however, we assert that stationarity is dead and should no longer serve as a central, default assumption in water-resource risk assessment and planning. … The world today faces the enormous, dual challenges of renewing its decaying water infrastructure and building new water infrastructure. Now is an opportune moment to update the analytic strategies used for planning such grand investments under an uncertain and changing climate." (Milly et al. 2008)

Water managers have, as a core of their function, managed climate variability for centuries. Basic ingredients of established design practice are the use of statistical analysis tools to derive design discharge or rainfall from long-term observations of those parameters. In dyke design, for instance, the derived design flood water levels are combined with a freeboard (a reasonable increase of the dyke) to arrive at the actual design defence level. The freeboard accounts for:

- Uncertainties in the hydrological analysis as well as in engineering;
- Wave run-up; and
- Subsidence.

The above quotes are taken here as two aspects of the current discourse of what implications climate change has on the planning and operation of hydraulic infrastructure. Some argue that the current statistical tools available are sufficient to accommodate the uncertainties of non-stationary conditions within the time series (imposed under climate change). Others argue that the lifetime of water infrastructure (in comparison to climatic time scales) allows for it to be adapted over time in a sequential manner. This, however, seems to imply that climate change is happening at a gradual or linear pace. This is far from certain. Regional shifts in climate, such as in average annual rainfall may happen at a much faster pace than the global means.

If we look at the flood management case in weighing these aspects, it needs to be noted that the decision on what kind of design flood should be applied is based on a risk benefit trade-off, established not only on scientific principles but also event-dependent. A city or industrial complex will be protected with a higher safety standard than an agricultural area. Flood management policy has already shifted in various places towards an approach beyond the largely politically driven myth of 'absolute safety from flooding'. Such 'integrated flood management' approaches recognise the value of flood protection measures, yet also recognise their limits, such as the residual risks if, for example, levees fail or are overtopped (WMO 2004). This can be done by employing tools such as land use planning controls, flood-proofing of key infrastructure, flood forecasting, emergency preparedness planning for levee failure scenarios, and risk sharing solutions (e.g. flood insurance schemes, catastrophe bonds, etc.).

The drought case is of course more complex in terms of its predictability, duration and the set of mitigation measures available. In particular, the design and operation of water storage infrastructure is an area of concern. Even under a climate variability scenario, droughts receive far less attention than floods. The scientists who argue along the lines of the second quote (above) work on the assumption that a 'business as usual' approach in our current water infrastructure development practices may lead to severe consequences at a later stage, and that it is more cost-effective in the long run to take preventive or mitigation measures today. As the analytical tools currently available to develop and operate water infrastructure under non-stationary conditions may not be fully sufficient, and the societal demands on water managers for socially equitable and environmentally sustainable solutions increase, major efforts will be required in the research and development of alternative solutions that combine the strengths of various scientific disciplines.

One of the shortcomings of IPCC scenarios is that the time scale of projections is longer than that required by decision makers to develop policies for the short term (Baethgen and Goddard 2013). Climate change adaptation, therefore, requires planning strategies not just for the distant future, but for natural variations in climate that occur annually.

Box 4.3: Caribbean water infrastructure

Guyana, one of the most flood prone countries in the Caribbean region, received a loan of USD$ 25 million to fund a climate change adaptation project geared primarily towards flood protection. Sections of the seawall that defend approximately 25 percent of the country's coastal region have been heightened in efforts to protect people and infrastructure from increasing incidents of flooding from sea surge that overtops the seawall (CDB 2013). Such an approach is necessary, yet eventual political ramifications in terms of who takes part in decision-making within such a multi-sectoral scheme must be taken into account.

In 2010, Hurricane Tomas affected several islands in the Caribbean. The island of St. Lucia was particularly hard-hit by the heavy rains that accompanied the cyclone: up to 635 mm of rain within a 24 hour period. This unusually heavy rainfall event resulted in landslides that damaged the infrastructure of the John Compton Dam, which provides water to over half of the island's population. Within a relatively short period of time, the dam was again compromised in December 2013 by a trough that brought heavy rainfall resulting in siltation. Events such as these highlight the need to adapt to extreme inter-annual climate variability as well as longer term projected impacts of climate change.

4.3 Techniques for assessing impacts

A key component of any climate change adaptation effort, regardless of its scale, is to make a reasonably reliable assessment of potential impacts of climate change under different projected conditions, including those with and without the implementation of adaptation measures. To appreciate their significance, assessments of impacts have to be characterised by uncertainties inherent to different stages of the assessment process.

4.3.1 Climate change assessment frameworks

Assessing the impact of climate change on water resources is generally conducted within a larger framework. This should support the selection and formulation of adaptation policies and measures to enhance resilience and reduce vulnerability of water resource systems in the face of the impending climate change. The IPCC Working Group II Report (Carter et al. 2007) identifies five types of Climate Change Impact, Adaptation and Vulnerability (CCIAV) assessment frameworks (see Box 4.4 below), differentiated by their purpose and focus of assessment, available methods, and approaches to deal with uncertainty. Generally, assessments are shifting focus from being mostly research-centred to supporting policy analysis and decision-making with emphasis on the involvement of stakeholders. Uncertainties are recognised as inherent features of the assessment process that need to be managed rather than reduced (see Chapter 5).

Box 4.4: CCIAV assessment frameworks

The IPCC (Carter et al. 2007) identifies five types of CCIAV assessment frameworks:

- **Impact assessment**: a first–generation, top-down scenario-based approach that still dominates the CCIAV literature.
- **Adaptation assessment**: a bottom-up approach that focuses on assessing measures to enhance the resilience of a system exposed to the risk of climate change.
- **Vulnerability assessment**: a bottom-up approach that is closely associated with the adaptation approach, but focuses more on the risks themselves to reduce their impacts.
- **Integrated assessment:** provides a platform to coordinate and represent interactions and feedback among different CCIAV assessment studies.
- **Risk management**: emphasises the characterisation and management of uncertainties and caters directly to policy and decision-making. Can be applied to facilitate the integrated analysis of mitigation and adaptation policies.

4.3.3 An overview of impact assessment methods

The majority of the impact assessment studies found in the literature are based on the IPCC seven-step assessment framework as described in Table 4.4 below. In this top-down approach, scenarios are selected to represent a range of potential socio-economic conditions that are usually based on the IPCC SRES storylines (Figure 2.8). Corresponding scenarios of greenhouse gas releases are then run through GCMs to produce climate change scenarios that each contain a set of hydrological and meteorological variables necessary for simulating the given water resources system. Alternatively, these scenarios can be created using synthetic or analogue methods. A modelling tool is commonly used to assess the response of the water resources system to climate change scenarios.

How useful are these methods to help you to manage your water resources on the ground? What type of information do you need from meteorologists?

1	Define problem: requires the identification of the specific goals of the assessment, the sectors, systems, and regions of interest, the time horizon, and the data needs of the study
2	Select method: dependent on the availability of resources, models, and data, ranging from qualitative and descriptive to quantitative and prognostic
3	Test method/sensitivity: involves model validation, sensitivity testing, and uncertainty analysis to ensure the credibility of the tools applied in the assessment
4	Select scenarios: based on the projection of conditions expected to exist over the study period in the absence of climate change, and on the projection of conditions associated with

	possible future changes in climate
5	Assess biophysical/socio-economic impacts: estimating the differences in environmental and socio-economic conditions projected to occur with and without climate change
6	Assess autonomous adjustments: analysis of responses to climate change that generally occur in an automatic or unconscious (spontaneous) manner
7	Evaluate adaptation strategies: analysis of different means of reducing damage costs through exogenous or planned adaptation, requiring deliberate policy

Table 4.4: The seven-step assessment framework of the IPCC
(Carter et al. 1994)

The assessment process is conducted in several iterations to establish baseline conditions and to represent autonomous and planned adaptation. The performances of different adaptation measures and policies are assessed based on a set of criteria that reflects the priorities established by the planning agency. Ideally, those criteria should be chosen to strike a balance among the three key principles of IWRM: economic efficiency, environmental protection, and social equity.

4.3.4 Types of climate change scenarios

A scenario is not a prediction of the future state of the world but rather an "alternative image of how the future can unfold" (IPCC 2013). There are three main methods for generating climate change scenarios. The most common method is using output from General Circulation Models also called Global Climate Models (GCMs), simulated using greenhouse gas releases representing socio-economic scenarios. GCMs are sometimes statistically downscaled to bring it to a finer resolution, particularly for smaller land masses such as SIDS (Chadee, Sutherland, and Agard 2014). Synthetic scenarios can be created to represent a range of potential climate changes. Analogue scenarios can be created using historic observed conditions or those from another area (Feenstra et al. 1998).

Climate change scenarios based on General Circulation Models

GCMs are computer applications designed to simulate the earth's climate system for the purpose of projecting potential climate scenarios. They range in complexity from simple energy models to the 3D Atmosphere-Ocean GCMs (AOGCMs; see section 2.2.2). In an impact assessment study, greenhouse gas conditions based on SRES are run through a GCM to produce climatic projections. They can be run based on equilibrium conditions, where both current and future climates are assumed to arrive at their greenhouse gas concentrations instantly. More representative, yet more expensive, GCMs can be run assuming that future climate is attained through a steady increase in greenhouse gas releases.

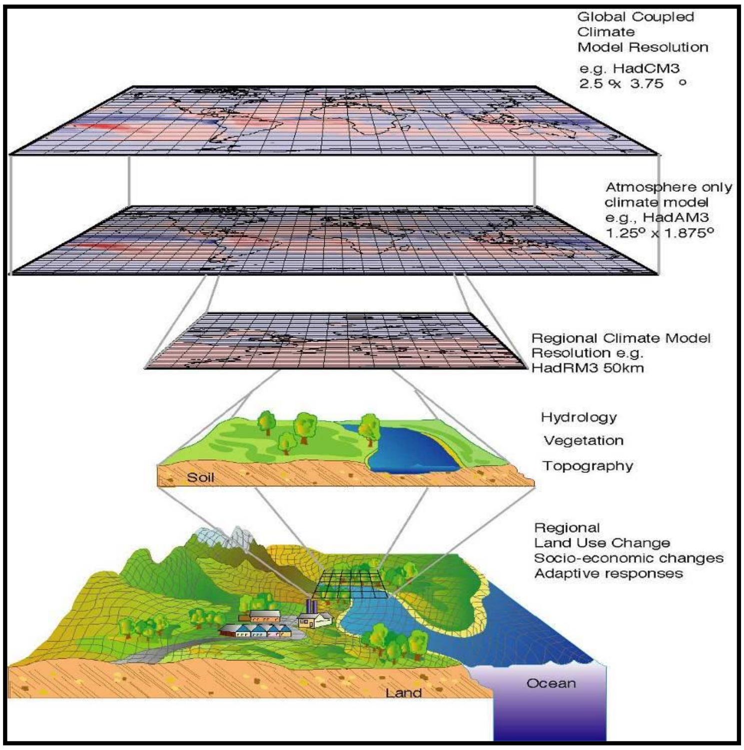


Figure 4.5: Differences in spatial resolutions among climate and water resources models
(World Climate Programme 2007)

The spatio-temporal resolution of GCM output is much lower than that required for assessing hydrological conditions, making it unusable directly for hydrological modelling (see Figure 4.5 above). Output from GCM models can be used to run regional climate models (RCMs), which produce climate change scenarios of a resolution amenable to water resource models. Alternatively, output from GCMs can be statistically downscaled based on ground measurements. Downscaled models for the Caribbean region show areas of increased precipitation for December to February, with region-wide decreases from June to August, particularly around the Greater Antilles. Barbados and Trinidad, however, show increases rather than decreases in summer precipitation to the 2080s. It is important to note that there is no consensus across all models for changes in precipitation (Chadee, Sutherland, and Agard 2014).

Synthetic climate change scenarios

Synthetic scenarios are based on combined incremental changes in meteorological variables. They are commonly applied to study the sensitivity of an exposure unit to a wide range of variations in climate, for example, synthetic temperature time series can be created by combining baseline data with a uniform temperature change (e.g. +1, +2, and +3°C). Precipitation synthetic data are usually created using a uniform percentage change (e.g. 5, 10, and 15 percent). Synthetic scenarios are inexpensive and easy to apply and can be selected to represent a wide spectrum of potential climate changes. They are usually adopted for exploring system sensitivity prior to the application of more detailed and credible, GCM-based scenarios. However, assumption of uniform changes in meteorological variables is not physically based, and synthetic variables may not be internally consistent with each other. For example, increased precipitation should be always associated with increased clouds and humidity.

Analogue climate change scenarios

Two types of analogue scenarios can be used. Temporal analogue scenarios are based on using past warm climates as scenarios of future climate. Spatial analogue scenarios are based on using contemporary climates in other locations as scenarios of future climate in study areas. However, the IPCC (Carter et al. 1994) has made recommendations against using the analogue scenarios. The main objection to temporal analogues is that anticipated future climate anomalies are comparatively greater than observed anomalies over the past century which had different drivers and were probably more likely due to natural causes. Spatial analogues require that the study site be very similar to that from which historical data was gathered and even so, it is unlikely to represent a true future climate scenario. Since temporal analogues of global warming were not caused by anthropogenic emissions of greenhouse gases, no valid basis exists that spatial analogues are likely to be similar to those in the future.

What is your opinion about the use of either one of these two climate change scenarios?

4.3.5 Assessing responses of water resources systems to climate stressors

In its broadest interpretation, a water resources system is composed of interlinked natural and social components (Figure 4.6 below). Climate change and variability have a direct and significant impact on precipitation and evapotranspiration, which are the main drivers of hydrological responses that determine the potential of floods and droughts – the two main classes of water-related hazards. Through structural and non-structural measures, including for example dams, canals, floodplain zoning, and regulations, societies manage water resources to secure clean water supply and provide flood protection.

Due to the complexity and highly variable nature of most water resources systems, it is generally a challenging task to assess their responses under changing climatic conditions. Several methods and tools have been developed to study the different components of water resources systems, including surface run-off, groundwater flow, and water quality. However, most of these tools are applied individually, making it difficult to assess the overall behaviour of the system. However, a few integrated water simulation models have been developed to provide a holistic representation of water resources systems, including those related to demand side and water regulation. Some also include support for economic and policy analysis features. For example, economic modelling approaches were used to estimate water demand and supply in Grenada for the period 2011-2050. The study analysed residential, tourism, and domestic demands under the A2, B2 and BAU scenarios with the aim of prompting governments, institutions, private sector, and civil society to develop effective climate change adaptation and mitigation measures (Economic Commission for Latin America and the Caribbean 2011).

The following sections provide a brief overview of the types of water resources assessment methods.

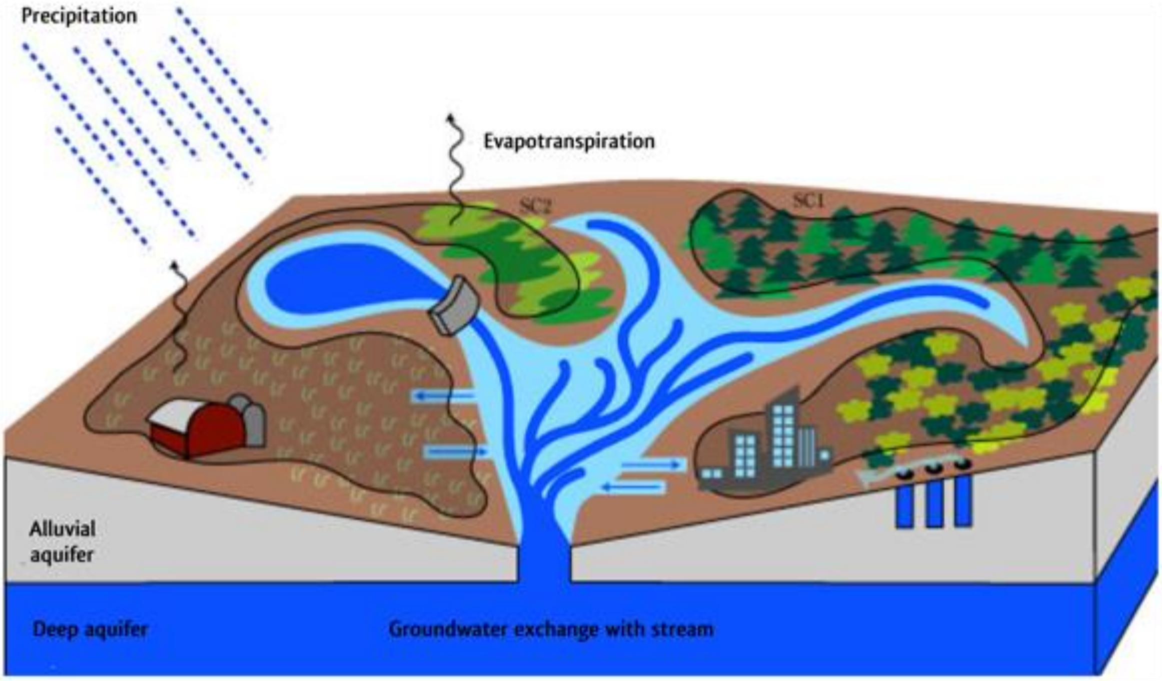


Figure 4.6 Conceptual representation of a water resources system
(UNFCCC 2005)

4.3.6 Methods for assessing individual processes in water resources systems

Due to the complexity and wide range of the physical and social processes underlying water resources systems, the analysis and development of tools to simulate these processes have historically followed distinct lines of research. Consequently, many of the water resources assessment studies reported in literature have focused on one or only a few of the water resources sub-systems, mostly those related to physical processes. These include, for example, analyses of impacts on a river as a result of changes in rainfall and snowmelt patterns, groundwater stocks in response to a reduction of infiltration, and water quality as a result of increases in temperature. A good overview of several modelling tools used in this type of climate change impact studies can be found in UNFCCC (2005). Although these studies are relatively straightforward and inexpensive to apply, they provide minimal consideration of the management and social aspects of water resources systems.

Box 4.5: Vulnerability of water resources to climate change studies within the Caribbean

Under the project Mainstreaming Adaptation to Climate Change (MACC), several Caribbean countries undertook an assessment of the vulnerability of water resources to climate change and variability. Two such studies were conducted in Belize and Jamaica.

Belize North Stan Creek Watershed

The Belize Enterprise for Sustainable Technology (BEST) conducted a pilot assessment of the effects of climate change on the vulnerability of water resources of the North Stan Creek Watershed (NSCW) of Belize to climate variability and climate change. Data on future climate conditions were used for water balance calculations on the hydrologic soil complexes in delineated water management units, using geographic information systems (GIS) and water resources tools to determine runoff. The vulnerability index of the watershed was represented by the ratio of the sum of anthropogenic and vegetation water demands to available water as determined by the difference between the rainfall and the potential evapotranspiration.

Clarendon, Jamaica

As part of the vulnerability assessment for the limestone aquifer of Clarendon, Jamaica, the SEAWAT groundwater quality modelling package was used to examine how climate change and sea level rise will impact on a coastal limestone aquifer. The model was used to estimate the likely magnitude of sustainable groundwater abstractions that could be supported under various climate change scenarios; the results can then be used to develop adaptation options for the aquifer (WRA 2008).

Integrated assessments

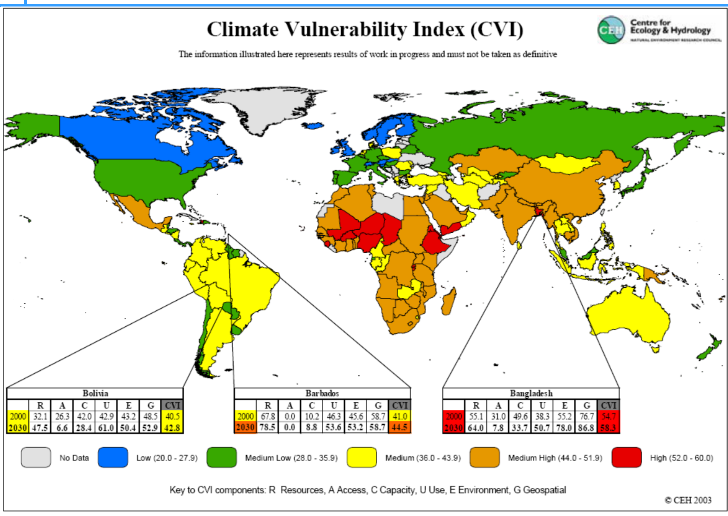
Are you aware of the application of any of these integrated assessment approaches in your region? What would be more appropriate, a focus on floods, droughts, or both?

Climate change is characterised by a multitude of different impacts on different sectors. In order to formulate a well-designed policy, it is necessary to have a complete overview on all impacts and their uncertainties. This can be done by making a model in which all of these impacts (and uncertainties) are integrated. Integrated assessments can address real-world problems that lie across or on the intersection of various scientific disciplines. They can help understand complex phenomena. In risk management they can contribute to, or form, a central part of risk assessment, response assessment, goal and strategy formulation, implementation, evaluation, and monitoring (Toth and Hizsnyik 1998). Various approaches have been developed, like the Environmental Vulnerability Index, the Social Vulnerability Index, and the Flood Vulnerability Index (for websites, see below). Sullivan and Meigh introduced a Climate Vulnerability Index (CVI) that can help to identify those human populations most at risk from the impacts of climate change (see Box 4.6 below) (Sullivan and Meigh 2005).

Box 4.6: The Climate Vulnerability Index (CVI)

The CVI is based on a framework that incorporates a wide range of issues. It is a holistic methodology for water resources evaluation in keeping with the sustainable livelihoods approach used by many donor organisations to evaluate development progress. The scores of the index range on a scale of 0 to 100, with the total being generated as a weighted average of six major components. Each of the components is also scored from 0 to 100. The six major categories or components are shown below.

CVI component	Sub-components/variables
Resource (R)	• assessment of surface water and groundwater availability • evaluation of water storage capacity, and reliability of resources • assessment of water quality, and dependence on imported/desalinated water
Access (A)	• access to clean water and sanitation • access to irrigation coverage adjusted by climate characteristics
Capacity (C)	• expenditure on consumer durables, or income • GDP as a proportion of GNP, and water investment as a percentage of total fixed capital investment • education level of the population, and the under-five mortality rate • existence of disaster warning systems, and strength of municipal institutions • percentage of people living in informal housing • access to a place of safety in the event of flooding or other disasters
Use (U)	• domestic water consumption rate related to national or other standards • agricultural and industrial water use related to their respective contributions to GDP
Environment (E)	• livestock and human population density • loss of habitats • flood frequency
Geospatial (G)	• extent of land at risk from sea level rise, tidal waves, or land slips • degree of isolation from other water resources and/or food sources • deforestation, desertification, and/or soil erosion rates • degree of land conversion from natural vegetation • deglaciation and risk of glacial lake outburst



(Dessai and van der Sluijs 2007, UNEP 2009)

Methods for integrated assessment of climate change impact on water resources systems

A more recent approach that is being applied increasingly in climate assessment studies is based on a holistic integrated simulation of the physical, management, and social aspects of water resources systems. This approach views water resource management not as a supply problem, but also as one where demand management and economic efficiency are important issues that need to be considered explicitly. In addition, great emphasis is placed on policy and decision-making analysis. Considering the challenging task of capturing all these elements in one integrated environment, few models have been successfully implemented (Assaf et al. 2008).

Box 4.7 below presents a list of some of the commonly used water resources management models.

Box 4.7: A list of water resources management models

UNFCCC (2005) compiled the following list of water resources management models:

- **WEAP**: water supply, demand management and policy analysis model;
- **IWR**-**MAIN**: water demand forecasting and conservation management;
- **SWAT**: a water balance and crop growth model mainly used to simulate agricultural activities; http://swat.tamu.edu/workshops/instructional-videos/;
- **SEAWAT:** a three dimensional variable density groundwater flow and transport model
- **HEC suite**: a set of models that simulate different components of watershed systems; and
- **Aquarius**: an optimisation model with focus on economic efficiency; http://aquaticinformatics.com/resources/aquarius-resources/video-library/.

One of the leading water resource system simulation models is the Water Evaluation and Planning (WEAP) Model. In contrast to most simulation models, WEAP explicitly represents water demand alongside water supply elements and provides an extensive policy and economic analysis tools. WEAP21 was applied as the principle tool in a major climate change impact assessment study authorised by the state of California (Purkey et al. 2008).

Summary

Climate change impacts on water resources at the global and the regional level, as well as on various water use sectors, have been highlighted. An overview is given of frameworks to assess climate change impacts to support adaptation planning, most of which make use of GCMs and include socio-economic story lines. These frameworks have been organised collectively under the umbrella term “Climate Change Impact, Adaptation, and Vulnerability Assessment” (CCIAV). Climate scenarios are often processed via different models to assess the impact on water resources systems to support adaptation planning. Many water modelling tools assess individual aspects of water resource systems, however, only a few integrated water simulation models have been developed to provide a more holistic representation.

Suggested Readings

Barnett, Mark. 2010. The Impact of the Recent Drought on the National Water Commission (NWC) Water Supply Services to Kingston & St. Andrew

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Cheung, W.W.L., Lam, V.W.Y., Sarmiento, J. L., Kearney, K., Watson, R., Zeller, D. and Pauly, D. (2010).Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. Global Change Biology 16, 24–35.

Contreras-Lisperguer, R. and de Cuba, K. 2008. The Potential Impact of Climate Change on the Energy Sector in the Caribbean Region: An effort to understand how climate change may impact the productivity of existing and future energy production systems in the Caribbean. Organisation of American States

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Gamble, D., Campbell, D., Allen, T. et al. 2010. Climate change, drought, and Jamaican agriculture: local knowledge and the climate record

IPCC (2014). Climate Change 2014: Impacts, Adaptation and Vulnerability. Chapter 29.

Jiménez Cisneros, B.E., T. Oki, N.W. Arnell, G. Benito, J.G. Cogley, P. Döll, T. Jiang, and S.S. Mwakalila, 2014: Freshwater resources. In: Climate Change 2014: Impacts,Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 229-269.

Magrin, G., Gay García, C., Cruz Choque, D. et al. (2007) Latin America. In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, eds.). Cambridge University Press, Cambridge, UK.

Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s. 1.Climate Change. 2.Environmental Health. 3.Mortality – trends. 4.Risk Assessment. I.World Health Organisation

Taylor, M. A., Whyte, F. S., Stephenson, T. S. and Campbell, J. D. (2013), Why dry? Investigating the future evolution of the Caribbean Low Level Jet to explain projected Caribbean drying. Int. J. Climatol., 33: 784–792. doi: 10.1002/joc.3461

UN ECLAC, 2011: An Assessment of the Economic Impact of Climate Change on the Water Sector in Grenada. Final Report. United Nations Economic Commission for Latin America and the Caribbean (UN ECLAC) 120 pp

Water Resources Authority. 2008. Vulnerability and capacity assessment: Southern Clarendon Pilot Project, Jamaica. Final Project Report prepared under Mainstreaming Adaptation to Climate Change (MACC) Project for the World Bank and the Caribbean Community Climate Change Centre (CCCCC). Kingston, Jamaica: WRA.

Videos

Climate Smart Agriculture: http://www.fao.org/news/audio-video/detail-video/en/?uid=10562

What are General Circulation Models: Q&A on Climate Models: https://www.youtube.com/watch?v=ZtK8oqQm7wQ

5. DEALING WITH UNCERTAINTIES

Goal

The aim of this chapter is to familiarise the participants with the uncertainties involved in predicting and adapting to the expected impacts of climate change. This chapter follows from Chapter 2 on observed and projected climatic changes. Uncertainties are introduced in trying to quantify the variables that combine to produce the outputs of the climate models discussed in Chapter 2. Understanding the sources of these uncertainties can allow us to better manage them, the basis of the risk-based approach to prediction discussed in Chapter 4 (Section 4.3.1).

The projected climatic changes are the result of models that include many variables to produce an output (as explained in Chapter 2). One of the key questions with regards to climatic projections is that of uncertainty and the underlying risks due to these uncertainties. Issues of uncertainty surrounds natural variability in climate, model uncertainty created by imperfect models and variety in downscaling methods, the variations in the range of future emissions, as well as the science itself (changes to the dominant physical processes controlling the regional climate system and how these may possibly change in the future). One example of this is the case of the Atlantic Ocean acting as a heat sink leading to an ‘apparent hiatus’ in global warming discussions (Lee 2014).

In order to understand the underlying uncertainties within the climate system; an understanding of what climate is and the drivers of the general climate must first be understood, Box 5.1 reiterates the basics of climate and the factors which drive it; to which we now have the added influence of human contributions. More details on climate drivers were provided in Chapter 2.

Box 5.1: Drivers of Climate

What is Climate?
According to the IPCC (2013) climate is "…usually defined (in a narrow sense); as the average weather or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years." The classical period is 30 years, as defined by the World Meteorological Organization (WMO). These quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.

What are the Drivers of Climate?

External Drivers

- Solar forcing
- Orbital variations

Internal Drivers

- Plate Tectonics and Volcanic Activity
- Albedo
- The Greenhouse Effect

5.1 Dealing with uncertainties in environmental management

The recognition that, when dealing with environmental issues, severe uncertainties and value-loadings exist has resulted in the development of new approaches to science. Historically, several methods were employed by ancient civilisations such as the Mayans, who faced similar extreme climatic changes. They were able to adapt to rising sea levels by turning those lands affected into wetland farms (similar to rice paddy agriculture) (Turner and Sabloff 2012).

Precautionary or post-normal sciences deal with situations where facts are uncertain, values are in dispute, stakes are high, and decisions are urgent (Ravetz 2005). Additionally, water management is increasingly moving from a practice consisting of more or less straightforward tasks (e.g. ensuring a certain quantity and quality of water supply) to situations with large uncertainties, value-loading, and various kinds of political and social issues (e.g. controversies around the building of dams, insufficiently accurate hydrological models). This leads to a situation where policies become based less on facts and more on guiding principles, which are expressed as avocations for the protection of certain interests. Traditional science and engineering cannot adjudicate among such conflicting values. It is principally a political task to weigh risks as a function of probability and expected consequence (including the prevailing uncertainties) in the political discourse with the wider public and the stakeholders. Such discourse also provides an opportunity to weigh the opportunities derived by accepting a certain level of (residual) risk, e.g. by allowing certain land uses in flood-prone areas. This is essential to arrive at a robust adaptation policy design that integrates a perspective on poverty reduction and livelihood security.

Clearly, this also applies to adapting to the impacts of climate change in water resources management. Uncertainty, variability, and risk are probably the most important consequences of climate change (Aerts and Droegers 2009). As seen earlier (Chapter 4), various climate change projections may be inconsistent or lack accuracy at regional and local scales. Traditionally, water management has been based on historical climate and hydrological data, assuming stationarity in weather and in the behaviour of water systems (Ludwig and Moench 2009). With a changing climate, it becomes questionable if planning for variability and extremes can continue to be solely based on historical data. Experience from the past may no longer be a reliable guide for the future (Pahl-Wostl et al. 2007).

The challenges for the future lie in the improvement of climate predictions at the time and spatial scales required by water resources managers. However, it is also equally important to allow for a collaborative framework between the climate information community and the water resources management community to gain a better understanding of the respective information requirements and methods employed by each community. However, coping with future uncertainties also requires a more adaptive and flexible approach to realise a faster adaptation cycle that allows the rapid assessment and implementation of the consequences of new insights (Pahl-Wostl et al. 2007). Adaptive water management aims at institutional flexibility and a central role for stakeholders (Aerts and Droegers 2009). Its goal is to increase adaptive capacity to cope with uncertain developments, rather than trying to find optimum solutions (Pahl-Wostl et al. 2007).

5.2 Typology of uncertainties

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Uncertainty can be classified on a gradual scale running from ‘knowing for certain’ to ‘not knowing’ (Dessai and van der Sluijs 2007) (see Figure 5.2). Three classes of uncertainty are explained in Box 5.2.

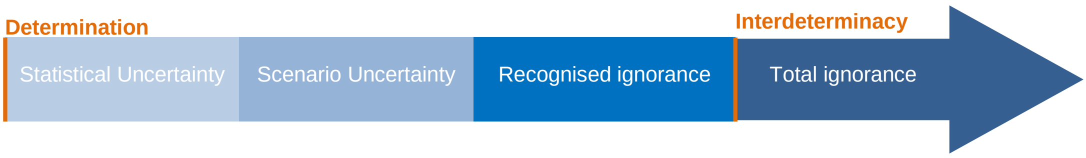


Figure 5.1: Uncertainty levels between determinism and total ignorance
(Dessai and van der Sluijs 2007)

Box 5.2: Levels of uncertainty

Statistical uncertainty concerns the uncertainties that can be adequately expressed in statistical terms, e.g. as a range with associated probability. Examples include statistical expressions for measurement inaccuracies, uncertainties due to sampling effects, and uncertainties in model-parameter estimates. In the natural sciences, scientists generally refer to this category if they speak of uncertainty, thereby often implicitly assuming that the involved model relations offer adequate descriptions of the real system under study, and that the (calibration) data employed is representative of the situation under study. However, when this is not the case, 'deeper' forms of uncertainty are at play, which can surpass the statistical uncertainty in size and seriousness and which require adequate attention.

Scenario uncertainty concerns uncertainties that cannot be adequately depicted in terms of chances or probabilities, but that can only be specified in terms of (a range of) possible outcomes. For these uncertainties, it is impossible to specify a degree of probability or belief, since the mechanisms that lead to the outcomes are not sufficiently known. Scenario uncertainties are often construed in terms of 'what-if' statements.

Recognised ignorance concerns those uncertainties that we somehow realise are present, but for which we cannot establish any useful estimate, e.g. due to limits to predictability and knowability ('chaos') or due to unknown processes. A way to make this class of uncertainties operational in climate risk assessment studies is by means of surprise scenarios. Usually there is no scientific consensus on the plausibility of such scenarios, although there is some scientific evidence to support them. Examples are the accelerated sea level rise, or the possible shutdown of the thermohaline ocean circulation.

Continuing on the scale beyond recognised ignorance, we arrive in the area of **complete ignorance** ('unknown unknowns') of which we cannot yet speak and where we inevitably grope in the dark.

(Dessai and van der Sluijs 2007, UNEP 2009)

5.3 Uncertainty and climate change

One thing is for certain: under climate change, uncertainty will increase. When making climate change impact assessments, a 'cascade' of uncertainty arises (Dessai and van der Sluijs 2007) (see Figure 5.1 and Box 5.3). For example, there are uncertainties associated with future emissions of greenhouse gases and sulphate aerosols, uncertainties about the response of the climate system to these changes at global and local scales, and uncertainties associated with the impact models and the spatial and temporal distributions of impacts. Climate change impacts such as changes in temperature, precipitation, run-off, or heating-degree days are therefore characterised by uncertainties regarding their magnitude, timing, and spatial distribution. Models may even show opposite signs, for example, some projections show more precipitation, whereas others show less. In addition, uncertainties also exist when trying to understand current vulnerabilities to the impacts of climate change for the purpose of identifying adaptive responses.

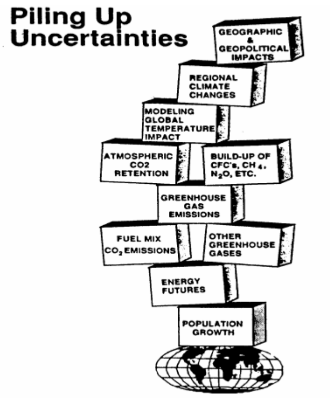


Figure 5.2: Possible impacts of climate change are characterised by high levels of uncertainty

Box 5.3: Feedbacks

One factor that complicates climate science – and therefore leads to wide ranges of uncertainty – is the existence of feedbacks. These are interactions between different parts of the climate system in which a process or event sets off changes which, in turn, influence the initial trigger. One example is the reduction of ice and snow, both on land and at sea. Ice, being white, reflects up to 90 percent of the sun's radiation reaching its surface back out into space, preventing it from intensifying atmospheric warming. But when it melts, it may expose earth, vegetation, rock, or water, all of which are darker in colour and therefore more likely to absorb radiation instead of reflecting it. So the initial melting can cause a feedback which helps to quicken its pace.

Another possible feedback is the thawing of the permafrost in high northern latitudes. As it melts, it could release large quantities of carbon dioxide and methane, which at the moment are retained below the frozen soil layer. If that happens, it will accelerate the warming that is already underway. Another expected feedback: higher temperatures of both land and ocean have the tendency to reduce their uptake of atmospheric CO_2, increasing the amount that remains in the atmosphere. These are all positive feedbacks because they intensify the original process. Negative feedbacks, on the other hand, are changes in the environment that lead to a compensating process and mitigate the change itself.
(UNEP 2009)

5.4 Adaptation to climate change under uncertainty

Dessai and van der Sluijs (2007) put forth two distinct approaches in climate change adaptation: prediction-oriented and resilience–oriented approaches. The first focuses on characterising, reducing, managing, and communicating uncertainty, resulting in increasingly sophisticated modelling tools and techniques to describe future climates and impacts. The second approach accepts that some uncertainties cannot be reduced. The emphasis is on learning from the past. These two approaches are not mutually exclusive, but are best seen as complementary. Following are some examples of both approaches.

Meadows outlined that one of the key concepts in environmental education is that of knowledge and uncertainty and addressed the following fact: "We don't even understand how much we don't understand" (Meadows 1989). Therefore, we tend to make decisions under uncertainty which can be devastating and as a result, the management of the risks involved is of utmost importance. Meadows also outlined the process by which such risks can be managed:

1. Assessment and slow experimentation;
2. Constant, truthful evaluation of results; and
3. Willingness to change strategies.

As previously mentioned in Chapter 3 (Section 3.1), disaster risk management strategies and approaches are key to adaptation and mitigation in light of uncertainty. Adaptation strategies must also take into consideration the uneven distribution of climate impacts and the introduced factors of uncertainties due to various scales.

The Caribbean has already been experiencing climatic extremes, which are climate variability effects. One such example is the drought in St. Lucia in early 2010 (Farrell, Trotman, and Cox 2010), followed by Hurricane Tomas in October 2010, which hit the island causing widespread flooding and resulted in 14 fatalities (CDEMA 2010).

Additional issues in the context of uncertainty

1. Data integrity;
2. Acknowledgement that in considering any aspect of the future there will always be uncertainties;
3. Models do not fully quantify all sources of uncertainty; and
4. Some sources of uncertainty are inherent and irreducible.

Sources of Uncertainty in Climate Projections

The general goal of scientific investigation is to decrease the uncertainty associated with important but unknown quantities, such as, for example, the future availability of water. The level of uncertainty in some cases can be accurately defined; however, in some cases, the uncertainty cannot be specified or reduced. Therefore, understanding the range of uncertainty is important. This is the case with future climate change projection outputs produced by models.

There are several reasons why the future climate is uncertain:

1. Greenhouse gas concentrations affect the climate: Emissions of greenhouse gases in the future are unknown.

2. There is natural variability of the earth's climate system: Just like the weather is impossible to forecast perfectly, the chaotic nature of the earth's climate system makes it impossible to know perfectly how the climate will evolve in the future.

3. The models used for making climate projections reflect approximations of our current state of knowledge or Level of Scientific Understanding (LOSU) which is incomplete (refer to Chapter 2),

4. There are errors and simplifications in the models and basic responses, such as the temperature increase for a given increase in greenhouse gas concentrations ("climate sensitivity"), is not known.

Averaging is therefore the best route and as a result, climate projections are best used as ensembles, or collections of different projections that attempt to explore the range of climate uncertainty. In general, for near term time frames and smaller spatial scales, climate variability is the most important source of uncertainty (Brown 2014).

5.4.1 Prediction-oriented approaches

The IPCC approach

The IPCC impact assessment method described in Chapter 4 provides an example of a prediction-oriented approach, which relies heavily on uncertain information by using climate change scenarios as drivers for impacts from which adaptation strategies are developed.

Risk approaches

A broad definition of risk assessment is the process of identifying, evaluating, selecting, and implementing actions to reduce risk to human health and to ecosystems (Dessai and van der Sluijs 2007).

Central to risk assessment is the management of uncertainties, which allows the risk of something to be determined (in its simplest form, this risk would be calculated as probability times consequence). Risk assessment and risk management have been widely applied to a number of environmental problems, but only very recently to climate change.

Dessai and van der Sluijs (2007) present an environmental risk assessment/risk management framework that includes the following steps:

1. Identification of the key climatic variables affecting the exposure units being assessed;
2. Creation of scenarios and/or projected ranges for key climatic variables;
3. Carrying out a sensitivity analysis to assess the relationship between climate change and impacts;
4. Identification of the impact thresholds to be analysed for risk with stakeholders;
5. Carrying out risk analysis;
6. Evaluation of risk and identification of feedbacks likely to result in autonomous adaptations; and
7. Consultations with stakeholders, analysis of proposed adaptations and recommendation of planned adaptation options.

While this framework is conceptually simple, it is difficult to implement due to the complexity of climate change. Like the IPCC approach, uncertainty is taken into account using climate scenarios (Step 2), but this particular risk approach is not completely scenario-driven. It is more dependent on stakeholder involvement and their definition of critical impact thresholds.

Safety chain and integrated risk management approaches

The safety chain, or hazard life cycle concept, originates from the United States and includes four links: 1) mitigation, 2) preparedness, 3) response, and 4) recovery (ten Brinke et al. 2008). In the Netherlands, this risk management approach has been adopted and slightly adjusted - instead of the mitigation link, two links are distinguished, pro-action and prevention. This allows for discrimination between risk reduction measures in spatial planning (pro-action) and measures such as dykes and storm surge barriers (prevention). A definition of the links used in this approach is presented in Table 5.1. A similar approach is used in Switzerland under the term ‘integrated risk management’ (Figure 5.3).

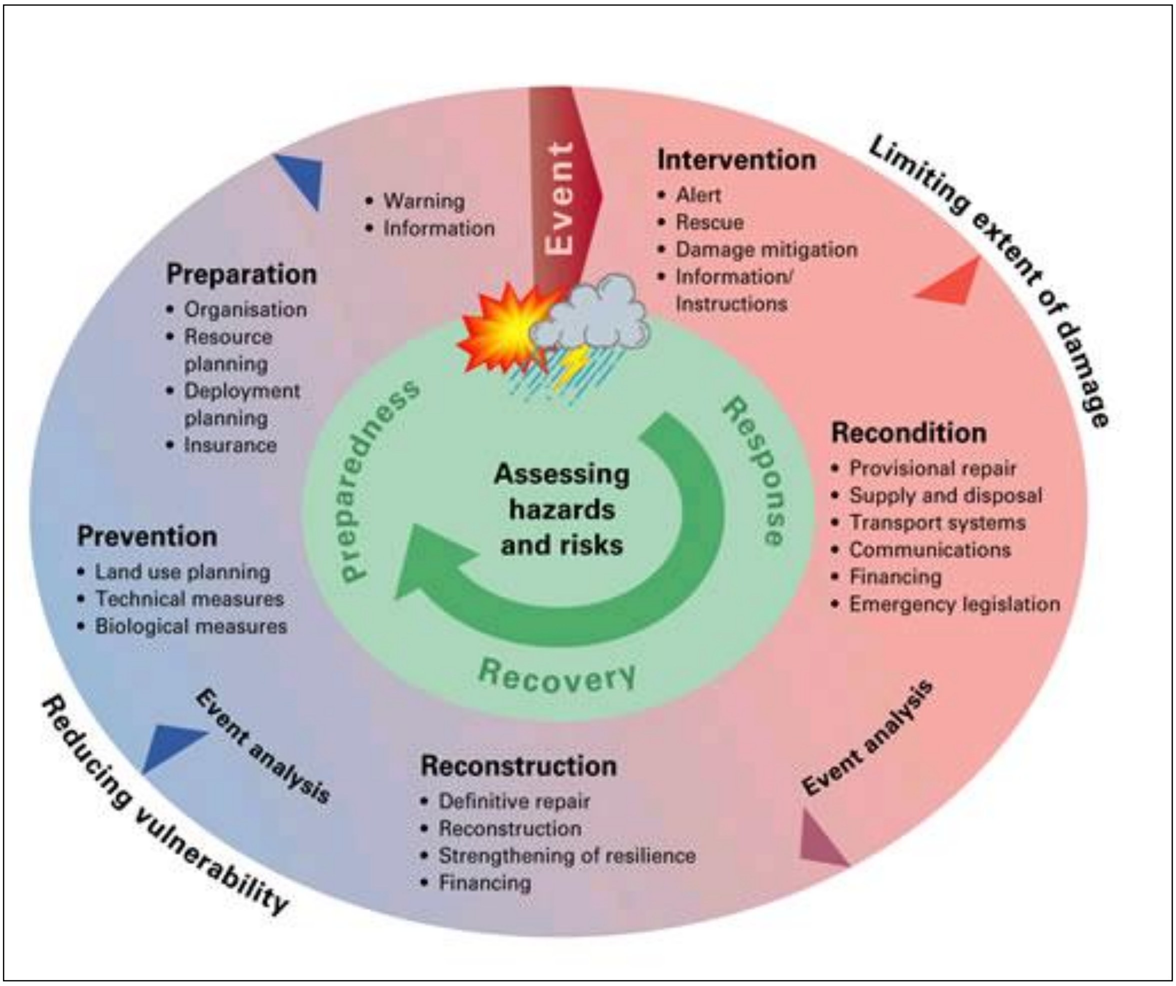


Figure 5.3: Integrated risk management
(PLANAT n.d.)

	Link	Definition
Risk management	Pro-action	Eliminating structural causes of accidents and disasters to prevent them from happening in the first place (e.g. by building restrictions in flood-prone areas)
	Prevention	Taking measures beforehand that aim to prevent accidents and disasters, and limit the consequences in case such events do occur (e.g. by building dykes and storm surge barriers)
Crisis management	Preparation	Taking measures to ensure sufficient preparation to deal with accidents and disasters in case they happen (e.g. contingency planning)
	Response	Actually dealing with accidents and disasters (e.g. response teams)
	Recovery	All activities that lead to rapid recovery from the consequences of accidents and disasters, and ensuring that all those affected can return to the 'normal' situation and recover their equilibrium.

Table 5.1: The definition of the successive links in the safety chain
(ten Brinke et al. 2008)

An example of risk management is the Caribbean Climate Online Risk and Adaptation Tool (CCORAL), a Caribbean-specific web-based platform. Box 5.4 below explains the use of this tool in influencing the decision making process in managing risk in the developmental stages of projects.

Box 5.4: Case Study: CCORAL

CCORAL is used to identify climate risks and build resilience into development activities. It is a tool that is used in the screening process for water related policies, legislation, plans, budgets, and projects to assess climate risks and identify possible options to enhance climate resilience

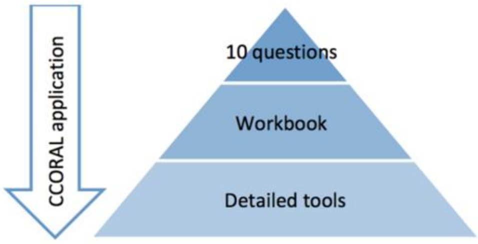
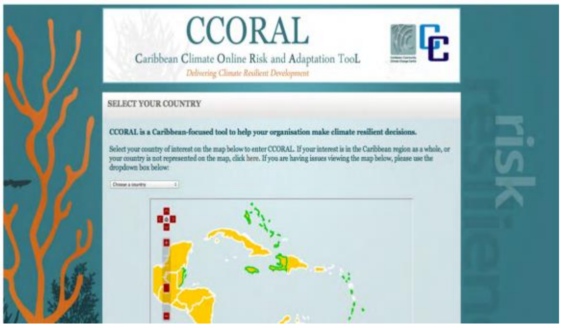


Figure 1 - Overview of CCORAL process



Use of CCORAL for water related policies and strategies
Examples of policies and strategies: Policies relating to water resources allocation and abstraction management and developing planning as well as water dependent sectoral policies for agricultural development and municipal supplies.

Use of CCORAL for water related legislation and regulations:
Examples of legislation and regulation: Legislation governing water resources and allocation including: municipal suppliers of water for agricultural purposes, private and industrial water abstraction and discharge. This can also include development planning guidance.

Use of CCORAL for water-related projects, programmes and operational activities:
Examples of projects: 'Hard' infrastructure investments with long lifetimes, for example reservoirs, intakes, treatment works, pipelines, and other assets. "Soft" investments such as technical studies, data collection, and other information services which underpin planning activities.

5.4.2 Resilience-oriented approaches

Non-structural measures: Social Protection policies

One of the key adaptation interventions is social protection. Social protection consists of policies and programmes designed to reduce poverty and vulnerability by promoting efficient labour markets, diminishing people's exposure to risks, and enhancing their capacity to protect themselves against hazards and interruptions. Ultimately, the aim is to enhance the capacity of the poor and vulnerable persons to manage different risks (economic, environmental, and social) through policy interventions, including social insurance, social assistance, transfer/welfare programmes, labour market programmes, Community-based Investment Funds, and national health insurance. Alternatively, social protection can be placed in the context of social risk management, which constitutes three types: risk reduction, risk mitigation, and risk coping (Hicks and Wodon 2001). It therefore includes all interventions from public, private, voluntary organisation and social networks, to support communities, households, and individuals, in their efforts to prevent, manage, and overcome a defined set of risks and vulnerabilities. Usually, in response to levels of vulnerability, risk and deprivation are deemed unacceptable. Arguably, it is not only 'welfare' and 'relief' but more, given the emphasis on liberating human potential and promoting equality of opportunity. While recognising that social protection incorporates 'safety nets', some researchers posit that it is a 'spring board' for a longer term developmental approach (investment in capacity building), and should therefore be an integral part of a country's development strategy.

The way forward is to rethink programmatic areas with the aim to integrate climate and environmental change into development policies and to optimise opportunities for creating a single strategic vision of addressing vulnerabilities (environmental or social) of specific groups, especially women and children. Social protection provides an excellent opportunity.

Are risk approaches in your country focusing more on prevention, or towards response/recovery?

Engineering safety margin and anticipating design

In the design of dykes, it is common practice to apply an engineering safety margin on top of the design flood level. This is to compensate for physical processes not foreseen in the design water level (e.g. overtopping by waves) and for uncertainty in the prediction of design flood levels (e.g. accuracy in the flood estimation) (Figure 5.4 below). These safety margins mainly account for statistical uncertainty and unrecognised ignorance; scenario uncertainty is only accounted for in the design flood. A safety margin based on observed variability does not seem to be a good way to cope with recognised ignorance, such as the unknown probability of high-impact events and possible surprises (e.g. accelerated sea level rise from the Greenland ice sheet and West Antarctica). Thus, there is a need for mapping the unknowns – experience from the past may no longer be a valid base for decisions, especially when changes go beyond natural variability.

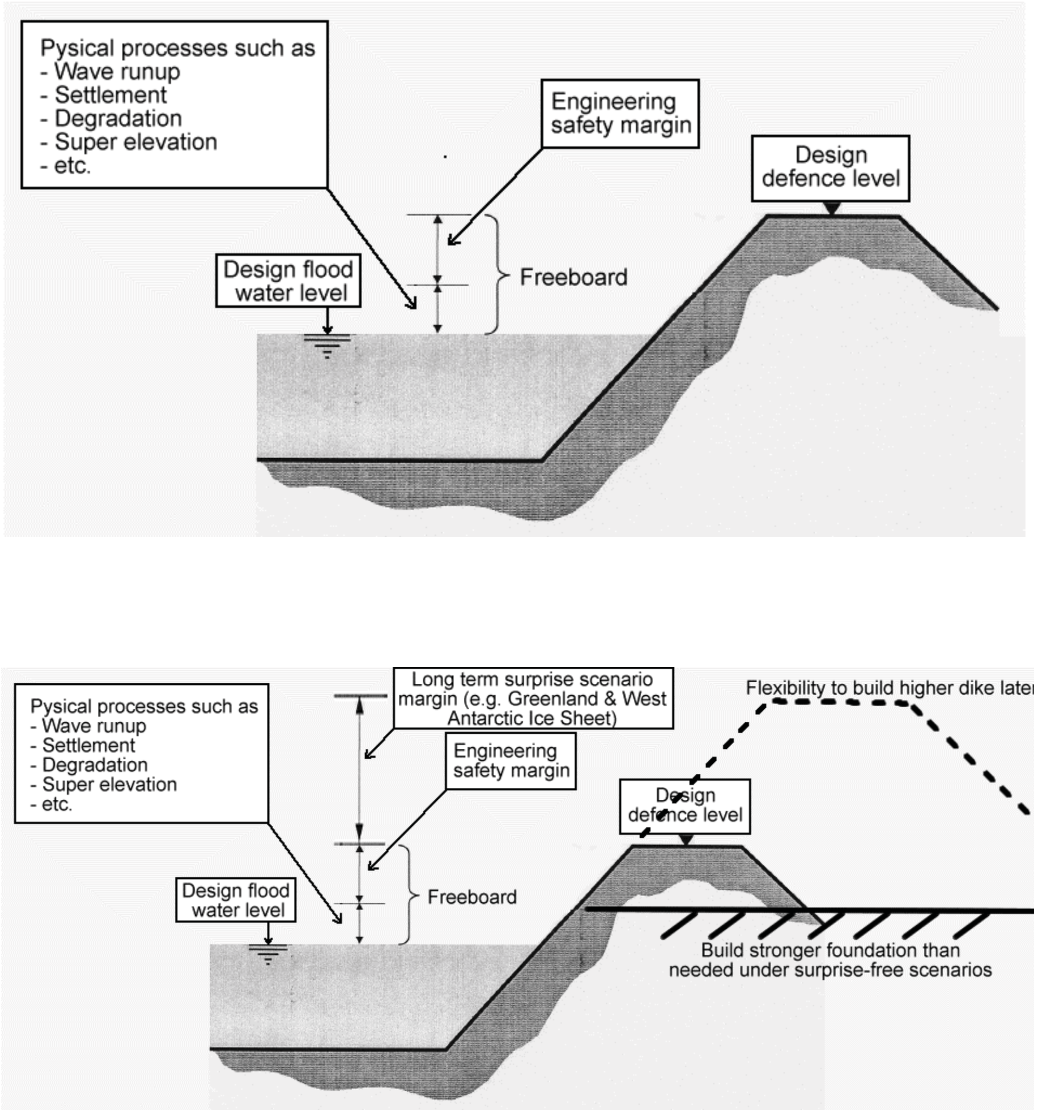


Figure 5.4: Engineering safety margin for a dyke (a) and flexible design, anticipating imaginable surprises (b)
(Dessai and van der Sluijs 2007)

An innovative way to take uncertainty of the type ‘recognised ignorance’ into account in the design of dykes is anticipating design. 'Surprise-free' scenarios can be used to choose the design flood level. The uncertainty related to the possibility of a substantially higher sea level rise can be included in the design by building a foundation that is strong enough to carry a dyke for a design flood level corresponding to that upper boundary, but dimensioning the dyke itself using the design flood level.

This provides the flexibility to construct a higher dyke later with lower costs, if needed (Figure 5.4b above). Similarly, dykes can be protected against erosion to cater for overload where appropriate. This creates a situation where the inflow into the floodplain during an extreme event can be reduced substantially. Such measures should ideally be part of an integrated risk management approach that would identify the most desirable locations for overtopping, adjusting the land use behind the levee at those locations, maintain an early warning and emergency response system, and consider the use of insurance and flood proofing options there.

Box 5.5: Structural engineering techniques as coastal defense mechanisms in the Caribbean

In the Caribbean, Guyana and Barbados have employed the use of structural engineering techniques as coastal defence mechanisms. The boardwalk on the south coast of Barbados (image below) which spans a kilometre in length and is 1.8 to 3.7 m deep (6 – 12 feet), has increased beach width by almost 20 metres. The structure is therefore both, environmentally stable and supports coastal resilience by preventing the destruction from natural disasters and natural beach erosion, inclusive of exacerbated climatic effects.

Aerial view of the boardwalk on Barbados' south coast
Source: www.Barbados.org 2014

The 450 km (280 miles) long seawall that runs along much of Guyana's coastline (image below), protects the capital city of Georgetown from inundation by rising sea levels and high tides. With 90 percent of the population of Guyana living and work along its thin 425 km long low-lying coastal strip, the seawall structure is needed for the protection of not just the coastline, but the lives of the settlers in this area (Persaud 2014).

Guyana's raised seawall
Source: Taken by Dr. P.E. Bynoe

Summary

A short introduction is given on the various aspects that add to the uncertainties when dealing with climate change and how this can be included in environmental management approaches. Prediction- and resilient-oriented approaches are presented as two different options for climate change adaptation. They have been illustrated with some examples.

Suggested Readings

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- Flood Vulnerability Index: www.unesco-ihe-fvi.org
- Social Vulnerability Index: http://webra.cas.sc.edu/hvri

6. MEASURES FOR ADAPTATION

Goal

The aim of this session is to present participants with the range of adaptation measures for a number of projected climate change impacts and to discuss indicators for their applicability in given climatic and socio-economic environments.

6.1 Introduction

In previous chapters, participants were provided with a basis for understanding the drivers, impacts, and assessment techniques of climate change along with the principles, guidelines, challenges, and opportunities of adaptation (see Chapters 2, 3, and 4). Although adaptation to climate change may seem as a relatively new concept because of the increased recognition gained within the past three decades (e.g. IPCC Assessment Reports (1 – 5), UNCED, UNFCCC, MDGs, SDGs, NAPs, UNEP Green Economy, etc.), it is not a new concept. Climate systems are naturally variable (Brekke et al. 2009), and thus, societies have always had to cope or adapt when climate change and climate variability affected the availability of water resources.

There are various strategies for managing water resources. Today, water managers' routine activities include water allocation among multiple and often competing uses, minimisation of risks, and adaptation to changing circumstances such as variability in water storage levels and water demand due to seasonal effects and/or population growth. In the Caribbean, a wide range of adaptation techniques have been applied over many decades, including capacity expansion (e.g. building new reservoirs, such as the man-made reservoir in Apes Hill, Barbados in Figure 6.1), changing operating rules for existing water supply systems, managing water demand (e.g. water restrictions imposed in Trinidad and Tobago in 2009 and 2010), and changing institutional practices. Within this context, historical climate and hydrological records provide the basis for the determination of reliable water yields and assessment of flood and drought risk. Underpinning these investigations is the assumption that the statistical properties (e.g. means and standard deviations) of the climatic and hydrological variables remain constant over time. This concept is known as the assumption of stationarity. However, the prospect of climate change means that the key climate and hydrological variables will vary, as will water demand. Milley et al. supported that "climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks" and that the assumption of stationarity is no longer valid (Milly et al. 2008).

Figure 6.1: The man-made reservoir at Apes Hill Golf Club in Barbados
Source: Tripadvisor 2014

Furthermore, climate-induced effects may be nonlinear and carry the potential for surprises beyond those already incorporated in water supply system designs and existing water management strategies (Kabat and van Schaik 2003)

Figure 6.2: Prevention Mitigation and Adaptation.

6.2 Adaptation measures

Forecasts of climate change may remain debatable for some time; evidence of increased climate variability is incontestable, and the severity of that variability demands urgent responses from water managers. The reassuring aspect of this argument is that adaptation options for coping with climate variability now will also help to reduce the impact of climate change in the future. These measures include the conventional technological elements of water infrastructure – such as storage reservoirs, boreholes, recharge wells, and sand wells – but with an emphasis on techniques for boosting the yield of available resources (rainwater harvesting - see Box 6.1, water recycling/reuse, desalination). Various types of water infrastructures are found throughout the Caribbean, with the most common ones being water distribution systems, supply wells, reservoirs, and rainwater harvesting. Sand wells are used to increase water availability by storing rainwater, usually in river beds and banks, through the processes of damming, filtration, and storage. Sand wells are best suited for rural areas with a semi-arid climate. Thus, these structures are not common in the Caribbean.

Are you aware of the application of any of these integrated assessment approaches in your region? What would be more appropriate, a focus on floods, droughts or both?

Box 6.1: The Caribbean Catastrophe Risk Insurance Facility (CCRIF)

With regards to financial mechanisms available for relief and development after natural disasters, the Caribbean Catastrophe Risk Insurance Facility (CCRIF) can provide immediate financial liquidity to Caribbean governments for post-disaster relief and recovery needs (World Bank 2007). The 2004 hurricane season (in particular hurricanes Charley, Frances, Ivan, and Jeanne) prompted the collaborative efforts of CARICOM Heads of Government, the World Bank, key donor partners, and other regional governments (World Bank 2007) to form CCRIF in 2007 as the first multi-country risk pool in the world (CCRIF 2014). CCRIF helps to relieve the short-term financial difficulties usually encountered by small developing economies in the aftermath of a natural disaster (CCRIF 2014). Currently, 16 governments are members of CCRIF: Anguilla, Antigua and Barbuda, the Bahamas, Barbados, Belize, Bermuda, the Cayman Islands, Dominica, Grenada, Haiti, Jamaica, St. Kitts and Nevis, Saint Lucia, St. Vincent and the Grenadines, Trinidad and Tobago, and Turks and Caicos (CCRIF 2014). Since the establishment of CCRIF in 2007, there have been eight pay-outs to seven member governments totalling some USD$32M (see table below).

No.	Event	Country Affected	Payouts (USD$)
1	Earthquake, 29 Nov 2007	Dominica	528,021
2	Earthquake, 29 Nov 2007	St. Lucia	418,976
3	Tropical Cyclone Ike, Sep 2008	Turks and Caicos Islands	6,303,913
4	Earthquake, 12 Jan 2010	Haiti	7,753,579
5	Tropical Cyclone Earl, Aug 2010	Anguilla	4,282,733
6	Tropical Cyclone Tomas, Oct 2010	Barbados	8,560,247
7	Tropical Cyclone Tomas, Oct 2010	St. Lucia	3,241,613
8	Tropical Cyclone Tomas, Oct 2011	St. Vincent and the Grenadines	1,090,388
	Total for the period 2007 - 2013		**USD$32,179,470**

CCRIF pay-outs to member governments from 2007 to 2013
(CCRIF 2014)
*CCRIF does not cover flooding.

Adaptation benefits enormously from improved forecasting and climate modelling. This stresses the need for strengthening of data-gathering initiatives, as many hydrological stations in developing countries have become defunct over the years through lack of investment. Risk-sharing and access to credit for affected families are among the financial mechanisms that are being adapted to be responsive to floods and droughts. On a more structural level, modification of land-use patterns, crop selection, and tillage practices can also be considered.

Why may an insurance company that is based in the Caribbean not want to provide coverage against floods?

One of the key adaptation interventions is social protection. Social protection consists of policies and programmes designed to reduce poverty and vulnerability by promoting efficient labour markets, diminishing people's exposure to risks, and enhancing their capacity to protect themselves against hazards and interruptions. Ultimately, the aim is to enhance the capacity of poor and vulnerable persons to manage different risks (economic, environmental, and social) through policy interventions, including social insurance, social assistance, transfer/welfare programmes, labour market programmes, Community-based Investment Funds, and national health insurance. Alternatively, social protection can be placed in the context of social risk management, which constitutes three types: risk reduction, risk mitigation, and risk coping (Hicks and Wodon 2001). It therefore includes all interventions from public, private, voluntary organisation and social networks, to support communities, households, and individuals, in their efforts to prevent, manage, and overcome a defined set of risks and vulnerabilities.

The way forward is to rethink programmatic areas with the aim to integrate climate and environmental change into development policies and to optimise opportunities for creating a single strategic vision of addressing vulnerabilities (environmental or social) of specific groups, especially women and children. Social protection provides an excellent opportunity.

6.2.1 Classification and overview of relevant climate change adaptation measures

The terms adaptation and mitigation were defined and discussed in Chapter 3. Earlier in this chapter, it was mentioned that adaptation is nothing new (see Box 6.1) and the majority of adaptation measures occur spontaneously, depending on the individual needs and capacities of a given sector of society. This is termed autonomous adaptation. Planned adaptation, on the other hand, results from decisions that have been made based on the awareness that conditions have changed, or are about to change (UNFCCC 2006).

Have you heard of completely new adaptation measures and approaches? Before discussing the adaptation measures for climate change, do you think that we have done our homework in terms of climate variability in a sufficient manner so far (e.g. in establishing flood and drought early warning systems in developing countries)? What are the implications?

There are various other ways of classifying adaptation options (UNFCCC 2006). Adaptation can be reactive or anticipatory. The first occurs after the impacts of climate change have become manifest, while the second takes place before impacts are apparent. Table 6.1 below (UNFCCC 2007) lists an overview of reactive as well as anticipatory sectoral adaptation options and responses as provided by developing countries in their communications to UNFCCC.

Vulnerable sectors	Anticipatory adaptation	Reactive adaptation
Water resources	• Better use of recycled water • Conservation of catchment areas • Improved water management system • Water policy reform (pricing, irrigation policies) • Flood control, drought monitoring	• Protection of groundwater resources • Improved management/maintenance of water supply systems • Protection of catchments • Improved water supply • Ground- and rainwater harvesting, desalinisation
Agriculture and food security	• Development of tolerant/resistant crops • Research and development • Soil-water management • Diversification/intensification of food/plantation crops • Policy measures (tax incentives, subsidies, free markets) • Early warning systems	• Erosion control • Dams for irrigation • Fertiliser use and application • Introducing new crops • Soil fertility maintenance • Planting and harvesting times • Different cultivars • Education and outreach on soil/water conservation and management
Human health	• Early warning systems • Improved disease/vector surveillance/monitoring • Improvement of environmental quality • Changes in urban/housing design	• Public health management reform • Improved housing/living conditions • Improved emergency response
Terrestrial ecosystems	• Creation of parks/reserves, protected areas, biodiversity corridors • Identification/development of resistant species • Vulnerability assessment of ecosystems • Species monitoring • Development/maintenance of seed banks • Including socio-economic aspects in management policy	• Improvement of management systems, including deforestation, reforestation, afforestation • Promoting agroforestry • National forest fire management plans • Carbon storage in forests
Coastal zones and marine ecosystems	• Integrated coastal zone management • Coastal planning and zoning • Legislation for coastal protection • Research and monitoring of coasts and coastal ecosystems	• Protection of economic infrastructure • Public awareness for protection of coastal and marine ecosystems • Building seawalls and beach enforcement • Protection of mangroves, coral reefs, sea grasses, and littoral vegetation

Table 6.1: Adaptation measures in key vulnerable sectors highlighted in national communications of developing countries
(UNFCCC 2007)

Adaptation can also be categorised in terms of structural, physical and institutional mechanisms as described in Table 6.2 below.

Category	Examples of adaptation options	
Structural/Physical	Engineered and built environment	Sea walls and coastal protection structures; flood levees and culverts; water storage and pump storage; sewage works; improved drainage; beach nourishment; flood and cyclone shelters; building codes; storm and waste water management; transport and road infrastructure adaptation; floating houses; adjusting power plants and electricity grids.
	Technological	New crop and animal varieties; genetic techniques; traditional technologies and methods; efficient irrigation; water augmentation and watr saving technologies including rainwater harvesting; conservation agriculture; food storage and preservation facilities; hazard mapping and monitoring technology; early warning systems; building insulation; mechanical and passive cooling; renewable energy technologies; second-generation biofuels.
	Ecosystem-based	Ecological restoration including wetland and floodplain conservation and restoration; increasing biological diversity; afforestation and reforestation; conservation and replanting mangrove forest; bushfire reduction and prescribed fire; green infrastructure; controlling overfishing; fisheries co-management; assisted migration or managed translocation; ecological corridors; ex situ conservation and seed banks; community-based natural resource management; adaptive land use management.
	Services	Social safety nets and social protection; food banks and distribution of food surplus; municipal services including water and sanitation; vaccination programmes; essential public health services including reproductive health services and enhanced emergency medical services; international trade.
Social	Educational	Awareness raising and integrating into education; gender equity in education; extension services; sharing local and traditional knowledge including integration into adaptation planning; participatory action research and social learning; community surveys; knowledge-sharing and learning platforms; international conferences and research networks; communication through media.
	Informational	Hazard and vulnerability mapping; early warning and response systems including health early warning systems; systematic monitoring and remote sensing; climate services including improved forecasts; downscaling climate scenarios; longitudinal data sets; integrating indigenous climate observations; community-based adaptation plans including community-driven slum upgrading and participatory scenario development.
	Behaviourial	Accommodation; household preparation and evacuation planning; retreat and migration, which has its own implications for human health and human security; soil and water conservation; livelihood diversification; changing livestock and aquaculture practices; crop-switching and changing cropping practices, patters, and planting dates; silvicultural options; reliance on social networks.
Institutional	Economic	Financial incentives including taxes and subsidies; insurance including index-based weather insurance schemes; catastrophe bonds; revolving funds; payments for ecosystem services; water tariffs; savings groups; microfinance; disaster contingency funds; cash transfers.
	Laws and regulations	Land zoning laws; building standards; easements; water regulations and agreements; laws to support disaster risk reduction; laws to encourage insurance purchasing; defining property rights and land tenure security; protected areas; marine protected areas; fishing quotas; patent pools and technology transfer.
	Government policies and programmes	National and regional adaptation plans including mainstreaming climate change; subnational and local adaptation plans; urban upgrading programmes; municipal water management programmes; disaster planning and preparedness; city-level plans, district-level plans, sector plans, which may include integrated water resource management, landscape and water shed management, integrated coastal zone management, adaptive management, ecosystem-based management, sustainable forest management, fisheries management, and community-based adaptation.

Table 6.2: Structural, social and institutional adaptation measures
(IPCC 2014b)

Another distinction can be made with respect to the system in which adaptation takes place - the natural or human system. Within the human system, a distinction can be made between public (governments at all levels) and private (individual households, commercial companies) interests (Table 6.3 below). Also, see Section 3.1 for other types of adaptation.

		Anticipatory	Reactive
Natural systems			Changes in length of growing season Changes in ecosystem composition Wetland migration
Human systems	**Private**	Purchase of insurance Construction of houses on stilts Redesign of oil rigs	Changes in farm practices Changes in insurance premiums Purchase of air conditioning
	Public	Early warning systems New building codes, design standards Incentives for relocation	Compensatory payments, subsidies Enforcement of building codes Beach nourishment

Table 6.3: Matrix showing five prevalent types of adaptation to climate change, including examples of adaptation
(UNFCCC 2006)

When getting into technologies for adaptation, a distinction can be made between soft and hard technologies (UNFCCC 2006). Soft technologies include insurance, crop rotation, and setback zones, as well as information and knowledge. Hard technologies could be seawalls, drought-resistant seeds, and irrigation technology. In many cases, successful adaptation will include a mixture of soft and hard technologies. UNFCCC (2006) further classifies these into traditional, modern, high, and future technologies. According to the IPCC (2014), the use of engineered and technological adaptation options remain as the preferred adaptive responses to date.

It is questionable whether society can rely on autonomous adaptation to deal with the expected impacts of climate change and increased variability. Thus, it is widely acknowledged that there is a need for anticipatory planned adaptation, which could take the following forms (UNFCCC 2006):

1. Increasing the ability of infrastructure to resist impacts of climate change (e.g. reinforcing dykes);
2. Increasing the flexibility of vulnerable systems managed by humans (e.g. changing management practices);
3. Enhancing the adaptability of vulnerable natural systems (e.g. reducing other stresses);
4. Reversing trends that increase vulnerability (e.g. reducing human activities in vulnerable areas, preserving natural systems that reduce vulnerability);
    - Diversifying or widening crop base (planting other crops such as vegetables and hill rice);
    - Improved farming practices by practising intercropping to resist pest infestation;
    - Planting of a new variety of cassava known as the ‘Amazon stick’ with strains that can ripen in approximately 4 months;
    - Improving farm management; and
    - Improving public awareness and preparedness (e.g. early warning systems). In parts of Belize, Suriname, Dominica, and Guyana, adaptation measures are based on local indigenous knowledge (some examples of

these local adaptation measures may be summarised as relocation to higher ground during floods or to areas near water sources during droughts).

Kabat and van Schaik (2003) give an overview of options for adaptation grouped according to the following categories (Tables 6.4a–c):

- Robust policies;
- Technological and structural measures; and
- Risk-sharing and spreading.

Robust policies

Over centuries, societies and ecosystems have adapted to climate variability and climate change in an evolutionary way. Today, the rapidity of changes in hydrological regimes requires more immediate and more concerted efforts. Policies and operating rules focused on optimum exploitation of available water resources need to be adjusted. Sea level rise, shrinking natural lakes and desertification all force changes of land-use and livelihoods. The increasing susceptibility of flood plains to extreme events means that governments have to consider more rigid spatial planning as a coping option. Resettlement is neither popular nor desirable, but it may eventually become inevitable where the risk associated with a particular place may start to outweigh perceived benefits and therefore may become unacceptable to society.

The policy concepts and processes directly related to, and considered applicable for the purpose of adaptation planning, include IWRM (Global Water Partnership 2000), Integrated Flood Management (WMO 2004), and Integrated Coastal Zone Management (UN 1992). All these concepts are adaptive in nature and consider management options in broad development contexts. This is essential for the robustness of policies in the natural resource management context. Observers of the international water policy development process are aware that certain specific issues tend to 'flare up' and dominate the agenda for a certain time, mostly driven by current events such as floods, droughts, food prices, biofuels, and so on.

It is essential to realise that policies that are developed in such an event context have a very limited lifetime. If, for example, based on an extreme flood event, the floodplain use is severely restricted or resettlement programmes are implemented without consideration of the floodplain benefits, such policy may have negative impacts on food and livelihood security. Similarly, if ecosystem conservation or pollution control leads to narrowly aimed policies that prevent the necessary investments in water resources development, there are often unconsidered consequences for water availability under climate variability and change, as well as for food and livelihood security. Robust policies should therefore be based on the broad aims and principles of IWRM, Integrated Flood Management and Integrated Coastal Zone Management. The processes suggested by those concepts provide the means for mediating different interests and competing uses of water resources.

What do you think are some of the reasons why IWRM policies in the Caribbean have not been drafted and finalised?

A fundamental aspect of any coping strategy therefore must be mainstreaming of climate issues into national water management policy. To implement such policies, there is the need to have a legal and institutional framework in place in order to allow all stakeholders to become part of the process and manage the resources according to agreed rights, powers, and obligations. An overview of policy instruments that can be used is presented in Table 6.4a.

<table>
<tr><th>International</th><th>National</th></tr>
<tr><td>International conventions on climate change (UNFCCC);
International trade (particularly WTO); and
Polluter-pays principle influences ODA/Funds.</td><td rowspan="3">National poverty reduction strategies;
National strategic Interests;
National water policies and IWRM Plans;
National Adaptation Plans of Action (NAPAs);
National Adaptation Plans (NAPs);
Disaster management policies;
National drought preparedness and mitigation plans;
Economic instruments and water markets;
Risk management cross-cutting in development plans;
Strengthened functions of watershed authorities;
Integrated catchment management;
Non-water planning, e.g. urban areas, refuges;
Adaptive spatial planning and resettlement; and
Livelihood diversification (in particular for highly climate dependent sectors such as rain-fed agriculture).</td></tr>
<tr><th>Regional</th></tr>
<tr><td>Regional adaptation plans of action;
Regional strategic action plans for IWRM;
Transboundary plans and inter-state cooperation;
Informal bi-national cooperation; and
Regional institutions.</td></tr>
</table>

Table 6.4a: Compendium of policy instruments for adaptation
(Kabat and van Schaik 2003)

Technological and structural measures

The list of coping options in Table 6.4b may seem like a catalogue of water management infrastructure and operating techniques. It is true that coping with climate change does not involve many entirely new processes or techniques, perhaps with the exception of advances in the structure, quality, and resolution of climate information products, such as seasonal or inter-annual climate predictions. It should, however, be made clear that this is not an argument for 'business as usual'. Existing instruments, methods, and measures may need to be introduced at a faster pace, and applied in different locations, at different scales, within different socio-economic context and in new combinations.

<table>
<tr><th>Storage and recirculation</th><th>Early warning systems</th></tr>
<tr><td rowspan="3">Large reservoirs;
Small reservoirs;
Groundwater;
Artificial recharge;
Borehole drilling;
Sand dams;
Scavenger/gallery wells;
System maintenance;
Supply leakage control;
Irrigation equipment maintenance;
Irrigation canal leakage;
Rainwater harvesting;
Water reuse/recycling; and
Desalination.</td><td>Near real time (hours to days);
Short-term (days to weeks);
Medium-term (month to season); and
Long-term (years to decades).

Communicate forecasts to end-users.</td></tr>
<tr><th>Operations/system improvements</th></tr>
<tr><td rowspan="3">Reservoir operations rules;
Integrated, optimised reservoir systems;
Retrofitting existing structures;
Irrigation scheduling;
Water demand management;
Indigenous coping strategies;
Precipitation enhancement;
Soil conservation and tillage practices; and
Crop varieties.</td></tr>
<tr><th>Flood/storm surge control</th></tr>
<tr><td>Structures (levees, dykes, diversions, detention watersheds); and
Preventative operations.</td></tr>
</table>

Table 6.4b: Compendium of technological and structural adaptation options
(Kabat and van Schaik 2003)

In the Caribbean, there has been an increase in flash flooding incidences in Dominica, St. Lucia, St. Vincent, and Trinidad and Tobago (see Figure 6.3). Thus perhaps strategies, methods, and techniques from countries that have had to deal with a high frequency of flash floods for decades should be considered as part of the Caribbean adaptation process. While this is not expected to be a rapid or smooth transition, the message that there may be adaptation solutions for the water sector found in places that have experienced climatic conditions in the past, and that are now expected to become commonplace elsewhere, should be a driving principle of adaptation planning. In fact, it is one of the driving principles of adaptation planning in the Caribbean as it is a practical measure for improving coping strategies in flood-prone areas. It is important that mitigation measures incorporate a systems approach to address both, the terrestrial and marine environments, as upstream effects are easily transferred downstream - especially in the instances of flash flooding.

Figure 6.3: Flooding in Diego Martin, Trinidad and Tobago, in August 2013 (left) and flooding in Georgetown, St. Vincent and the Grenadines, in December 2013 (right)
Source: Wanda Babb in Trinidad and Tobago Guardian Online 2013 (left), and Thomson Reuters Foundation/Alison Kentish 2013 (right)

What it also means is reviewing existing operations in the light of very different hydrological circumstances. Watershed infrastructure is essential to protect against, and reduce the impact of, water-related disasters along with new civil works like disaster shelters in risk-prone areas. It can be very practical to improve existing infrastructure, such as roads, drains, natural ponds and lakes, dams and reservoirs, and processes like soil conservation of steep slopes and sediment control into reservoirs. However, proper skills for operation and maintenance and the financial means to carry them out are equally important.

As far as specific management measures are concerned, as a general rule, reservoirs provide the most robust, resilient, and reliable mechanism for managing water under a variety of conditions and uncertainties. However, other combinations of non-structural measures (e.g. demand management, agricultural conservation practices, pricing, regulation, relocation) may provide comparable outcomes in terms of gross quantities of water supply, but not necessarily in terms of system reliability. The choice of alternatives depends on the degree of social risk tolerance and perception of scarcity, as well as the complexity of the problem.

The possibilities for coping with the uncertainties of climate change and variability are manifold – both in the number of strategies and in the combinations of management measures that comprise a strategy. There is no single 'best' strategy. Each depends on a variety of factors, e.g. economic efficiency, risk reduction, robustness, resiliency or reliability. However, adaptation strategies need to be developed, implemented and monitored through participatory cross-sectoral policy processes such as IWRM or Integrated Flood Management. Only if this succeeds, the resulting solutions to adapt practices in the water management and planning domain will have a chance to be socially equitable, economically efficient, and environmentally sustainable. Furthermore, such process would need to be employed to minimise the risks that adaptation measures are counterproductive to the climate change mitigation agenda.

Can we cope without additional storage under more variability? What is the role of existing storage facilities? How are we rating in terms of maintenance and safety of those facilities?

The hydrological rules have changed. Continually updated assessments of meteorological and hydrological data need to be an integral part of water resources planning and management. Continued efforts are required from the climatological and hydrological research communities to absorb those data and transform them into results adequate for adaptation planning.

Risk sharing and spreading

Disaster insurance is a classic means for dividing risks and losses among a higher number of people over a long-time period (Table 6.4c). Payouts on natural disasters are potentially massive (see Table 6.1), and very much higher than any single small or medium-sized insurance company could bear. For this reason, there is an active market in re-insurance. The cost of premiums can be very high for major infrastructure, and many governments do not take out insurance cover, choosing instead to bear the replacements cost of the partial losses that inevitably occur from their capital budgets. Provided long-run costs of replacement remain less than the cost of premiums, this is a sensible approach – for societies, this approach relies on government investment into replacement. A major problem arises when a disaster is of such magnitude that it overwhelms the capacity of an economy to bear the cost from the national recurrent budget. Recognising that climate-related hazards are not only inevitable, but are likely to continue increasing, insurance mechanisms are seen to have a role in sharing and spreading risks.

Insurance	Finance
Primary insurers Re-Insurance Micro-insurance	Development banks Private Micro-lenders

Table 6.4c: Compendium of risk sharing and spreading options
(Kabat and van Schaik 2003)

6.3 Adaptation focus themes

In the following section selected examples are presented to illustrate a range of adaptation focuses that might be taken in view of particular national or local expected impacts.

Adaptation focus 1: Integrated water resources development and management

Integrated water resources management is widely recognised as the most effective way to optimise water availability for all uses, although the institutional strengthening it demands poses challenges to many developing countries. With IWRM and its extension to integrated catchment management comes an increased flexibility to cope with large fluctuations in rainfall and river flows (Kabat and van Schaik 2003). Agricultural and irrigation technology have made it possible to continue feeding a world population that has tripled in the past century. On the negative side, many water management systems and policies are not well adapted to responding to the modern paradigm of water management that calls for managing the resource in a sustainable manner under conditions of uncertainty. The degree to which IWRM approach can be implemented and put into practice depends on the adaptive capacity of countries' institutions (see Suggested Reading for an IWRM case study in Jamaica).

Increasing the production efficiency of water by improving irrigation efficiency is the simplest answer to water scarcity and climate variability. The initial step is to improve the water available within irrigation and drainage systems.

Adaptation focus 2: Integrated flood management

Adaptation measures in the flood management context should involve a best mixture of structural and non-structural measures, with the aim of minimising the losses of life from flooding and maximising the net benefits derived from the floodplains (WMO 2004). This approach is also referred to as Integrated Flood Management or flood management within the context of IWRM.

- Structural measures include for instance dams, levees, diversion channels, detention ponds, flood proofing, and so on; and
- Non-structural measures include flood forecasting and warning systems, spatial planning, source-control, emergency preparedness and response procedures, insurance, flood risk awareness programmes, and so on.

In recent years, a number of countries have developed adaptation strategies to deal with more extreme flood events. Those strategies involved as a first step detailed scientific assessments of observed and projected change of climate variables and their expected impact on the water resources of the specific country. The strategies are generally based on the precautionary and risk management principles. Some countries have given consideration to adjust flood defences by introducing design factors or allowances to account for expected changes to river discharge, sea level, and wave activity, among others. Other countries are recommending a more diversified approach in the form of a combination of measures to allow flood defences to be overtopped during an extreme event without compromising their structural integrity, and at the same time to minimise the residual flood risks through spatial planning, emergency preparedness, and response programmes, as well as flood insurance.

In terms of river flood, flash flood or tidal flood, flood forecasting and warning systems are considered baseline systems for the protection of life and property in the context of climate variability and climate change. Many countries are lacking substantial capacity in that field and climate change places the establishment or improvement of such systems in a priority position. Such systems can be considered part of no-regret adaptation options, meaning their establishment is beneficial within a climate change scenario, but also when climate does not change. A commonly used technique for assessing the cost and benefits of adaptation options is a cost-benefit analysis (CBA). In CBA, costs and benefits are expressed in monetary terms for comparison in an attempt to determine the likely efficiency of intended adaptation investment options. Decision makers can utilise the results of a CBA and compare it to the costs if no action is taken at all.

Flood forecasting needs to encompass all stages and aspects of floods, such as rainfall and coastal sea levels (meteorological predictions), water levels in rivers and floodplains (hydrological predictions), and projections of, for example, the damage to agriculture and infrastructure (economic or impact predictions). Long-term hydrological forecasts typically have a lead-time of a month or more. These can only give a general indication whether there would be a risk of increased flooding, and if the predicted floods are likely to be average, below or above average. This information can, however, be of great value to reservoir operators in semi-arid regions. These hydrological predictions depend very strongly on forecasting accuracy for weather and climate on seasonal time scales. Medium-term hydrological forecasts have a lead-time of a week or so, and should provide more accurate estimates of the flood conditions. These forecasts mainly depend on the quality of rainfall forecasts and information from the upper watersheds, additional short-term climate information, and the quality of a distributed hydrological model used to calculate run-off and river flows. Finally, short-term hydrological forecasts, with a lead-time of a few days, focus on river water levels and the extent and depth of inundation areas. This forecast is derived from a real-time observation of rainfall and river flows in the upper watershed, combined with hydrological and hydraulic models, which calculate or estimate water levels in the river and water storage in the inundated areas (Kabat and van Schaik 2003).

Adaptation focus 3: Drought preparedness and mitigation

There are both traditional (indigenous) and technological approaches to coping with the risk of drought. Any technological management of drought requires medium- (seasonal) to long-term (annual to decadal) climate forecasts and, therefore, the appropriate modelling tools. This information then has to be translated into early warning and response mechanisms.

Supply-side drought protection measures include the following:

- Supplies of water should be augmented by exploiting surface water and groundwater in the area. However, intensive groundwater withdrawals for drought management, is not a sustainable remedy.
- Transfers can be made from surface water sources (lakes and rivers) and from groundwater, if socio-economically and environmentally acceptable.
- Storage of water can be increased. Groundwater reservoirs (aquifers), which store water, when available, can be more advantageous than surface water

storage, despite the pumping costs, because of the reduction in evaporation losses.

In recent years, the emphasis in action plans to combat drought has increasingly shifted from supply-side management by provision of water resources in required quantities to effective demand-side management of the finite and scarce freshwater resource.

Possible demand-side measures include:

- Improved land use practices;
- Watershed management;
- Rainwater/run-off harvesting;
- Recycling water (e.g. use of treated municipal wastewater for irrigation);
- Development of water allocation strategies among competing demands;
- Reduction of wastage;
- Improvements in water conservation via reduction of unaccounted water; and
- Water pricing and subsidies.

Drought contingency planning also requires thorough consideration, including:

- Restrictions of water use;
- Rationing schemes;
- Special water tariffs; and
- Reduction of low-value uses such as agriculture (Kabat et al. 2003)

Adaptation focus 4: Integrated Urban Water Management (IUWM)

In a world where rapid population growth appeals to the need for sustainable urban development, IUWM provides a framework for planning, designing, and managing urban water systems (Global Water Partnership 2013). IUWM includes environmental, economic, social, technical, and political aspects of water management as it brings together freshwater, wastewater, storm water, and solid waste (Global Water Partnership 2013). Figure 6.4 illustrates the coordinating structure that should promote communication between departments, levels of government, local communities, and stakeholders in IUWM.

Box 6.2: Caribbean actions towards adopting an IUWM framework

For the Caribbean, actions towards adopting IUWM framework came about after a high level session (HLS) of Caribbean Water Ministers which was held in October 2013 in Barbados. One of the outcomes of the HLS prompted an IUWM Workshop on 26 June, 2014, which was hosted by Global Water Partnership – Caribbean. At the IUWM Workshop, Professor Kalanithy Vairavamoorthy recognised that problems such as irregular water supply systems, untreated wastewater, and the inefficiency of water supply systems are common among most countries in the Caribbean (Global Water Partnership-Caribbean 2014)(GWP-C 2014). He went on to highlight the potential of wastewater management in the Caribbean and gave a few suggestions such as wastewater recycling and reuse, recognising the values of biogas and nutrients in wastewater, using treated wastewater to dilute seawater and decrease desalination costs, developing faecal sludge into a safe fertiliser, etc. which would seek to maximise benefits.

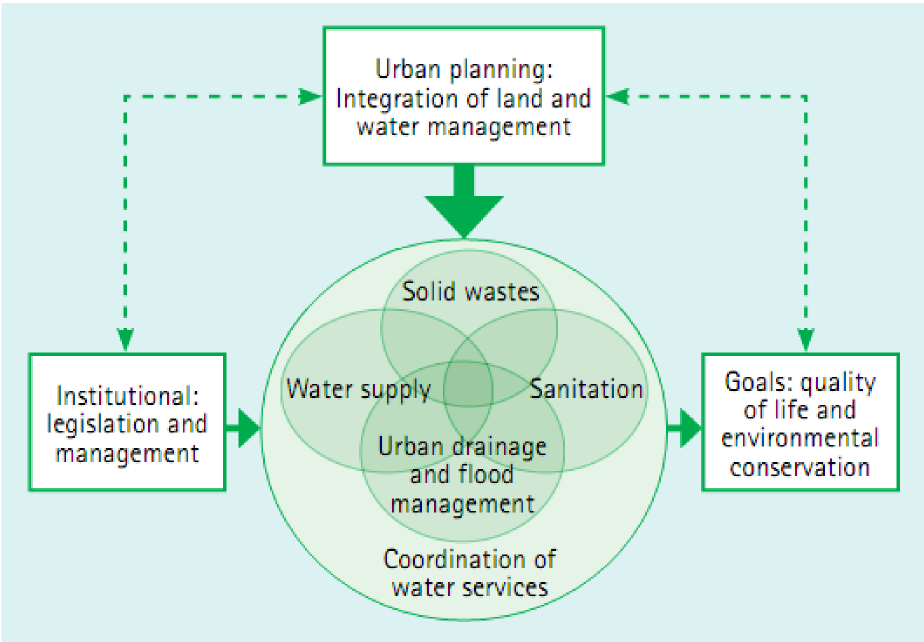

Figure 6.4: Coordinating structure of IUWM
(Global Water Partnership 2013)

Adaptation focus 5: Weather and climate information

Climate prediction and weather forecasting are vital elements in the coping strategies. Meteorologists are getting better at tracking and forecasting extreme weather associated with cyclones and typhoons with reasonable accuracy over periods of a few days or weeks. Increasing understanding of the El Niño/La Niña phenomena and other climate anomalies means that predicting seasonal climate variations for specific regions is also becoming more accurate. In this context, Regional Climate Outlook Forums (RCOFs) have been instrumental in providing consensus seasonal climate outlooks before the onset of the rainy season to support climate adaptation in various sectors.

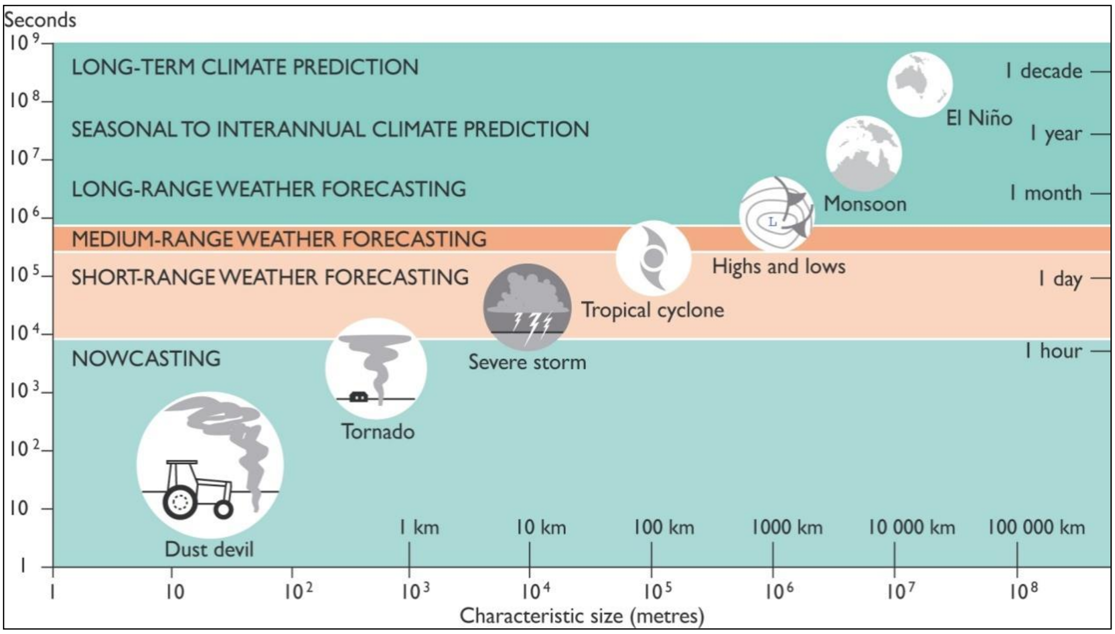

Figure 6.5: Weather and climate information products with corresponding spatial and temporal scales
Source: Adapted from: J.W., Zillman, WMO Bulletin 48 (2) April 1999)

Box 6.3: The Guyana Mangrove Restoration Project

In an effort to mitigate the effects of climate change on Guyana's mangrove ecosystems (see image below), the Government of Guyana along with the European Union funded the Guyana Mangrove Restoration Project. The project commenced in February 2010 with the main objective of seeking commitment of Guyanese toward the protecting mangrove forests through capacity development, education, awareness, monitoring, and restoration. It is important that stakeholders are aware that mitigation and rehabilitation efforts can maintain and sustain the various services and value of their natural ecosystems.

Mitigation efforts in Guyana's Mangrove Restoration Project
Source: http://www.mangrovesgy.org/home/

Figure 6.5 provides an overview of weather and climate information products reaching from now casting to climate predictions with their characteristic spatial and temporal scales. Strengthening the provision of weather and climate information products is considered an essential tool for adaptation to climate variability, and in the long term to climate change. Investment in climate and weather information products should be considered a priority as the benefits arising are immediate and materialise under any climate change scenario.

Adaptation focus 6: Ecosystem maintenance

Policy decisions at the governmental level for protecting the natural ecosystems from the adverse impacts of climate change need special attention. Effective responses depend on the understanding of the likely regional changes in the climate and ecosystem. Monitoring of those changes is essential to adjust management practice and can be considered no-regret options. The current state of knowledge suggests that the impacts on ecosystems from unmitigated climate change would be disastrous and unprecedented in human history, and that adaptation measures for ecosystems would only be effective for lower levels of climate change. Existing policies to protect and preserve the natural ecosystem would also be useful in the climate change regime. Reducing the present stresses on the natural ecosystems such as habitat fragmentation and destruction, overexploitation, pollution, and introduction of alien species will provide various ecosystems with some space and time to adjust within specific limits, and therefore need to be recognised as adaptation measures.

Some of the adaptation measures to protect natural ecosystem are (GWSP 2005):

- Conservation of wild biodiversity: strengthening of Protected Area Network;
- Sustainable improvement in traditional agriculture to protect forest and meadows;
- Protection of the marine ecosystems;
- Protection of the coastal zones; and
- Protection of freshwater wetlands.

Ecosystem services such as water purification, livelihood provision (particularly in a subsistence livelihood context), or flood mitigation may be negatively affected by climate change; however, the impact of climate change on those services is subject to ongoing research and may hold various surprises as climate change proceeds. The IPCC AR4 (Fischlin et al. 2007) indicates that ecosystems in drylands, mountain and Mediterranean regions may be most vulnerable. The IPCC AR5 indicated that climate change is affecting SIDS growth and development as SIDS are already feeling the impacts (CDKN 2014). The IWRM process, based on the involvement of all stakeholders and the principles of environmental and ecological sustainability, has the potential to integrate the fate of vital terrestrial and aquatic ecosystems for life support of future generations under climate change.

Summary

Adaptation is nothing new and the majority of adaptation measures occur spontaneously in response to the specific circumstance of a given sector of society. The ‘best mix’ and sequence of adaptation measures should be established as part of a risk assessment process. No-regret and low-regret options that provide benefits even under a climate variability scenario are preferred options. The adaptation challenge is not merely a technical challenge but a societal process with strong requirements for broader stakeholder engagement. In the Caribbean, there are examples of adaption options that have been implemented based on local indigenous knowledge. Adaptation options have to be developed in a highly localised context and with significant uncertainty concerning the future state of the local resource.

Suggested reading

CPWC (2009) Environment as Infrastructure. Perspective Paper on Water and Climate Change Adaptation. The Co-operative Programme on Water and Climate (CPWC): Den Haag, The Netherlands. http://www.waterandclimate.org/index.php?id=5thWorldWaterForumpublications810

CPWC (2009) IWRM and SEA. Perspective Paper on Water and Climate Change Adaptation.

CPWC (2009) Producing Enough Food. Perspective Paper on Water and Climate Change Adaptation.

CPWC (2009) Water Industry. Perspective Paper on Water and Climate Change Adaptation.

CPWC (2009) WASH Services Delivery. Perspective Paper on Water and Climate Change Adaptation.

Global Water Partnership (2013) Tool Box Jamaica- Implementing Environmental Management Systems (EMS) for Sustainable Tourism, Case #53,

7. ADAPTATION TO CLIMATE CHANGE IN WATER MANAGEMENT

Goal

The aim of this module is to familiarise the participants with the way adaptation to climate change can be incorporated into water resources management at all levels.

7.1 Introduction

As explained in chapters 1 and 4, water quality and availability are substantially affected by climate change manifestations. What changes are actually expected that have a direct impact on water availability and management? In quantity terms, global precipitation is expected to increase or decrease by 20 percent; under an intermediate low-emissions scenario the Caribbean region is expected to observe a five to six percent decrease in annual rainfall. Also expected are more intense and more frequent floods and droughts (Chapters 2 and 4). These changes will have direct impacts on the way people use and manage their water resources.

There is a need to change the way water is being used and managed. The question is how is that change going to be brought about?

Integrated water management aims to ensure that communities are provided with access to sufficient resources, that water is available for productive use, and that the environmental function of water is secured. On all three levels, management is challenged by climate variability manifestations and they have to be considered when setting out management strategies.

To do so, adaptation to climate variability has to be incorporated into water resources management planning.

7.2 How can IWRM help?

Management measures have to be feasible, effective and acceptable (Global Water Partnership n.d.). Measures for climate change adaptation through IWRM should form part of wider adaptation strategies and in the broader context of sustainable water management. Development policies have to be reviewed in relation to new climatic developments and it needs to be assessed whether these policies still hold. Commendably, in 2002 Caribbean States committed to developing IWRM plans by 2005. To date some nine Caribbean territories have developed/drafted IWRM Roadmaps/Action Plans, however not all of these take climate change impacts into consideration. At the local and national levels, capacities to cope with or adapt to climate variability can be addressed in the context of planning for IWRM. As GWP puts it: “The best way for countries to build capacity to adapt to climate change is to improve their ability to cope with today’s climate variability”. In other words, improving the way we use and manage water today will make it easier to address the challenges of tomorrow (Box 7.1).

Adaptation strategies through water management will need to combine 'hard' (infrastructural) with 'soft' (institutional) measures (see Chapter 6). The three main challenges are:

- Establishing dynamic organisations that are able to respond strategically and effectively to changing circumstances;
- Making decisions based on predictions rather than historical data; and
- Securing funding.

What contribution could water management make to address immediate issues in flooded rural communities?

Box 7.1: Why is it important to address climate change manifestations in water management?

- Impacts of climate change on freshwater systems and their management are mainly due to the observed and projected increases in temperature, evaporation, sea level, and precipitation variability.
- The number of people in severely stressed river basins is projected to increase significantly (three to five times in 2050 as compared to 1995).
- Semi-arid and arid areas are particularly exposed to the impact of climate change on freshwater.
- Higher water temperatures, increased precipitation intensity and longer periods of low flows will lead to more pollution and impacts on ecosystems, human health, and water system reliability and operating costs.
- Climate change affects the function and operation of existing water infrastructure as well as water management practices.
- Adaptation procedures and risk management practices for the water sector are being developed in some countries and regions that recognise the uncertainty of projected hydrological changes.
- The negative impacts of climate change on freshwater systems outweigh its benefits.

(IPCC 2007c)

7.3 Possible management measures

What are possible management actions that can address the challenge?

In a situation of water stress

Water stress (pg. 54), indicated by the ratio of withdrawal to availability over a particular period, is high in much of northern Africa, southern Africa, western and central Asia, the Indian subcontinent, northern China and Mongolia, Mexico and northern areas of Central America, the western coastal regions of South America, as well as particular areas of Argentina and Brazil, and southern Thailand (IPCC 2007c, UNDP 2007). Here sustained rainfall deficits and increased water demand potentially increase water stress. SIDS are particularly vulnerable to increased water stress due to limited water resources that restricted by nature of the size of these islands, limited surface area for harnessing runoff, their need for economic development, and the close connection between land and sea (Cashman, Nurse, and Charlery 2010, Falkland 1999, Payet and Agricole 2006). Population growth in the Caribbean region has also contributed to water stress, especially in those cases where population growth rate has exceeded the capacity of water distribution infrastructure; such is the case in the islands of Antigua and Barbuda, Barbados, and Saint Kitts and Nevis. When measuring water stress, not all aspects of vulnerability are captured, as it does not consider climatic variability. The most vulnerable areas in terms of climate-related water shortages are semi-arid and low-income countries with high annual variations and seasonal concentration of precipitation. Within these areas, people whose access to water supply is linked to rainfall, surface run-off, and recharge of water bodies are the most vulnerable. From this it can be seen that small island states are therefore highly vulnerable to the impacts of climate change and variability on freshwater resources.

Adaptation interventions will consist of the following measures to increase water availability:

- Reduction of water waste;
- Increased efficiency in the tourism sector;
- Increased efficiency in agriculture - 'more crop per drop'; and
- Saving water in domestic use.

Measures to achieve these goals include those articulated in Table 7.1 below.

Management measure	Constraints
Water pricing	Controversial as it may affect poor people's access to water)
Seasonal water rationing during times of shortage;	Only effective if compliance can be controlled
Adapt industrial and agricultural production to reduce water wastage;	Technical feasibility must be considered
Increase capture and storage of surface run-off;	Requires low slopes and impermeable surfaces for best results
Reuse or recycle wastewater after treatment;	Reduces demands on potable water; potential for health impacts
Desalination of salty or brackish water	costly
Better use of groundwater resources; and Rainwater harvesting.	Risk of siltation; dependent on rainfall
Forecasting for the short and long terms	Technology dependent
Incorporate industrial ecology when planning for industry development (see Box 7.3)	May require collaboration between sectors
Land management including planning and zoning.	May be disparities between local land use and national development plans
Use water-saving technology (Box 7.2)	Initial cost of technology may deter use

Table 7.1: Water supply management measures

Box 7.2: Using technology for water-conservation

Toilets are often the main source of water use within a home. Waterless toilets are an eco-friendly, cost effective option for waste disposal that can significantly reduce water consumption within communities. In 2011, several of these toilets were installed in various locations of St. Catherine, Jamaica in order to improve health conditions of communities that do not have access to running water. The toilets work by separating liquid and solid waste as it enters the bowl. Both are exposed to a continuous flow of air that dehydrates the solid waste and causes the liquid to evaporate quickly. A wind-driven extractor directs odour into the atmosphere

In a situation of water quality risks

Climate change affects water quality. Increases in frequency and severity of storms and floods put water distributions systems at risk of damage. Inadequate drainage systems in many urban areas are likely to fail as a result of increases in the frequency of intense rainfall events (see Chapter 2). In lakes and reservoirs, increase in water temperatures resulting from anthropogenic warming will affect water quality as a result of impacts on water chemistry. Increased temperatures in rivers reduce the oxygen content and therefore the capacity of rivers to purify themselves. Increase in rainfall may result in more nutrients, pathogens, and toxins being washed into water bodies.

What could be some special measures during seasons of high precipitation?

Interventions will focus on reversing water quality effects associated with climate change, such as algal blooms as a result of higher temperatures, or contamination because of higher precipitation.

Box 7.3 An island approach to Industrial ecology

Fresh water supply and waste management are principal environmental concerns for pharmaceutical manufacturing firms in Puerto Rico. Some ideas from the Yale Center for Industrial Ecology included construction of a storm-water facility, common treatment in a dedicated wastewater plant, and extending agricultural and other businesses. As of 2008, 13 facilities in the Barceloneta pharmaceutical area are in the manufacturing stage. Most of these companies have agreed to address energy and water constraints simultaneously through the supply wastewater to a co-generation plant and will get back energy in the form of steam from the power station. The companies share a 38 000 m^3/day capacity wastewater secondary treatment facility built primarily for the treatment of pharmaceutical wastewater (industry-specific utility sharing), and financed by the companies. Sludge from the plant is converted into a fertiliser that is applied to an adjacent hay farm where 68 000 kg of hay are harvested annually and sold as animal feed (by-product exchange).

Another example in Puerto Rico involves a large trans-shipment port project called the Port of the Americas. In conjunction with the Port project, there is a proposal for the development of a group of value added industries near the port. Already present on the chosen site are two power plants, an old oil refinery, and a desalination facility. New development can incorporate the water, material, and energy flows of these existing facilities to improve resource efficiency. An example is a beverage manufacturing operation which uses excess desalinated water as a primary input, low-pressure steam from the power plants to provide refrigeration and cooling and packaging materials generated from reuse/recycling of materials from the surrounding value added industries

(Deschenes and Chertow 2004, Chertow, Ashton, and Espinosa 2008)

Possible measures are:

- Improvements to sustainable urban drainage systems - green landscaping, integrated flood management, and grass drains, for example;
- Upgrading or standardising of water treatment;
- Better monitoring of infrastructure;
- Better monitoring of regulations and standards;
- Improved enforcement of regulations; and
- Special measures during high precipitation seasons.

Adaptation interventions in water will require a combination of good practice and longer-term measures to address specific climate change drive impacts on the resources.

Interventions with short-term benefits	Interventions with long-term benefits
• Rainwater harvesting; e.g. In Carriacou • Increased use of drought orders and water rationing during periods of low rainfall, backed up by promotion of water-saving measures and monitoring and enforcement measures; • Public awareness campaigns to encourage voluntary reductions in water use and increases in water use efficiency, particularly during periods of high water stress; (Ideas for Water Awareness Campaigns www.gwp.org/toolbox) • Reuse of wastewater in processes not requiring potable water (e.g. irrigation, industrial use) ; UNEP: Sourcebook of Alternative Technologies for Freshwater Augmentation in Latin America and the Caribbean • Improved monitoring of water quality, particularly during high-risk periods (e.g. drought, temperature extremes, intense precipitation events) ; • Water quality warnings and advice to public on water treatment during low-quality episodes; • Use of seasonal and shorter-term forecasts to plan water use; • Introduction of water pricing schemes, with safeguards to ensure access for poor and vulnerable groups (e.g. pricing only applicable above certain usage per capita/household/business, or above certain ratio of water use to productivity for businesses).	• Incorporation of information on potential future changes in water availability into policy and planning frameworks; Integration of rainwater harvesting systems in domestic and commercial buildings; Vieux Fort St Lucia, Rain harvesting structures provide at least 3,000 cubic meters of water for the pools and bathrooms of a hotel. Minimum standards for water use efficiency in new buildings; • Investment in less water-intensive industries; • Strategic importation of water-intensive products; • Concentration of certain water-intensive activities in wetter seasons; • Upgrading of water treatment infrastructure; IDB and EU funded programme to improve water and sanitation infrastructure in Guyana • Improved water quality monitoring systems; • Separation of drainage and wastewater systems, improved run-off management; • Upgrading of water distribution systems (reduce leakage, evaporation) ; • Mainstreaming of climate and weather forecasts in water management sector; • Construction of desalination plants, use of groundwater from aquifers (but note cost and sustainability issues);Cayman islands, Turks & Caicos, the Bahamas, Trinidad and Barbados are examples of SIDS that currently use desalination technology • Development of international mechanisms for management of shared water resources.

Table 7.2: Possible short- and long-term benefit measures

7.4 Within the institutional context of watershed management

Water management and climate issues are often addressed in different institutional settings. Water management may fall within a ministry of water or department for water affairs, whereas climate change is usually addressed within a ministry of environment. Equally at the watershed level, climate change measures may be the responsibility of environmental agencies, whereas the watershed organisation is usually concerned with allocation and pollution control (Cap-Net 2008). The challenge is to prepare watershed organisations to take up responsibilities in addressing climate change adaptation, together with local authorities and environmental agencies.

River Basin Organisations (RBOs) are specialised organisations set up by political authorities, or in response to stakeholder demands to deal with the water management issues in a watershed, a lake watershed, or across an important aquifer. RBOs provide a mechanism for ensuring that land use and needs are reflected in water management - and vice versa. Their role in water resource management may include education of watershed communities, developing natural resources management and planning, programmes of remediation of degraded lands and waterways, consensus building, facilitation, and conflict management (Global Water Partnership 2013)

What are key River Basin Organisation functions that would help to assist municipalities and communities to address climate change effects?

Typical functions of watershed organisations are:

- Water allocation;
- Pollution control;
- Monitoring;
- Watershed planning;
- Economic and financial management;
- Information management; and
- Organisation of stakeholder participation.

In implementing these functions at the watershed level, watershed organisations have practical instruments to properly address climate change manifestations. As such the possible adaptation measures mentioned earlier in this chapter fall within the mandates and responsibilities of the RBOs. In the Table 7.3 below, we match some of the possible measures with functions of the RBO.

Possible adaptation measures	RBO function	Anticipated effect
Water pricing, cost recovery, investment	Economic/financial management	Reduced per capita consumption, Improved efficiency
Seasonal water rationing, re-allocation, managing water use	Water allocation, Pollution control	Availability and access improved, Uninterrupted flow, Purification function secured
Flood and drought risk mapping, infrastructure, scenario development	Watershed planning	Reduced impact of extreme events
Increase capture and storage of surface run-off	Watershed planning	Improved availability, Reduced polluters in the system
Reuse and recycle, better regulation, pressure for improved sanitation	Pollution control, Water allocation, Watershed planning	Improved availability, Reduced groundwater pollution
Groundwater usage	Water allocation, Watershed planning	Improved availability
Rainwater harvesting, warning systems	Water allocation, Stakeholder participation	Improved availability, Reduced drainage damage
Improving drainage systems and water treatment	Pollution control, Watershed planning	Reduced pollution, Improved availability and recovery
Better monitoring	Information management, Monitoring	Improved action responding to real needs

Table 7.3: Some possible adaptation measures and functions of watershed organisations

Box 7.4: IWCAM in the Fond D'or Watershed St. Lucia

The Fond D'or Watershed is the second largest watershed in St. Lucia, however, as a result of inappropriate management there has been a deficit in water supply to the surrounding communities. In order to assist the communities obtain a more reliable water supply a Rain Water Harvesting Pilot Project was undertaken within Fond d'Or Watershed. With funding assistance from the European Development Fund, the Global Environment Facility – Integrated Watershed and Coastal Area Management (GEF-IWCAM) Demonstration Project installed thirty (30) rainwater harvesting systems in private residences, health centres, schools and a police station. Other steps taken towards integrated management of this watershed has included a participatory approach through the Fond D'Or Watershed Management committee which is made up of community members, government representatives and other key stakeholders; development of a map of current and proposed land use; and an education and awareness campaign.

7.6 Adaptation at the appropriate level

Can you think of other desirable or less desirable effects of proposed adaptation measures?

Developing countries are likely to suffer most from negative impacts of climate change. In developing countries, the climate-sensitive sectors such as agriculture and fisheries are economically more important than in developed countries. Reducing vulnerability of these sectors and societal groups needs to be at the centre of adaptation strategies, ensuring that livelihoods are sustained. Limited human, institutional, and financial capacities to anticipate and respond to direct and indirect impacts, particularly at community level, make it essential that strategies are developed and implemented at the appropriate level. Small Island States are again among those countries that are often limited by human, institutional, and financial capacity. Despite opportunities for tertiary level education in the Caribbean, the region still suffers from a lack of qualified human resources due to the migration of university graduates to 'greener pastures'. A recent study by the World Bank ranked three Caribbean countries, namely Guyana, Grenada, and Jamaica, as having the highest incident of 'brain drain' with as much as 89 percent of tertiary level graduates migrating to seek jobs elsewhere (World Bank 2011). The UNFCCC recognises that some of the climate change adaptation options identified by SIDS may be costly and beyond their financial capacity therefore requiring international assistance.

In some parts of the world, local authorities play a crucial role in addressing poverty, improving access to basic water services, and sustainable management of water resources. However, they often lack the knowledge and capacity to reach these expectations. They are the most decentralised representative governance structures that have responsibilities for providing basic services. In this context, they are the first responsible authorities to ensure that the needs of vulnerable sectors and players are addressed in adaptation strategies and their livelihoods protected. In a Caribbean context, there is often no local authority, rather, it is the central government that controls how resources are managed. Furthermore, any local authorities in Small Island States of the Caribbean tend to be limited in power. In some islands, other sectors are able to make positive contributions to water resource management, albeit a secondary benefit of the organisation's primary purpose. For example, a tour company In Dominica, the Portsmouth Indian River Tour Guides Association (PIRTGA), has contributed to greater local appreciation of local biodiversity and stronger collective management of the natural resources associated with the Indian River through the activities (CTO 2007).

Local authorities are expected to provide or facilitate water and sanitation services, but they are also increasingly being expected to use participatory approaches to maximise stakeholder inputs to planning, management decisions, and stakeholder responsibility for water demand management. Local authorities have roles in watershed water management agencies, both as users and as community representatives, and they will be expected to endorse regulatory approaches that support sustainable management of water resources, including environmental and ecosystem protection. With increasing decentralisation, local authorities have been charged with greater responsibilities, yet often have widely varying competence, experience, and capacity. Their effectiveness influences development, poverty, environment and health, yet they remain one of the most challenging institutions to reach with assistance for improved water management. User associations, environmental NGOs, interest groups, and others have an important role in mobilising stakeholders for the development of adaptation strategies and to ensure their participation in implementation. In the framework of planning for adaptation in the context of IWRM, consultation with and participation of stakeholders is central to the process. They ensure that gender equity issues are properly addressed and that the most vulnerable sectors and water users are adequately considered when strategies are developed.

In this context, a distinction can be made between private and public adaptation. Private adaptation is initiated and implemented by individuals, households, or other private entities and usually serves the interests of those who implement it (Box 7.4). Public adaptation is initiated and implemented by public authorities and should usually serve the interest of the community. Ideally, the public authority solicits the inputs of individuals, interest groups, or other representatives of private entities to develop a strategy that meets public interests based on private requirements. However, that demands a substantial capacity by the public authority to organise participation and translate inputs in strategic policies and implementation. Local parties also have to be informed of and be sufficiently familiar with adaptation scenarios and the tools and techniques at their disposal. Substantial capacity-building efforts directed towards local authorities and civil society representatives will be required.

Box 7.5: Private Sector Adaptation

In 2007 Coca Cola Company set a goal to return to communities and nature the amount of water equivalent to what the company uses in its products and their production making it the first multinational corporation to take such action. This involves reducing the amount of water used in its beverages, recycling water used in processing, and investing in locally relevant projects to replenish water. Some small island states in South and Southeast Asia have benefitted from the efforts of the Coca Cola bottling plants in their countries.

Nova Oceanic Energy Systems Inc. in partnership with a number of other organisations has started to introduce near shore wave energy converters in a number of Caribbean states. These converters act in the same way as submerged breakwaters in reducing coastal erosion, while simultaneously converting absorbed wave energy in distributed clean power generation for desalinisation and electric power technology that could contribute to poverty reduction in SIDS.

The Government of St. Lucia requires private water suppliers, such as water bottling companies to have an abstraction license. Minimum base-flow between the wet and dry season has been determined to be 150 litres, therefore, restrictions have been put in place to limit how much water that can be abstracted per day and per month.

Summary

Climate change adaptation measures can be incorporated into water resources management at all levels. IWRM aims to ensure that communities are provided with access to sufficient resources, that water is available for productive use and that the environmental function of water is secured. On all three scores, management is challenged by climate variability manifestations and these have to be considered when setting out management strategies. To do so, adaptation to climate variability has to be incorporated into water resources management planning.

Think about it:
If local authorities, communities, and interest groups are essential for adequate adaptation to climate change and the needs of vulnerable groups are to be addressed, how is this to be considered in scenarios and strategies developed by central governments?

Water resources management instruments can help address climate change. There are various phases in a planning process where adaptation can fit in. It also matches adaptation measures with water resources management functions.

Suggested reading

Cap-Net (2005) Integrated Water Resources Management Plans: Training Manual and Operational Guide. Cap-Net: Delft, The Netherlands.

Cap-Net (2008) Integrated Water Resources Management for Watershed Organisations: Training Manual and Facilitators' Guide. Cap-Net: Pretoria, South Africa.

CPWC (2009) Planning Better WRM. Perspective Paper on Water and Climate Change Adaptation. The Co-operative Programme on Water and Climate (CPWC): Den Haag, The Netherlands. http://www.waterandclimate.org/index.php?id=5thWorldWaterForumpublications810

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CPWC (2009) Water Resources and Services. Perspective Paper on Water and Climate Change Adaptation.

Global Water Partnership (2009) Better Water Resources Management - Greater Resilience Today, More Effective Adaptation Tomorrow. Perspectives on water and climate change adaptation. GWP: Stockholm, Sweden.

The World Bank. (2011). Migration and Remittances Factbook 2011, Second Edition. The World Bank, Washington, DC, http://siteresources.worldbank.org/INTLAC/Resources/Factbook2011-Ebook.pdf, viewed 17 November, 2011.

Videos

WWF. The work of the Mara Watershed Management Initiative.
https://www.youtube.com/watch?v=5ycEKvmADGs
Strengthening Integrated Water Management and Small Reservoirs in the Volta Watershed. https://www.youtube.com/watch?v=QO56brSRqug

Part 2:
Facilitators' Guide

SAMPLE COURSE PROGRAMME

Day 1

Time	Topic	Content
09:00 – 10:30	Introduction	Introduction of programme and participants
11:00 – 12:30	Introduction to Integrated Water Resources Management (IWRM) and climate change	IWRM principles and concepts are introduced and the way IWRM may help addressing climate change adaptation will be discussed in this session. Presentation is followed by group discussion.
13:30 – 14:30	Understanding drivers and impacts of climate change – Drivers	*Introduction and discussion* The physical science basis of climate change and the associated drivers are introduced.
14:30 – 15:30	Group discussion	Random groups – report back
16:00 – 17:30	Understanding drivers and impacts of climate change – Impacts	*Introduction and discussion* An understanding of how climate change will impact water resources and ecosystems and how this may affect water use is discussed.

Day 2

Time	Topic	Content
08:30 – 09:00	Recap of previous day	*Relevant topics are revisited and clarified.* Participants are asked to volunteer to summarise the presentations and discussions in no more than three challenging statements that aim to trigger discussion.
09:00 – 10:30	Strategy development and planning for adaptation	*Introduction and discussion* What basic principles can be employed for adaptation planning in the water context? Processes that have been developed for preparing adaptation strategies and projects, and examples of adaptation planning are discussed.
11:00 – 12:30	Exercise	Groups formed according to 4 cases – define ToRs of different teams in a climate change adaptation project in the water sector
13:30 – 15:00	Impacts of climate change on water use sectors	*Introduction and discussion* What are the climate change impacts on water resources at global and regional levels? The expected impacts for various water use sectors are highlighted.
15:30 – 17:30	Exercise	Same groups as previous session discuss impacts on: Case 1 – agriculture and rural floods Case 2 – navigation and agriculture Case 3 – infrastructure and urban floods Case 4 – ecosystems and fisheries.

Day 3

Time	Topic	Content
08:30 – 09:00	Recap of previous day	
09:00 – 10:30	Techniques for assessing impacts	*Introduction and discussion* Building on the previous session, new techniques for assessing the identified impacts will be introduced.
11:00 – 12:30	Dealing with uncertainties	*Introduction and discussion* Introduction to the various aspects that add to the uncertainties when dealing with climate change and how this can be included in environmental management approaches. Includes a presentation of prediction and resilient oriented approaches as two different approaches in climate change adaptation.
13:30 – 18:00	Field visit	

Day 4

Time	Topic	Content
08:30 – 09:00	Recap of previous day	
09:00 – 10:30	Exercise	The 4 groups design and plan a risk assessment dealing with uncertainties strategy using the climate vulnerability indices for their respective cases.
11:00 – 12:30	Instruments and measures for adaptation	*Introduction and discussion* Overview of adaptation measures and their typology.
13:30 – 15:00	Exercise	The 4 groups propose adaptation measures for their respective cases.
15:30 – 18:00	Role play	

Day 5

Time	Topic	Content
08:30 – 09:00	Recap of previous day	
09:00 – 10:30	Adaptation to climate change in water management	*Introduction and discussion* The session addresses water resources management instruments available and how they can help addressing climate change. It considers the phases in a planning process and where adaptation can fit in. It also matches adaptation measures with water resources management functions.
11:00 – 12:30	Exercise	The 4 groups are challenged to strategise and incorporate adaptation in water resources management planning.
13:30 – 14:30	- cont'd -	Working groups
14:30 – 15:30	- cont'd -	Reporting back and discussion
16:00 – 16:30	General discussion	Lessons to be taken home
16:30 – 17:30	Course evaluation and closure	

SESSION OUTLINES

Session 1

Title: Introduction to Integrated Water Resources Management (IWRM) and climate change
Learning objectives At the end of this session, participants will: ● Be able to describe the meaning of IWRM and its main principles; ● Understand the main reasons for taking an IWRM approach; and ● Be aware of some areas where IWRM can assist adaptation to climate change.
Needs/requirements for the session Presentation equipment Flip charts or other group exercise reporting tools Breakout space
Short summary The session introduces the main principles and concepts of IWRM and addresses the question how it can help adaptation to changing climatic conditions for improved water availability and quality.
Time allocation Presentation and discussion: 45 minutes Exercise: 45 minutes Total: 1 hr 30 minutes
Exercise Group discussion. Depending on the size of the group, divide into 3 or 4 groups and discuss the following questions: Having gone through the basic principles of IWRM, you will probably be able to assess the situation in your own country when it comes to implementation of IWRM. Some of the questions you may want to answer are: ● What is the evidence of commitment to IWRM in your country? ● Is there any adoption of water management principles in your country? ● How are men and women affected differently by changes in water resources management in your country? ● How adaptable are management practices in your country? ● What are climate change manifestations in your country that IWRM could address?

Session 2

Title: Drivers and impacts of climate change
Learning objectives At the end of this session, participants will: ● Be able to explain the basic concepts of climate variability and climate change; ● Be aware of the language used by IPCC to communicate confidence and uncertainty; ● Understand the basis behind the Special Report of Emission Scenarios; and ● Be able to identify climate change impacts on the water cycle, ecosystems and water use.
Needs/requirements for the session Computer and projector Breakout space
Short summary It is imperative to understand the physical science basis of climate change and the associated drivers before looking into their possible consequences. Water, as the life-giving resource and the one that will be most affected by climate change, needs special attention. Water managers need to understand how climate change is going to impact water resources and ecosystems and how this may affect water use.
Time allocation Introduction and discussion on drivers: 60 minutes Group discussion and report back: 60 minutes Introduction and discussion on impacts: 90 minutes

Total: 3 hrs 30 minutes
Exercise Group discussion. Depending on the size of the group, divide in 3 or 4 random groups and discuss the following questions: • Have you already noticed any changes in the climate of your region? Are these changes in agreement with IPCC observations and projections? • What were the impacts on water resources? • What do you think will be future changes and how might they affect water resources? End the exercise with brief (5-minute) oral reports to the whole group.

Session 3

Title: Strategy development and planning for adaptation
Learning objectives At the end of this session, participants will be able to: • Identify the main principles and processes that have been proposed for the process of preparing adaptation strategies; • Explore some major sources of substantive guidance for adaptation planning; • Explore through a case example the possibilities of transposing adaptation principles into a project context; and • Identify the linkages between adaptation plans and mitigation plans and possible conflicting measures between the two.
Needs/requirements for the session Presentation equipment Flip charts or other group exercise reporting tools Breakout space
Short summary The session sheds light on the question of which basic principles can be employed for adaptation planning in the water context. Also explored are the processes that have been developed for preparing adaptation strategies and projects. The session will further explore and discuss an example of adaptation planning, especially how those principles can be transposed to a national adaptation project context.
Time allocation Presentation: 40 minutes Discussion: 20 minutes Exercise: 120 minutes Total: 3 hrs
Exercise Group exercise and presentation to plenary. → See exercise description and sample solution.

Session 4

Title: Impacts of climate change on water use sectors
Learning objectives At the end of this session, participants will: • Understand the implications of climate change for water resources by world region; • Be able to explain the expected consequences of climate change for major water use sectors; • Understand the different CCIAV frameworks; and • Understand various methods to generate climate scenarios.
Needs/requirements for the session Computer and projector Breakout space
Short summary Impacts of climate change are not expected to be uniform and will vary over different geographic regions. The session discusses the climate change impacts on water resources at global and the regional levels. The expected impacts for various water use sectors are also highlighted. The IPCC identified several frameworks to assess climate change impacts, organised collectively under the umbrella term Climate Change Impact, Adaptation and Vulnerability Assessment (CCIAV). In the majority of CCIAV studies, climate scenarios are projected using General Circulation Models (GCMs) based on socio-economic storylines. Climate scenarios are then processed via different models to assess the impact on water resources systems to support adaptation planning.

Time allocation Introduction and discussion of impacts on water use sectors: 90 minutes Exercise and plenary presentations: 120 minutes Introduction and discussion on techniques for assessing impacts: 90 minutes Total: 5 hrs Note: The exercise on techniques for assessing impacts will be combined with the exercise for dealing with uncertainties.
Exercise Case descriptions are provided in the exercises section. The participants will be split in four groups following descriptions of the cases. The groups will then discuss the expected impacts on the sectors identified in the respective cases: Case 1 – agriculture and rural floods Case 2 – navigation and agriculture Case 3 – infrastructure and urban floods Case 4 – ecosystems and fisheries.

Session 5

Title: Dealing with uncertainties
Learning objectives At the end of this session, participants will: ● Understand the various types of uncertainties involved in dealing with climate change; ● Be aware of the consequences uncertainty has for environmental management; and ● Be able to explain the differences between prediction- and resilience-oriented approaches and to illustrate this with examples.
Needs/requirements for the session Computer and projector Breakout space
Short summary A short introduction is given on the various aspects that add to the uncertainties when dealing with climate change and how this can be included in environmental management approaches. Prediction- and resilient-oriented approaches are presented as two different ways to address climate change adaptation. They are illustrated with some examples.
Time allocation Introduction and discussion: 90 minutes Exercise and plenary presentations combined with exercise on techniques for assessing impacts: 90 minutes Total: 3 hrs
Exercise Based on the 4 cases, the same groups will carry out a risk assessment, using the CVI presented below in the next section. They will then identify major uncertainties.

Session 6

Title: Instruments and measures for adaptation
Learning objectives At the end of this session, participants will be able to: ● Understand the concept of adaptation to climate change and variability; ● Explain the difference between adaptation and mitigation and provide arguments for why adaptation to climate change and variability is necessary; ● Distinguish various typologies of adaptation options; and ● Identify possible adaptation measures for various sectors and climate change impacts.
Needs/requirements for the session Presentation equipment Flip charts or other group exercise reporting tools (e.g. laptops) Breakout space
Short summary The session will provide the participants with an overview of adaptation measures and their typology. In a group exercise they will propose realistic adaptation measures for selected cases (provided) or, alternatively, within their own country/region.
Time allocation Presentation: 40 minutes

Discussion: 50 minutes Exercise: 90 minutes Total: 3 hrs
Exercise Group discussion and presentations. Use the same groups as in earlier exercises to consistently work with different aspects of one case per group. The groups propose suitable instruments and measures for adaptation as presented for their respective cases.

Session 7

Title: Adaptation to climate change in water management
Learning objectives At the end of the session participants will be able to: ● Understand the water resources management instruments available to address climate change manifestations; ● Strategise the use of different policies and instruments; and ● Promote adaptation at the appropriate level.
Needs/requirements for the session Presentation equipment Flip charts or other group exercise reporting tools Breakout space
Short summary IWRM aims to ensure that communities are provided with access to sufficient resources, that water is available for productive use and that the environmental function of water is secured. On all three scores, management is challenged by climate variability manifestations and these have to be considered when setting out management strategies. To do so, adaptation to climate variability has to be incorporated into water resources management planning. The session addresses water resources management instruments available and how they can help address climate change. It considers the phases in a planning process and where adaptation can fit in. It also matches adaptation measures with water resources management functions. Finally, the participants are challenged to strategise and incorporate adaptation into water resources management planning.
Time allocation Presentation and discussion: 90 minutes Exercise: 150 minutes Reporting back and discussion: 60 minutes Total: 5 hours
Exercise Groups work to incorporate climate change adaptation strategies and measures into IWRM planning. Tasks are described in the Exercises section.

EXERCISES

Session 3: Strategy development and planning for adaptation

Exercise 1

Example of providing structure to a climate change adaptation project for the water sector

Note: This example is based on the case of an arid developing country where substantive research needs have been identified as part of a preliminary assessment. Therefore, emphasis is laid on strengthening the understanding of specific impacts for the water sector in that area. This may be applied differently in places where substantive research projects have already been completed or in a different climatic and socio-economic context.

The project objectives for this example are to:

- Create a national environment to facilitate use of climate information in:
  - Water resources planning;
  - Operation of water infrastructures; and
  - Disaster management.
- Carry out scientific assessments of climate change impacts on water resources and build awareness;
- Assess impacts of climate change on existing or proposed water system operation rules, system design and sizing, policies and water use strategies;
- Develop knowledge through applied research in water management issues related to climate predictions, variability and change; and thereby
- Contribute towards sustainable development by evolving adaptation strategies for planning and operation of water resources infrastructure and disaster management.

The following working groups have been devised to support the project. Note that roles vary from among substantive scientific research tasks, coordination and facilitation tasks, and strategic planning and policy-making tasks. Participants may select the appropriate number of groups (4 or 5) for the exercise.

Working Group 1: Climate Information Group

Terms of Reference: The Group will work closely with the national and international climate data providers such as climate modelling institutions, regional model developers, and so on. Apart from meeting the requirements of this project, this working group (WG), once established, has the potential to meet the requirements of other climate change studies carried out by different sectors. For this purpose, the Group shall work closely with WG 10 (Inter-ministerial Coordination Group) and develop mechanisms to obtain inputs from other sectors. The Working Group will be responsible for providing following climate information for use by other groups:

(i) GCMs Scenarios/database;
(ii) Downscaling and Regional Climate Models;
(iii) Climate and ocean interaction modelling for sea roughness;
(iv) Seasonal climate outlooks; and

(v) Numerical weather products.

Working Group 2: Data and Information Group

Terms of Reference: Various groups will require different kinds of historical information and data. These data should be managed in such a way that they are easily available to all the groups and are appropriately archived for use in all future climate studies. The Group will be working on:

(i) Assessment and compiling of available data;
(ii) Assessment of data needs;
(iii) Building platform for data sharing and management;
(iv) Assessment of data gaps; and
(v) Recommendations on strengthening monitoring network for future needs and monitoring impacts of adaptation strategies.

Working group 3: Water Demand Group

Terms of Reference: Future demands for water from different sectors are likely to change with the warming climate. In order to develop the adaptation strategies, it is essential to assess these demands in close collaboration with various users. The Group will:

(i) Assess current and future demands;
(ii) Interact with other Ministries;
(iii) Interact with various users; and
(iv) Explore possibilities of demand management.

Working Group 4: Groundwater Group

Terms of reference: The Group will work in collaboration with WG 5 (Water Resources Assessment) for overall assessment of water resources and will implement the following actions to study impacts of climate change on groundwater:

(i) Groundwater recharge and its quality;
(ii) Groundwater/freshwater interface in the coastal areas; and
(iii) Lakes and lagoons in coastal areas.

Working Group 5: Water Resources Assessment Group

Terms of Reference: The Group will focus on assessment of surface water resources in quantitative and qualitative terms. It will have close interaction with the Working Group 1 (Climate Information Group) and Working Group 4 (Groundwater group). The Group will work on:

(i) Study of inflow and outflow of surface water reservoirs;
(ii) Study of reservoir evaporation and water quality;
(iii) Drainage system studies; and
(iv) Studies of river water quality.

Working Group 6: Planning, Adaptation and Management Group

Terms of Reference: The Group will synthesise inputs from different Groups. It will use the information produced by WGs 3, 4, and 5 and will develop mechanism and inputs for mainstreaming the climate risk information generated in:

(i) National water resources planning;
(ii) Assessment of current and future development projects;
(iii) Adaptation of policies and plans; and

(iv) Environmental management of various water bodies.

Working Group 7: Coastal Zone Management Group

Terms of Reference: The Group will be responsible for assessing impacts of climate change on the following coastal elements and their impacts on various natural elements and human-made coastal structures or infrastructure in coastal areas:

(i) Waves and currents patterns;
(ii) Monitoring sea levels and land topography;
(iii) Dynamics and ecosystems of the lakes;
(iv) Outlets of rivers and lagoons;
(v) Coastal erosion;
(vi) Impacts on coastal protection works; and
(vii) Infrastructure in coastal areas.

Working group 8: System Operation and Maintenance Group

Terms of Reference: The Group will be responsible for assessing the sensitivity of following water infrastructure structures to impacts of climate change in water availability:

(i) Dams;
(ii) Infrastructure (barrages, bridges, pump houses, and so on);
(iii) Canals; and
(iv) Drainage systems.

Working group 9: Information and Awareness Group

Terms of Reference: Working Groups 9 and 10 are outreach groups and will be responsible for communicating the results of the project to the outside world. The Group will develop communication strategies with the public and professionals and will be responsible for improving:

(i) Awareness among water professionals;
(ii) Awareness among other sectors;
(iii) Public awareness;
(iv) Awareness through education; and
(v) Interaction with NGOs, farmers' cooperatives and water users associations to achieve the above.

Working Group 10: Inter-ministerial Coordination Group

Terms of reference: The Group will be responsible to interact with following to assess their information needs and communicate results of the assessments periodically:

(i) Different ministries and users;
(ii) Other watershed states;
(iii) Local communities/government;
(iv) Private sector; and
(v) NGOs.

Propose possible measures

Type of measures	Flood prone situation	Drought prone situation	Impaired water quality	Health effects
PREVENTION/ IMPROVING RESILIENCE Measures				

Type of measures	Flood prone situation	Drought prone situation	Impaired water quality	Health effects
PREPARATION Measures				
REACTIVE Measures				
RECOVERY Measures				

Case descriptions for subsequent exercises:

Caribbean case studies

Case 1: North Stann Creek Watershed

The North Stann Creek Watershed (NSCW) extends from near the centre of the Belizean coastline westwards to the Maya Mountain divide. The population of the watershed is estimated at 12,243 (April 2008). The main urban area, Dangriga Town, has 10,800 residents. The NSCW is Belize's main citrus producing area and contributes significantly to the Gross Domestic Product (GDP). The citrus industry sustains significant losses when there are extremes in temperature and rainfall. Citrus Processing Plants make the largest contribution of organic load to the North Stann Creek River; the water quality in Stann Creek is thus not satisfactory. The communities in the Stann Creek and Belize district are particularly susceptible to flood events during Belize's rainy season. During the past decade, unprecedented flood events have disrupted lives, livelihoods, and economic growth of the country. The determination of the vulnerability of the water resources provides a predictive capability to address possible negative and positive outcomes consequent of climate variability and climate change.

Case 2: Gonaives, Haiti

Clean water is a scarce resource for the people of Haiti. In recent years, climate change has exacerbated the problem. Many Haitians depend on rainwater and groundwater for their daily use. During periods of drought, some walk several kilometres in search of water but often what is found is of poor quality, leading to waterborne illnesses such as typhoid and diarrhoea. Haiti's territory is 75 percent mountainous, where 50 percent of the mountains are steeper than 40 degrees. The country is located on the trajectory of hurricanes. Governance, capacity, and finance challenges reduce the country's ability to adapt; the response capacity from local institutions is low. Flooding is a major problem in almost all of Haiti's 30 major watersheds, because of intense seasonal rainfall, storm surges in the coastal zones, a deforested and eroded landscape, and sediment-laden river channels. The city of Gonaives, Haiti, typifies the country's vulnerability to storms. Gonaives is situated in a valley, surrounded on three sides by hills and mountains; on the fourth side, by the Caribbean Sea. Water running out of the mountains is channelled to the city and into the neighbouring Savane Desolee. This topography caused deadly flooding in both 2004 and 2008 from tropical storms in the North-East. Coastal plains are increasingly subject to saltwater infiltration, leading to saltier soils that farmers can no longer cultivate. Deliberate overflowing of the Peligre hydropower dam, in order to maintain the power supply in metropolitan Port-au-Prince, greatly exacerbates flooding in the Artibonite Valley.

Case 3: Georgetown, Guyana

Georgetown, the capital of Guyana, is an example of coastal city that is highly susceptible to sea-level rise and flooding, as much of the population lives at or below sea level with some portions being located between 19.7 inches (0.5 m) and 39.4 inches (1 m) below sea level. Almost all of Guyana's agricultural production occurs along the coastal plain and is therefore at risk of inundation and salinisation of soils. Seawalls provide protection, however, flooding occurs after large waves top the seawalls or heavy rains occur. Sea level along the Guyana coastline is rising faster than the global average which will exacerbate future increases from further global warming. Because of increased flooding, the Ministry of Agriculture is already encouraging residents to relocate farther inland.

Case 4: Rio Cobre, Jamaica

Rio Cobre River, in south central Jamaica, is the main river in Jamaica that flows to Kingston Bay. The water resources are highly stressed with the demand being 94 percent of the exploitable yield. Rio Cobre is expected to have a deficit of 40 million m^3/yr from 2050 and a deficit of 100 million m^3/yr from 2080. The communities surrounding the watershed are at risk of floods which have claimed many lives and caused significant property damage over the decades. Rio Cobre River is important for recreation and subsistence fishing, therefore, the quality of the water is of concern since the watershed is subject to urban runoff containing untreated or partially treated domestic wastewater from poorly functioning sewage treatment facilities.

International Case Studies

Case 5: Riverine flooding in Asia

A river basin is situated in a developing country in Asia with a monsoonal climate. Population density is already high as is the poverty rate and the population is projected to further increase in the coming three to five decades. Even though there are urbanization trends, the majority of inhabitants live in rural areas where livelihoods are directly linked to (subsistence) agriculture. Riverine flooding has been an annual feature of the past. Smaller (e.g. annual) floods are essential for maintaining soil fertility, riverine ecosystem health, and for replenishing water supplies in surface water reservoirs and in groundwater systems connected to the floodplain. Negative impacts of larger floods are high losses of life, destruction of crops and livelihoods, disruption of the transport infrastructure, and damage to houses and other infrastructure. The recurrent flooding also leads to a deviation of development funds towards disaster relief.

Case 6: Water and agriculture in sub-Saharan Africa

A river catchment is situated in a developing country in sub-Saharan Africa. There is one rainy season (October to March), with generally a dry period in January. Population density is relatively low. Most livelihoods are dependent on rainfed agriculture. Artificial fertilizers are used sparsely because of high costs. Soil moisture conservation has been part of traditional farming practices, but because of mechanization is now less common. The population is projected to further increase in the coming three to five decades. Even though there are urbanization trends, the majority of inhabitants live in rural areas where livelihoods are directly linked to (subsistence) agriculture.

Case 7: Urbanisation in Latin America

A coastal mega city is situated in a developing country in Latin America at the mouth of a large river. In recent years storms and high river discharges have resulted in flooding of some lower parts of the city. This has resulted in overflow of sewer systems and pollution of drinking water sources and the outbreak of waterborne diseases. During long drought periods the availability of sufficient drinking water could not be guaranteed. Because of migration from rural areas to the city, population density is projected to further increase in the coming three to five decades, forcing further developments in high-risk areas.

Case 8: Fisheries in SE Asia

A river basin is situated in a tropical developing country in SE Asia. Population density is high and the population is projected to further increase in the coming three to five decades. Even though there are urbanization trends the majority of inhabitants are living in rural areas where livelihoods are directly linked to (subsistence) agriculture and fisheries. Smaller (e.g. annual) floods are essential for maintaining soil fertility, riverine ecosystem health, and for replenishing water supplies in surface water reservoirs and in groundwater systems connected to the floodplain. The river is an important habitat for the commercially important fish *Carnitop*, which spends part of its life cycle in upstream tributaries and part of it in downstream mangrove forests. *Carnitop* needs clear water and its food source is very sensitive to pesticides.

Session 4: Impacts of climate change on water use sectors

Based on the cases presented, the groups will discuss the expected climate impacts on the sectors identified in the respective cases:

Case 1-agriculture and floods
Case 2-sanitation and health
Case 3-agriculture and floods
Case 4-recreation and fisheries
Case 5 – agriculture and rural floods
Case 6 – navigation and agriculture
Case 7 – infrastructure and urban floods

Session 5: Dealing with uncertainties

For the cases, the same groups will carry out a risk assessment, using the Climate Vulnerability Index (CVI). Identify major uncertainties.

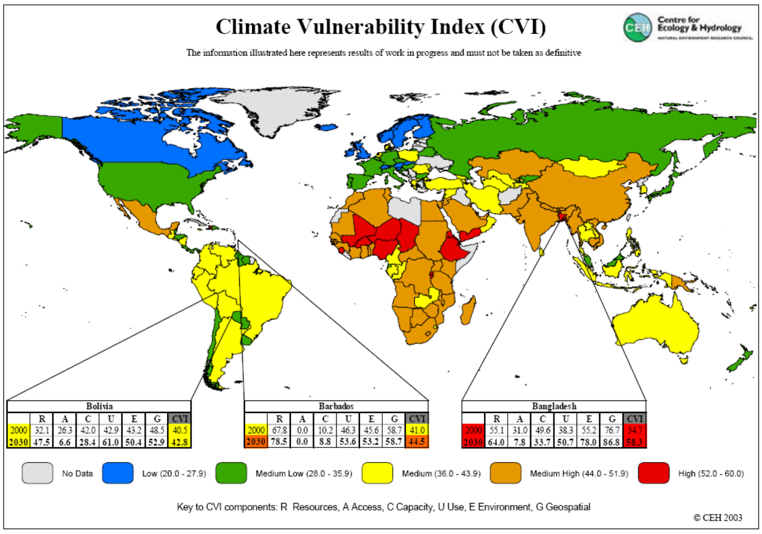
The Climate Vulnerability Index

The CVI is based on a framework that incorporates a wide range of issues. It is a holistic methodology for water resources evaluation, in keeping with the sustainable livelihoods approach used by many donor organisations to evaluate development progress. The scores of the index range on a scale of 0 to 100, with the total being generated as a weighted average of six major components. Each of the components is also scored from 0 to 100.

The six major categories or components are shown below.

CVI component	Sub-components/variables
Resource (R)	• assessment of surface water and groundwater availability • evaluation of water storage capacity, and reliability of resources • assessment of water quality, and dependence on imported/desalinated water
Access (A)	• access to clean water and sanitation • access to irrigation coverage adjusted by climate characteristics
Capacity (C)	• expenditure on consumer durables, or income • GDP as a proportion of GNP, and water investment as a percent of total fixed capital investment • education level of the population, and the under-five mortality rate • existence of disaster warning systems, and strength of municipal institutions • percentage of people living in informal housing • access to a place of safety in the event of flooding or other disasters
Use (U)	• domestic water consumption rate related to national or other standards • agricultural and industrial water use related to their respective contributions to GDP
Environment (E)	• livestock and human population density • loss of habitats • flood frequency
Geospatial (G)	• extent of land at risk from sea level rise, tidal waves, or land slips • degree of isolation from other water resources and/or food sources • deforestation, desertification and/or soil erosion rates • degree of land conversion from natural vegetation • deglaciation and risk of glacial lake outburst

Table 1: The six major categories of the Climate Vulnerability Index (CVI)



Climate Vulnerability Index *Source: Sullivan and Meigh 2005*

Session 6: Instruments and measures for adaptation

Each group is assigned to one of the case studies (above) for which they have to work out and present the following issues:

1. Identify a set of likely impacts on the state of water resources in terms of spatial and temporal distribution (including extreme events) and quality. Your assumption is that those impacts have been assessed at least as 'likely' by a scientific impact assessment.
2. Use these impacts to define a set of measures that need to be considered in adapting to the projected impacts and explain for each measure what should be the intended effect. This set of measures preferably should exist of a combination of policy measures, technological measures, and measures aiming at risk sharing.
3. Classify these measures according to Table 2 (lecture notes): Are they anticipatory or reactive and do they apply to the natural system or to the human system?
4. For each measure you select, provide indications on the following criteria:

   - Are the measures economically justifiable even if the projected impacts turn out to be smaller? (i.e. can they be labelled no-regret or low-regret measures?)
   - Are there major known constraints to their application, e.g. financial/political constraints, acceptability by stakeholders?
   - Do the measures compromise climate change mitigation targets in the sense of significantly increasing GHG emissions?
   - Try to identify possible externalities of applying such measures, e.g. in the areas of livelihood security, food security, ecosystem health, and poverty reduction.

Session 7: Incorporating Climate Change Adaptation in Water Resources Management Planning

Description:

The working groups of the previous exercises are expected to elaborate further their respective cases.

Assignment to the groups:

Develop a strategy for adaptation to climate change using the concepts, principles, tools and techniques presented during the week.

In developing the strategy, consider the following elements:

- Problem analysis;
- Scenarios and models;
- Principles and concepts of IWRM;
- Health impacts;
- Legal options;
- Financial and economic impacts;
- Possible adaptation measures;
- Strategy development for different sectors and dealing with uncertainties;
- Planning process and stakeholder participation;
- Capacity building;
- Community and watershed level activities; and
- The roles of watershed organisations and local authorities.

Use the IWRM planning cycle and identify the actors at each stage of the cycle, actions to be taken, expected outputs and indicators for success.

Tip: useful material: Cap-Net training manual IWRM plans (2005)

Role Play:

Option 1 (Caribbean) - Lake Roseau

This role play is based on a fictitious case study which has combined elements from a number of different situations taken from throughout the Caribbean. It is loosely based on elements from the Nariva Swamp in Trinidad, Lake Antoine in Grenada, and the John Compton Dam in St Lucia, with a few twists added. Lake Roseau is located on the imaginary island of Sinesterria, which too is an amalgam of characteristics of Caribbean islands. As such it is permissible in participating in the role play to use a degree of creative imagination. However, whatever you do must not be based on fantasy or fantastical assumptions but on what we know and sound science. In this example it becomes clear that water levels are dropping in the lake, which affects many stakeholders. This process is steered by a complex set of natural and anthropogenic drivers and climate change is likely to be one of them. Climate change scenarios for the Caribbean predict a decrease in annual rainfall for the island of Sinesterria. Predications of climate change should be taken from the work on Regional Climate models, most of which has been carried out by the Climate Modelling Group in the Department of Physics at the University of the West Indies, Jamaica. For your purposes you may assume that Sinesterria is located somewhere in the Eastern Caribbean. You should use a variety of sources and published information on the likely climate changes in the Region.

Description of Lake Roseau

Lake Roseau is a freshwater lake in Sinesterria located at an elevation of 550 m. It has a surface area 30 km²; and average depth 6 m with a maximum depth of 25 m. Lake Roseau lies south-west of the capital Bestown and was constructed to generate hydropower for the country with a maximum installed capacity of 10 MW as well as to provide water for development. The power generated accounts for 35 percent of the power demand of the country and supplies electricity at 50 percent of the cost of the nearest currently available alternative, fossil fuel. Thus Lake Roseau is an important asset of the Sinesterria Power Limited (SinPoL). The man-made lake has a surface area of 30 km², the northern and upstream area is bordered by a State Protected Area which is managed by a local environmental NGO Ha'xhoo under a management contract with the Ministry of the Environment and Climate Change. This covers an area of some 300 km^2 and is the last remaining habitat of the endangered Sinisterria Parrot, which has recently been placed on the CITES Red List of Threatened Species in the Endangered category.

The area is subject to encroachment by indigenous farmers who still practice slash and burn agriculture as well as exploitation of certain tree species. The area is an important watershed area and contributes significantly to the inflow to the storage reservoir. The southern part of the reservoir has been developed as a banana growing area which depends on irrigation of the crop for its productivity. Banana farming is carried out by two farming companies. Bananas contribute significantly to the GDP and export earnings of the country and a loss in production would have an adverse impact on the country. The reservoir has become an important wildlife area and supports populations of migrating birds. There is pressure to develop parts of the area as a high-end tourist destination. These proposals have been made by a multi-national boutique hotel chain (EcoExploit) in which the sister of the Minister of Finance and Economic Development has a majority share in the local branch of the company EcoExploitS and is managing director. There are other tourism operations that feature the area in their offerings.

Downstream of the reservoir, the area along the river has a mix of developing small-scale high-tech niche agro-industrial production alongside small farmers engaged in horticulture. The High-tech farming firms export and sell their products on the international market whilst the small scale farmers are an import source of fresh produce for the local market, saving scarce export exchange. The mouth of the Petitfluv River forms an important wetland area of some 100 km², with associated mangroves. The wetland enjoys a certain degree of environmental protection through the Ministry of Environment and Climate Change but this has been consistently ignored as funds for regulation and enforcement have been consistently cut-back over many years. As a result parts of the area have been cleared and developed for rice cultivation by small farmers who were relocated to the area some 40 years ago under a government scheme. When rice production became non-viable due to low buying price on the international market a large part of the area was abandoned and a certain amount of re-forestation for silviculture took place by the Ministry of Social Welfare and Settlements to provide an alternative source of income. Fisherfolk utilise the mangrove area for artisanal fishing, with some oversight by the Fisheries Division of the Ministry of Food and Rural Affairs. This ministry also accredits cooperatives and has been trying to get the small farmers and fisherfolk to form and join cooperatives, with some limited success.

Water levels in the reservoir fluctuate depending on climatic conditions and the demand for electricity. In the early years, this was low and there was sufficient storage in the reservoir and flow in the Petitfluv River to meet demands. However, as demand for electricity has increased and other factors such as increasing demand, flows in the river have decreased. The introduction of the requirement to maintain minimum environmental flows has further decreased the available water resources. Furthermore, activities around the reservoir are having an impact on the dam such as increased rates of erosion and sedimentation, over-application of agro-chemicals, which are having severe impacts on water quality. Because of the growth of the capital Bigtown, there is an increasing need for further water supplies to meet growing municipal demands. The Municipality of Bigtown has been trying to persuade the government to approve a proposal to take water from the Petitfluv River as an additional source of supply.

With so many competing demand the Ministry of Water and Energy, through its Petitfluv River Management Agency (PeRiMA) proposes to restrict the use of water as it believes that this is the only way all parties can benefit from the Roseau Lake in the long term. Especially with expected effects of climate change, immediate action is needed.

PeRiMA calls for a meeting to discuss and present its plans to the following stakeholders: the small-scale farmers' cooperatives including the indigenous farmers, the agro-industry association, the tourism industry interests EcoExploitS, Bigtown Municipality, the fisherfolk association, Ha'xhoo, the banana industry, SinPoL, ministry of Environment and Climate Change, the Sinesterria Environment, and and Research Utilisation Managers (SERUM).

Option 2 (International) - Lake Naivasha

Please read the following description of Lake Naivasha, Kenya from Wikipedia (http://en.wikipedia.org/wiki/Lake_Naivasha). In this description, it becomes clear that water levels are dropping in the lake, which affects many stakeholders. This process is steered by a complex set of natural and anthropogenic drivers and climate change is likely to be one of them. Climate change scenarios predict a decrease in annual rainfall in the Naivasha area.

Description of Lake Naivasha

Surface area 139 km^2; average depth 6 m; maximum depth 30 m; surface elevation 1,884 m.

Lake Naivasha is a freshwater lake in Kenya, lying north-west of Nairobi, outside the town of Naivasha. It is part of the Great Rift Valley. The name derives from the local Maasai name *Nai'posha*, meaning 'rough water' because of the sudden storms which can arise. The lake has a surface area of 139 km^2, and is surrounded by a swamp, which covers an area of 64 km^2, but this can vary largely depending on rainfall. It is situated at an altitude of 1,884 m. The lake has an average depth of 6 m, with the deepest area being at Crescent Island, with a depth of 30 m. Njorowa Gorge used to form the lake's outlet, but it is now high above the lake and forms the entrance to Hell's

Gate National Park.

The lake is home to a variety of wildlife; over 400 different species of bird have been reported. There is a sizeable population of hippos in the lake. There are two smaller lakes in the vicinity of Lake Naivasha: Lake Oloiden and Lake Sonachi (a green crater lake). The Crater Lake Game Sanctuary lies nearby, while the lakeshore is known for its population of European immigrants and settlers. Between 1937 and 1950, the lake was used as a landing place for flying boats on the Imperial Airways passenger and mail route from Southampton in Britain to South Africa. It linked Kisumu and Nairobi.

Floriculture forms the main industry around the lake. However, the largely unregulated use of lake water for irrigation is reducing the level of the lake and is subject of concern in Kenya. Fishing in the lake is also another source of employment and income for the local population. The lake varies in level greatly and almost dried up entirely in the 1890s. Having refilled, water levels are now dropping again. The town of Naivasha (formerly East Nakuru) lies on the northeast edge of the lake.

The water level of Lake Naivasha is dropping and therefore the Lake Naivasha Riparian Authority (LNRA) proposes to restrict the use of water. LNRA believes that this is the only way its members can benefit from the lake in the long term. Especially with expected effects of climate change, immediate action is needed.

LNRA calls for a meeting to discuss and present its plans to the following stakeholders[1]: the small scale farmers; the floriculture sector; the tourism industry; Naivasha municipality; the ministry for water and irrigation; fishermen’s association and the Kenya Marine and Fisheries Research Institute (KMFRI).

How to play

Roles

Each stakeholder is represented by a participant and another participant acts as a Guardian Angel of the stakeholder. In this case, there are up to eleven stakeholders, meaning that up to 22 participants play and the rest of the participants observe. All participants are involved in the role play, as a stakeholder, guardian angel or as an observer. The responsibilities are presented in Table 1 below.

[1] The description and opinions of the stakeholders are loosely based on IUCN/LNRA (2005). Lake Naivasha: Local Management of a Kenyan Ramsar Site. IUCN Eastern Africa Regional Programme, Nairobi and Lake Naivasha Riparian Association, Naivasha. 78 pp.

Role	Responsibility
Stakeholder	Prepares goals and a strategy for the meeting together with Guardian Angel, Participates actively in the play and places him or herself in the shoes of the stakeholder (only thinks about the greater picture if that is important for him or her as a stakeholder), Implements the suggestions of the Guardian Angel, and Carries out a self-evaluation during the feedback session reflecting on the goals and strategy.
Guardian Angel	Prepares goals and a strategy for the meeting together with the stakeholder by giving messages on slips of paper, helps the stakeholder in following the agreed strategy.
Observer	Gives feedback on the play (identifying the stakeholders' goals and strategy, negotiation skills etc.), Makes links between the role play and how this is related to reality (what can you learn from this role play), and Respects the players and realises that they are acting.

Table 2: Roles and responsibilities of participants

Based on the information in Table 3 and the description of the lake, the Stakeholder prepares for the Stakeholder Forum. NOTE: The Stakeholder characteristics are handed out to each of the stakeholders and the other stakeholders do not know what the characteristics of the others are. A stakeholder is free to formulate their own attitude and perspective within the general guidelines of their characteristics.

During this time and his or her Guardian Angel also has time to prepare for the Stakeholder Forum. During this time, the Guardian Angel and Participant agree on goals they want to achieve as outcome of this meeting and a strategy to achieve these goals. Goals can be, for example, an agreement on water restriction or to prevent an agreement on water restriction. The PeRiMA prepares an agenda for the meeting and prepares itself for chairing the session as well as formulating goals and a strategy. During the play, the observers try to figure out the goals of the different stakeholders and assess if they have reached these goals. During the preparation time, the observers could agree to distribute tasks between themselves (focus on a specific stakeholder for example).

Stakeholder Characteristics

Caribbean role play

Stakeholder	Characteristics[2]
PeRiMA	Wants sustainable management of the lake; Realises the potential effects of climate change; Does not trust other Ministries; Derives revenues from abstraction licences; Thinks the municipality only takes note of short-term issues; Over-confident; and Wants to leave the meeting with an agreement.
SinPoL	Wants to increase the height of the dam to increase power generation capacity; Is concerned about the impact of climate change and variability on its power generation; Wants to maximise revenues from the power generation; and Realises that activities in the watershed/catchment are adversely affecting its operations and is willing to consider a Payment for Environmental Services agreement.

Stakeholder	Characteristics[2]
Ha'xhoo	More concerned over the conservation of the Protected area and the fate of the Sinesterria Parrot; Sees activities of indigenous farmers as a threat if left unchecked so is willing to work with them; Faces funding challenges to maintain its work; Totally opposed to further tourism development in the area; Would be opposed to heightening the dam as this would lead to loss of habitat; and Has partnered with SERUM on many occasions.
Small-scale farmers' cooperatives including rice growers, horticulturalists, and indigenous farmers NOTE: These could be split into a further two or three.	Know the area very well, lived there for generations; Realise the need for restrictions in order to maintain their crops Feel restrictions should mainly (if not only) apply to others as they have a historic right to the water; Do not like SinPoL as they affect the availability of water; Indigenous farmers are indifferent to Ha'xhoo would change their mind if they got some benefit from their association; Prepared to cooperate with Bigtown as this is a main market for them; Rice farmers wish to expand their use of the wetland that was abandoned and convert more land to production to increase their margins; Believe that the PeRiMa is biased against them; and Have been noticing the effects of a changing climate.
Banana Growers	Feel they have every right to use as much water as they need as they provide employment and are the main contributors to economic growth, hence climate change does not affect them they think; Arrogant, don't want to be at the meeting; Try to 'play' the Municipality and the Ministry; and Do not want an agreement on water restrictions, unless it does not apply to them.
EcoExploitS & Tourism industry	Depends on the ecosystem for its income; Is supported by the Ministries of Finance and Economic Development, and Tourism; Is willing to liaise with the PeRiMA; Thinks that abstraction of water should be limited as this could adversely affect the development of tourism in the area; Wants access concessions from Ha'xhoo; and Climate Change – what's that?
Agro-industry Association	Have very little reliance on water from the river as they use harvested rainwater; Partnering with Ha'xhoo and SERUM to ensure maintenance of biodiversity; Mostly foreign-funded and owned, developing close ties with foreign donors; and Supportive of EcoExploitS as they need the support of the Ministry of Finance and Economic Development for their tax concessions.
Bigtown Municipality	Tends to value employment and growth over sustainability; Doesn't believe climate change will influence the area much; Is not so much 'in touch' with the small-scale farmers, fishermen and conservationists as they do not contribute to the economy of the town; Supportive of EcoExploit as they see that the town can benefit from providing services and hence employment; Believe that they can cope with climate change by having more water supplies; and Mayor is married to the MD of EcoExploitS.

Stakeholder	Characteristics[2]
Ministry of Environment and Climate Change	Very aware of climate change and potential impacts and the need to adapt; Believes an agreement on restricted use seems needed; Is not aware of the local sensitivities; Appreciates the invitation as it feels it is not often listened to by rest of the government and the public; Tends to support Ha'xhoo and SERUM; Has an uneasy relationship with Ministry of Water and Energy and hence PeRiMA; Sees farming in any form as a threat to the environment, but may be sensitive to solid arguments; and Has offers of grant aid for climate change adaptation projects.
Fishermen's union	Supports all initiatives that would maintain the water flows into the swamp and mangrove area as their livelihood would otherwise be threatened; Not well-organise; and Feel overlooked.
SERUM	Has a permanent station on the lake; Economic and scientific interest; Wishes to develop bio-industries utilising the biodiversity of the area; Lake offers good potential for international research cooperation; Knows that the agroindustry is close to potential European donors; Historical link to Ha'xho; Very worried about the potential effects of climate change on the ecology of the lake; and Also concerned about sustainable fisheries and maintenance of biodiversity.

Table 3: The characteristics of the Caribbean role play stakeholders

International role play

Stakeholder	Characteristics[3]
LNRA	Wants sustainable management of the lake; Realizes the potential effects of climate change; Does not trust the floriculturists; Thinks the municipality only takes note of short-term issues; Over-confident; and Wants to leave the meeting with an agreement.
Small-scale farmers' association	Know the area very well, lived there for generations; Realize the need for restrictions; Feel restrictions should mainly (if not only) apply to the floriculturists; Do not like the floriculturists and feel that these foreign-owned companies do not care about the lake at all; and Believe that the municipality is 'owned' by the floriculturists.
United floriculturists	Feel they have every right to use as much water as they need as they provide employment and are the main contributors to economic growth of the area; Arrogant, don't want to be at the meeting; Try to 'play' the municipality and the Ministry; and Do not want an agreement on water restrictions, unless it does not apply to them.
Tourism industry	Depends on the ecosystem for its income; Is supported by the Ministries of Tourism and Environment and Natural Resources and the Kenya Wildlife Services; Likes to liaise with the LNRA; Thinks the large industries should not abstract water from this

[3] Are fictive and do not always reflect reality

Stakeholder	Characteristics[3]
	vulnerable ecosystem (floriculturists); and Constructively looking for an agreement.
Naivasha municipality	Tends to value employment over sustainability; Doesn't believe climate change will influence the area much; Is not so much 'in touch' with the small-scale farmers and fishermen; and Is very upset by rumours that they are 'owned' by the floriculturists.
Ministry of Water and Irrigation	Is not aware of the local sensitivities; Appreciates the invitation; Believes an agreement on restricted use seems needed; Tends to support the floriculturists, but may be sensitive to solid arguments; Has the potential to make or break the agreement (support LNRA or floriculturists); and Feels important.
Fishermen's union	Supports all initiatives that would help increase the water level in the lake; Not well-organized; and Feel overlooked.
KMFRI	Has a permanent station on the lake; Economic and scientific interest; Lake offers high potential for international research cooperation; Knows that the floriculturists are close to potential European donors (EU, Dutch government); Historical link to the fisheries; and Very worried about the potential effects of climate change on the ecology of the lake.

Table 4: The characteristics of the international role play stakeholders

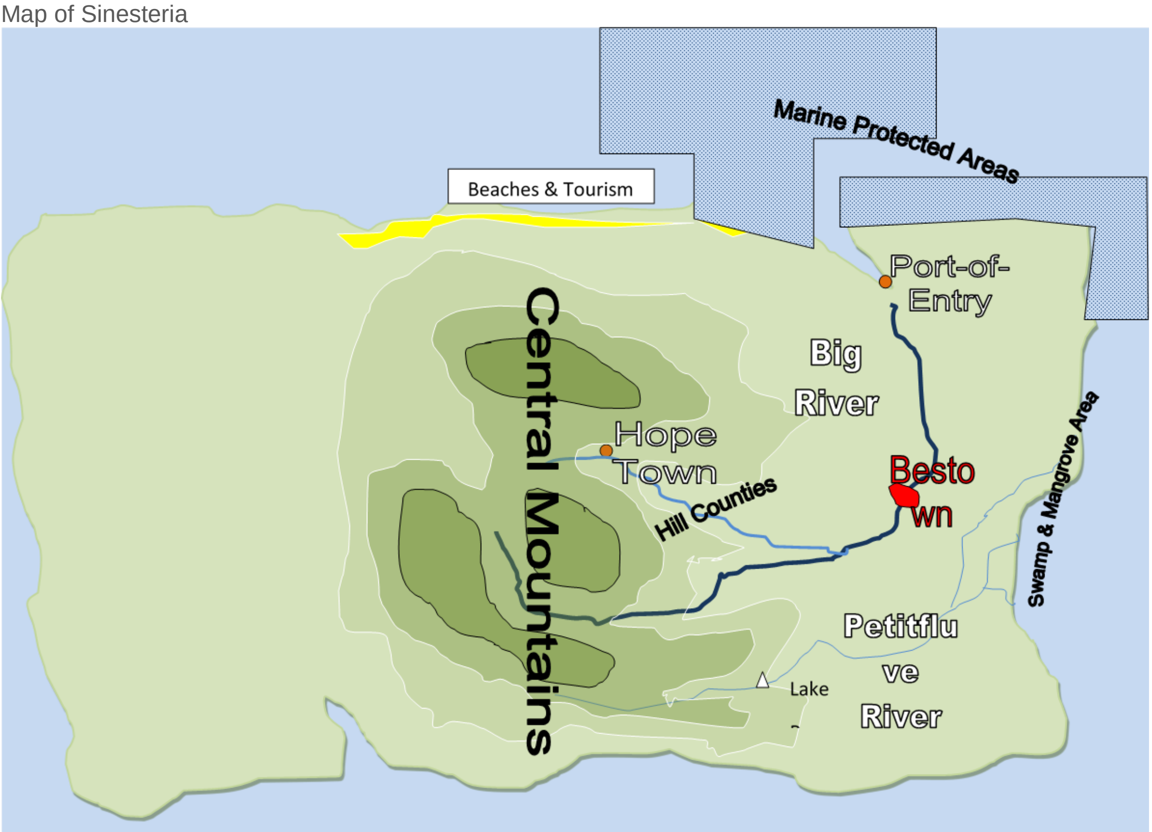
During the play the stakeholders sit in a half-circle opposite the observers in such a way that the stakeholders can all see each other. The Guardian Angels sit behind the stakeholders, write their suggestions on slips of paper, and hand these to their respective stakeholders. The PeRiMA opens the meeting and the play starts. During the play, the observers are ignored. The facilitator intervenes if the meeting is not progressing or if the discussion becomes 'too intense'. The play runs for about 30 minutes. After this, the observers give their feedback.

If agreed by all participants the play goes again. In this case the Stakeholder and Guardian Angel change position and the play starts again, followed by a second round of feedback.

Facilitation

The course facilitator(s) explain(s) the process and keeps track of time. It is important to reserve enough time for the whole session, as sometimes the play itself or the feedback session evolve into very useful discussion and insights about stakeholder participation. The facilitator can also spice up the meeting (if needed) by slipping notes to the stakeholders, stimulating them to take more extreme positions in the debate. The facilitator stops the play when it is going in circles, entering a status quo or if time demands. The facilitator leads the feedback sessions and ends the whole role play with some concluding remarks and lessons learned. Role Play Exercise

Map of Sinesteria



PLANNING A WORKSHOP AND

DEVELOPING TRAINING SKILLS

Content:

- What to consider when planning a workshop
- Dynamics and energisers
- Icebreaking
- Planning workshops on climate change and water resources

This chapter has been designed to support those people who will develop training activities on adaptation to climate change impacts and how IWRM can help.

Introduction

Training activities with adult participants have specific needs that have to be considered when planning the event to ensure training objectives are met. Adult learners favour learning by doing, by sharing experiences and by the application of new knowledge in real work environments.

The planning process is a tool that you, as the facilitator, can use to enhance the learning process of the participants.

1. **Target group**
   Considering that training has to be adapted for different audiences, you have to be sure that your training materials address different needs and that they meet the requirements of the trainees' profiles. It is also important to identify the material you will use and anticipate all your needs during the planned sessions.

2. **External factors**
   A good preparatory exercise to do is to project possible training scenarios. In this way, you can try to control external factors that may influence the training event, for example, holidays, weather conditions and political events. This exercise also gives you the opportunity to identify particular opportunities that may come up.

3. **Internal factors**
   It is important to be realistic and plan capacity building according to your strengths and the extra support you are able to raise. Following are some practical tips for planning, conducting, and evaluating the training course.

A. Before the training

- Set your training objectives.
- Identify and evaluate the training method, and choose the most suitable one for your goals.
- Identify your regional/local counterparts.
- Prepare a budget adjusted to your needs and costs, consider all expenditures and keep an amount for rainy days.
- Solicit financial support.
- Identify the material developed from expert sources and plan review and integration.

- Address administrative and venue issues (restrooms, breakout rooms for working group sessions, layout of the meeting room, access to internet, air conditioning, connections, evacuation route, etc).
- Decide how you will measure the objectives.
- Try to establish the situation or knowledge of the participants (e.g. use an application form, ask participants to write a motivation or an analysis of the situation in their region).
- Identify the improvements you are aiming for.
- Identify assignment responsibilities.
- Prepare energisers and dynamic sessions while planning the content.
- Make a list of materials and equipment you will need.

B. During the training

- Assign 'policing' or organisational roles to volunteer participants.
- Assess and address special needs of participants and trainers.
- Make sure material is circulated on time.
- Add interactive sessions to the technical sessions, as practical application of concepts and principles as part of the learning process.
- Plan daily recaps to evaluate the activities and understanding by the participants, but be careful that recaps are not just summaries of presentations.
- Consider the breaks you need and the way to bring participants back to the session (play music, ring a bell, turn on/off lights).

C. After the training

- Measure the achievements of the objectives by the indicators identified.
- Review feedback from trainers and participants. Assess what improvements can be made to the programme, materials, or facilitation.
- Review the effectiveness of the chosen training method and allocated time.
- Identify any remaining training gaps, and include them in future plans.
- Review your financial results.

If you plan to replicate your training activity, then you have to work on preparing follow up activities:

1. Meet in groups by regions or countries (depending on the number of participants and the target group you identified for the follow up).
2. Prepare a proposal to run an activity in your region/country or watershed level making use of the programme and materials of the training just conducted on IWRM and climate change.
3. You need to:
   - Identify the target group;
   - Identify the duration of the activity;
   - Establish the contents according to the length and the needs and characteristics of the region or country;
   - Identify regional or local speakers/experts;

- Make a list of requirements to run your training activity;
- Identify responsible persons;
- Make a timetable;
- Identify funding; and
- Prepare a presentation to share in plenary.

Some icebreaking / energising suggestions

Breaking the ice is very important when you are working with adult learners. You are not only responsible for the quality of the material and to guarantee delivery but also for group dynamics. Some icebreakers are presented to help trainers to organise the session, but you can be creative and use your own.

Team building icebreakers

Activity to meet each other (15 minutes)

Divide the meeting participants into groups of four or five people by giving them names according to the issues of the workshop, like lake, river, rain, spring, etc. You can use colours or other references. You can also give the participants a chocolate or candy with different label, so they meet with the people who share the same label of candy.

Tell the newly formed groups the rules and their assignment. Prepare a clear and simple guide to make it easy. The assignment can be something easy, such as to find five things they have in common, that have nothing to do with work (no body parts and no clothing). This helps the group explore shared interests more broadly.
One person (a volunteer) of the group must take notes and be ready to read their list to the whole group upon completion of the assignment. Then ask each group to share their list with the whole group.

Animal card (30 minutes)

You can distribute cards with images of animal in pairs, or use opposite cards and ask to the participants to meet with the other person who has the matching card. Each one has to introduce the other participant to the plenary telling something special about the other participant. You can prepare the main question that must be something personal, something that makes him/her special or different. Allow 10 minutes for the pairs to meet and the remaining 20 minutes for introductions to the rest of the group.

The treasure box (30 minutes)

Bring a dark bag or box and ask to the participants to give you something that must be important to them; avoid pencils or pens and instead suggest eyeglasses (in their case), driver's license, rings, watches, etc. When you get all the treasures in the bag, draw one and ask to the owner to say his or her name and to say something personal that very few people know. The group will decide if the information is personal enough to recover the treasure and if not, the participant has to try again. Don't be easy on the person, keep the item until the group is satisfied.

Roll the ball (20 minutes)

Another way to introduce the participants is to bring a small and colourful ball to toss around and to ask the participants to stand up and present themselves one by one, as they catch the ball. Assure that all the participants receive the ball. You can also use the same exercise when the people are tired and ask them to say the name of the person to whom they throw the ball. The one who fails will have a punishment: sing, dance, or something else that the group decides.

The name game (15 minutes)

Sit the participants in a circle. One of the persons (or a leader) starts the game by saying "Hi! My name is...". Then the person next to the beginner continues by saying "Hi! My name is ... and sitting next to me is ...". This continues around the circle, until the last person introduces him-/herself and also has to introduce the entire circle! This is a great way to learn names.

Other activities to develop during the workshop

The baby picture game

Each person is instructed before the course to bring a baby picture of him or herself. Collect all the pictures and carefully put them on a large paper sheet on the wall, assigning a number to each picture and prepare a big envelop on the side; keep them there until the last day. The participants must identify each of the participants from their baby picture, linking the number to the name, and put this in the envelope during the workshop. On the last day of the training, the person who guessed the most names and pictures right will win a prize.

Sharing chairs

Everyone gets a chair and sits in a circle. The leader reads out a list of items. If any of them apply to a participant, he or she must move the appropriate number of seats clockwise. For example: 1. “Anyone with one brother, move one seat clockwise. If you have two brothers, move two seats.” 2. “Anyone with black hair, move one seat clockwise.” 3. “Anyone over the age of 21, move three seats counter-clockwise.” 4. “Everyone wearing brown shoes move one seat.” The fun happens when you move, but your neighbour doesn't, and you must sit on his/her lap! Sometimes, you can have three people occupying the same chair!! Make sure you have lots of categories so that everyone gets several chances to move.

Dr. Mix-Up

All the participants stand in a circle, holding hands. Select one person to be "Dr. Mix-Up". That person leaves the room for a moment. When he/she is gone, everyone else does their best to get tangled up, by climbing over arms, under legs etc., without letting go of their neighbours’ hands. When the circle is suitably tangled, everyone yells "Dr. Mix-Up! Come and fix us!". Dr. Mix-Up then comes in and tries to untangle the circle by directing individuals to go under arms, around bodies, etc.

Shoe factory

Have the group stand in a large circle shoulder to shoulder. Then have everyone remove their shoes and put them in the centre. After the group has formed a pile with their shoes, the leader directs everyone to choose two different shoes other than their own. They should put them on their feet (halfway if they are too small). The group then needs to successfully match the shoes and put them in proper pairs by standing next to the individual wearing the other shoe. This will probably result in a tangled mess and lots of giggles!

Suggested reading

Advanced Systems Technology Corp (1999) Facilitator's Guide for the Strategic Planning Module. Crofton, Maryland.

Cap-Net (2007) Planning Short Training Courses: A Network Management Tool. Cap-Net: Pretoria, South Africa.

Glossary

Adaptation
Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, thereby moderating harm or exploiting beneficial opportunities. Various types of adaptation can be distinguished including anticipatory, autonomous and planned adaptation.

Analogue Scenarios
Analogue scenarios are constructed by identifying recorded climate regimes which may resemble the future climate in a given region. Both spatial and temporal analogues have been used in constructing climate scenarios.

Anticipatory adaptation
Adaptation that takes place before impacts of climate change are observed. Also referred to as proactive adaptation.

Aquifers
A body of permeable rock able to hold or transmit water.

Atmosphere
The gaseous envelope surrounding the Earth. The dry atmosphere consists almost entirely of nitrogen and oxygen, together with trace gases including carbon dioxide and ozone (IPCC 2007c).

Autonomous adaptation
Adaptation that does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. Also referred to as spontaneous adaptation.

Biofuel
A fuel created from organic matter or combustible oils produced by plants. Examples of biofuel include alcohol, black liquor from paper-manufacturing process, wood, and soybean oil.

Biosphere
The part of the Earth system comprising all ecosystems and living organisms in the atmosphere, on land or in the oceans, including derived dead organic matter (IPCC 2007c).

Carbon storage
An approach to mitigating the contribution of carbon emissions to global warming based on capturing carbon dioxide (CO_2) from large point sources such as fossil fuel power plants. In this way, the carbon dioxide might then be permanently sequestered from the atmosphere.

Climate change
Any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), which defines climate change as "a

change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods" (IPCC 2007c).

Climate variability
Variations in the mean state and other statistics (such as standard deviations, statistics of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).

Cryosphere
The component of a climate system consisting of all snow and ice (including permafrost) on and beneath the surface of the Earth and its oceans.

Desalination
A process that removes any excess salt and other minerals from water or soil (soil desalination). http://en.wikipedia.org/wiki/Desalination - cite_note-1

Detention watersheds
A type of stormwater management facility installed on, or adjacent to, tributaries of rivers, streams, or lakes that is designed to protect against flooding as well as downstream erosion by storing water for a limited period of a time. They are also referred to as 'dry ponds', 'holding ponds' or 'dry detention watersheds'. There are some detention ponds called 'wet ponds', which are designed to permanently retain some volume of water at all times.

Drought
In general terms, drought is a 'prolonged absence or marked deficiency of precipitation', a 'deficiency that results in water shortage for some activity or for some group', or a 'period of abnormally dry weather sufficiently prolonged for the lack of precipitation to cause a serious hydrological imbalance' (Heim, 2002). Drought has been defined in a number of ways: agricultural drought relates to moisture deficits in the topmost 1 metre or so of soil (the root zone) that affects crops; meteorological drought is mainly a prolonged deficit of precipitation; and hydrologic drought is related to below-normal streamflow, lake and groundwater levels. A megadrought is a long, drawn out and pervasive drought, lasting much longer than normal, usually a decade or more.

Ecosystem
The interactive system formed from all living organisms and their abiotic (physical and chemical) environment within a given area. Ecosystems cover a hierarchy of spatial scales and can comprise the entire globe, continents (biomes) or small, well-circumscribed systems such as a small pond.

El Niño
A warm-water current that periodically flows along the coast of Ecuador and Peru, disrupting the local fisheries. The oceanic event is associated with a fluctuation of the inter-tropical surface pressure pattern and circulation in the Indian and Pacific Oceans, called the Southern Oscillation. This coupled atmosphere-ocean phenomenon is collectively known as *El Niño*-Southern Oscillation. During an *El Niño* event, the prevailing trade winds weaken and the equatorial countercurrent strengthens, causing warm surface waters in the Indonesian area to flow eastward and overlie the cold waters of the Peru Current. This event has great impact on the wind, sea surface temperature, and precipitation patterns in the tropical Pacific. It has climatic effects

throughout the Pacific region and in many parts of the world. The opposite of an *El Niño* event is called *La Niña* (see below).

Enhanced Greenhouse Effect
Also referred to as *human/ anthropogenic* forcing refers to the additional heat retained by the climate system due to human-based emissions since the industrial revolution that have expedited the global warming process, inducing climate change.

Eutrophication
The process by which a body of water (often shallow) becomes (either naturally or by pollution) rich in dissolved nutrients, with a seasonal deficiency in dissolved oxygen.

Evapotranspiration
The combined process of water evaporation from the Earth's surface and transpiration from vegetation.

Feedback
An interaction mechanism between processes; it occurs when the result of an initial process triggers changes in a second process, and that in turn influences the initial one. A positive feedback intensifies the original process, and a negative feedback reduces it.

Flash flood
Flooding that occurs suddenly and rapidly in low-lying areas, differentiated from regular flooding in that it usually occurs within six hours of the flood-triggering event. It is usually caused by heavy rain followed by a thunderstorm, hurricane, or tropical storm. Flash floods can also occur after the collapse of a dam.

Fossil fuels
Fuels that contain a high percentage of carbon and hydrocarbons. They are created through the anaerobic decomposition process of buried dead organisms that lived up to 300 million years ago. Fossil fuels range from those with low carbon and hydrogen ratios like methane, to liquid petroleum used in automobiles, to non-volatile materials composed of almost pure carbon, like anthracite coal.

General Circulation Models (GCMs)
Also termed *Global Climate Models* are the numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties. These global models generally simulate global temperatures which are compared with observations over climate timescales.

Global warming
The increase in the average temperature of the Earth's surface air and oceans. The Intergovernmental Panel on Climate Change (IPCC) concludes that anthropogenic greenhouse gases are responsible for most of the observed temperature increase since the middle of the twentieth century, while natural phenomena such as solar variation and volcanoes produced most of the warming from pre-industrial times to 1950 and resulted in a small cooling effect afterward.

Greenhouse effect
The process in which the absorption of infrared radiation by the atmosphere warms

the Earth. In common parlance, the term 'greenhouse effect' may be used to refer either to the natural greenhouse effect, due to naturally occurring greenhouse gases, or to the enhanced (anthropogenic) greenhouse gases, which results from gases emitted as a result of human activities. (see *enhanced greenhouse effect*)

Greenhouse gases
Gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, its atmosphere and clouds; this property causes the 'greenhouse effect'. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (NO_2), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. The Kyoto Protocol (see below) addresses CO_2, N_2O and CH_4, and also the greenhouse gases sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) (see Chapter 2 for more details).

Hydrological cycle
Also referred to as the water cycle, it describes the continuous movement of water above and below the surface of the Earth. Water undergoes changes in its states (liquid, vapour, and ice) at various points in the water cycle although the total balance of water on Earth remains constant over time.

Hydropower
Also known as water power, this is power or energy that is derived from the force or moving water; it may be harnessed for purposes such as commercial electric power.

Hydrosphere
As defined in physical geography, the zone continuing the combined mass of water found on, under, and over the surface of a planet, including seas, lakes, aquifers, etc.

Kyoto Protocol
The Kyoto Protocol was adopted at the Third Session of Conference of the Parties (COP) to the UN Framework Convention on Climate Change (UNFCCC) in 1997 in Kyoto, Japan. It contains legally binding commitments, in addition to those included in the UNFCC. Countries included in Annex B of the Protocol (most member countries of the Organisation for Economic Cooperation and Development (OECD) and those with economies in transition) agreed to reduce their anthropogenic greenhouse gas emissions (CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6) by at least 5 percent below 1990 levels in the commitment period 2008 to 2012. The Kyoto Protocol entered into force on 16 February 2005.

La Niña
The cold phase (or opposite effect) of *El Niño*, during which the cold pool in the eastern Pacific intensifies and the trade winds strengthen.

Level of Scientific Understanding (LOSU)
This is an index on a 4-step scale (High, Medium, Low and Very Low) designed to characterise the degree of scientific understanding of the radiative forcing agents that affect climate change. For each agent, the index represents a subjective judgement about the reliability of the estimate of its forcing, involving such factors as the assumptions necessary to evaluate the forcing, the degree of knowledge of the physical/ chemical mechanisms determining the forcing and the uncertainties surrounding the quantitative estimate.

Lithosphere
The hard and rigid outer layer of the planet which includes the crust and uppermost

mantle and can run to 80 km deep.

Multicriteria analysis
An evaluation methodology developed for complex problems with many objectives within a decision-making process. It takes into consideration a full range of social, environmental, technical, economic, and financial criteria.

Non-structural measures
According to United Nations International Strategy for Disaster Reduction (UNISDR), non-structural measures are defined as any measure not involving physical construction, and that uses knowledge, practice or agreement to reduce risks and impacts, in particular through policies and laws, public awareness raising, training and education.

Permafrost
Perennially frozen ground that occurs where the temperature remains below 0^oC.

Phenology
The study of natural phenomena that recur periodically (e.g. development stages, migration) and their relation to climate and seasonal changes.

Photic Zone
Surface layer of the ocean that receives sunlight. The uppermost 80 m or more of the ocean, which is sufficiently illuminated to permit photosynthesis by phytoplankton and plants, is called the euphotic zone. The thicknesses of the photic and euphotic zones vary with the intensity of sunlight as a function of season and latitude and with the degree of water turbidity. The bottommost, or aphotic, zone is the region of perpetual darkness that lies beneath the photic zone and includes most of the ocean waters.

Planned adaptation

Adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state.

Radiation
Any process in which energy is emitted by one ‘body’ and travels through a medium or space, and ultimately to be absorbed by another ‘body’.

Radiative forcing
The change in the net vertical irradiance at the tropopause due to an internal and external change in the forcing of the climate system, such as change in concentration of CO_2 or the output of the sun (IPCC 2007c).

Rainwater harvesting
The accumulation and storing of rainwater. It has been practiced in areas where there is more than sufficient water for drinking and for domestic and agricultural usage.

Regional Climate Model (RCM)
A Climate model at higher resolution over a limited area. Such models are used in downscaling global climate results over specific regional domains.

Resilience
The ability of a social or ecological system to absorb disturbances while retaining the

same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change.

Scenario (generic)
A plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about key driving forces. (e.g., rate of technology change, prices) and relationships. Scenarios are neither predictions nor forecasts and sometimes may be based on a “narrative storyline.” Scenarios may be derived from *projections,* but are often based on additional information from other sources.

Social equity
Equality, fairness and impartiality for all in terms of access to resources, the ability to participate in political and cultural life, and self-determination in meeting basic needs.

Spatio-temporal resolution
Precision of measurement with respect of space and time.

Standard deviation
In probability theory and statistics, standard deviation refers to the measure of the variability or dispersion of a population, a data set, or a probability distribution. A low standard deviation indicates that the data points tend to be very close to the mean value, while high standard deviation indicates that the data are ’spread out’ over a large range of values.

Structural measures
According to UNISDR, structural measures are known as any physical construction to reduce or avoid possible impacts of hazards, or application of engineering techniques to achieve hazard-resistance and resilience in structures or systems (UNISDR 2004).

Synthetic Scenarios
Scenarios where particular climatic (or related) elements are changed incrementally by plausible though arbitrary amounts. They are commonly applied to study the sensitivity of an exposure unit to a wide range of variations in climate.

Thermocline
The region in the world’s ocean, typically at a depth of 1 kilometre, where the temperature decreases rapidly with depth and which marks the boundary between the surface and the ocean.

Thermohaline circulation
Large-scale, density-driven circulation in the ocean, caused by differences in temperature and salinity.

Thermophilic
A condition of relatively high temperatures, between 45 and 80 °C (113 and 176 °F).

Vulnerability
The degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and the variations to which a system is exposed, its sensitivity, and its adaptive capacity.

Waterborne diseases
Diseases caused by pathogenic microorganisms, which are directly transmitted when contaminated water is consumed.

Wetlands
Transitional, regularly waterlogged areas of poorly drained soils, often found between an aquatic and a terrestrial ecosystem, that are fed from rain, surface water or groundwater. Wetlands are characterised by a prevalence of vegetation adapted for life in saturated soil conditions.

Acronyms

AOGCM	Atmosphere-Ocean Global Circulation Models
APF	Adaptation Policy Framework
Cap-Net	International Network for Capacity Building in Integrated Water Resource Management
CCIAV	Climate Change Impact, Adaptation and Vulnerability
CFCs	Chlorofluorocarbons
CH_4	Methane
CO_2	Carbon Dioxide
CVI	Climate Vulnerability Index
δD	Deuterium
DFID	United Kingdom Department for International Development
FAO	Food and Agriculture Organisation of the United Nations
GCMs	General Circulation Models or Global Climate Models
GHG	Greenhouse Gases
GWA	Gender and Water Alliance
GWP	Global Water Partnership
H_2O	Water
HEC	Hydrologic Engineering Center
IFM	Integrated Flood Management
IPCC	Intergovernmental Panel on Climate Change
IWRM	Integrated Water Resources Management
LDCs	Least Developed Countries
LOSU	Level of Scientific Understanding
MDGs	Millennium Development Goals
MFW	Marine and Freshwater
N_2O	Nitrous Oxide
NGOs	Non-governmental Organisations
NAPAs	National Adaptation Programmes of Action
ppm	Parts per million
PR	Polar Regions
RBO	River Basin Organisation
RF	Radiative Forcing
SRES	Special Report of Emission Scenarios
SWAT	Soil and Water Assessment Tools
TER	Terrestrial
UN	United Nations
UNDP	United Nations Development Programme
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNESCO-IHE	United Nations Educational, Scientific and Cultural Organisation Institute for Water Education
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations Children's Fund
WEAP	Water Evaluation and Planning
WHO	World Health Organisation
WMO	World Meteorological Organisation

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